DETECTION OF TRAPPED MINER ELECTROMAGNETIC SIGNALS ABOVE COAL MINES

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prepared for

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF MINES

by

ARTHUR D. LITTLE, INC.
Cambridge, Massachusetts

FINAL REPORT ON
CONTRACT NO. JO188037
Technical Support of Through-the-Earth
EM Transmission Measurement Program

July 1980

Arthur D. Little, Inc.

REPORT DOCUMENTATION PAGE

1. Report No.	2.	3. Recipient's Accession No.
4. Title and Subtitle DETECTION OF TRAPPED MINER ELECTROMAGNETIC SIGNALS ABOVE COAL MINES		5. Report Date July 1980
		6.
7. Author(s) Robert L. Lagace, James M. Dobbie, Thomas E. Doerfler, William S. Hawes, Richard H. Spencer		8. Performing Organization Report No. ADL-81978
9. Performing Organization Name and Address Arthur D. Little, Inc. 15 Acorn Park Cambridge, Massachusetts 02140		10. Project/Task/Work Unit No.
		11. Contract or Grant No. JO188037
12. Sponsoring Organization Name and Address Office of the Assistant Director – Mining Bureau of Mines Department of the Interior Washington, D.C. 20241		13. Type of Report FINAL May 1978 – July 1980
		14.
15. Supplementary Notes		

16. Abstract

This report assesses the expected detectability, on the surface above mines, of electromagnetic signals produced in the frequency band of 630 to 3030 Hz by a rescue transmitter activated by miners trapped underground. This assessment is based on a statistical analysis of experimental signal and noise data taken at a representative sample of coal mine sites well distributed over the United States underground coal fields.

Regression analyses are performed to characterize the signal transmission behavior of overburdens as a function of depth and frequency. The predicted signal behavior is then combined with experimentally based distributions of the background noise, and aural detection characteristics of signals in noise, to generate curves of the expected probability of detection for trapped miner signals versus overburden depth and operating frequency. The implications of these results, and associated recommendations, are presented regarding the detectability of trapped miners, sensitivity analyses and confirmatory tests, and operational utilization considerations for the trapped miners and the search and rescue team on the surface.

17. Originator's Key Words Trapped Miner Location; Communications-Mine, Coal Mines; Through the Earth Communications-Electromagnetic; Electromagnetic Propagation-Conducting Media; Signal Detection; Probability of Detection; Statistical Sampling; Statistical Analysis	18. Availability Statement

19. U.S. Security Classif. of the Report Unclassified	20. U.S. Security Classif. of This Page Unclassified	21. No. of Pages 288	22. Price

USBM JO188037

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Department of the Interior
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FOREWORD

This report was prepared by Arthur D. Little, Inc., Cambridge, Massachusetts, under USBM Contract No. JO188037. The contract was initiated under the Coal Mine Health and Safety Program. It was administered under the technical direction of the Pittsburgh Mining and Safety Research Center with Mr. John Durkin acting as the technical project officer. Mr. William McCarty was the contract administrator for the Bureau of Mines.

This report is a summary of the work recently completed as part of this contract during the period May 1978 to July 1980, and Contract HO346045, Task Order No. 3, Task B, during the period March 1976 to October 1977. This report was submitted by the authors in July 1980.

No inventions or patents were developed, and no applications for inventions or patents are pending.

The authors wish to thank John Durkin, Harry Dobroski, Wymar Cooper and Carl Ganoe, of the United States Bureau of Mines, Pittsburgh Mining and Safety Research Center, for their encouragement and assistance in this work; Howard E. Parkinson, presently of the United States Department of Energy, Carbondale Energy Technology Center, for the initial support of this work; A. Farstad and D. Kalvels of the Westinghouse Geophysical Instrumentation Systems measurement team for their cooperation and perseverance; and all the United States coal mining companies who contributed to the success of this program by providing the measurement team access to their mines and the cooperation required.

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I. SUMMARY

A. OVERVIEW

In response to the Coal Mine Health and Safety Act of 1969, the Bureau of Mines of the United States Department of the Interior embarked upon a program to perform research and development aimed at increasing the survivability of miners trapped underground after a coal mine disaster. A principal ingredient of this program was the development of practical and effective means to detect, locate, and communicate with miners trapped within extensive mine workings.

This report assesses the expected detectability, on the surface above mines, of electromagnetic signals produced by a rescue transmitter activated by miners trapped underground. This assessment is based on a statistical analysis of experimental signal and noise data taken at a representative sample of coal mine sites well distributed over the United States underground coal fields.

B. OBJECTIVES

This study had two main objectives. The first was to characterize the electromagnetic signal transmission behavior of overburdens above the coal mines. The second was to estimate the likelihood of successfully detecting electromagnetic signals transmitted by miners trapped beneath these overburdens. A secondary objective was to formulate an approach, based on search theory, for the allocation of post-disaster search efforts aimed at detecting the largest number of miners capable of being rescued per unit of search effort.

C. APPROACH

A theoretical approach to the characterization of overburden signal transmission behavior was impractical, because of the variability and complexity of the overburden material of coal mines. Therefore, an approach based on measured signal data taken at mines well distributed throughout the U.S. coal fields was chosen. To make inferences concerning signal transmission characteristics over the entire population of U.S. underground coal mines, we adopted a statistical approach at the outset. We selected a representative sample of mines and performed regression analyses to characterize the signal transmission behavior of overburdens as a function of depth and frequency. The predicted signal behavior was then combined with experimentally based distributions of the background noise, and aural detection characteristics of signals in noise. These were used to generate curves of the expected probability of detection for trapped miner signals versus overburden depth and operating frequency.

The overall program objectives were accomplished through a collaborative effort which took advantage of the skills and resources of three parties; namely: Arthur D. Little, Inc., as the experiment design and data analysis team; Westinghouse Geophysical Instrumentation Systems as the measurement team; and the United States Bureau of Mines, Pittsburgh Mining and Safety Research Center, as the overall coordination and support team.

D. RESULTS

The final results in the form of expected probabilities of detection are plotted in Figure I-1. These plots represent the likelihood, on the average, of trapped miner signals being detected on the surface above U.S. coal mines having the indicated overburden

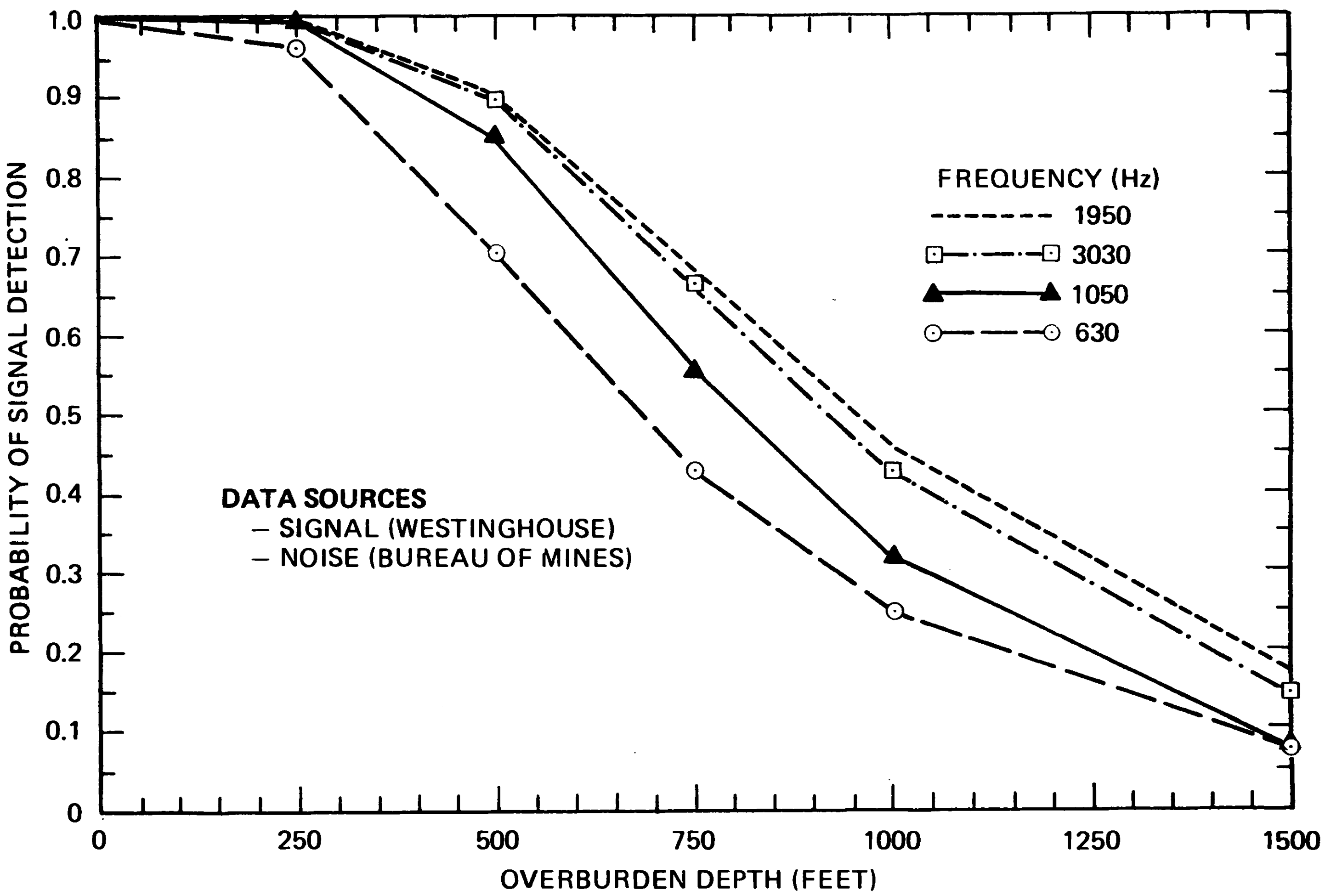

FIGURE I-1 PREDICTED PROBABILITY OF SIGNAL DETECTION VERSUS OVERBURDEN DEPTH BY FREQUENCY FOR THE GENERAL INSTRUMENTS TRANSMITTER depths. The plots apply for the General Instruments transmitter and aural detection by a searcher using a Collins receiver equipped with a headset.

At any particular mine site and given overburden depth, trapped miner signals can either be detected or not be detected during a search exercise. If such a detection experiment is repeated at several mines having the same overburden depth, the predicted expected percentage of experiments that will achieve signal detection at each operating frequency is as shown in Figure I-1. For example, if the device were tested at many locations having a 750-foot overburden, it is expected that the transmitted signal would be detected at about 68 percent of the locations for the operating frequency of 1950 Hz, and at about 43 percent of the locations for 630 Hz. The curves also indicate that the chances of being detected are higher for signals in the upper part of the 630 to 3030 Hz frequency band.

Detailed discussion of some implications of these results is presented in Sections X and XI. The discussion centers on four areas:

- detectability related to overburden depth profiles, diurnal/seasonal noise variations, and miner distribution;
- sensitivity analyses and experiments;
- desirability of confirmatory tests; and
- operational utilization considerations from two points of view -- use of the in-mine transmitters by the trapped miners, and use of the surface detection equipment by the search and rescue team.

E. ORGANIZATION OF REPORT

Section II describes the events and circumstances which led to this comprehensive program involving the measurement and analysis of data from many coal mines. In Section III, the overall philosophy of the tests, the mine selection process, and the specific measurements performed at each mine are discussed. Section IV describes the process of compiling and verifying the extensive set of data taken at 94 mine sites to produce a final data base for both signal and noise. Section V presents the linear regression analyses of the signal data and the derived regression models describing the signal transmission behavior of U.S. coal mine overburdens as a function of depth and frequency. Section VI presents, using the transmission model of Section V, the signal strength expected on the surface for the planned General Instruments transmitter. Section VII characterizes the statistical distribution of the expected background noise on the surface. In Section VIII, probability distributions are generated for the signal-to-noise ratio expected on the surface at each frequency. Section IX describes the aural detection of pulsed CW tones in noise and presents signal-to-noise requirements for detection. In Section X, the results of the previous sections are combined to generate the final curves describing the expected probabilities of detection for trapped miner signals as a function of overburden depth and frequency. Section XI discusses the implications of these results and recommendations.

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II. THE NEED

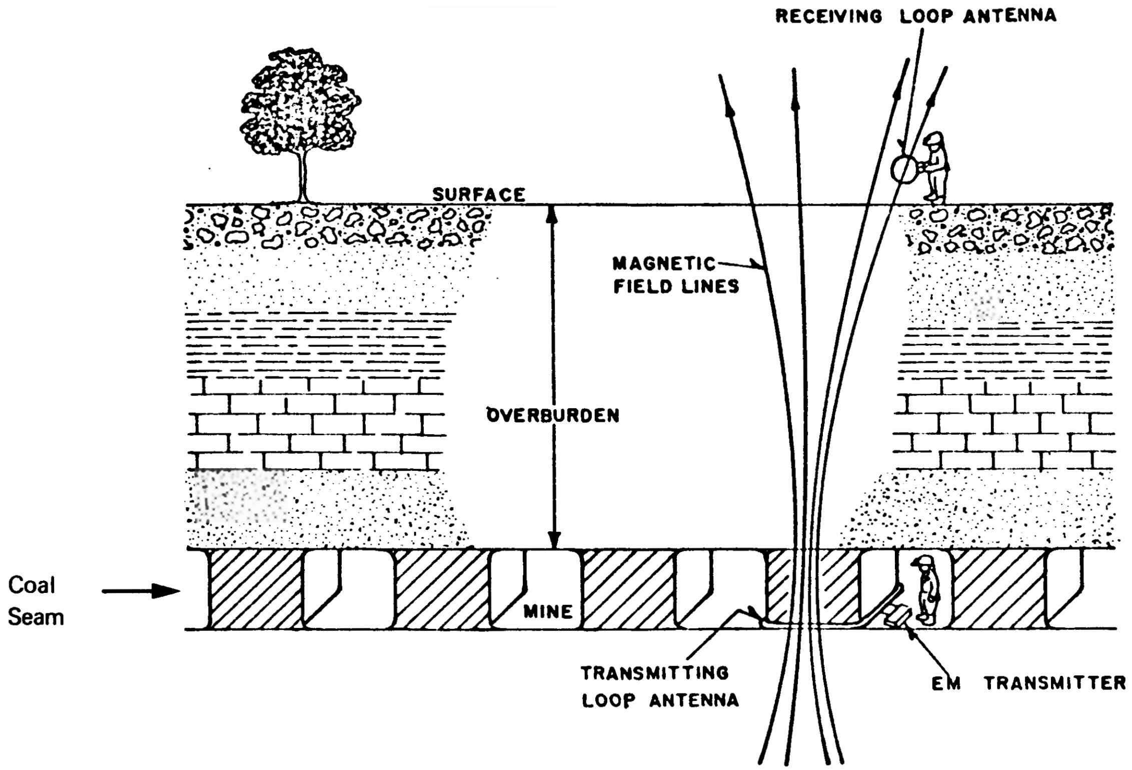
In response to the Coal Mine Health and Safety Act of 1969, the Bureau of Mines of the United States Department of the Interior embarked on a program to perform research and development aimed at increasing the survivability of miners trapped underground during coal mine disasters. A principal ingredient of this program was the development of practical and effective means to detect, locate, and communicate with miners trapped within the extensive mine workings. The sooner such miners can be found at a mine disaster site, the greater will be their chances of surviving. This benefit will accrue because of the more efficient and effective allocation of the limited mine rescue resources generally available at disaster sites to help rescue miners before they succumb to injuries or noxious mine environments.

Two means were conceived and developed to provide trapped miners with this location and communication capability: an electromagnetic (EM) signaling system, and a seismic signaling system. This report examines the potential effectiveness of the electromagnetic signaling system and is particularly concerned with the statistical analysis of experimental magnetic field strength data taken at 94 coal mine sites well distributed over the United States coal fields. The objective is to obtain an experience-based assessment of the probable effectiveness of this electromagnetic signaling system prior to initiating the formulation and promulgation of new regulations bearing on the use of such a system.

The need to conduct this specific, comprehensive program involving field measurements and analysis of data from a large number of coal mine sites became apparent in 1975-76. At that time, the Bureau of Mines had completed development of electromagnetic trapped-miner signaling and receiving hardware. This hardware was based on intrinsic safety requirements and on available geological information regarding the anticipated severity of overburden signal attenuation characteristics. Namely, the average effective electrical conductivity of the overburden was considered to be approximately 0.01 mho/m. Performance estimates based on this value of conductivity predicted effective signal detections for an overburden depth of 1,000 feet using an intrinsically safe transmitter design utilizing the miner's cap lamp battery as a primary source of power.

Figure II-1 illustrates the principle of operation of the EM trapped-miner signaling device and associated detection/receiving hardware on the surface. The figure also depicts the sedimentary nature of both a coal seam and the numerous layers of different materials comprising the overburden above a coal seam. The EM signaling transmitter shown in Figure II-2 was developed by Collins Radio based on the above requirements and assumptions. This transmitter was tested at several deep mines in the Appalachian coal fields having overburden depths between 500 and 1,000 feet, and the results were successful as anticipated. However, this equipment was also tested at mines shallower than 500 feet; the results were unsatisfactory and unanticipated. Namely, some or all of the frequencies tested in the 630 to 3030 Hz band did not penetrate the overburden with significant strength to be detected on the surface at these shallow mine sites. Furthermore, the reasons for the lack of successful detections above the shallow overburdens were not apparent.

These unanticipated, negative results precipitated the need to establish a way to characterize the signal transmission behavior of overburdens above United States coal mines, and to assess the impact of this behavior on the expected detectability of trapped miner EM signals. Such a characterization and assessment is required before the promulgation of new regulations. This requirement led to the establishment of the extensive measurement and data analysis program whose results are presented in this report.



Source: Westinghouse, Ref. 1

FIGURE II-1 ILLUSTRATION OF ELECTROMAGNETIC (EM) TRAPPED MINER SIGNALING AND DETECTION SYSTEM

Source: U.S. Bureau of Mines

FIGURE II-2 COLLINS RADIO EM TRAPPED MINER TRANSMITTER MOUNTED ON MINER'S CAP LAMP BATTERY

III. THE EXPERIMENT

A. PHILOSOPHY OF TESTS

The objective of this study was twofold: first, to define a signal transmission measurement and analysis program to obtain a reliable data base for characterizing the signal transmission properties of overburdens in the United States coal fields; and second, to use this data base to predict the likelihood of successful performance of the EM trapped-miner signaling system. A transmission measurement program was required, because the limited information on, and the inherent variability and complexity of, overburden electrical characteristics above U.S. coal mines made a theoretical approach infeasible. Furthermore, we concluded that, in order to obtain results that would account for this variability, the measurement program should consist of simple measurements made at a large number of mines throughout the United States coal fields, instead of a comprehensive set of measurements made at only a few selected mines.

We also concluded that a representative sample of mines should be selected from the population of all coal mines on the basis of both the overburden depth and the number of miners employed at the mine. Namely, the sample should reflect proper concern both for the physical dependence of signal penetration on overburden depth and the number of miners exposed to potential disasters within each depth interval. Since this program would require the cooperation and participation of approximately one hundred mines, it was also important to design the tests to not interfere with mine production activities and to require a minimum time within the mine.

These criteria were satisfied by designing the experiments so that the in-mine test crew required only two people, who could conveniently hand-carry a minimum of equipment to one predesignated non-interfering location within the mine, set up and complete all tests, and leave the mine, all within a single working shift. This minimum interference with mine production operations was accomplished through the efficient design of the measurement procedures and the pre-test arrangements made with mine personnel prior to entering the mine.

It was further decided to accomplish the overall program objectives through a collaborative effort to take advantage of the available skills and resources of three parties, namely: Westinghouse Geophysical Instrumentation Systems, as the measurement team; Arthur D. Little, Inc., as the experiment design and analysis team; and United States Bureau of Mines Pittsburgh Mining and Safety Research Center (PMSRC), as the support team that provided vital staff resources and coordination to both the field measurement and the data analysis activities of this program. The remainder of this section briefly describes the mine selection and field measurement activities.

B. MINE SELECTION

To make meaningful inferences about the overall performance of the candidate EM detection system throughout the U.S. coal fields, it was necessary to conduct tests at a sufficient number of mines. Since experimental results were intended to be representative of a large number of active mines, each with unique physical and operational characteristics, it was necessary to utilize some type of sampling process to determine specific test locations for the program. By invoking statistical sampling theory in the selection process, it was possible to:

(1) assure the validity of estimated performance measures subsequently derived from test results;

(2) increase the precison of these estimates; and

(3) reduce or eliminate the possibility of built-in biases in interpreting test results.

It was decided at the outset of the program that test results from approximately one hundred different mine locations would be sufficient for estimating the transmission characteristics of the overburden above coal mines, and necessary to provide an adequate data base for estimating overall probability of successful signal detection on the surface in a meaningful quantitative sense.

1. The Statistical Mine Sample

Although a simple random sample of 100 mines could have been selected from the total mine population (in which case each mine would have an equal probability of being selected), it was reasoned that the sampling plan should reflect two additional important considerations; namely: (1) since the performance of the device was likely to be depth-dependent, the distribution of mines selected should take into account the greater variability in test results anticipated at greater depths than at lesser depths; and (2) since most mines are relatively small in terms of number of miners employed, the probability of mine selection within a depth interval should be based on the number of workers to be protected at the mine, thereby giving large mines a justifiably greater chance of being selected than smaller mines. By utilizing these two concepts in designing a sampling plan, it was felt that the analysis of test results would yield more meaningful and precise estimates of transmission behavior relative to all mines and miners eventually employing the device.

The population considered was identified from a computer listing of 1,222 active coal mines in the United States obtained from PMSRC. This computer listing was constructed by PMSRC from two independent computer data bases, one from MSHA that contained data on the number of miners at each mine, and one from the Bureau of Mines Eastern Field Operations Center that contained data on the maximum overburden depth at each mine. This listing included the mine name, address, maximum overburden depth, number of miners employed, and MSHA identification number. All mines were subsequently stratified according to maximum mine overburden depth values into 15 different depth intervals. Total miners employed at all mines contained within each depth interval were also tabulated. Although the sample could have been allocated proportional to the size of the strata (that is, the ratio of the number of mines sampled to the total number of mines would be constant within each interval), it was decided to vary the sampling fraction based on consideration (1) above.

To determine actual sampling fractions, a technique known as optimum allocation(2) was used, which is based on the principle that larger samples are required in strata that exhibit greater variability. This principle can be expressed as follows:

$$n_h = n \frac{N_h S_h}{\sum N_h S_h} \qquad (1)$$

where

n_h = sample size for the h-th stratum;

N_h = total number of mines in the h-th stratum;

S_h = variance of the characteristic being measured in the h-th stratum (e.g., the estimated probability of successful transmission at a specified frequency); and

n = total sample size (approximately 100 mines).

By estimating the relative variability S_h, it was determined that:

- 4 percent of the mines would be sampled in each of three strata less than 400 feet deep;
- 10 percent of the mines would be sampled in each of six strata between 400 and 1,000 feet deep; and
- 15 percent of the mines would be sampled in each of six strata greater than 1,000 feet.

These results are illustrated in Table III-1.

As stated in (2) above, the sample selection process within each depth interval was based on the number of miners employed at each mine. This technique, known as sampling with probability proportional to size, can be illustrated by the following simple example for five mines in a given depth interval:

Mine	Number of Miners	Probability of Being Selected
A	100	0.10
B	300	0.30
C	30	0.03
D	120	0.12
E	450	0.45
	1000	

The important features of the sampling procedure used in this program are summarized below:

- Each mine had a chance of being selected for this test.
- The chance (i.e., the probability of selection) was known beforehand and was based on the relative size of the mine in terms of miners employed.

Table III-1

Sampling Fractions by Depth Intervals

Maximum Mine Depth (feet)	Total number of Active Mines (N_h)	Sample Size (n_h)	Sampling Fraction	Total Number of Miners (all mines)
< 200	73	3	4%	3,359
201 - 300	166	6		7,669
301 - 400	203	8		10,837
401 - 500	169	17	10%	13,093
501 - 600	140	14		8,113
601 - 700	115	11		10,791
701 - 800	84	8		7,055
801 - 900	78	8		10,631
901 - 1000	57	6		6,746
1001 - 1200	58	8	15%	8,163
1201 - 1400	34	5		5,865
1401 - 1600	15	2		2,246
1601 - 2000	9	2		2,200
2001 - 2500	10	2		1,529
> 2500	11	2		2,322
Total	1222	102		100,619

Source: Arthur D. Little, Inc.
and United States Bureau of Mines Composite
Computer File based on MSHA and Bureau of Mines
Mine Data Files as of 1975.

- The selection process was random.
- All depth intervals were represented.
- Test results could be used to make valid inferences about all mines.

The sample of 102 mines selected in this manner for this program is given in Table A-1 of Appendix A, in which the selected mines are ordered by increasing depth intervals and by increasing number of miners per mine within each depth interval. Examination of this listing also reveals that the mines are well distributed among the major and minor underground coal-producing states in the United States coal fields.

2. The Final Mine Sample

The statistically selected mine sample described above and listed in Appendix A provided a guide for the organization and implementation of the field measurement program. Although a reasonable attempt was made to visit the specific mines selected, necessity, mine availability and practical travel schedule constraints introduced deviations from the originally selected sample of mines. However, we believe these deviations do not significantly affect or bias the results derived from the data obtained from this measurement program.

The following is a brief listing of reasons for deviation from the original mine selection plan, with respect to the specific mine, the anticipated overburden depth, or the number of miners employed at the mine:

- Delays in the availability of mine population information required that a number of mines already tested replace selected mines having similar characteristics;
- Some mines selected from the 1975 mine information data base no longer existed as operating mines at the time of the test program;
- In some cases, the data base information regarding maximum overburden depth and number of miners was found to be erroneous on arrival at the mine, requiring that the measurement team settle for a test site with a shallower overburden depth than planned;
- Some mines were not able to accommodate the measurement teams within the time frame of the planned field trip schedules;
- Occasionally, mines which can best be classified as "targets of opportunity" were visited on some of the field trips, because of their ready availability within the geographical region visited and/or favorable selection characteristics.

Care was taken to adhere to the spirit and form of the original selection list while coping with the realities imposed on the practical implementation of such an extensive field measurement program over a period of 24 months, from September 1977 to September 1979.

At the completion of the test program, measurements had been performed at 94 mine sites well distributed within the U.S. coal fields. The specific 94 mine sites sampled in this program are listed in Table B-1 of Appendix B, together with selected mine and test information about each mine site. The mines in Table B-1 are ordered by state within major coal-producing regions, and by county in each state, scanning from west to east and then southward within each state. Included in the table is the following information about each mine: its location, the seam, mine test number, Westinghouse field report number, seam thickness, number of miners, overburden depth, horizontal offsets between transmitter and receiver for both uplink and downlink transmission tests, the month and year of test, and mines with Bureau of Mines tape recorded data. A listing of mine test numbers associated with each field report has been included as Table B-2 for convenient reference.

Figure III-1 depicts the geographical distribution of actual mines tested by county within the U.S. coal fields. Examination of this map reveals that the counties tested are well distributed within the U.S. coal fields. Figure III-2 depicts the actual vs. planned distribution of selected mines vs. overburden depth intervals. Examination of Figure III-2 reveals that, for the practical reasons cited above, the actual distribution of mine sites reflects a substantial over-sampling of mines less than 300 feet deep and a corresponding under-sampling of mines with overburden greater than 700 feet deep. This means that the final mine sample was somewhat inefficient, in that it over-sampled shallow mines having a high anticipated probability of signal detection; namely, near unity. Furthermore, this occurred at the sacrifice of data needed for the deeper mines which were expected to exhibit much greater variability among test results. Attempts were made to provide mid-program corrections to this skewing of the sampling distribution of depth intervals. This corrective action was only partially successful for a number of reasons, the most important of which being the relative scarcity of mines having deep overburdens.

C. CONDUCT OF TESTS

The tests were designed to be as simple and straightforward as possible, not only to minimize the inconvenience to mine operators, but also to maximize the likelihood of obtaining usable data from measurements taken in demanding and hazardous environments. The primary objective was to measure uplink signal transmission through the overburden directly above a trapped-miner EM transmitter connected to a single turn loop of wire wrapped around

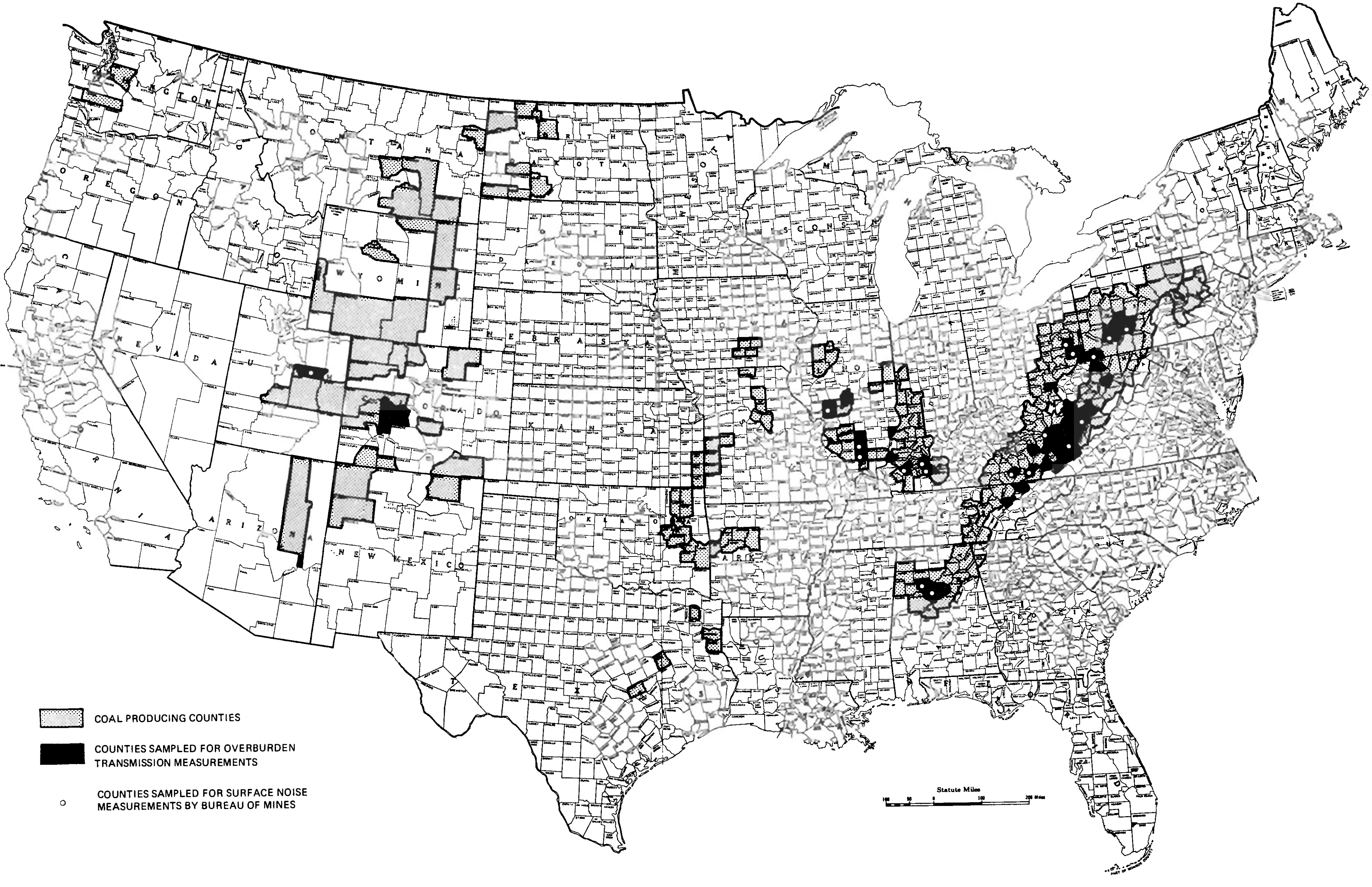


FIGURE III-1 GEOGRAPHICAL DISTRIBUTION OF MINES SAMPLED BY COUNTY IN U.S. COAL FIELDS

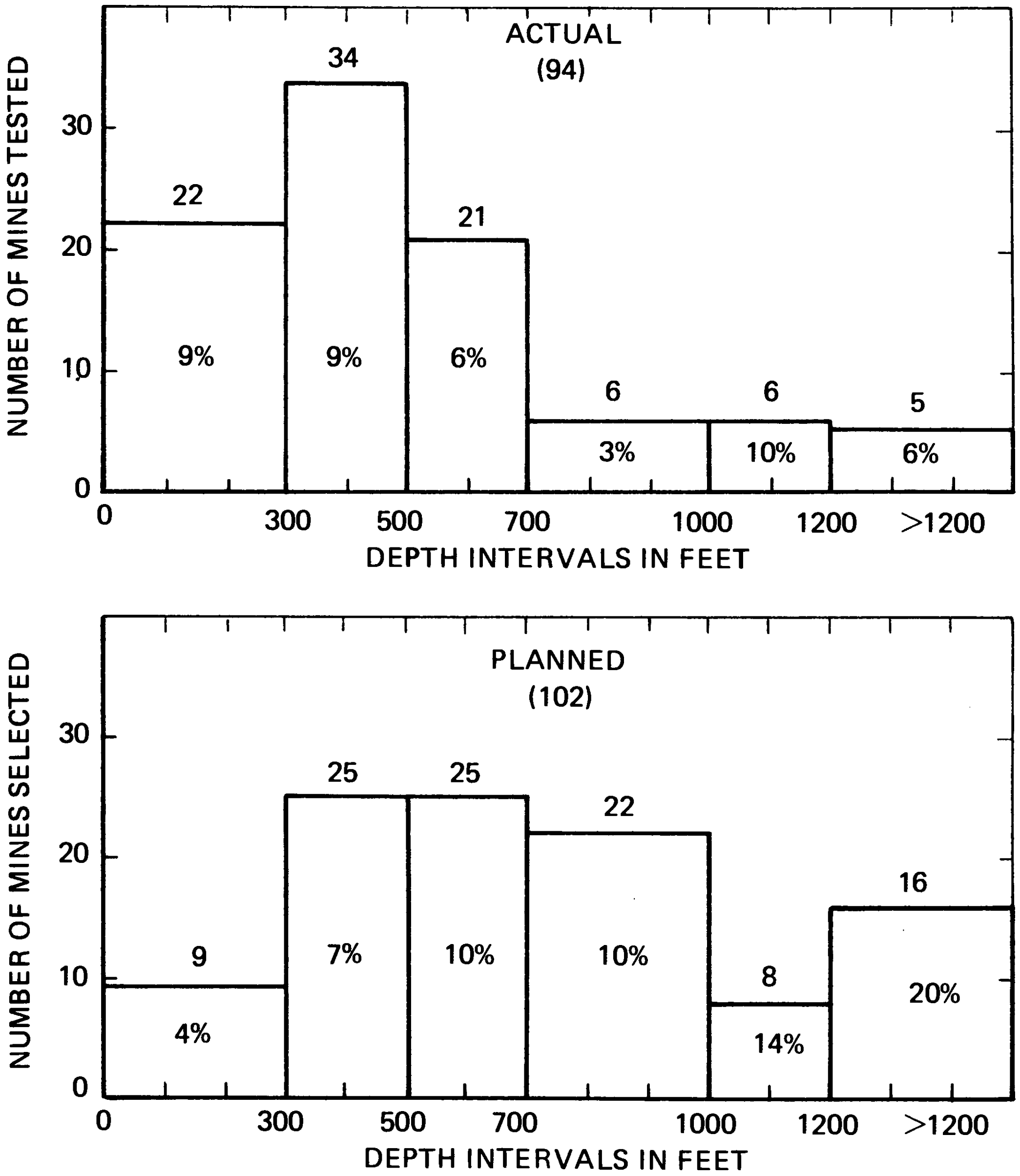


FIGURE III-2 DISTRIBUTION OF MINES SELECTED BY MAXIMUM OVERBURDEN DEPTH a coal pillar, depicted in Figure II-1. Note that the plane of the surface receive loop antenna must be oriented horizontally, not vertically, to detect the vertical component of magnetic field. In the vicinity of the point directly above the trapped-miner transmitter, the vertical component of the magnetic field will be significantly stronger than the horizontal. Therefore, the vertical component is the primary one used to detect trapped miners. The horizontal component, which experiences a null directly above the transmit antenna, is used to get a more precise location of the miner.

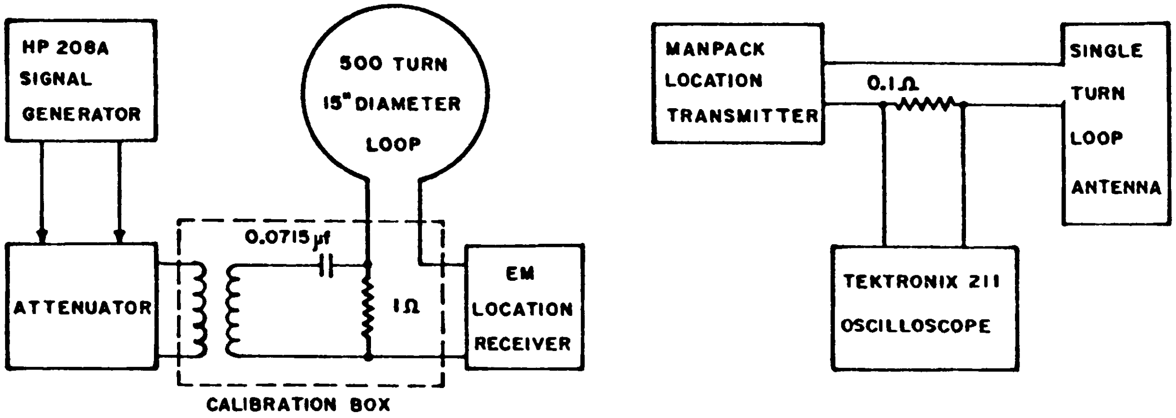
The small and lightweight Collins Radio trapped-miner transmit and receive equipment was used to gather the field strength data. This provided direct experience and results on the ability of signals from these devices to be successfully detected above coal mines in the presence of ambient noise, as well as providing the desired signal strength data. However, since the limited-power trapped miner transmitters might not be detectable above some deep or highly lossy overburdens, downlink transmission tests were also made. This was accomplished by using a significantly stronger transmitter on the surface, where it was possible to use heavy, bulky, high-power equipment. The goal was to utilize appropriately normalized downlink results, in the absence of valid uplink data, by applying the principle of reciprocity. A detailed description of equipment configurations and procedures used in the field measurement program is given in Reference 1. The following brief description is included to give the reader a sense of the measurements and procedures.

1. Uplink Measurements

The vertical component of signal magnetic field penetrating the overburden, and the corresponding vertical component of ambient noise magnetic field, were measured. Arrangements were made with the mine operator to choose a transmit location at the desired overburden depth that allowed the surface team to set up its equipment at an easily identified and accessible location directly above the mine transmit location. Most of the time, the measurement team was able to obtain the desired transmit/receive geometry, and sometimes this occurred at the sacrifice of some overburden depth. At other times, achieving this objective required considerable initiative, perseverance, and courage by the surface crew to reach, set up, and perform the measurements on narrow benches cut into steep mountainsides in the Appalachian coal fields.

Attempts were also made to select in-mine and surface measurement sites away from conducting cables, pipes, and other long conductors. In some instances, inductive coupling to these conductors might accidentally provide either an alternative lower-loss conducting path between the mine and the surface EM equipment, or perhaps a more favorable long-wire antenna effect. In many cases, tests had to be conducted in the presence of such structures, because it was not always possible to avoid them. This did not seriously impede the analysis of the associated data or the corresponding results, because in most cases the presence of the conductors did not appear to produce a significant discernible effect or trend in the data.

Figure III-3 is a block diagram of the mine subsurface EM transmitter equipment and the surface equipment used to detect and measure the strength of the received signal and noise. Figure II-2 is a photograph of the Collins EM transmitter attached to a miner's cap lamp battery. A one-turn loop of #12 wire was connected to the terminals at the top of the transmitter and wrapped around one (or sometimes two) coal pillars, as depicted in Figure II-1. The 0.1-ohm precision resistor in series with the loop was used with a portable Tektronix oscilloscope to monitor the shape, and measure the peak-to-peak value, of the loop current waveform for use in magnetic moment calculations.



SURFACE EQUIPMENT

(Receive)

SUBSURFACE EQUIPMENT

(Transmit)

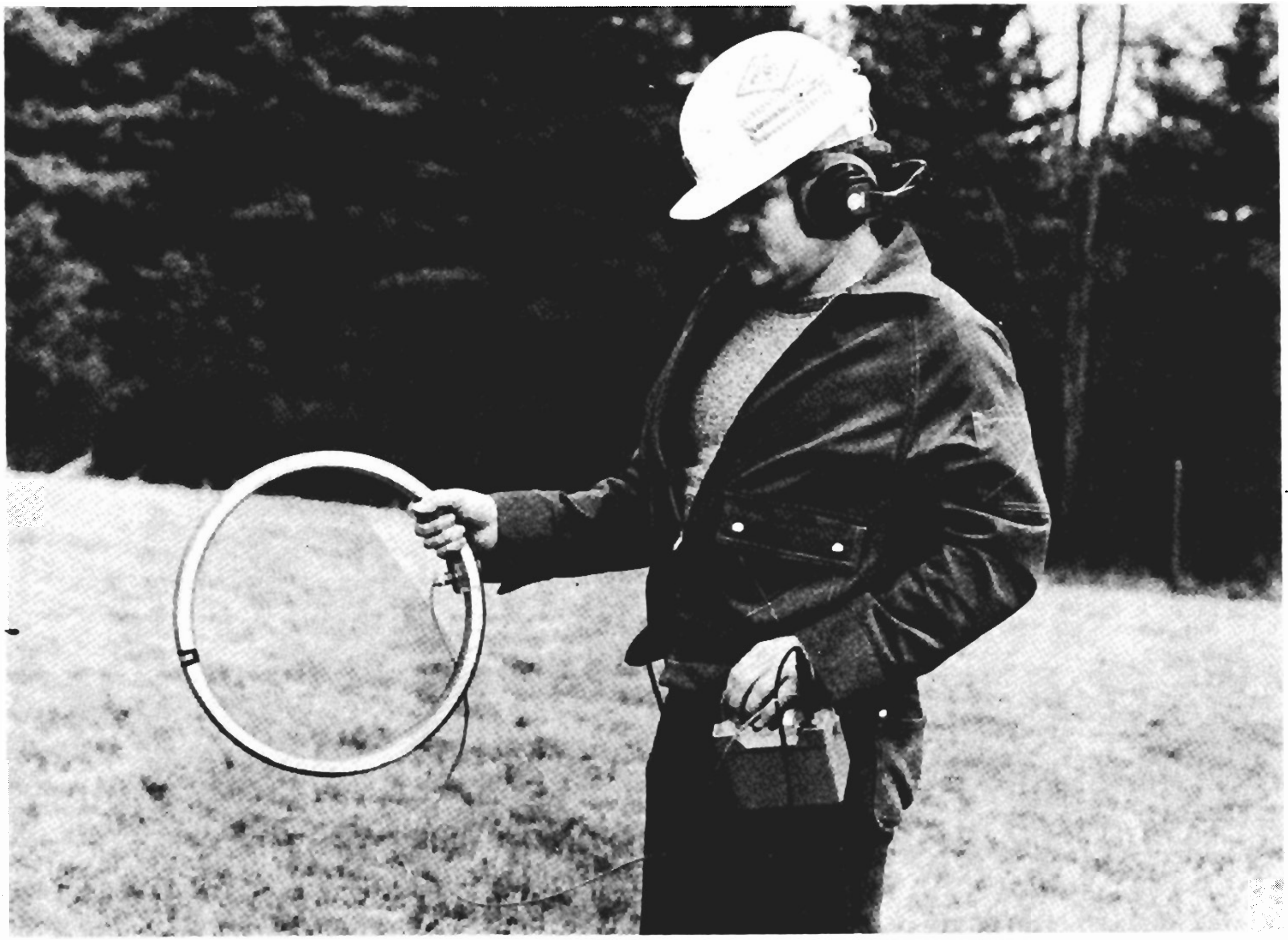
Source: Westinghouse, Ref. 1

FIGURE III-3 UPLINK TRANSMIT/RECEIVE MEASUREMENT EQUIPMENT

The surface measurement equipment consisted of the Collins EM receiver and 500-turn, 15-inch diameter loop antenna, as portrayed in Figure III-4. In this program, the plane of the receive loop was oriented horizontally, usually by laying it on the ground. The calibration box, attenuator, and portable Hewlett-Packard signal generator, shown in Figure III-3, allowed the use of a highly reliable substitution method to measure the absolute value of the magnetic field with the uncalibrated temperature-sensitive Collins receiver. The method(1) consisted of recording the signal generator voltage required to produce the same meter deflection on the EM receiver as that produced by the measured signal or noise magnetic field.

Four representative channels used by the trapped miner equipment were selected to assess performance variation with frequency across the band of interest. The channel frequencies chosen were 630, 1050, 1950, and 3030 Hz, each of which are located halfway between harmonics of the 60 Hz power grid frequency.

The measurements were performed according to the following prearranged schedule to compensate for the lack of communication between the in-mine and surface teams. A preset amount of time was allowed for both surface and in-mine measurement teams to get into place and set up their equipment before the test. Test commencement time was typically set at 10:00 a.m. The hour was divided into four 15-minute segments, each allocated to a series of uplink and downlink signal and noise measurements at one of the four frequencies. The test sequence was initiated by 630 Hz downlink transmissions, using the equipment described below, for the first seven and a half minutes of the first 15-minute segment. The second seven-and-a-half minutes of the 15-minute segment consisted of uplink transmissions at 630 Hz. This sequence of operations was repeated during the following three 15-minute



Source: U.S. Bureau of Mines

FIGURE III-4 SURFACE SEARCHER USING RESCUE RECEIVER HARDWARE (Loop antenna oriented for miner localization – rotate 90^{o} for miner detection) segments for the frequencies of 1050, 1950, and 3030 Hz, respectively. Afterward, the first 15-minute sequence was usually repeated, in case either the surface or the in-mine team was unable to meet the test initiation schedule. In many cases, the complete one-hour test sequence was repeated. Finally, when possible, noise readings were taken at the beginning or end of the seven-and-a-half minute segments, to provide an approximate comparison between measured signal levels and ambient noise levels measured a short time before or after the signal. However, it was not always possible to accomplish this during the measurement sequence,in which case the noise measurements were taken after the signal tests were completed.

2. Downlink Measurements

The downlink measurements utilized the same receive equipment configuration in the mine as used on the surface for uplink measurements. However, the downlink transmitter on the surface consisted of an audio frequency signal generator, a pulse interrupter, and a high-fidelity, high-power amplifier driving a one-turn, 500-foot periphery loop antenna deployed on the surface of the ground. This equipment was capable of transmitting both pulsed CW tones and voice transmissions into the overburden. It was also capable of generating CW RMS magnetic moments of up to 20,000 Amp-m^2, independent of frequency, to provide improved penetration capability in deep and/or high-loss overburdens. Transmit moments generated in the mine ranged between about 300 and 1,500 Amp-m^2 depending on loop size and frequency. In mines with relatively shallow overburdens, less than approximately 700 feet deep, voice transmission was attempted to gather information related to the more difficult problem of successfully transmitting voice through the overburden.

3. Bureau of Mines Surface Noise Measurements

During the last half of the field measurement program, the Bureau of Mines' Pittsburgh Mining and Safety Research Center conducted an independent series of surface noise measurements at 27 of the mine sites. These measurements were made during the uplink/downlink measurements conducted by the Westinghouse field measurement team. The Bureau of Mines equipment consisted of the Collins 500-turn, 15-inch diameter receive loop antenna fed through an appropriate preamplifier into a wideband instrumentation tape recorder. The recordings were later analyzed by PMSRC, using digital FFT (Fast Fourier Transform) analysis equipment to generate RMS noise level information in selected narrow bandwidths centered on each of the four channel frequencies of 630, 1050, 1950, and 3030 Hz. Detailed descriptions(3) of this equipment and the FFT analysis can be obtained from the Bureau of Mines Technical Project Officer.

4. Additional Supporting Information

To assist the overall assessment of the signal transmission data, the measurement team obtained a wide range of additional supporting information on each mine and its environment. This information included mine size, age, power usage, type of mining and haulage, number of miners, overburden thickness, seam mined, seam thickness, a geologic log of the overburden strata near the specific test site, approximate analysis of the coal, general descriptions of the in-mine and surface test sites and environmental conditions, and a mine map showing the part of the mine where the test site was located. These maps depicted the location of the rails, belts, power lines, water lines, gas lines, bore holes, and other objects and surface features that might have some bearing on the measured field data.

IV. DATA COMPILATION AND VERIFICATION

A. APPROACH

The painstaking task of compiling and verifying the extensive data taken by the Westinghouse measurement team at 94 mine sites, prior to detailed statistical analysis by Arthur D. Little, Inc., was undertaken as a collaborative effort between Arthur D. Little, Inc., and the U.S. Bureau of Mines, Pittsburgh Mining and Safety Research Center. PMSRC performed the initial tasks of gathering, verifying, and coding measured and supporting data from the Westinghouse field reports as they were received. They then assembled an easily accessible computer data file, consisting of the original data and derived parameters, on a mine-by-mine basis. This process included checks for completeness and consistency in the data obtained from the field reports and the clarification of questionable issues with the Westinghouse measurement team.

When the computer data file had been assembled for all 94 mine sites, it was sent in a compatible computer tape format to Arthur D. Little, Inc., for final verification and extensive analysis. This phase of the work was a laborious one, for the following two reasons: First, it was necessary to produce a final, verified, and complete data base of both signal and noise data obtained from an extensive and specialized field measurement program, conducted over an extended period of time, by different field crews, under widely varying and difficult environmental and operational conditions. Second, it was necessary to assess the relevance to the determination of depth and frequency relationships, of a large number of observed, and possibly important, experimental conditions existing at each test site, such as distance from conductors, transmitter/receiver horizontal offset, overburden composition, environmental conditions, etc. Any such measurement program is prone to the generation of some erroneous data, inconsistencies, and secondary variables of questionable importance. These had to be ferreted out, assessed, and resolved by a specially tailored, iterative purging process to arrive at a final data base that could be used with confidence.

This section is devoted to describing the principal elements of the purging process, and the results in terms of preliminary and final data bases for signal and noise. This phase of the work also involved a considerable amount of successful collaboration between ADL and PMSRC technical staff as we sought to resolve questions regarding signal and noise data and experiment configurations within the mines and on the surface.

In addition, data taken by a Bureau of Mines PMSRC measurement team was analyzed and eventually chosen to serve as the final surface noise data base. During the second half of the measurement program, the PMSRC team made independent surface noise recordings at 27 mine sites. The noise levels on these recordings were found to be at variance with many of the Westinghouse readings taken with the trapped-miner surface receiver. These discrepancies led to a comparative analysis of the Bureau and Westinghouse noise data by ADL and Bureau technical staff, resulting in the decision to use the Bureau of Mines noise data.

B. DESCRIPTIVE STATISTICS

1. Signal Verification and Purging Process

A number of initial listings, cross-tabulations, and preliminary analyses were performed in order to discern trends and relationships, and to formulate methods to identify "outliers" in the data that appeared to deviate from the sample averages. For example, several key quantities were rank ordered by depth for each of the four frequencies to examine any obvious trends. These variables were the surface magnetic field as measured, the surface magnetic field normalized for a nominal in-mine magnetic moment of 750 Amp-m^2, the in-mine magnetic field as measured, the in-mine magnetic field normalized for a nominal magnetic moment of 7,500 Amp-m^2, both the uplink transmission loss (TLU) in dB, and the downlink transmission loss (TLD) in dB, defined below, ΔTL, defined as the difference between uplink and downlink transmission losses (TLU - TLD) in dB, the in-mine moment ($M_m = N_m I_m A_m$), and the surface magnetic moment ($M_s = N_s I_s A_s$). N, I, and A are the transmit loop number of turns, current in amperes, and area in square meters, respectively. The transmission loss is defined as the amount by which the presence of the overburden decreases the magnetic field signal strength below the field strength produced by an infinitesimal static magnetic dipole of the same strength. Namely, TLU and TLD are defined as follows:

$$\mathrm{TLU} = -20 \log\left(\frac{2\pi D^3}{M_m}\right) - \mathrm{SEMF} + 120 \quad (\mathrm{dB}) \qquad (2)$$

$$\mathrm{TLD} = -20 \log\left(\frac{2\pi D^3}{M_s}\right) - \mathbf{MEMF} + 120 \quad (\mathrm{dB}) \qquad (3)$$

where SEMF and MEMF are surface and in-mine vertical components of magnetic field strength in dB re 1 μA/m, respectively; M_m and M_s are the in-mine and surface transmit magnetic moments in Amp-m^2, respectively; and D is the overburden depth in meters.

The above quantities were then cross-tabulated by depth and frequency and aggregated in eight depth intervals to give means, standard deviations, maximum and minimum values, and number of mines within each depth interval. The data aggregated by depth interval were also subjected to initial linear regression analyses, the most useful being the regression between field strength and the logarithm of depth at each measured frequency. Tabulations and regression results showed a strong relationship of decreasing signal strength vs. log of depth, indicating a power law type of behavior. A weaker relationship was found between decreasing signal strength with increasing frequency. These results indicated the general nature of the relationships expected, but did not explain significant variations from this behavior on a mine-by-mine basis.

An attempt was made to identify mines exhibiting systematic deviant behavior as a function of proximity to long conductors in the mine or on the surface, or large horizontal offset of the transmit and receive antennas. To assist in this endeavor, an attempt was made to identify and classify so-called "average" transmission loss behavior vs. frequency within each of the eight depth intervals. This classification exercise proved to be fruitless, because of the completely unsystematic behavior displayed by the aggregated transmission loss versus both frequency and depth. Namely, it did not increase monotonically with increasing frequency, nor did it increase monotonically with increasing depth interval. This completely unsystematic behavior of the aggregated transmission loss, together with its wide variability about the average, led to the conclusion that the magnetic field strength itself, instead of the derived transmission loss originally intended, should be the primary variable of interest to characterize the transmission characteristics of mine overburdens of the U.S. coal fields. However, we did conclude that both transmission losses (TLU and TLD) and the quantity ΔTL would, in conjunction with other key identifiers, be highly useful for tagging so-called "outlier" readings demanding closer scrutiny on a mine-by-mine basis.

Comprehensive screening, verification, and purging processes were initiated on the uplink and downlink data to identify those data points requiring closer examination. This was accomplished principally through the generation of a screening chart constructed with the mines rank ordered by depth, and characterized in terms of four key indices of potential problem behavior. The four key indices were:

- Transmission loss negative or suspiciously deviant. A negative transmission loss indicates a field strength reading greater than that obtainable from an equivalent infinitesimal dipole moment in free space (i.e., in the absence of the overburden). This could indicate a grossly erroneous reading, or the presence of a lower loss propagation path between the surface and the mine, likely caused by nearby electrical conductors.

- Δ TL outliers greater than or equal to 10 dB. This would indicate a large unexpected difference in the uplink and downlink transmission characteristics.

- Outlier values of the normalized surface magnetic field greater than or equal to 10 dB from corresponding preliminary regression estimates based on the unpurged data base. All surface magnetic field values were adjusted to those for a nominal transmit moment of 750 Amp-m^2 for this calculation.

- Receiver/transmitter loop horizontal offset tangents greater than 0.1, where the offset tangent is defined as the ratio of the horizontal offset between centers of transmit and receive loops to the overburden depth.

The following columns were also added to the chart to aid the screening process: mine number, indication of **no test** performed, indication of missing signal levels, indication of questionable noise readings, and the values of the ratio of transmit loop radius to the overburden depth for those mines with offset tangents greater than 0.1. Any mine data scoring on one or more of the four key indices described above on any frequency were examined in detail, down to the field report and final report level, to determine

(a) whether the tabulated magnetic field strength levels were correctly transcribed into the computer data base, and (b) if correctly transcribed, whether they should be retained as valid readings or be excluded as defective data or as data falling into a special restrictive category.

The final judgments regarding exclusion of data were always conservative, in the sense that data were retained unless the weight of evidence against them was clearly strong. As a result, very few data points were excluded, and only for the following reasons:

- Defective receiver equipment, or suspected defective equipment coupled with highly deviant readings (as determined from the Westinghouse field reports and/or final report);

- Negative transmission losses greater than or equal to $|-4|$ dB; negative transmission losses less than $|-4|$ dB were allowed because sample calculations indicated that overburden depth reporting errors on the order of 10 to 20 percent (a rare but real possibility at some mines in this program) could produce errors on the order of 2 to 5 dB in the calculated transmission loss. These infrequent errors stemmed from the absence of accurate information on site depth or absolute horizontal location of the in-mine and surface measurement sites.

- Signal levels based on the use of the temperature calibration chart, not on the signal injection method. These chart-based levels are less reliable, because they are based on laboratory-prepared charts of receiver response versus receiver temperature in degrees Farenheit, which depend on estimating the physical receiver temperature in the test environment. This comparatively unreliable method was used as a fallback when the signal substitution method was unavailable.

- Very large horizontal offset tangents; i.e., greater than 0.45 in conjunction with deep overburdens. Only two mines fell into this category, having not only a large tangent but a numerically large horizontal offset, which placed the antennas significantly far apart horizontally.

A fifth category was also used in a few instances to delete some data; namely:

- Signal levels judged to be less reliable than corresponding levels derived from Bureau of Mines surface tape recordings. These levels were subsequently replaced by the Bureau of Mines values.

The initial screening, verification, and purging (deleting) of the data were performed in this manner. The transmission losses (TLU, TLD) were calculated based on the originally recorded information on loop antenna areas, dimensions, currents, and numbers of turns, used at the 94 mine sites, as recorded by the Westinghouse measurement team for both uplink and downlink transmission tests. The loop currents in the surface antennas were true sinusoids, and measured with an RMS meter; therefore, the derived antenna magnetic moments were the required RMS values for the fundamental frequency of the transmitter. However, the in-mine currents were exponential, periodic ac waveforms, not sinusoids, and the recorded approximate "RMS currents" were derived from the peak-to-peak values recorded with the portable oscilloscope on the basis of a sinusoidal waveform assumption. These current values did not represent the required true RMS values for the loop current component at the fundamental frequency of the in-mine transmitter. Therefore, we obtained a more accurate and dependable estimate of the in-mine RMS fundamental current and also of the uplink transmission loss, TLU, in order to allow a more accurate and reliable screening and purging of data, and subsequent data analysis based on all magnetic field readings normalized to a unit strength of M = 1 Amp-m^2. This was accomplished by the method described in Appendix C.

2. Tabulation of Magnetic Moments and Screened Signal Data

The RMS values of in-mine fundamental loop current, computed by the method of Appendix C, were used to generate the required fundamental magnetic moments for the in-mine loop antennas tabulated in Table IV-1. The corresponding RMS values of fundamental magnetic moment for the surface loop antennas are tabulated in Table IV-2.

The RMS values of the fundamental in-mine magnetic moment (M_{FUND}) listed in Table IV-1 were used to regenerate the key evaluation indices of TLU and ΔTL for a revised screening and verification chart to make the final data purge. This final assessment resulted in the purging of only one additional uplink data point. Table IV-3 presents a complete tabulation of the RMS values, at the transmitter fundamental frequency, of all the uplink vertical magnetic field strengths measured on the surface above mines, appropriately annotated to indicate the specific nature of missing data and to indicate which data points were selected for deletion, and the specific reason for each deletion. Table IV-4 presents the corresponding results for the RMS values, at the transmitter fundamental frequency, of all the downlink vertical magnetic field strengths measured in the mines, appropriately annotated as in Table IV-3.

Table D-1 of Appendix D presents a more comprehensive tabulation of the screened, but undeleted, values of surface and in-mine vertical magnetic field strengths, rank ordered by mine

Table IV-1

In-Mine Collins Transmitter RMS Magnetic Moment (MMFund) At Fundamental Operating Frequency Versus Frequency and Depth at 94 Coal Mine Sites

RMS Moment in Amp-m^2

Mine No.	State	Depth (ft.)	Frequency (Hz) 630	1050	1950	3030
93	KY	69	193	143	87	58
91	KY	190	735	612	415	288
8	KY	200	1410	1079	671	450
18	PA	210	970	774	501	341
36	WV	216	1310	1026	651	440
33	WV	230	141	137	125	108
65	WV	233	936	760	501	344
17	PA	239	1142	909	587	399
71	PA	239	1141	890	563	380
12	WV	250	847N	698N	468N	323N
10	OH	254	847	698	468	323
66	WV	256	936	760	501	344
85	KY	260	1087	871	565	385
44	AL	262	906	741	493	339
47	KY	262	639	543	379	266
92	KY	262	1324	1037	658	445
9	OH	264	847	698	468	323
11	WV	264	766	619	405	277
24	KY	270	549	474	338	240
51	IL	279	718	601	410	285
55	IL	289	1444	1119	704	474
43	AL	295	618	528	370	261
54	IL	308	926	756	501	344
21	PA	325	759	631	427	296
30	KY	325	1197	948	608	413
35	WV	325	1324	1037	658	445

N = No test measurement performed.

Source: Arthur D. Little, Inc., Westinghouse(1,4), and U. S. Bureau of Mines(5).

Table IV-1(Continued)

Mine No.	State	Depth (ft.)	Frequency (Hz)			
			630	1050	1950	3030
94	KY	328	447	306	176	115
32	WV	331	1089	870	563	383
13	PA	341	1197	948	608	413
20	PA	341	1173	931	599	407
19	PA	348	415	339	224	154
60	WV	351	1025	826	540	369
64	WV	354	1055	846	550	375
42	AL	358	815	672	451	312
88	KY	380	531	457	323	229
59	WV	387	847	698	468	323
87	KY	400	1087	871	565	385
2	KY	403	618	528	370	261
3	KY	403	618	528	370	261
67	WV	420	1439	1115	701	472
56	WV	423	855	700	466	321
25	VA	426	1192	932	591	399
69	WV	430	1220	957	609	412
14	PA	446	1264	995	635	430
68	WV	449	847	698	468	323
52	IL	459	858	706	471	325
40	AL	469	1099N	870N	558N	379N
82	OH	469	959	779	513	352
37	PA	479	1444	1119	704	474
49	KY	479	926	755	501	344
74	PA	479	1324	1037	658	445
72	PA	482	888	726	482	331
41	AL	485	847	698	468	323
63	WV	485	1102	878	567	386
86	KY	499	1324	1037	658	445

Table IV-1 (Continued)

Mine No.	State	Depth (ft.)	Frequency (Hz) 630	1050	1950	3030
80	OH	500	847N	698	468	323
39	WV	508	1197	948	608	413
28	VA	518	1746	1325	818	547
7	VA	520	1613	1232	765	513
83	OH	541	815	672	451	312
84	OH	561	964	782	515	353
22	WV	569	1346	1049	663	447
29	VA	581	1727	1269	764	507
58	WV	581	1028	816	524	356
1	KY	600	1599	1206	741	495
15	PA	600	931	759	502	345
81	OH	600	558	481	342	243
31	VA	620	1410	1079	671	450
73	PA	626	2047	1527	930	620
53	IL	649	1516	1169	731	492
89	AL	649	906	741	493	339
75	PA	658	1471	1134	710	478
6	KY	674	1545	1172	724	484
62	WV	686	936	760	501	344
16	PA	689	847	698	468	323
26	VA	689	1203	952	611	414
27	VA	689	1017	929	727	546
50	IL	745	1299	1017	646	437
38	WV	781	2216	1639	992	659
4	IL	800	1438	1097	680	456
61	WV	846	936N	760N	501N	344N

Table IV-1 (Continued)

Mine No.	State	Depth (ft.)	Frequency (Hz) 630	 1050	 1950	 3030
70	WV	915	1467	1132	709	477
45	TN	945	1265	986	623	420
77	UT	1000	1220N	957N	609N	412N
48	KY	1010	1319	1020	641	431
57	WV	1050	1412	1081	672	451
46	TN	1191	1123	896	580	395
76	UT	1197	1031	819	527	358
23	VA	1200	1688	1279	789	527
78	UT	1200	2047	1527	930	620
34	WV	1342	2045	1526	929	619
5	KY	1397	1545	1172	724	484
79	CO	1401	1342	1039	653	440
90	AL	1551	2047	1527	930	620

Table IV-2

Surface Transmitter RMS Magnetic Moment (MMDN) at Fundamental Operating Frequency versus Frequency and Depth at 94 Coal Mine Sites

RMS Moment in Amp-m^2

			Frequency (Hz)			
Mine No.	State	Depth (ft.)	630	1050	1950	3030
93	KY	69	1860	1860	1860	1860
91	KY	190	1896	1896	1896	1896
8	KY	200	N	N	N	N
18	PA	210	3600	3600	3600	3600
36	WV	216	4800	4800	4800	4800
33	WV	230	1183	1183	1183	1183
65	WV	233	8944	8944	8944	8944
17	PA	239	3600	3600	3600	3600
71	PA	239	2175	2175	2175	2175
12	WV	250	10560	10560	10560	10560
10	OH	254	3600	3600	3600	3600
66	WV	256	4992	4992	4992	4992
85	KY	260	2340	2340	2340	2340
44	AL	262	1045	1045	1045	1045
47	KY	262	852	852	852	852
92	KY	262	3400	3400	3400	3400
9	OH	264	18000	18000	18000	18000
11	WV	264	1019	1019	1019	741
24	KY	270	5800	5800	5800	5800
51	IL	279	4125	6600	6600	6600

N = No test measurement performed.

Source: Arthur D. Little, Inc., Westinghouse,(1,4) and U.S. Bureau of Mines.(5)

Table IV-2(continued)

Mine No.	State	Depth (ft.)	Frequency (Hz) 630	1050	1950	3030
55	IL	289	N	N	N	N
43	AL	295	7250	7250	7250	7250
54	IL	308	1671	1671	1671	1671
21	PA	325	11850	7900	10270	7900
30	KY	325	6680	6680	6680	6680
35	WV	325	9600	9600	9600	9600
94	KY	328	N	N	N	N
32	WV	331	7250	7250	7250	7250
13	PA	341	9235	9235	9235	9235
20	PA	341	9235	9235	9235	9235
19	PA	348	9235	9235	9235	9235
60	WV	351	3252	3252	3252	3252
64	WV	354	4430	4430	4430	4430
42	AL	358	12361	12361	12361	12361
88	KY	380	837	837	837	837
59	WV	387	3930	3930	3930	3930
87	KY	400	6145	6145	6145	6145
2	KY	403	655	655	655	655
3	KY	403	655	655	655	655
67	WV	420	2465	2465	2465	2465
56	WV	423	2033N	2033N	2033N	2033N
25	VA	426	8700	8700	8700	8700
69	WV	430	3250	3250	3250	3250
14	PA	446	9235	9235	9235	9235
68	WV	449	2325	2325	2325	2325
52	IL	459	2540	2540	2540	2540
40	AL	469	8700	8700	8700	8700
82	OH	469	N	N	N	N
37	PA	479	9600	9600	9600	9600
49	KY	479	8250	8250	8250	8250

Table IV-2 (continued)

Mine No.	State	Depth (ft.)	Frequency (Hz) 630	1050	1950	3030
74	PA	479	N	N	N	N
72	PA	482	7315	7315	7315	7315
41	AL	485	15164	18662	15164	15164
63	WV	485	5460	5460	5460	5460
86	KY	499	4389	4389	4389	4389
80	OH	500	3402	3402	3402	3402
39	WV	508	11200	11200	11200	11200
28	VA	518	3112	3112	3112	3112
7	VA	520	12200	12200	12200	12200
83	OH	541	6168	6168	6168	6168
84	OH	561	3568	3568	3568	3568
22	WV	569	11600	11600	11600	11600
29	VA	581	5048	5048	5048	5048
58	WV	581	10024	10024	10024	10024
1	KY	600	4875	4875	4875	4875
15	PA	600	9235	9235	9235	9235
81	OH	600	7352	7352	7352	7352
31	VA	620	8450	8450	8450	8450
73	PA	626	3416	3416	3416	3416
53	IL	649	8470	8470	8470	8470
89	AL	649	9562	9562	9562	9562
75	PA	658	N	N	N	N
6	KY	674	18810	18810	18810	18810
62	WV	686	N	N	N	N
16	PA	689	13200	13200	13200	13200
26	VA	689	14500	14500	14500	14500
27	VA	689	N	N	N	N
50	IL	745	16000	16000	16000	16000
38	WV	781	16000	16000	16000	16000
4	IL	800	7260	7260	7260	7260
61	WV	846	17700	17700	17700	17700

Table IV - 2 (continued)

Mine No.	State	Depth (ft.)	Frequency (Hz) 630	1050	1950	3030
70	WV	915	4008N	4008N	4008N	4008N
45	TN	945	17004	17004	17004	17004
77	UT	1000	19240	25095	18403	20076
48	KY	1010	23100	23100	23100	23100
57	WV	1050	13068	13068	8712	13068
46	TN	1191	19800	19800	19800	19800
76	UT	1197	19550	25500	18700	20400
23	VA	1200	19575	19575	19575	19575
78	UT	1200	8954	12210	9768	9768
34	WV	1342	19600	19600	19600	19600
5	KY	1397	15700	15700	15700	15700
79	CO	1401	22200	27750	24050	24050
90	AL	1551	23125	27750	22200	23125

Table IV-3

Surface Vertical Magnetic Field
Signal Levels vs. Overburden Depth
Measured by Westinghouse
at 94 Coal Mine Sites
Using Collins ULF Transmitter

RMS Signal Level in dB re 1 μA/m

Symbols:

N = No test measurement performed
F = Failure to detect transmitted signal
D = Outlier reading deleted from initial regressions
S = Received, but value not recorded

			Frequency (Hz)			
Mine No.	State	Depth (ft.)	630	1050	1950	3030
93	KY	69	57.00	56.0	53.00	52.0
91	KY	190	44.00	41.0	36.00	33.0
8	KY	200	48.80	49.0	44.10	45.8
18	PA	210	48.00	48.0	42.00	44.0
36	WV	216	53.00	53.0	51.50	49.0
33	WV	230	26.00	29.0	32.00	31.0
65	WV	233	44.00	44.0	40.00	40.0
17	PA	239	45.00	42.0	36.00	34.0
71	PA	239	54.00[5]	52.0	43.00[5]	39.0[5]
12	WV	250	N	N	N	N
10	OH	254	46.25	40.1	42.20	40.3
66	WV	256	16.00	17.0	15.00	16.0
85	KY	260	45.00	44.0	39.00	40.0
44	AL	262	48.00	47.0	44.00	41.0
47	KY	262	43.00	41.5	40.00	33.0
92	KY	262	47.50	46.5	44.00	38.0
9	OH	264	41.20	41.4	37.45	34.7
11	WV	264	44.00	45.0	42.00	43.0D[4]
24	KY	270	39.00	37.5	35.50	36.0
51	IL	279	26.00	33.0	29.00	30.0

Source: Arthur D. Little, Inc., Westinghouse(1,4) and U.S. Bureau of Mines.(5)

Table IV-3(continued)

			Frequency (Hz)			
Mine No.	State	Depth (ft.)	630	1050	1950	3030
55	IL	289	44.00	43.0	37.00	34.0
43	AL	295	43.00	36.0	34.00	41.0D[4]
54	IL	308	40.00	37.0	26.00	23.0
21	PA	325	30.00	25.0	17.00	5.0
30	KY	325	35.00	33.0	32.00	33.0
35	WV	325	43.00	42.0	37.00	35.5
94	KY	328	27.50	20.0	7.00	-4.0
32	WV	331	32.00	31.0	24.00	31.0
13	PA	341	36.00	36.0	36.00	31.0
20	PA	341	35.00	35.0	30.00	28.0
19	PA	348	23.00	22.0	18.00	14.0
60	WV	351	40.00	S	37.00	35.0
64	WV	354	34.00	34.0	31.00	31.0
42	AL	358	35.00	36.0	31.00	29.0
88	KY	380	29.00	28.0	26.00	23.0
59	WV	387	30.00	30.0	23.00	21.0
87	KY	400	30.00	28.0	24.00	24.0
2	KY	403	32.30	29.3	23.60	17.9
3	KY	403	30.30	27.0	20.80	10.9
67	WV	420	38.00	36.0	31.00	29.0
56	WV	423	35.00	33.0	29.00	27.0
25	VA	426	33.00	31.0	20.00	43.0D[4]
69	WV	430	F[5]	F[5]	32.00[5]	25.0[5]
14	PA	446	33.00	30.0	19.00	9.0
68	WV	449	F	F	F	F
52	IL	459	29.00	25.0	20.00	14.0
40	AL	469	N	N	N	N
82	OH	469	8.00[5]	8.0[5]	1.00[5]	-9.0[5]
37	PA	479	33.00	32.0	26.00	21.0
49	KY	479	30.50	29.5	27.00	24.0

Table IV-3 (continued)

Mine No.	State	Depth (ft.)	Frequency (Hz)			
			630	1050	1950	3030
74	PA	479	28.00	25.0	F	15.0
72	PA	482	26.00	24.0	18.00	16.0
41	AL	485	21.50	21.5	15.50	13.5
63	WV	485	30.00	26.0	16.00	18.0
86	KY	499	26.00	24.0	18.00	14.0
80	OH	500	N	9.0	-7.00	- 7.0
39	WV	508	29.00	26.0	18.00	13.0
28	VA	518	14.00	19.0	8.50	8.0
7	VA	520	S[1]	52.3D[1]	47.40D[1]	43.1D[1]
83	OH	541	15.00	12.0	6.00	- 3.0
84	OH	561	13.00	20.0	12.00	5.0
22	WV	569	8.00D[2]	17.9D[2]	21.60D[2]	6.6 D[2]
29	VA	581	28.00	25.0	22.00	19.5
58	WV	581	27.00	24.0	19.00	15.0
1	KY	600	20.70	14.3	5.85	0.5
15	PA	600	17.00	16.0	12.00	10.0
81	OH	600	15.00	11.0	2.00	-11.0
31	VA	620	23.00	21.0	17.00	17.0
73	PA	626	F	F	F	F
53	IL	649	20.00	10.0	10.00	S
89	AL	649	22.00	20.0	16.00	10.0
75	PA	658	27.00	15.0	12.00	3.0
6	KY	674	24.10D[2]	20.7D[2]	13.00D[2]	- 9.9D[2]
62	WV	686	6.00	4.0	0.00	- 6.0
16	PA	689	10.00	7.0	5.00	- 3.0
26	VA	689	19.00	17.0	14.00	9.0
27	VA	689	21.00	19.0	17.00	16.0
50	IL	745	4.00	-7.0	0.00	-16.0
38	WV	781	22.00	17.0	5.00	-11.5
4	IL	800	-7.70	-8.9	F	F
61	WV	846	N	N	N	N

TableIV-3 (continued)

Mine No.	State	Depth (ft.)	Frequency (Hz) 630	1050	1950	3030
70	WV	915	F[5]	F[5]	- 6.00[5]	F[5]
45	TN	945	16.00D[3]	9.0D[3]	10.00D[3]	- 6.0D[3]
77	UT	1000	N	N	N	N
48	KY	1010	13.00	8.0	4.00	0.0
57	WV	1050	18.00	14.0	7.00	3.0
46	TN	1191	6.00	1.0	F	-17.0
76	UT	1197	F[5]	2.0[5]	F	F[5]
23	VA	1200	F	F	F	F
78	UT	1200	13.00	7.0	2.00	- 5.0
34	WV	1342	- 2.00	- 8.0	-20.00	-24.0
5	KY	1397	3.26	F	- 0.02	- 7.0
79	CO	1401	- 1.60D[2]	-11.0D[2]	F	F
90	AL	1551	- 2.00	- 9.0	-12.00	-16.0

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[1] Defective surface receiver

[2] Reading based on temperature calibration chart, not on signal injection method

[3] Very large horizontal offset between surface receiver and in-mine transmitter

[4] Transmission loss, TLU| ≥ -4 |dB;
i.e.: SEMF ≥ free space field + 4 dB

[5] Substituted field value from Bureau of Mines tape recordings judged to be more reliable than Westinghouse readings

Table IV-4

In-Mine Magnetic Field (Mainly Vertical) Signal Levels (MEMF) vs. Overburden Depth Measured by Westinghouse at 94 Coal Mine Sites

RMS Signal Level in dB re 1 μA/m

Symbols:

N = No test measurement performed
F = Failure to detect transmitted signal
D = Outlier reading deleted from initial regressions
S = Received, but value not recorded

Mine No.	State	Depth (ft.)	Frequency (Hz) 630	1050	1950	3030
93	KY	69	67.50	67.0	67.50	68.00
91	KY	190	52.50	53.0	51.00	51.00
8	KY	200	N	N	N	N
18	PA	210	62.00	61.0	61.00	60.00
36	WV	216	64.00	64.0	63.00	64.00
33	WV	230	42.50	42.5	43.00	42.50
65	WV	233	76.00D[2]	69.0D[2]	70.00D[2]	70.00D[2]
17	PA	239	55.00	54.0	54.00	51.00
71	PA	239	61.00	62.0	61.00	60.00
12	WV	250	60.47	56.4	57.50	56.47
10	OH	254	60.10	56.1	51.12	50.90
66	WV	256	F	F	36.00	40.00
85	KY	260	55.00	54.0	54.00	54.00
44	AL	262	39.00	47.0	50.00	50.00
47	KY	262	48.50	49.0	51.00	49.00
92	KY	262	-5.00D[1]	-11.0D[1]	-11.00D[1]	-16.00D[1]
9	OH	264	68.00	64.1	60.70	60.10
11	WV	264	32.90	28.4	34.40	35.60
24	KY	270	56.00	53.0	57.00	55.00
51	IL	279	71.00D[4]	71.0D[4]	66.00	65.00

Source: Arthur D. Little, Inc., Westinghouse,(1,4) and U.S. Bureau of Mines.(5)

Table IV-4(continued)

Mine No.	State	Depth (ft.)	Frequency (Hz) 630	1050	1950	3030
55	IL	289	N	N	N	N
43	AL	295	61.00	60.0	60.00	58.00
54	IL	308	48.00	46.0	F	40.00
21	PA	325	60.00	55.0	55.00	59.00
30	KY	325	56.00	56.0	56.00	56.00
35	WV	325	61.00	60.0	60.00	60.00
94	KY	328	N	N	N	N
32	WV	331	53.00	53.0	53.00	52.00
13	PA	341	58.00	57.0	56.00	52.00
20	PA	341	47.00	53.0	52.00	52.00
19	PA	348	55.00	54.0	53.00	52.00
60	WV	351	53.00	50.0	51.00	50.00
64	WV	354	54.00	54.0	54.00	54.00
42	AL	358	62.00	61.0	60.50	60.50
88	KY	380	35.00	35.0	32.00	33.00
59	WV	387	49.00	50.0	48.00	45.00
87	KY	400	52.00	52.0	52.00	52.00
2	KY	403	33.30	30.3	27.30	21.80
3	KY	403	28.30	21.3	15.30	10.80
67	WV	420	41.00	48.0	F	54.00D[4]
56	WV	423	N	N	N	N
25	VA	426	36.10	39.1	47.10	45.30
69	WV	430	F	F	30.00	32.00
14	PA	446	49.00	49.0	46.00	46.00
68	WV	449	27.00	28.0	26.00	25.00
52	IL	459	38.00	34.0	31.00	31.00
40	AL	469	56.00	53.0	50.00	48.00
82	OH	469	N	N	N	N
37	PA	479	51.00	50.0	48.00	45.00
49	KY	479	50.00	49.0	49.00	49.00

Table IV-4 (continued)

			Frequency (Hz)			
Mine No.	State	Depth (ft.)	630	1050	1950	3030
74	PA	479	N	N	N	N
72	PA	482	53.00	52.0	51.00	49.00
41	AL	485	25.00	36.0	32.00	36.00
63	WV	485	54.00D[4]	46.0	46.00	48.00
86	KY	499	41.50	F	37.00	35.00
80	OH	500	36.00	30.0	F	24.00
39	WV	508	51.50	47.0	45.00	42.50
28	VA	518	F	F	F	10.00
7	VA	520	48.70	49.2	48.70	51.20
83	OH	541	39.00	21.0	32.00	25.00
84	OH	561	37.00	32.0	20.00	24.00
22	WV	569	51.00	51.0	50.00	52.20
29	VA	581	42.00	40.0	37.00	36.00
58	WV	581	48.00	48.0	45.00	44.00
1	KY	600	48.75D[4]	43.8	33.75	30.75
15	PA	600	47.00	45.0	44.00	44.00
81	OH	600	41.00	38.0	32.00	26.00
31	VA	620	42.00	41.0	41.00	41.00
73	PA	626	F	33.0	33.00	F
53	IL	649	39.00	35.0	27.00	20.00
89	AL	649	41.50	40.5	38.50	38.00
75	PA	658	N	N	N	N
6	KY	674	F	-5.7D[2]	F	F
62	WV	686	N	N	N	N
16	PA	689	41.00	39.0	36.00	33.00
26	VA	689	40.00	52.0D[4]	49.00	52.00D[4]
27	VA	689	N	N	N	N
50	IL	745	36.00	33.0	23.50	18.00
38	WV	781	38.00	33.0	27.00	20.50
4	IL	800	46.20D[4]	22.2	4.70	-0.78
61	WV	846	18.00D[3]	16.0D[3]	18.00D[3]	16.00D[3]

Table IV- 4 (continued)

Mine No.	State	Depth (ft.)	Frequency (Hz) 630	1050	1950	3030
70	WV	915	N	N	N	N
45	TN	945	19.00D[3]	F	13.00D[3]	4.00D[3]
77	UT	1000	25.00	28.0	21.00	20.00
48	KY	1010	38.00	37.0	36.00	34.00
57	WV	1050	15.00	8.0	0.00	-1.00
46	TN	1191	34.50	32.0	27.50	23.00
76	UT	1197	28.00	26.0	17.00	11.00
23	VA	1200	15.00	14.0	15.00	18.00
78	UT	1200	29.00	29.0	25.00	22.00
34	WV	1342	F	15.0	3.00	F
5	KY	1397	F	F	F	F
79	CO	1401	F	F	F	F
90	AL	1551	-2.00	-6.0	F	-26.00

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[1] Defective surface receiver

[2] Reading based on temperature calibration chart, not on signal injection method

[3] Very large horizontal offset between surface receiver and in-mine transmitter

[4] Transmission loss, TLU|≥ -4|dB; i.e.: SEMF ≥ free space field +4 dB

[5] Substituted field value from Bureau of Mines tape recordings judged to be more reliable than Westinghouse readings

depth, together with the key indices of uplink transmission loss (TLU), downlink transmission loss (TLD), and Δ TL. Also included are the mine number, the in-mine antenna area, the mine fundamental current (I_{FUND}), the mine fundamental magnetic moment (MM_{FUND}), the Westinghouse tabulated in-mine current (I_{WEST}), and I_{EST}, I_{DEL}, I_{DIFF}, and I_{DIFF2}, which are comparative estimates of loop current and current differences explained in Appendix D.

3. Conclusions Related to Other Variables

The above screening, verification, and purging process included not only data analysis, but the detailed examination of mine maps and both quantitative and subjective information from the Westinghouse field reports and final report. As a result, we came to a number of other conclusions regarding the likely relevance of several test conditions and variables for characterizing the primary overburden transmission characteristics from the data set. These conclusions are listed below:

- The presence of long electrical conductors, such as power lines, phone lines, pipes, rails, etc., located near the transmit and/or receive antennas, did not appear to produce consistent, recurring or systematic, deviant behavior in the measured signal strength, either on the surface or in the mine. Although there were a few mines in which significantly large deviations of an enhancing nature were observed, and likely caused by coupling to electrical conductors, such large deviations were the exception rather than the rule in the presence of conductors. As a result, the few very large deviant points were classified as exceptional "outliers" and deleted from the data base. Most of the other deviant points were retained without being given any special attention, because their negative transmission losses were not greater than | -4 | dB.

- Corrections to the field strength readings to account for the finite size of the transmit antenna relative to the overburden depth as compared to that for an infinitesimal magnetic dipole antenna were not warranted. The objective was to determine the magnetic field strength relationship with overburden depth for the kind and size of loop antennas to be used under disaster conditions, not what might occur if one were to use an infinitesimal ideal magnetic dipole.

- Corrections to the measured magnetic field strengths, based on homogeneous earth theoretical propagation models, to account for horizontal offsets from the point directly above or below the transmitters were not justifiable on a mine-by-mine basis. Reasons for this conclusion include (a) the approximate nature of the model itself; (b) the errors incurred in depth estimation as a result of horizontal positioning errors and/or lack of precise overburden depth information at some mines; (c) the absolute sizes of the horizontal offsets compared to the finite but similar sizes of the transmit and receive antennas, and to the overburden depth; and (d) the relatively small corrections predicted for the near overhead conditions at most mine sites. Namely, we believe that these factors, taken together, are likely to lead to corrections that are not meaningful. As in the case with nearby conductors, there were a few mines with extremely large offsets, and the data from these were deleted as non-representative on the initial data screening.

Therefore, all magnetic field strength data retained in the data base for subsequent statistical analysis should be considered representative of behavior observed at or near "ground zero," for all practical purposes; namely, directly above or below (i.e., coaxial with) the appropriate transmitters. This also implies, of course, that the data and results should also apply to configurations having horizontal offsets of up to several hundred feet, particularly at deep mines. This is not surprising, because the vertical component of magnetic field exhibits the slowly varying cosine-type dependence with horizontal offset in the vicinity of the transmit loop vertical axis. For large offsets, on the order of the overburden depth, the horizontal magnetic field component should start to predominate at about a level more than 10 dB below the peak vertical field strength directly above the transmitter. In addition, the results should apply even in the presence of electrical conductors; except, for example, in rare pathological cases where the conductor provides a direct alternative signal path (up a borehole, for example) to the surface receiver. Although it was judged unnecessary and impractical for the purposes of this study to devote additional effort to the extraction of perhaps marginal relationships on the influence of nearby conductors and horizontal offsets from the data base, some scientific benefits may be obtainable from more detailed analyses of the data base by others in the future.

C. THE FINAL UPLINK SIGNAL DATA BASE

The final "expanded" surface signal data base used for the final statistical analyses is presented in Table IV-5. This data base was created by replacing, where possible, both missing and deleted data with appropriately adjusted downlink in-mine field strength values, or by readmitting data points previously deleted

TableIV-5

Final Screened Surface Signal Data with Substitutions and Replacements -- Vertical Magnetic Field Levels vs. Overburden Depth from 94 Coal Mine Sites

RMS Signal Level (SEMF) in dB re 1 μA/m

Symbols:

N = No test measurement performed
F = Failure to detect transmitted signal
a = Substituted in-mine value adjusted for difference between in-mine and surface transmit moments;
SEMFA = MEMF - 20 log (MMDN/MMFUND)
b = Readmitted surface value originally deleted during first purge

			Frequency (Hz)			
Mine No.	State	Depth (ft.)	630	1050	1950	3030
93	KY	69	57.00	56.00	53.00	52.00
91	KY	190	44.00	41.00	36.00	33.00
8	KY	200	48.80	49.00	44.10	45.80
18	PA	210	48.00	48.00	42.00	44.00
36	WV	216	53.00	53.00	51.50	49.00
33	WV	230	26.00	29.00	32.00	31.00
65	WV	233	44.00	44.00	40.00	40.00
17	PA	239	45.00	42.00	36.00	34.00
71	PA	239	54.00	52.00	43.00	39.00
12	WV	250	38.55a	32.80a	30.43a	26.18a
10	OH	254	46.25	40.10	42.20	40.30
66	WV	256	16.00	17.00	15.00	16.00
85	KY	260	45.00	44.00	39.00	40.00
44	AL	262	48.00	47.00	44.00	41.00
47	KY	262	43.00	41.50	40.00	33.00
92	KY	262	47.50	46.50	44.00	38.00
9	OH	264	41.20	41.40	37.45	34.70
11	WV	264	44.00	45.00	42.00	43.00b
24	KY	270	39.00	37.50	35.50	36.00
51	IL	279	26.00	33.00	29.00	30.00

Source: Arthur D. Little, Inc., Westinghouse,(1,4) and U.S. Bureau of Mines.(5)

Table IV-5 (continued)

Mine No.	State	Depth (ft.)	Frequency (Hz)			
			630	1050	1950	3030
55	IL	289	44.00	43.00	37.00	34.00
43	AL	295	43.00	36.00	34.00	29.12a
54	IL	308	40.00	37.00	26.00	23.00
21	PA	325	30.00	25.00	17.00	5.00
30	KY	325	35.00	33.00	32.00	33.00
35	WV	325	43.00	42.00	37.00	35.50
94	KY	328	27.50	20.00	7.00	-4.00
32	WV	331	32.00	31.00	24.00	31.00
13	PA	341	36.00	36.00	36.00	31.00
20	PA	341	35.00	35.00	30.00	28.00
19	PA	348	23.00	22.00	18.00	14.00
60	WV	351	40.00	38.10a	37.00	35.00
64	WV	354	34.00	34.00	31.00	31.00
42	AL	358	35.00	36.00	31.00	29.00
88	KY	380	29.00	28.00	26.00	23.00
59	WV	387	30.00	30.00	23.00	21.00
87	KY	400	30.00	28.00	24.00	24.00
2	KY	403	32.30	29.30	23.60	17.90
3	KY	403	30.30	27.00	20.80	10.90
67	WV	420	38.00	36.00	31.00	29.00
56	WV	423	35.00	33.00	29.00	27.00
25	VA	426	33.00	31.00	20.00	18.53a
69	WV	430	F	F	32.00	25.00
14	PA	446	33.00	30.00	19.00	9.00
68	WV	449	18.23a	17.55a	12.07a	7.86a
52	IL	459	29.00	25.00	20.00	14.00
40	AL	469	38.03a	33.00a	26.14a	20.78a
82	OH	469	8.00	8.00	1.00	-9.00
37	PA	479	33.00	32.00	26.00	21.00
49	KY	479	30.50	29.50	27.00	24.00

Table IV-5 (continued)

Mine No.	State	Depth (ft.)	Frequency (Hz) 630	1050	1950	3030
74	PA	479	28.00	25.00	F	15.00
72	PA	482	26.00	24.00	18.00	16.00
41	AL	485	21.50	21.50	15.50	13.50
63	WV	485	30.00	26.00	16.00	18.00
86	KY	499	26.00	24.00	18.00	14.00
80	OH	500	23.92a	9.00	7.00	-7.00
39	WV	508	29.00	26.00	18.00	13.00
28	VA	518	14.00	19.00	08.50	8.00
7	VA	520	31.12a	29.28a	24.64a	23.67a
83	OH	541	15.00	12.00	6.00	-3.00
84	OH	561	13.00	20.00	12.00	5.00
22	WV	569	32.29a	30.13a	25.14a	23.93a
29	VA	581	28.00	25.00	22.00	19.50
58	WV	581	27.00	24.00	19.00	15.00
1	KY	600	20.70	14.30	5.85	0.51
15	PA	600	17.00	16.00	12.00	10.00
81	OH	600	15.00	11.00	2.00	-11.00
31	VA	620	23.00	21.00	17.00	17.00
73	PA	626	F	26.01a	21.70a	F
53	IL	649	20.00	10.00	10.00	-4.72a
89	AL	649	22.00	20.00	16.00	10.00
75	PA	658	27.00	15.00	12.00	3.00
6	KY	674	24.10b	20.70b	13.00b	-9.89b
62	WV	686	6.00	4.00	00.00	-6.00
16	PA	689	10.00	7.00	5.00	-3.00
26	VA	689	19.00	17.00	14.00	9.00
27	VA	689	21.00	19.00	17.00	16.00
50	IL	745	4.00	-7.00	0.00	-16.00
38	WV	781	22.00	17.00	5.00	-11.50
4	IL	800	-7.70	-8.90	-15.87a	-24.83a
61	WV	846	N	N	N	N

Table IV-5 (continued)

Mine No.	State	Depth (ft.)	Frequency (Hz) 630	1050	1950	3030
70	WV	915	F	F	-6.00	F
45	TN	945	16.00b	9.00b	10.00b	-6.00b
77	UT	1000	1.05a	-0.37a	-8.61a	-13.76a
48	KY	1010	13.00	8.00	4.00	0.00
57	WV	1050	18.00	14.00	7.00	3.00
46	TN	1191	6.00	1.00	-3.17a	-17.00
76	UT	1197	2.44a	2.00	-13.99a	-24.11a
23	VA	1200	-6.29a	-9.70a	-12.90a	-13.39a
78	UT	1200	13.00	7.00	2.00	-5.00
34	WV	1342	-2.00	-8.00	-20.00	-24.00
5	KY	1397	3.26	F	-0.02	-7.00
79	CO	1401	-1.60b	-11.00b	F	F
90	AL	1551	-2.00	-9.00	-12.00	-16.00

in the initial screening and purging process which resulted in Table IV-3. These substituted or readmitted values are indicated by the letter symbols a and b, respectively, beside each such data point represented in Table IV-5.

As indicated in Table IV-5, the substituted in-mine value has been adjusted in magnitude to reflect the value that would have been measured had the downlink transmitter been equal in strength to the uplink transmitter. The readmitted values designated by b were of three types. The most prevalent type was calibration chart readings for which corresponding in-mine measured values were missing and not available for substitution. In one case, the downlink value was a calibration chart reading judged less appropriate than the surface one. We concluded that a less precise calibration chart reading was better than no reading at all.

The second category of readmitted data was a single mine, No. 45, having a very large offset, but a reasonable transmission loss, so it was readmitted. Finally, a single data point from one mine having a borderline deleted transmission loss of -4.45 dB was readmitted, since this borderline value was more consistent with the other surface readings than the available downlink reading.

The data base of Table IV-5 is the one used in Section V, in conjunction with the in-mine magnetic moment data base of Table IV-1, to generate final normalized surface field strength values for each mine site for a reference transmitter having a magnetic moment of $M = 1$ Amp-m^2. Linear regression analyses were applied to these values to determine the expected transmission response characteristics of overburdens above mines in the U.S. coal fields.

Table D-2 of Appendix D presents a complete printout of the signal data bases of Tables IV-4 and IV-5 for both uplink and downlink magnetic field strengths on the surface and in the mine, rank ordered by depth, together with the following key variables:

- the in-mine fundamental magnetic moment,
- the in-mine fundamental current,
- the downlink surface transmitter magnetic moment,
- the in-mine magnetic moment as computed from the originally tabulated Westinghouse data,
- the three key indices, transmission loss up (TLU), transmission loss down (TLD) and ΔTL,
- the mine number, and
- two current comparison indices, I_{DIFF} and I_{DIFF2}.

Table D-3 presents a summary table of statistics for selected variables vs. frequency, averaged over all depth intervals. Table D-4 presents a tabulation of statistics for another set of key variables averaged within each of the eight depth intervals for each frequency. These more comprehensive tabulations of computer output of our cross-tabulations and other descriptive statistics have been included in Appendix D for convenient reference.

D. SURFACE NOISE DATA BASE

1. Verification and Assessment Process

As the measurement program progressed and noise data from a number of field measurements became available, a number of questions emerged regarding the quality and reliability of the surface noise data taken by the Westinghouse field measurement team. During the second half of the measurement program, a Bureau of Mines PMSRC team accompanied the Westinghouse team and made independent noise measurements at 27 mine sites using an entirely different method of data gathering. As previously described, the Westinghouse team used the Collins receiver with its loop antenna and the signal substitution method to record vertical magnetic field noise levels on the surface at each frequency. The Bureau PSMRC team used the same kind of loop antenna together with a wideband instrumentation-grade tape recorder to record raw vertical magnetic field strengths on the surface that were later processed and analyzed in the laboratory at PMSRC.

The data from the two measurement techniques were compared, and substantial differences were discovered between them. At several mines, the measurement team readings were significantly below the intrinsic self noise limits of the Collins receiver, indicating some conventional data acquisition errors. Even more serious, however, were the more systematic and substantial differences noticed at the two higher frequencies of 1950 and 3030 Hz. At these frequencies, the measurement team data were 10 to 20 dB higher than the Bureau data, while the data for the two lower frequencies, at least on average, were in good agreement. Furthermore, the frequency behavior of the Bureau of Mines data was more compatible with that of atmospheric noise data reported in the literature by other investigators.

To investigate these differences, corresponding noise levels for the 27 common mine sites were verified, and the values from both sources were tabulated in Tables IV-6 and IV-7. Then the common data pairs were plotted for each frequency, as indicated in Figures IV-1 through IV-4. Ideally, all data points should cluster about the 45-degree line shown on each graph. Although the Westinghouse individual meter readings should be expected to exhibit greater variability than the Bureau's readings derived from fast Fourier transform (FFT) analysis of tape recorded noise segments because of the FFT RMS "averaging" process, the two data sets should agree on the average. Furthermore, we would also expect an equal number of Westinghouse values greater than, as well as less than, corresponding Bureau values, since each

Table IV-6

Surface Vertical Magnetic Field Noise Levels
Measured by Westinghouse
with Collins Rescue Receiver
at 27 Coal Mines

"Average" Noise Levels in dB re 1 $\mu A/m/\sqrt{30\ Hz}$
for the 30 Hz Bandwidth Collins Receiver

			Frequency (Hz)			
Mine No.	State	Depth (ft.)	630	1050	1950	3030
93	KY	69	+ 4	- 3	-17	- 9
91	KY	190	+ 0	-20	D	D
71	PA	239	+35	+36	+18	+20
85	KY	260	-11	-11	-20	D
92	KY	262	-10	-10	-15	-10
55	IL	289	+30	+30	+30	+32
88	KY	380	-20	-19	-30	D
87	KY	400	+ 8	+ 5	- 4	+ 4
67	WV	420	- 3	-10	-20	+10
69	WV	430	+20	-20	+ 4	+20
52	IL	459	+ 4	- 6	- 7	- 7
82	OH	469	D	+21	+30	+ 7
74	PA	479	+20	+ 6	+ 4	+10
72	PA	482	- 3	- 4	- 2	- 2
86	KY	499	-10	-11	-16	-17
80	OH	500	N	N	N	N
83	OH	541	+18	- 5	- 6	- 6
84	OH	561	+ 1	+ 0	- 7	- 7
81	OH	600	- 2	+ 1	+ 3	+16
73	PA	626	+32	+20	+16	+30
53	IL	649	+20	+10	+10	+ 4
89	AL	649	+ 8	- 1	- 4	-10
75	PA	658	+10	+ 9	+ 9	+ 5
70	WV	915	+ 0	+20	+ 0	+ 0
76	UT	1197	-13	-10	- 4	-15
78	UT	1200	-10	-10	-10	-10
90	AL	1551	-15	-20	-12	-18

D = Deleted, erroneous reading below intrinsic receiver noise.

N = No test measurement performed.

Source: Arthur D. Little, Inc., Westinghouse,(1,4) and U.S. Bureau of Mines.(3)

Table IV-7

Surface Vertical Magnetic Field Noise Levels Derived from Bureau of Mines Tape Recordings at 27 Coal Mines

Equivalent RMS Noise Levels in dB re 1 $\mu A/m/\sqrt{30\ Hz}$
for a 30 Hz Bandwidth Surface Receiver

Mine No.	State	Depth (ft.)	Frequency (Hz)			
			630	1050	1950	3030
93	KY	69	- 1.3	- 5.6	-11.1	-14.6
91	KY	190	+ 5.8	- 2.6	-12.0	-16.8
71	PA	239	+37.8	+24.3	+15.0	+ 7.2
85	KY	260	- 6.2	-11.7	-19.1	-20.9
92	KY	262	- 3.1	-14.6	-20.6	-24.2
55	IL	289	+ 9.8	+ 1.3	-13.0	-17.9
88	KY	380	- 1.2	- 9.7	-14.1	-18.0
87	KY	400	-15.2	-17.7	-25.0	-34.8
67	WV	420	- 0.2	- 4.7	-13.0	-14.8
69	WV	430	+12.7	+10.3	- 3.0	-10.9
52	IL	459	- 0.2	- 6.7	-11.9	-20.8
82	OH	469	- 6.2	-12.7	-23.0	-25.9
74	PA	479	+20.8	+11.4	+ 5.0	- 0.8
72	PA	482	+ 6.8	+ 1.4	- 5.0	- 7.8
86	KY	499	- 2.2	- 5.7	-13.0	-21.9
80	OH	500	+21.8	+11.4	+ 9.0	- 3.8
83	OH	541	+20.8	+ 6.3	- 0.0	- 6.8
84	OH	561	+ 4.7	+ 0.3	- 8.0	- 7.9
81	OH	600	+ 3.8	- 3.7	-17.1	-25.9
73	PA	626	+29.8	+19.3	+18.0	+ 9.1
53	IL	649	+20.8	+14.3	+ 1.7	- 0.9
89	AL	649	+ 8.8	+ 2.4	- 3.0	-12.9
75	PA	658	+17.8	+10.3	+10.0	+ 6.2
70	WV	915	- 7.2	- 8.7	-17.0	-24.9
76	UT	1197	+ 6.8	+ 0.3	+ 1.0	+ 2.6
78	UT	1200	- 7.2	-11.6	-18.0	-23.9
90	AL	1551	- 8.2	-13.7	-21.0	-24.9

Source: Arthur D. Little, Inc., and U. S. Bureau of Mines.(3)

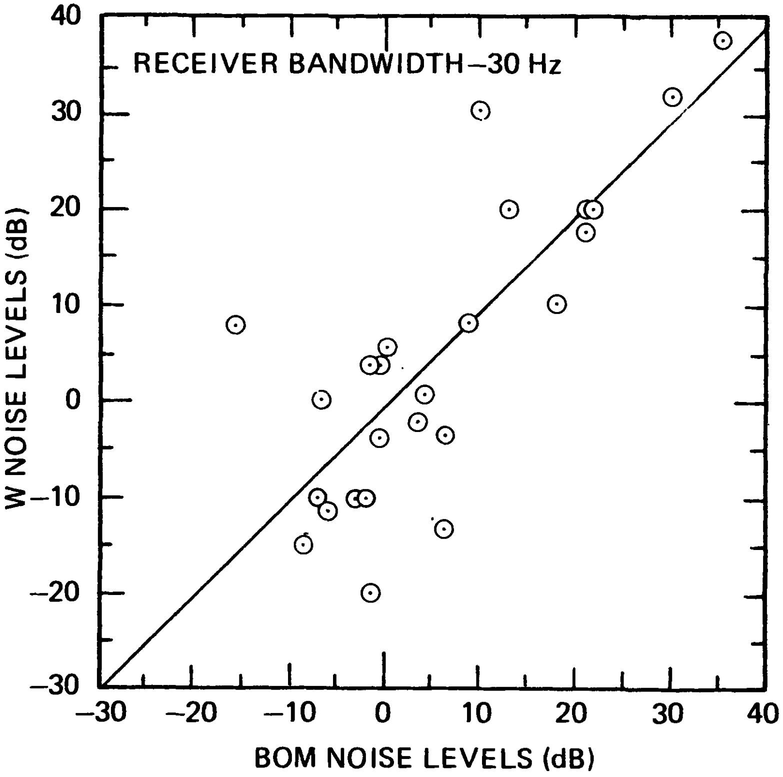

FIGURE IV-1 COMPARISON OF WESTINGHOUSE AND BUREAU OF MINES MEASURED NOISE LEVELS (dBre 1μA/m/$\sqrt{30\text{ Hz}}$) FOR 27 MINES AT 630 Hz

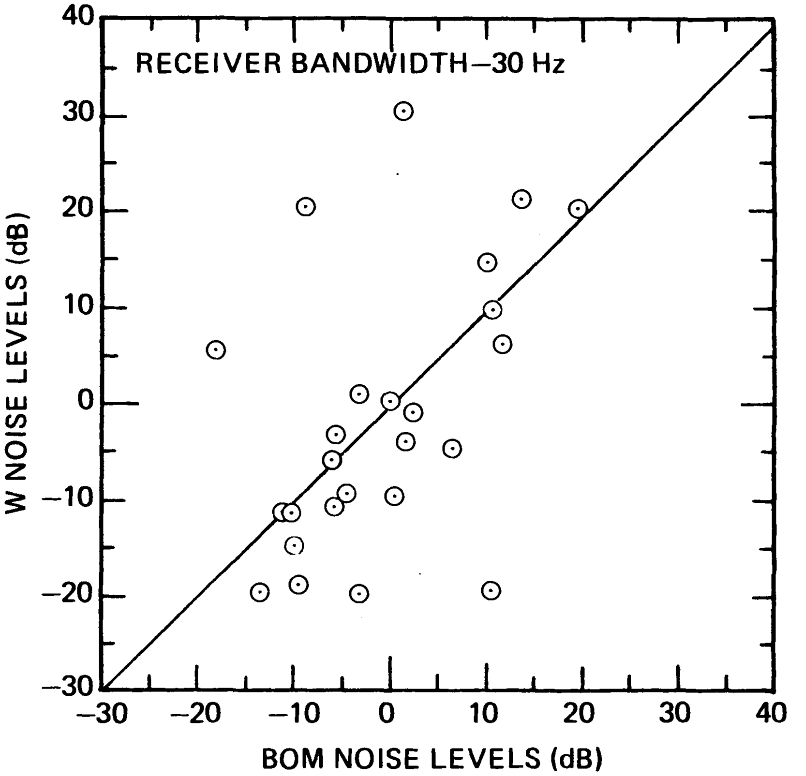

FIGURE IV-2 COMPARISON OF WESTINGHOUSE AND BUREAU OF MINES MEASURED NOISE LEVELS (dBre 1μA/m$\sqrt{30\text{ Hz}}$) FOR 27 MINES AT 1050 Hz

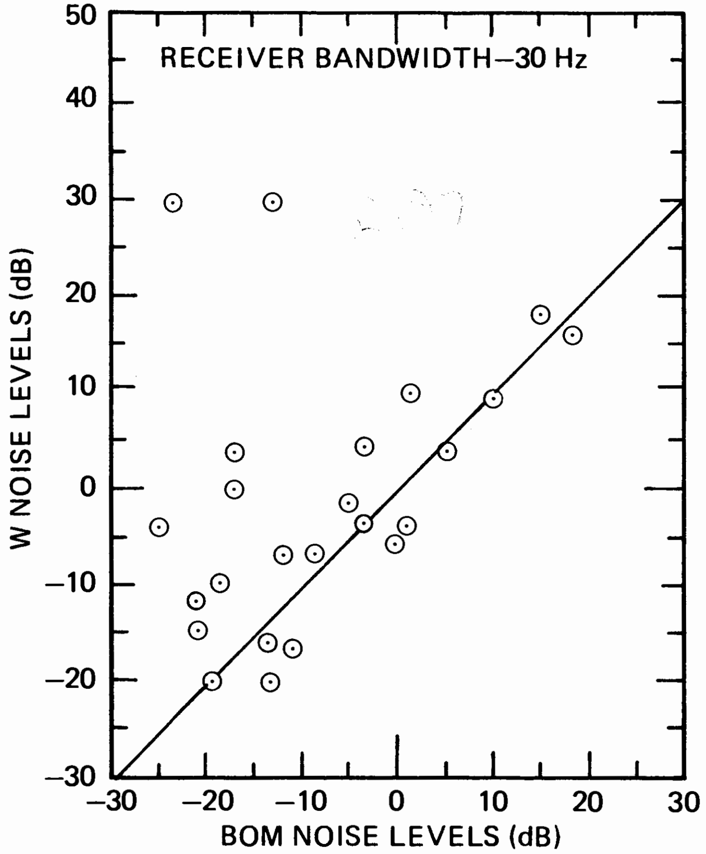

FIGURE IV-3 COMPARISON OF WESTINGHOUSE AND BUREAU OF MINES MEASURED NOISE LEVELS (dBre 1μA/m/$\sqrt{30\ Hz}$) FOR 27 MINES AT 1950 Hz

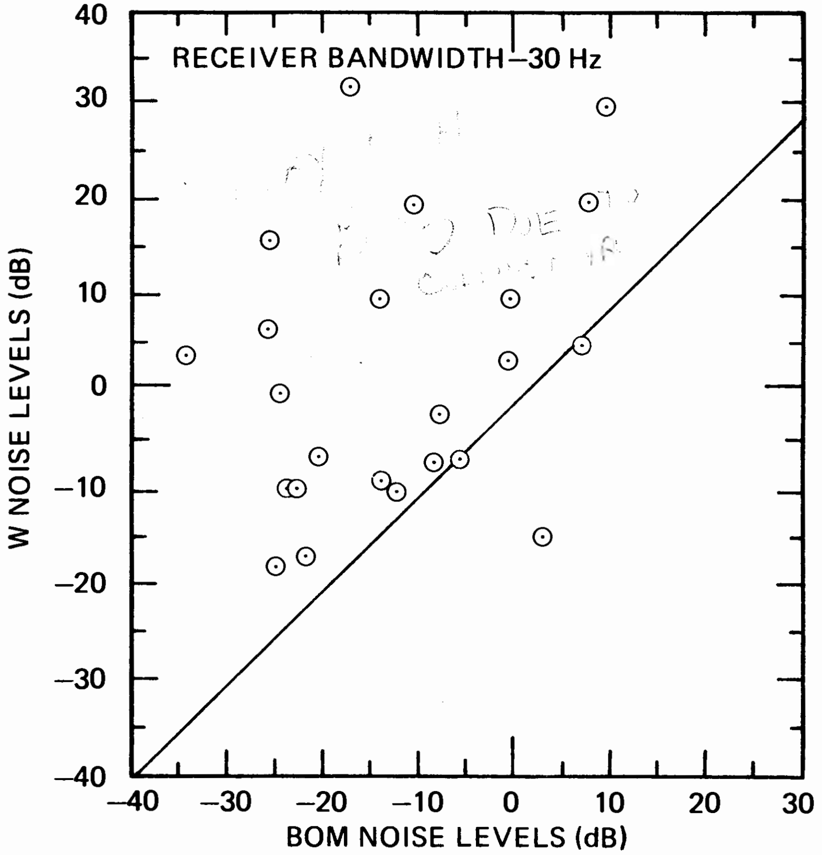

FIGURE IV-4 COMPARISON OF WESTINGHOUSE AND BUREAU OF MINES MEASURED NOISE LEVELS (dBre 1μA/m/$\sqrt{30\ Hz}$) FOR 27 MINES AT 3030 Hz

[illegible] !!

observation taken at each mine site can be considered as a random variable selected from the same underlying distribution of noise values. Thus, even under extreme variability conditions, points should exhibit a random departure above and below the line. Inspection of Figures IV-1 to IV-4 suggests that the two lower frequency plots generally exhibit this property and are in reasonable agreement. However, the noise values at 1950 Hz and 3030 Hz clearly do not. The Westinghouse readings are consistently higher than the corresponding Bureau ones, which is indicative of some form of bias in one of the data sets.

Similar plots of pairs of signal and noise readings taken with the Collins receiver at each mine site were constructed to determine the presence of any correlations between the measured signal and noise data. No statistically significant correlations were found between signal and noise data.

2. The Final Surface Noise Data Base

The procedures and equipment used to obtain noise data for both Westinghouse and Bureau of Mines measurement techniques were carefully reviewed to discover the sources of error and to assess the quality of the data. This review included detailed diagnostic measurements on the equipment in question. As a result of this review, it was decided to use only the Bureau of Mines noise data from 27 mine sites tabulated in Table IV-7 to represent the noise conditions above mines for the purpose of estimating probabilities of trapped-miner signal detection. These noise levels are the ambient background, believed to be broadband levels of atmospheric, not man-made, origin that are present between the high amplitude discrete harmonics of the ac power line frequency of 60 Hz. The principal reasons for the decision to use the Bureau of Mines data were:

- The Westinghouse measurement team used a modified version of the Collins surface receiver in which the front-end bandpass filter had been removed. This filter provided protection from interference by inputs below the receiver operating band. Without this filter, the receiver is susceptible to intermodulation between the frequently occurring large 60 Hz component of ac power line interference fields and the other interference components and noise being measured. As a result, this intermodulation caused the addition of significant interference power at the 1950 and 3030 Hz frequencies being measured.

- Noise readings below the Collins receiver intrinsic noise levels(3) of -21, -26, -31, -35 dB/1 μA/m/$\sqrt{30\text{ Hz}}$ at 630, 1050, 1950, and 3030 Hz, respectively, were reported by the measurement team at 19 mine sites.

- The frequency behavior of the Bureau data was consistent with the behavior of atmospheric noise data reported in the literature.(6,7,8)

- The Bureau data and Westinghouse data are in good agreement on the average at 630 and 1050 Hz for the 27 common mine sites. Furthermore, as shown in Section VII, the noise distribution plot at 630 Hz on normal probability paper comparing the Bureau noise values at 27 mines with the Westinghouse values measured at all 94 mine sites reveals excellent agreement between the two sets of data.

- The 27 Bureau mine sites were well distributed geographically among the 94 mine sites sampled throughout the U.S. coal fields for this measurement program.

3. Relationship to Reported Atmospheric Noise Data

It must also be noted, however, that the Bureau noise measurements were taken during the daylight morning hours (generally the time of day having low atmospheric noise activity) and during the months of May to September (the months having high atmospheric noise activity), and that atmospheric noise levels generally exhibit pronounced diurnal and seasonal variations. A comprehensive study and analysis of magnetic field noise above mines was not the objective of this contract. However, the question of the potential effect of this noise variability on the adequacy of the Bureau of Mines noise sample for making detectability estimates was briefly addressed.

Unlike the frequency band between 10 kHz and 32 MHz, only relatively few reported atmospheric noise measurements have been made below 10 kHz. In addition, even these meager noise data generally concern themselves with the vertical electric field strength and the horizontal magnetic field strength, and not with the 12 to 20 dB lower values of vertical magnetic field strength of greatest interest to trapped-miner detection. The general concern of the literature with the vertical electric and horizontal magnetic noise fields arises because of its applicability to surface-based, long-range radio communications. The behavior of the horizontal magnetic field noise is also important to the final localization of trapped miners which utilizes the null behavior of the horizontal signal magnetic field directly above the miner's transmit loop.

Our brief examination of the literature(6,7,8,9) on atmospheric noise reveals the following behavior characteristics for the vertical electric field and horizontal magnetic field noise components normally measured:

- Between approximately 500 and 5,000 Hz, the earth ionosphere waveguide exhibits a maximum in attenuation rate which significantly attenuates atmospheric noise contributions from distant thunderstorm activity. This attenuation rate behavior produces a pronounced minimum, or trough, in atmospheric noise levels between 1 and 3 kHz;

- For a particular geographical location, the highest noise levels usually occur during the nighttime hours of 8:00 pm and 4:00 am and in the local summer months, and the lowest levels usually occur during the morning hours of 8:00 am to 12:00 noon and in the local winter months;

- Regions having very little thunderstorm activity produce very small changes, on the order of 2 dB, in RMS noise levels on the average between the quiet morning periods and the noisy nighttime periods. Areas with high thunderstorm activity, on the other hand, may experience changes in noise level from 10 to 20 and sometimes as high as 30 dB between the daily quiet and noisy time periods.

- Regions with relatively low thunderstorm activity tend to display drops in noise level versus increasing frequency on the order of 20 dB from 600 Hz to 3,000 Hz (at the bottom of the noise trough), whereas areas with higher thunderstorm activity exhibit decreases on the order of 10 to 12 dB from 600 Hz to 2 kHz (at the bottom of the noise trough).

- Locations which experience significant diurnal changes in thunderstorm activity will generally exhibit larger increases in noise level in the 500 to 5,000 Hz band than experienced above and below this band, as a result of the high attenuation characteristics in this band.

We then compared the above atmospheric noise characteristics with those of the statistical noise distributions based on the Bureau of Mines noise data (3) that are derived and presented in Section VII of this report. If we further make the plausible assumption that the vertical magnetic field levels are at least proportional to the horizontal noise components, and exhibit roughly the same frequency, diurnal, and seasonal variations, we can make the following comparative observations:

- The average RMS value of the Bureau of Mines noise decreases by 20 dB from 630 Hz to 3030 Hz, similar to the behavior reported for atmospheric noise in areas of low thunderstorm activity;
- The Bureau of Mines levels are not inconsistent with those reported when adjusted for bandwidth and field component;
- The U.S. coal fields lie within the temperate zone, and could probably be classified as moderate to low-moderate regions of thunderstorm activity.

In addition, the normal distribution of the RMS values of the Bureau of Mines data taken at 630 Hz over the months from May to September are in excellent agreement with the normal distribution of the Westinghouse data taken over the months from February through November. These data were also typically taken during the same time period of 8:00 am to 12:00 noon, and over the same widespread geographical coal field areas as the Bureau of Mines data.

Consequently, the noise distributions derived in Section VII of this report, based on the Bureau of Mines noise data, can probably be considered representative of noise conditions expected over coal mines during daytime mine rescue search operations. In winter, levels may be about 10 dB lower, whereas in summer, during late afternoon or evening, high local thunderstorm activity, the levels may increase by perhaps 10 or even 20 dB in the vicinity of the 2,000 to 3,000 Hz noise trough. However, search operations are likely to be conducted during daylight hours, and for all practical purposes suspended during periods of abnormally high noise activity. Therefore, the Bureau of Mines noise data have been used in subsequent chapters as the basis for predicting the expected probabilities of detection of trapped-miner signals above U.S. coal mines. As a further check on the general applicability of this conclusion, a more thorough comparison of the Bureau of Mines noise behavior with additional reported atmospheric noise behavior may be warranted.

V. CHARACTERIZATION OF OVERBURDEN TRANSMISSION MODEL

A. RATIONALE

The objective is to characterize the overburdens above mines in the U.S. coal fields with respect to their response to trapped miner electromagnetic signals as a function of overburden depth and operating frequency. The overburdens above coal mines are sedimentary in nature. They consist of a large number of nearly horizontal layers of different materials and thicknesses, which in turn have differing electrical conducting properties as a result of variations in salts, water content, porosity, and a number of other factors. Therefore, for any given overburden depth, we can expect the signal transmission characteristics to vary significantly from location to location within the coal fields. Consequently, we adopted a statistical approach of sampling a representative number of mines within each of the depth intervals of interest in order to characterize the average transmission characteristics of overburdens, and their corresponding variability about the average, as a function of depth and operating frequency.

To accomplish this characterization, we found it helpful to think of the overburden above U.S. coal mines as a two-terminal pair electrical network having an unknown and randomly varying transfer function from mine to mine which must be determined experimentally. In particular, we wish to characterize the transfer function between the output surface magnetic field strength, H_z (corresponding to open circuit output voltage), and the input magnetic moment (corresponding to the input current) for the overburden network portrayed in Figure V-1. In circuit theory terms, we wish to define the output response to a unit input stimulus, which in this case is a magnetic moment $M = 1$ Amp-m^2. Once this is known, the output response can be

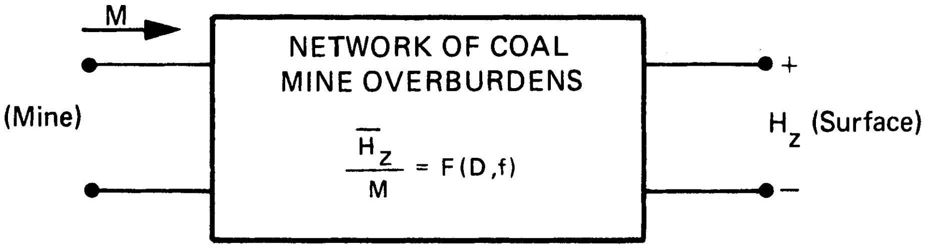

FIGURE V–1 TWO TERMINAL PAIR NETWORK ANALOGY FOR CHARACTERIZATION OF OVERBURDEN SIGNAL TRANSMISSION RESPONSE predicted for any input magnetic moment stimulus within the limits of operating frequency and loop geometry characterized.

To derive the transmission response function of coal field overburdens, it is necessary to normalize all the valid uplink field strength readings obtained on the surface at mine sites to the readings that would have been measured (in a noiseless environment) for a transmitter having a unity magnetic moment, $M = 1$ Amp-m^2. The magnetic moment of interest here is the RMS value of the magnetic moment at the fundamental operating frequency of the transmitter; namely, that portion of the transmitted signal which is capable of being detected by the narrowband rescue receiver on the surface. Therefore, each measured value of magnetic field on the surface listed in Table IV-5 was reduced by its corresponding value of transmitter fundamental magnetic moment, expressed in dB re 1 Amp-m^2, prior to being subjected to the statistical analyses described in this section. The field values in Table IV-5 also include adjusted field strengths derived from downlink transmission data in those cases where we judged it necessary and justifiable to replace an unreliable or unavailable uplink reading with one based on an acceptable downlink measurement. All analyses have been performed on the surface magnetic field strength signal data expressed in dB relative to 1 Amp/m normalized to a transmit magnetic moment of 1 Amp-m^2.

B. REGRESSION ANALYSIS OF SURFACE SIGNAL DATA

As described above, uplink and downlink signal strength data were normalized prior to statistical analysis. In this section, the regression analytical methods considered are described in some detail, and the results and conclusions pertaining to the expected behavior of surface signal strength as a function of overburden depth and frequency are presented.

1. Surface Signal Strength vs. Log Depth Model for the Final (Expanded) Data Base

a. Methodology

In formulating the problem for this stage of the analysis, signal strength is assumed to be related to depth in an unknown mathematical/statistical/physical form. Up to 94 data points were obtained as a result of field tests conducted at each of four frequency levels. Each data point can generally be denoted as S_{ij}, where the subscript i represents the specific frequency and the subscript j represents the specific depth of test for each mine at which tests were performed. Thus, each surface measurement S_{ij} taken in this program can be considered as a single observation of signal strength at a pre-determined frequency and overburden depth level at a particular mine. Specific values S_{ij} can be expected to vary in some unknown way; that is, the readings can be expected to differ if more than one measurement was taken at different times at the same mine location, or at the same depth at some other location within the mine, or at the same depth at a different mine.

The use of statistical regression theory requires an assumption that the observed values of S_{ij} represent a random sample from a normal distribution with mean dependent upon j (depth) and variance the same over all depths (that is, independent of j). Furthermore, if the relationship of the mean value of S_{ij} to depth can be expressed in linear terms, probability statements can be inferred from the derived regression model. The statistically-based, random mine selection process described in Section III was used to increase the reasonableness of the required assumption that all oberservations S_{ij} can be described by a common normal probability law. Although necessity and practicality dictated some deviation from the originally selected list of mines, we believe that the final mine sample provides a good enough approximation to the assumption to warrant the valid use of regression theory.

Several linear regression models were hypothesized and tried. The model found to best fit the behavior of the data is one in which the mean value of the normalized signal strength S_{ij} is linearly related to the logarithm of overburden depth, as shown in Equation (4).

$$S_{ij} = \alpha_i + \beta_i \log \mathrm{DEPTH}_j + \epsilon_{ij}, \qquad (4)$$

where:

S_{ij} is the normalized vertical magnetic field signal strength (expressed in dB re 1 μA/m) for the $i^{\underline{th}}$ frequency level and depth j, for a transmit moment of $M = 1$ Amp-m^2;

α_i and β_i are parameters to be estimated from the data;

depth is known and measured in meters; and

ϵ_{ij} represents a random variable that is normally distributed with expected value zero and variance σ_{ij}^2, which is the same for all values of j.

Equation (4) corresponds to a power law relationship, $H = c\,(\mathrm{Depth})^n$ for the surface magnetic field expressed in rationalized MKs units of Amp/m. Regression analysis of the S_{ij} data was subsequently performed in crder to address the following four basic concerns:

- Does the postulated linear relationship explain the data?

- If so, what are the best estimates of the parameters α_i and β_i?

- Does the inverse cubic relationship suggested by simple dc magnetostatic theory apply; that is, does $\beta_i =$ -60 ($n = -3$) for each frequency?

- Can regression results be used to make reliable predictions about the behavior of signal strength?

Four separate regression lines were subsequently derived using the log DEPTH model, one for each frequency. To make maximum use of the available field test data, and to provide additional data points at depths exceeding 700 feet, where several uplink readings were missing, the "expanded" version of the original uplink signal data base described in Section IV-C was used. This "expanded" data base includes the replacement of missing and/or unreliable surface readings with appropriately adjusted downlink in-mine values taken at the same site as described in Section IV-C. A statistical regression routine (the GLM procedure) published by SAS Institute, Inc.,(10) was used for this analysis. This routine performs a standard least-squares fit to the data, determining the parameters $\hat{\alpha}_i$ and $\hat{\beta}_i$ that uniquely minimize the following expression (for each i):

$$\sum_j \epsilon_{ij}^2 = \sum_j (S_{ij} - \hat{\alpha}_i - \hat{\beta}_i \log \text{DEPTH}_j)^2 \qquad (5)$$

Summary statistics useful for interpreting regression results are also provided by the routine.

b. Results

The derived regression lines for each of the four frequencies are plotted in Figures V-2 through V-5, which are also seen to include the actual observations (normalized) taken at each mine test site. Although it is readily apparent from inspecting the plots that a log-linear relationship is an appropriate one, a more formal and

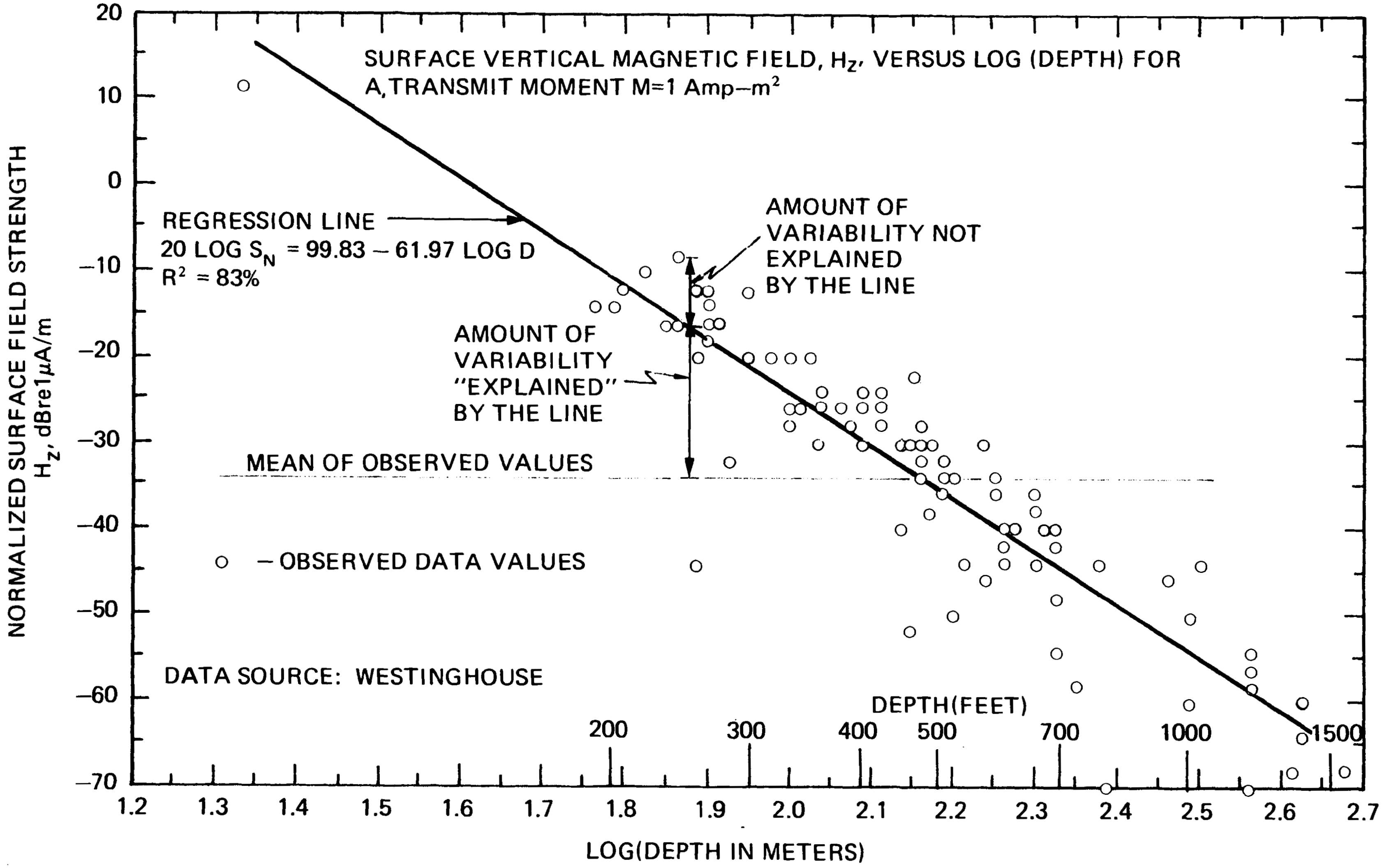

FIGURE V-2 UPLINK NORMALIZED OVERBURDEN SIGNAL RESPONSE DATA AND LINEAR REGRESSION LOG(DEPTH) MODEL AT 630 Hz

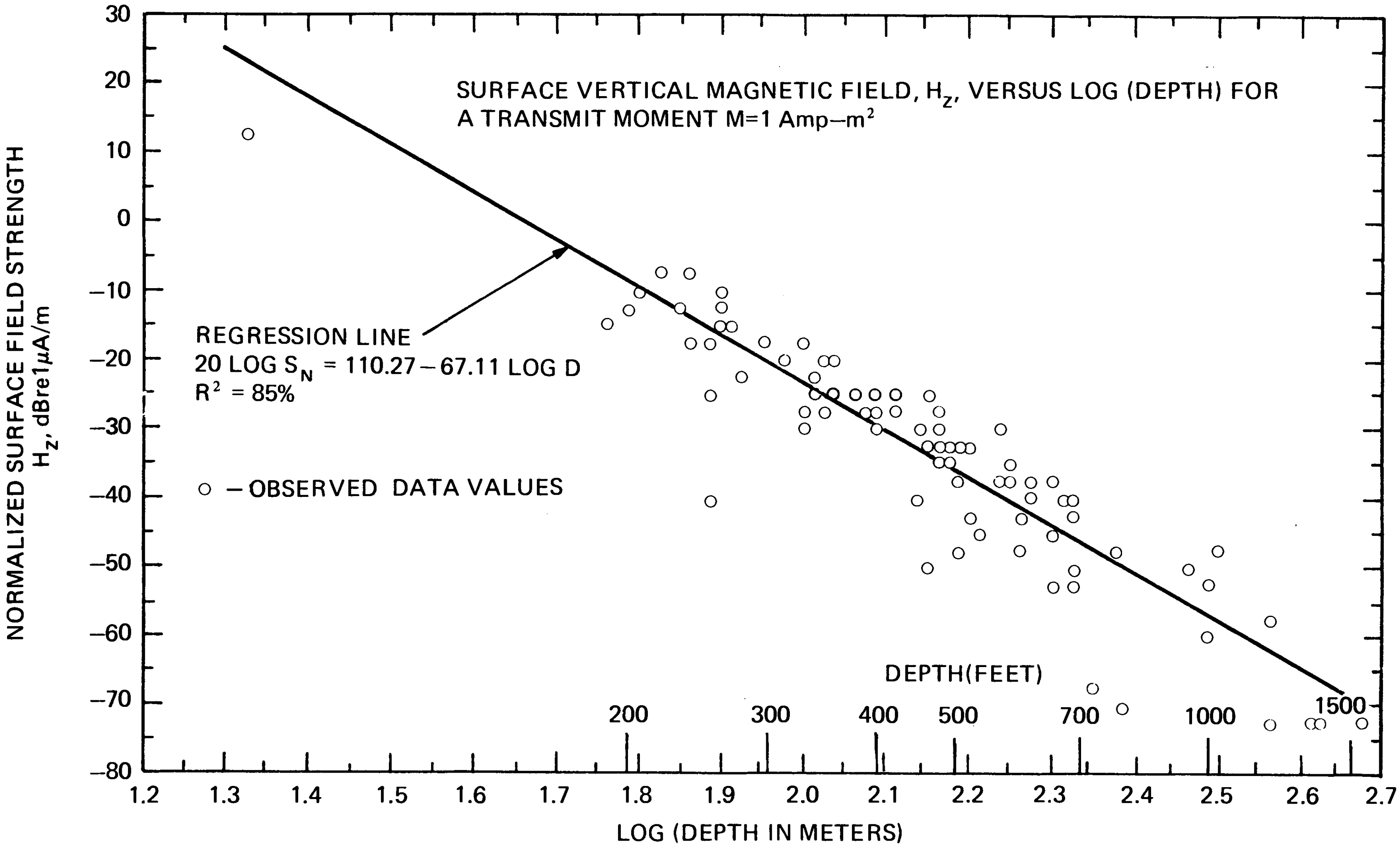

FIGURE V-3 UPLINK NORMALIZED OVERBURDEN SIGNAL RESPONSE DATA AND LINEAR REGRESSION LOG(DEPTH) MODEL AT 1050 Hz

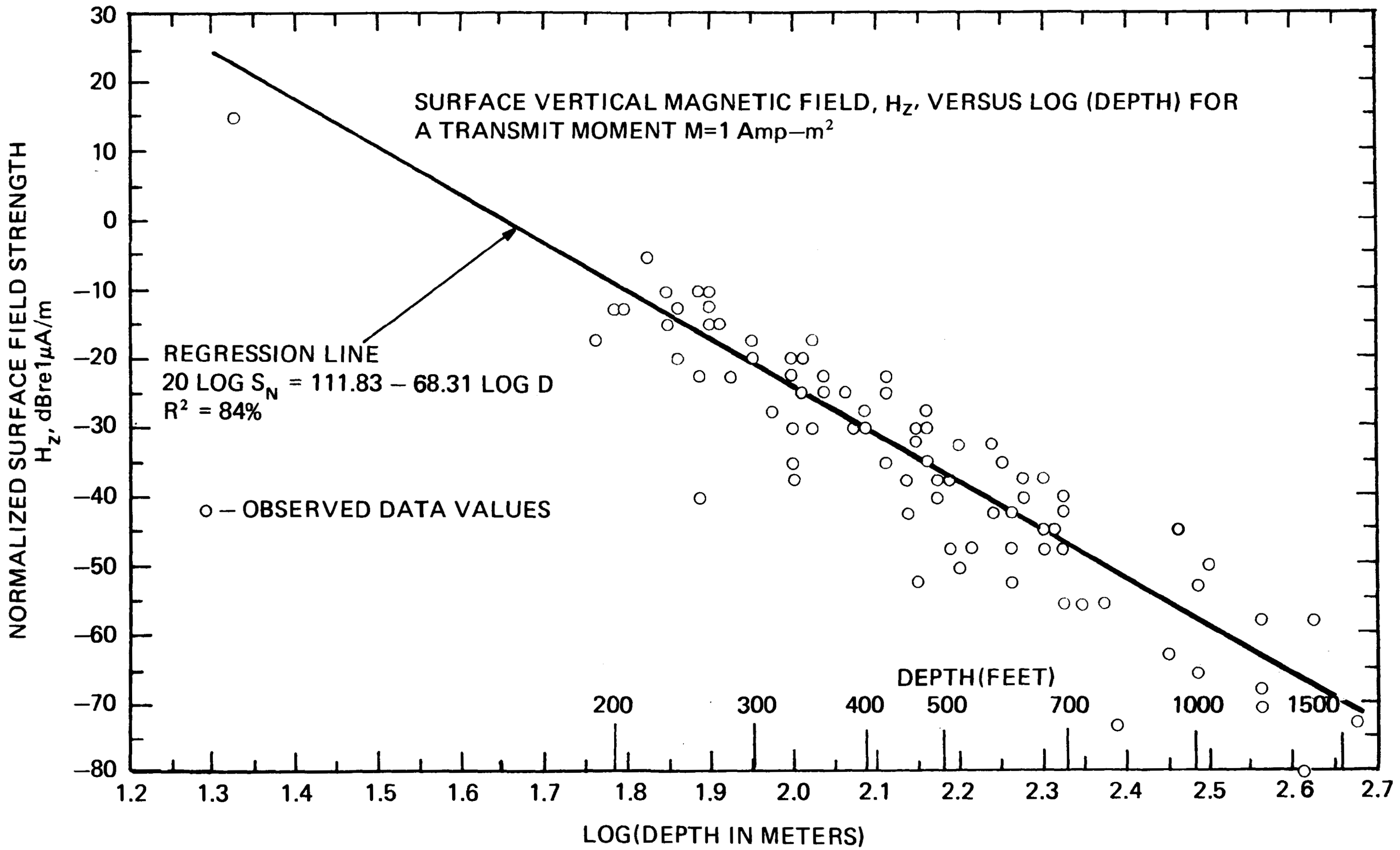

FIGURE V-4 UPLINK NORMALIZED OVERBURDEN SIGNAL RESPONSE DATA AND LINEAR REGRESSION LOG(DEPTH) MODEL AT 1950 Hz

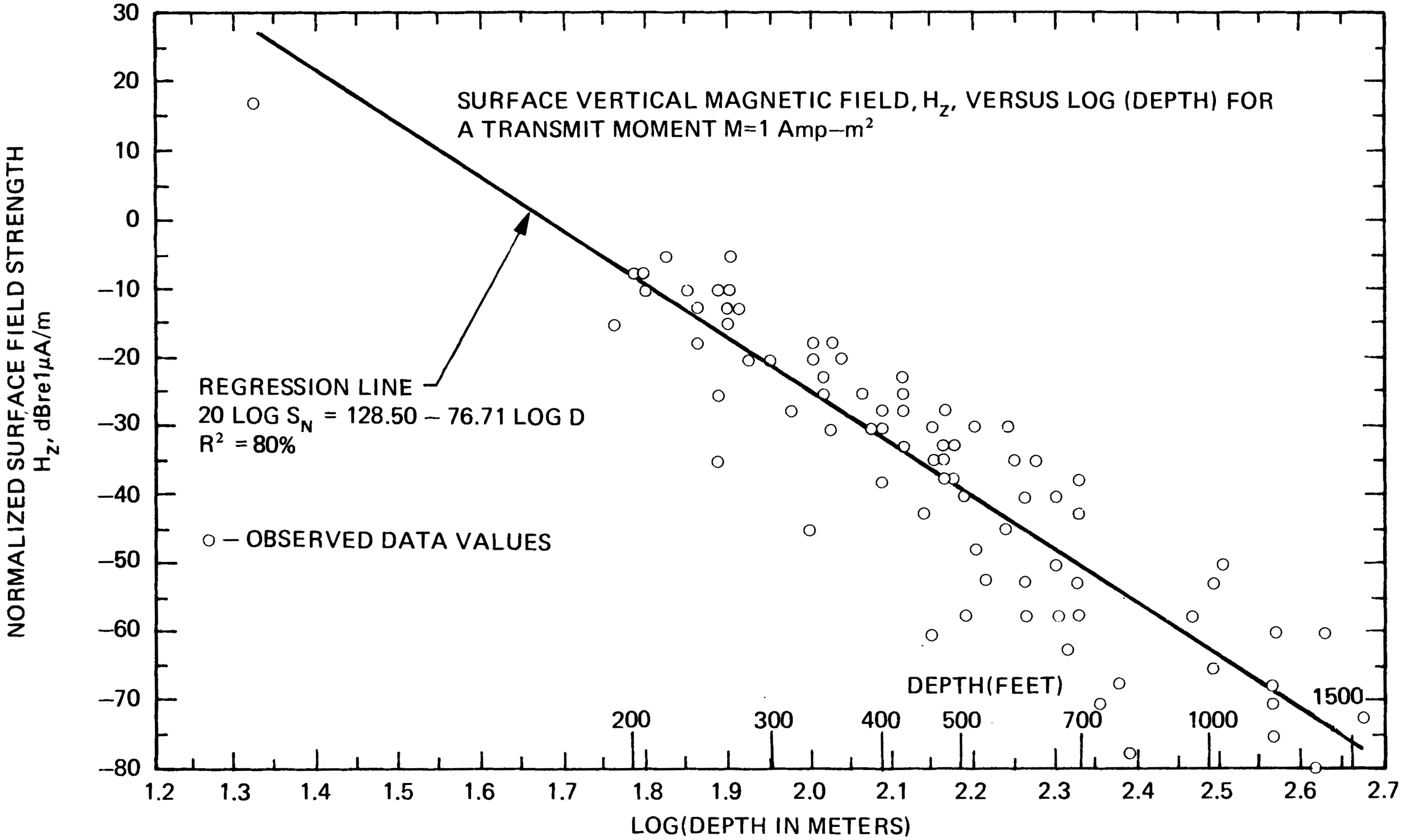

FIGURE V-5 UPLINK NORMALIZED OVERBURDEN SIGNAL RESPONSE DATA AND LINEAR REGRESSION LOG(DEPTH) MODEL AT 3030 Hz objective procedure is required to answer the four basic questions outlined earlier in this section. The methods for doing this will be described in some detail for the regression analysis of the 630 Hz data, the first one presented.

As is usually the case in the statistical treatment of data, the question of the existence of linearity can be stated in the form of a hypothesis to be tested; namely, do the data provide evidence of a "real" linear relationship of normalized signal strength to log depth? Expressed another way, it is clear that normalized signal strengths vary considerably, ranging from -70.8 dB re 1 μA/m to +11.3 dB re 1 μA/m over the 90 measurements taken at 630 Hz. Can some of this variability be explained or accounted for by a linear model, and, if so, to what extent?

A summary statistic used to quantify this statement is the coefficient of determination (R^2), which is defined as follows:

$$R^2 = \frac{\sum(S_{EST} - \overline{S})^2}{\sum(S_{OBS} - \overline{S})^2} \qquad (6)$$

where S_{EST} is the linear (regression) estimate, S_{OBS} is the observed signal value, and $\overline{S}$ is the average signal taken over all observations. The quantities are summed over all j observations, with 90 such terms used in the calculation for 630 Hz data. A graphical depiction of the elements of this expression is given in Figure V-2. For the case of 630 Hz, R^2 equals 83 percent. It should also be noted that the standard linear correlation coefficient, $R = \sqrt{R^2}$, equals 0.91 for 630 Hz data, indicating a very high degree of linearity. The actual statistical test for linearity is somewhat involved, in that it requires knowledge of distribution theory, and therefore will not be presented here. Detailed explanations are given in most statistical methods texts, such as Reference 11. Suffice it to say that the test statistics are such that the hypothesis of no true linear relationship between normalized signal strength and log depth can be rejected with less than a one percent chance of being wrong for each of the four regression lines presented in this section. Therefore, it has been established that the postulated linear relationship does indeed explain the data, and the estimating equation is as follows:

$$S_{EST} = 99.83 - 61.97 \log \text{DEPTH at 630 Hz.} \tag{7}$$

The third question concerns the applicability of the inverse cubic relationship over the range of data obtained in this measurement program. Again, this can be expressed as a hypothesis to be tested; that is, with the above formulation, does the slope of the regression line appear to be -60 (i.e. for n = -3), since S_{ij} = 20 log H in dB. Again, the necessary input to perform this test is provided by the regression routine. For the 630 Hz case, the test statistic is not significant, and we therefore conclude that the inverse cubic law is an appropriate one for these data. Another way to arrive at the same conclusion is to construct an interval estimate of the slope, rather than a point estimate. For the 630 Hz case, we are 95 percent certain that the true (unknown) slope is included in the interval (-2.8 to -3.4), which is seen to include -3.0, the hypothesized value.

The interval estimate depends on another important summary statistic, the standard error of estimate $\hat{\sigma}$, which is defined as follows:

$$\hat{\sigma} = \sqrt{\frac{\sum(S_{OBS} - S_{EST})^2}{N - 2}} \tag{8}$$

where N is the number of observations. The standard error is used in determining the reliability, or predictive capability, of the estimating equation and, as a result, addresses the final question of concern stated earlier. The smaller the standard error, the more reliable the predictions based on the equation are likely to be.

Regression results are summarized for all four frequencies in Table V-1, in addition to the earlier plots in Figures V-2 to V-5. Inspection of Table V-1 reveals the following:

(i) The linear relationship applies in each case; R^2 values are high at each frequency, implying that the model adequately explains the data.

(ii) The best estimates derived from the data reveal that the intercepts increase and slopes become more pronounced as frequency increases; however, there appears to be very little difference between 1050 Hz and 1950 Hz results.

(iii) The inverse cubic relationship applies only at the lowest frequency considered; estimated slopes differ significantly from -60 at each of the other frequencies.

(iv) Reasonably reliable predictions can be made from all regression models; standard errors are between 6 and 9 dB; for example, the theoretical average normalized signal strength expected from many tests at approximately 139 meters (450 feet) is estimated to be -33 ± 1.4 dB at 630 Hz, where the ±1.4 dB is calculated from the formula to estimate confidence limits; i.e., $\pm t\ \hat{\sigma}/\sqrt{N}$, where t is a statistical value based on sampling distribution theory.

It is evident that if this test program were replicated, and another sample of 94 different mine sites were selected, the analytical results would not be identical. However, the strength of each relationship derived in this study is such that we would expect linearity between signal strength and log depth, even though the estimated slope and intercept would change. The

Table V-1

Regression Results
For Surface Signal in dB versus Log Depth Model
Using Expanded Uplink Data Base

Frequency (Hz)	No. of obs.	Estimated intercept	Estimated slope	95% confidence interval for η = slope/20	Correlation coefficient (R)	R^2	Standard error ($\hat{\sigma}$)
630	90	99.83	-61.97	-2.8 to -3.4	0.91	0.83	6.65
1050	90	110.27	-67.11	-3.0 to -3.7	0.92	0.86	6.52
1950	91	111.83	-68.31	-3.1 to -3.7	0.92	0.84	7.08
3030	90	128.50	-76.71	-3.4 to -4.2	0.90	0.80	8.92

Source: Arthur D. Little, Inc.

magnitude of the change is expressed in terms of interval estimates that are based on the sample data at hand.

Two types of intervals have been estimated from the data. The smallest is referred to as a confidence interval, which is defined as a range of values computed from the sample that can be expected to include the true (but unknown) mean value with a known probability. Figures V-6 to V-9 display 95% confidence intervals with dashed lines. To illustrate this concept using Figure V-6, it follows from this field experiment that the probability is 0.95 that the interval from -6 dB to -12 dB includes the true mean normalized signal strength for a transmitter of magnetic moment $M = 1$ Amp-m^2 at 630 Hz and an overburden depth of 190 feet.

While the confidence interval represents a probability statement about a mean value over many trials, it is also of interest to quantify the expected outcome of a single trial. For example, what signal strength could we reasonably expect if we were to conduct one more test at a predetermined frequency and overburden depth? This situation is depicted by prediction intervals also plotted in Figures V-6 to V-9. To illustrate this concept, again using Figure V-6, the probability is 0.95 that another test performed at 630 Hz at a depth of 500 feet would yield a signal strength between -49 dB and -22 dB.

Also plotted in Figures V-6 to V-9 for comparison is a curve of the free space vertical field strength that would be measured on the surface in the absence of the lossy overburden material. For the depths and frequencies in question, this free space field does not vary with frequency. This field strength is computed from the simple equation:

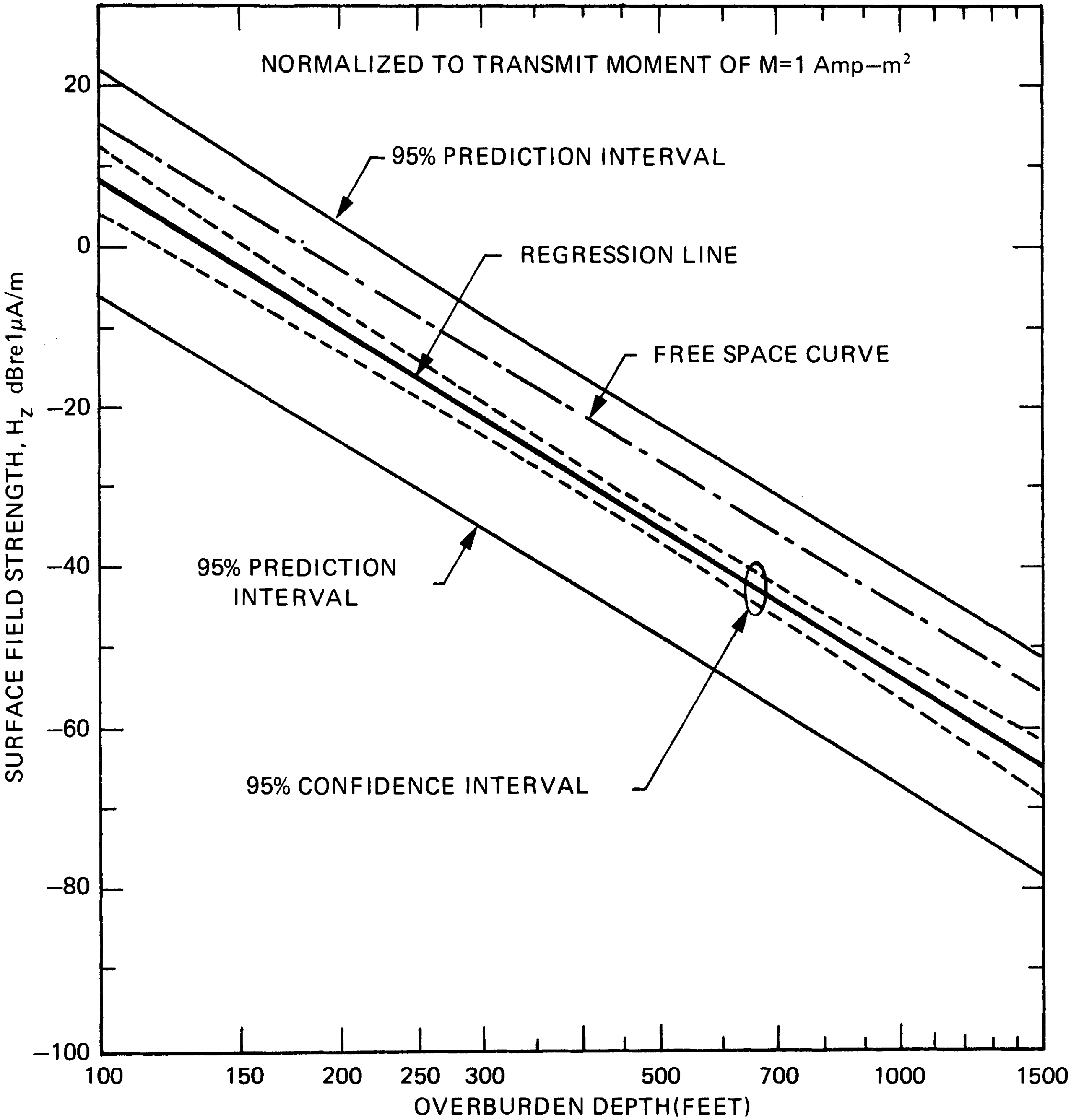

FIGURE V-6 **UPLINK REGRESSION RESULTS FOR 630 Hz–NORMALIZED VERTICAL SIGNAL STRENGTH, H_z, VERSUS DEPTH**

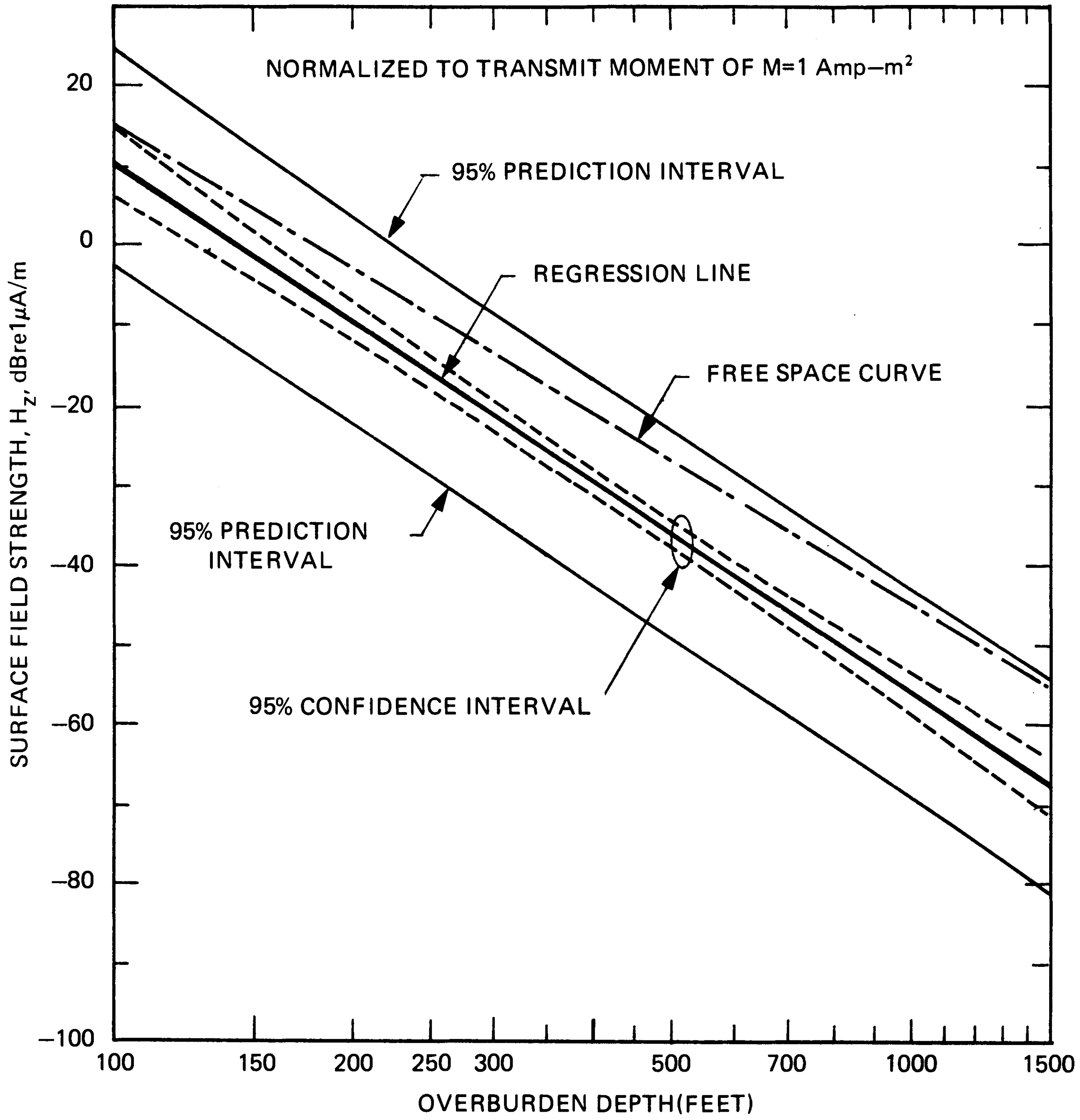

FIGURE V-7 UPLINK REGRESSION RESULTS FOR 1050 Hz—NORMALIZED VERTICAL SIGNAL STRENGTH, H_z, VERSUS DEPTH

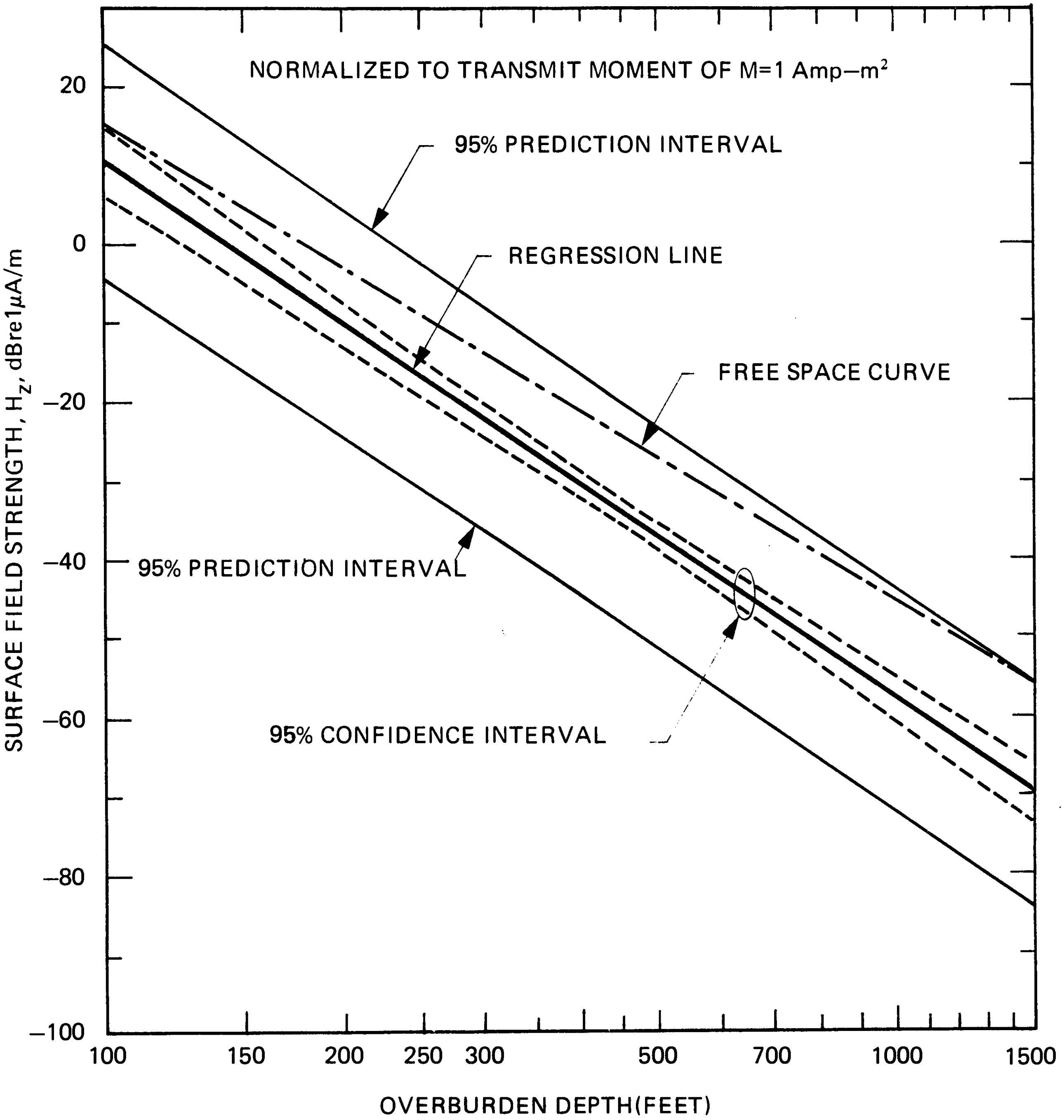

FIGURE V-8 **UPLINK REGRESSION RESULTS FOR 1950 Hz—NORMALIZED VERTICAL SIGNAL STRENGTH, H_z, VERSUS DEPTH**

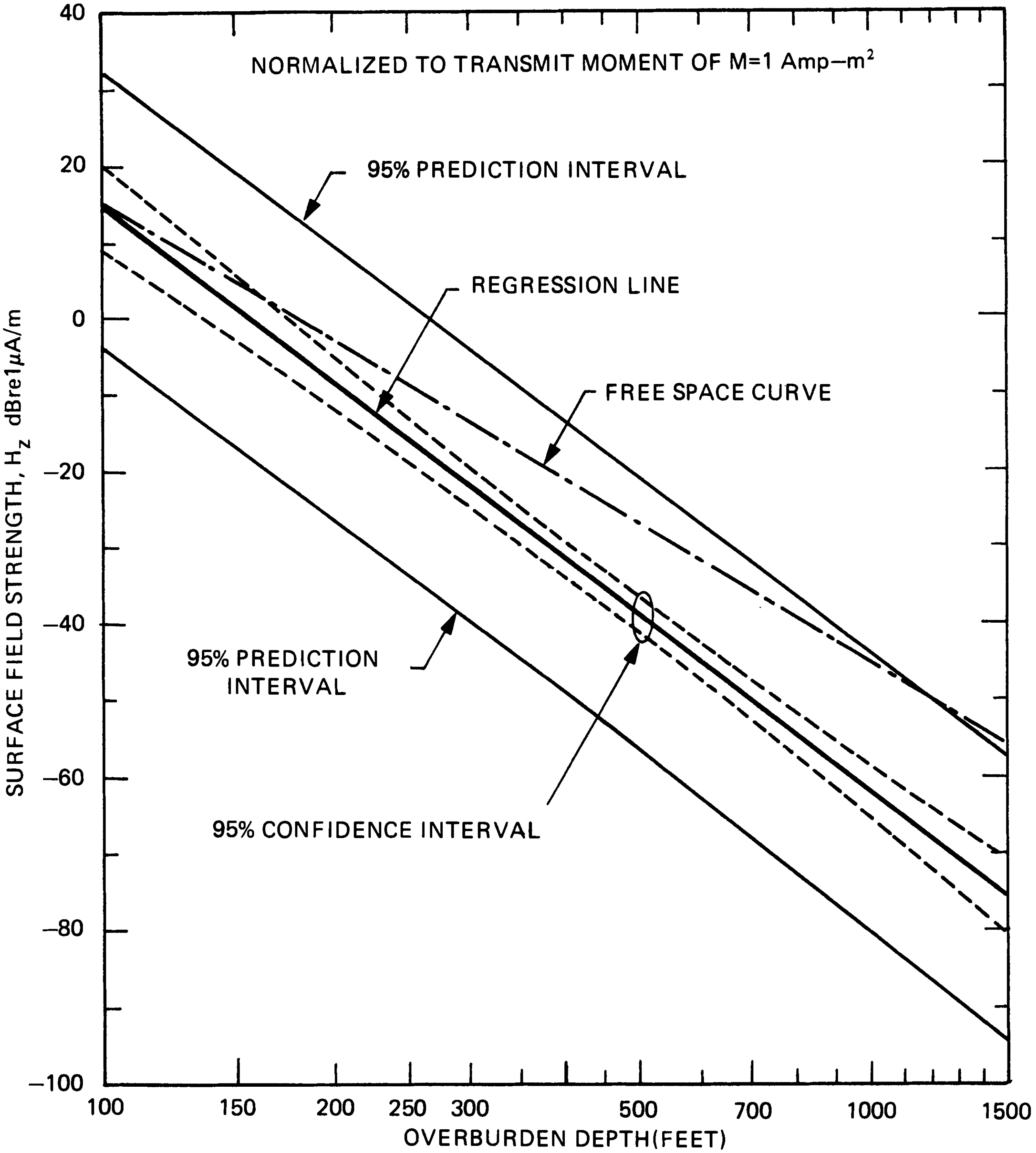

FIGURE V-9 UPLINK REGRESSION RESULTS FOR 3030 Hz—NORMALIZED VERTICAL SIGNAL STRENGTH, H_z, VERSUS DEPTH

$$H_z = \frac{M}{2\pi D^3} \text{ (Amp/m)}, \qquad (9)$$

where M is the transmitter magnetic moment set equal to 1 Amp-m^2 and D is the depth in meters.

Examination of Figures V-6 to V-9 reveals that the 95% prediction interval extends above the free space field values. This is not surprising, for there are several ways in which the normalized data can, under certain circumstances, exceed the free space values as discussed in Section IV. The ways include: a) depth estimation errors which can cause a data point to be plotted at a depth greater than the actual depth, b) the enhancing effects of nearby metal conductors creating more favorable transmission paths to the surface receiver, c) meter reading errors during data recording in the field, and d) errors introduced in the normalizing process caused by uncertainties in the accuracy of the values of the fundamental component of the in-mine transmit magnetic moments (MMFUND). In most cases, these discrepancies were less than 4 to 5 dB greater than the free space field and the data values were retained, as discussed in Section IV. The few data values that deviated grossly above the free space values were almost always associated with equipment malfunctions or suspected very strong coupling to nearby conductors. Therefore, these were deleted from the original data base as invalid data and replaced by more reliable, adjusted downlink in-mine field strength values when possible.

Figure V-10 summarizes the normalized average overburden response as a function of depth and frequency by plotting the four regression lines and the free space curve on one graph. The most useful part of the graph is to the right of the intersection of the regression lines; namely, between depths of 250 and 1500 feet. Examination of this plot reveals that the 630 Hz regression line

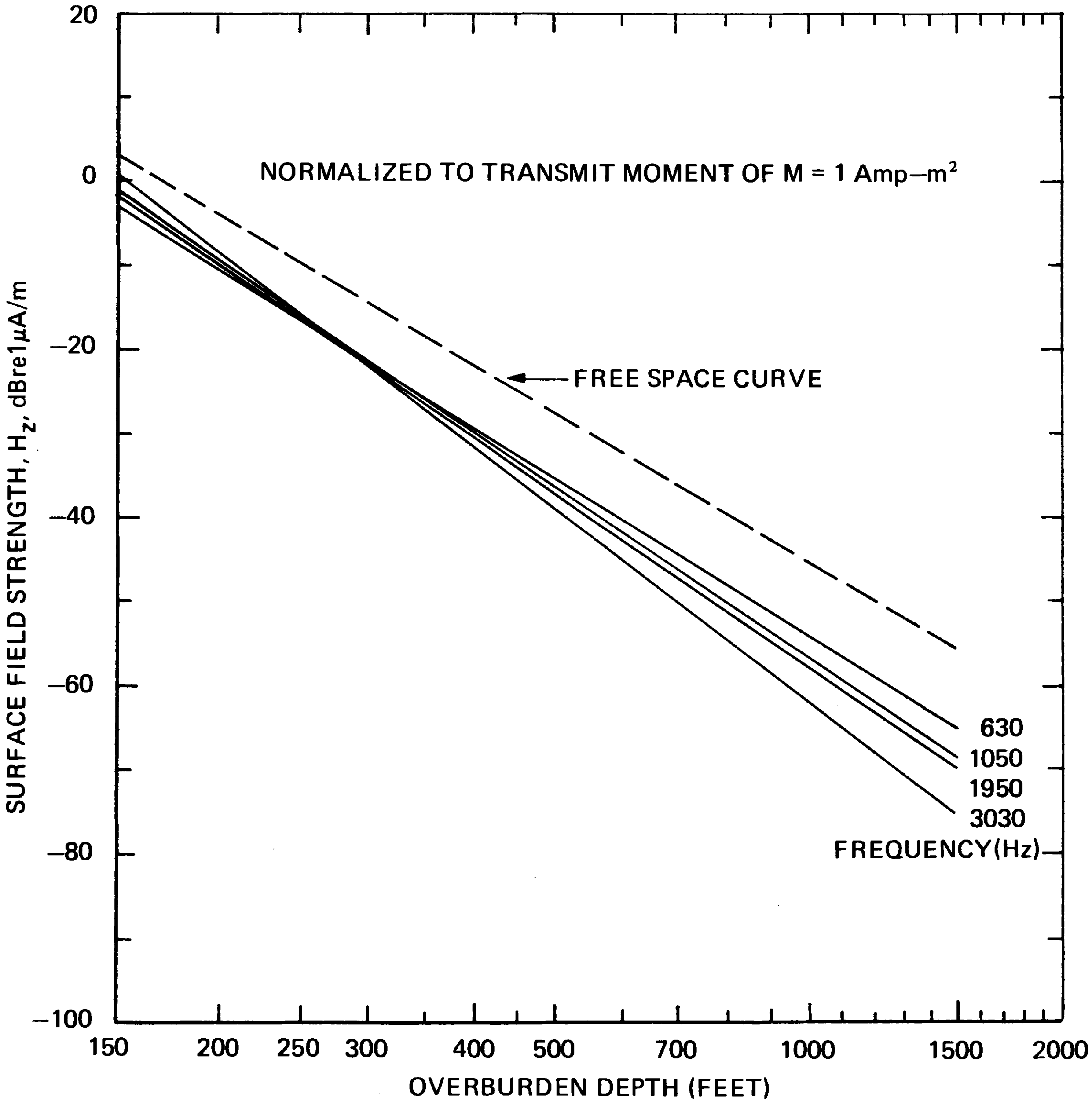

FIGURE V-10 NORMALIZED OVERBURDEN RESPONSE CURVES–UPLINK REGRESSION RESULTS, AVERAGE SURFACE VERTICAL SIGNAL STRENGTH, H_z, VERSUS OVERBURDEN DEPTH BY FREQUENCY runs nearly parallel to, and about 7-9 dB below, the free space curve. The 3030 Hz line dips more steeply and varies from about 7 dB below the free space curve at 250 feet to about 20 dB below at 1500 feet. The 1050 and 1950 Hz lines fall approximately halfway between the 630 and 3030 Hz curves.

Figure V-11 summarizes the frequency dependence across the 630 to 3030 Hz band over the 250 to 1500 feet overburden depth range of interest. This figure allows one to extrapolate performance to other frequencies in the 630 to 3030 Hz band of interest. It also shows that the frequency dependence of signal strength is relatively insignificant for depths less than about 500 feet, and that the change across the band is only about 10 dB even at the maximum depth of 1500 feet.

These summary normalized overburden response plots, together with the confidence and prediction levels of this section, can be used to generate estimates of signal strength produced on the surface above coal mines as a function of overburden depth and operating frequency for transmitters having any prescribed magnetic moment versus frequency characteristics in the 630 to 3030 Hz band. The utilization of the results, properties, and predictive capabilities of these regression models is described in Section VIII of this report. Actual computer output produced by the SAS regression routine is given in Appendix D for each frequency.

2. Other Models

For the sake of completeness, it should also be mentioned that several other models were examined as possible candidates for representing the data. Furthermore, these models, as well as the log depth regression model presented in the previous section, were also considered for the uplink data base purged of all questionable signal measurements, without replacements according to the

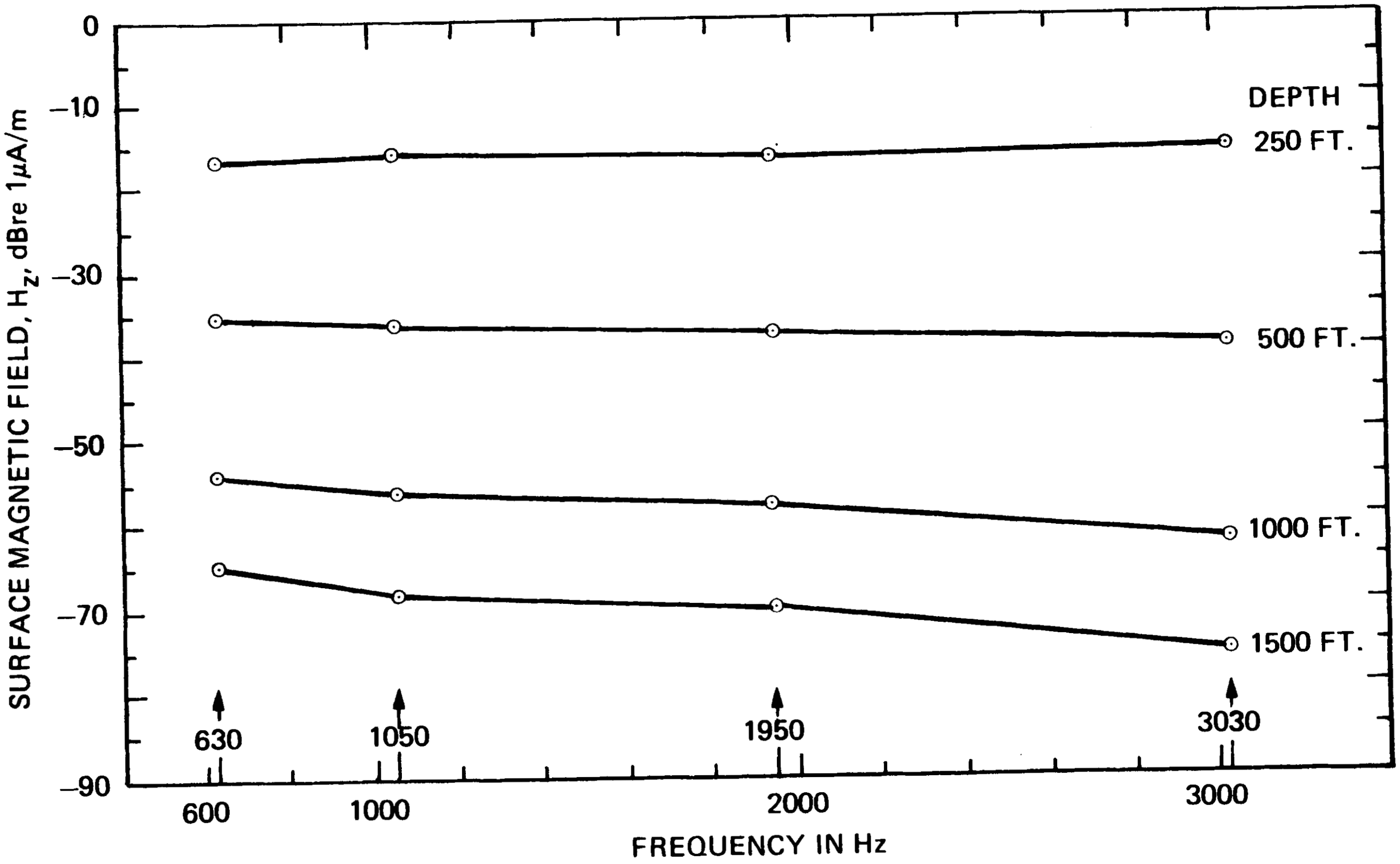

FIGURE V-11 NORMALIZED SURFACE VERTICAL MAGNETIC FIELD, H_z, VS FREQUENCY WITH DEPTH AS A PARAMETER process described in Section IV. These results will be discussed briefly in this section, since they were not used in subsequent steps necessary to calculate detection probabilities.

a. Log Depth Model for the Purged Data Base

In Table V-2, summary statistics similar to Table V-1 are given for the purged uplink data base measurements only. Not surprisingly, the models are very similar for the two data sets and lead to the same conclusions as stated in the previous section. There is no evidence that the utilization of the downlink signal data to augment the validated uplink signal measurements introduced bias into the results. The only effect in using the expanded data base appears to be a slight loss in precision in making estimates at the two higher transmission frequencies, as indicated by slightly higher standard errors.

b. The D^{-3} Exponential Model

In addition to the simple statistical model used to interpret the data, a modified version was also studied. The purpose of this approach was to acknowledge and make use of an approximate physical relationship that expresses signal strength as a function of a magnetostatic power law factor D^{-3} and an exponential attenuation factor e^{-bD} to account for resistive losses in the overburden. The underlying model initially considered in this analysis was the following:

$$H = \frac{a}{D^3} (e^{-bD}) \qquad (10)$$

where H is the measured signal strength in A/m, D is the overburden depth in meters, and a and b are parameters to be estimated from the (H,D) data pairs. The factor e^{-bD} was introduced as an alternative to the arbitrary power law by depth model to account for the known lack of agreement when using $(1/D^3)$ only.

Table V-2

Regression Results For Surface Signal in dB versus Log Depth Model Using Purged Uplink Data Base

Frequency (Hz)	No. of obs.	Estimated intercept	Estimated slope	95% confidence interval for η= slope/20	Correlation coefficient (R)	R^2	Standard error ($\hat{\sigma}$)
630	78	98.59	-61.41	-2.7 to -3.4	0.91	0.82	6.66
1050	78	109.01	-66.57	-3.0 to -3.7	0.92	0.85	6.50
1950	78	110.00	-67.39	-3.0 to -3.7	0.92	0.84	6.74
3030	75	121.72	-73.33	-3.2 to -4.1	0.89	0.80	8.60

Source: Arthur D. Little, Inc.

In order to take advantage of model fitting properties and summary statistics provided by computer routines, the above model was further modified as follows:

$$H_N = \frac{a}{D^3\ D^{c-3}}\ (e^{-bD}) \qquad (11)$$

With this formulation, normalized signal strength, S_N, expressed in dB re 1 μA/m units, assumes a linear form (in the sense that it is linear in terms of the parameters to be estimated); namely:

$$S_N = 20 \log H_N = \qquad (12)$$

$$20\ [\log a - 3 \log D - (c - 3) \log D - bD \log e].$$

The problem then reduces to deriving a least-squares estimate of the three parameters a, b, and c, which minimizes the sum of squares of differences between observed signal strengths and values estimated by the derived model. Furthermore, it is possible to determine which of the two parameters, b or c (or factors depending on them) is more effective in representing the observed deviation from the inverse depth cubed form. Regression estimates are given in Table V-3.

Inspection of goodness-of-fit statistics revealed a result similar to the simple log depth linear regression case at 630 Hz, in that neither term involving the parameters b and c contributed any explanatory capability. Although a significant contribution was apparent for the 1050 Hz and 1950 Hz frequency levels, the adjustment factor involving b, and/or the exponent of depth term involving c, were equally adequate, and there is no evidence as to which is preferable. However, there is rather strong evidence that the modified exponent of depth term involving c better explains the data taken at 3030 Hz than the exponential adjustment term involving b.

Table V-3

Least-Squares Estimate
(Depth Cubed Model)
(Using Expanded Uplink Data Base)

Frequency (Hz)	No. of observations	Estimated parameters			Standard error
		20 log a	c	b	
630	90	87.21	2.73	0.0023	6.66
1050	90	89.96	2.76	0.0037	6.46
1950	91	102.90	3.15	0.0016	7.11
3030	90	130.26	3.89	-0.0003	8.97

Source: Arthur D. Little, Inc.

Equation (11) can also be viewed as an oversimplified approximate relationship for the magnetic field above a small horizontal loop transmitter immersed in a homogeneous overburden of uniform conductivity. Although this model may appear to be more satisfying at first glance, because of its allusion to the physics of propagation in homogeneous conducting media, it does not provide as good and complete a representation of the data as the log depth power law model, and in some respects can even be misleading in the sense that it overly constrains the conductivity to be constant and independent of depth.

C. THE RECOMMENDED MODEL AND ITS APPLICABILITY

The signal strength(in dB)vs. log depth power law model of Section V-B1 is the most representative and practical regression model for predicting the detectability performance of trapped miner transmitters in the U.S. coal fields. The rationale for characterizing the relationship of signal strength to depth with a mathematical or statistical model is to permit the estimation of detection probabilities under actual trapped miner conditions. Many extraneous and uncontrollable factors can be expected to influence the detection system performance in any given real situation. However, by using the data obtained in this experimental program, we can in fact make probability statements about the strength of a signal reaching the surface when it is transmitted from relevant overburden depths in the frequency band of interest.

It is well known that statistical regression theory is a sound and useful tool for making inferences and probability statements about the behavior of one variable (signal strength) when another variable (depth) is known. Furthermore, the theory is simple and straightforward and has wide-ranging applicability in scientific and engineering studies. It is particularly appropriate in this case, since the model explicitly takes into account random fluctuations known to exist that influence the signal strength levels ultimately received at the surface from a transmitter located at identical overburden depths.

It has already been shown that a simple regression model describes the observed data from the sampled mine locations remarkably well. Since mines were randomly chosen, the regression relationships derived from sample results should be representative of all signal transmission conditions for similar overburden depths. The statistical model clearly describes the data, has a sound analytical framework, and allows for the straightforward quantification of probability estimates. Since no bias appears to have been introduced by augmenting uplink transmission data with downlink data when the former were unattainable, the simple regression model with estimated parameters given in Table V-1 is used in the subsequent analyses required to estimate detection probabilities.

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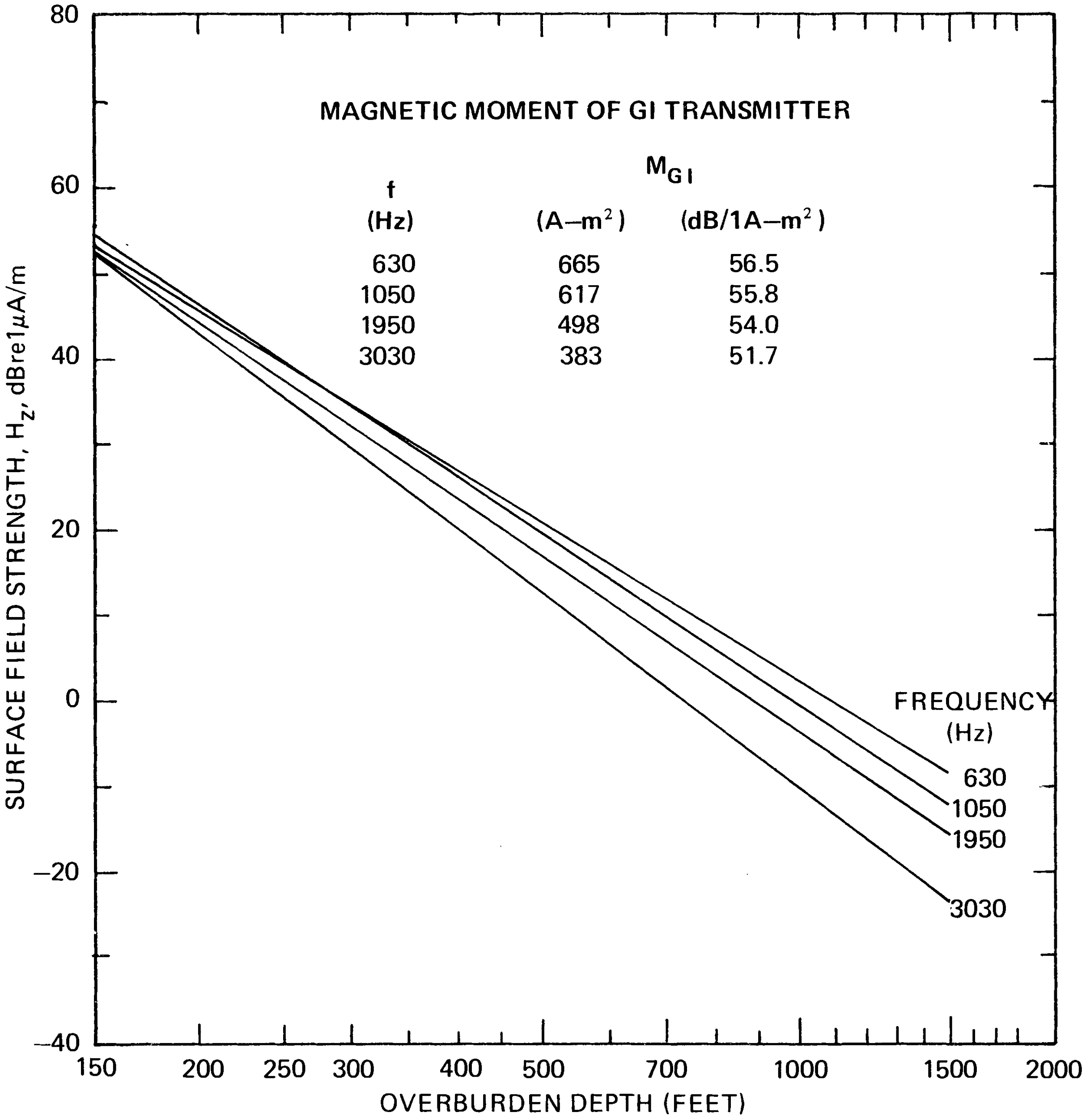
VI. SIGNAL ESTIMATES FOR THE GENERAL INSTRUMENTS TRANSMITTER

Having derived the overburden transmission response model presented in Section V-B1, it becomes a straightforward matter to estimate the expected overburden signal strength response as a function of overburden depth and frequency for the newly developed General Instruments rescue transmitter for trapped miner applications.

The GI transmitter signal strengths on the surface can be obtained by first computing the expected magnetic moment at each of the operating frequencies, and then translating each of the overburden response curves of Figure V-10 upward by an amount equal to the value of the magnetic moment expressed in dB relative to 1 Amp-m^2. Figure VI-1 depicts the results of this translation for the General Instruments transmitter.

The indicated values of GI transmitter magnetic moments shown in Figure VI-1 were computed by the same method used to compute the fundamental RMS magnetic moment for each of the measurement program in-mine loop configurations described in Appendix C. The circuit configuration for this calculation is the same as that shown in Figure C-1, but without the 0.1-ohm precision reference resistor used in the field to measure loop current. The GI transmitter characteristics of V_s and R_s are identical to those used for the Collins transmitter$^{(3)}$. The GI loop antenna consists of 300 feet of number 18 wire, arranged in the shape of a square. This loop configuration was chosen because it best represents the practical implementation of the strategy that the miners will be instructed to follow in the event that they are required to utilize the trapped miner transmitter. Namely, the miner will be instructed to deploy the complete length of wire around a coal pillar in such a manner as to create the largest



MAGNETIC MOMENT OF GI TRANSMITTER

f (Hz)	M_{GI} (A–m^2)	M_{GI} (dB/1A–m^2)
630	665	56.5
1050	617	55.8
1950	498	54.0
3030	383	51.7

FIGURE VI-1 PREDICTED UPLINK RESPONSE CURVES FOR GENERAL INSTRUMENTS TRANSMITTER—AVERAGE SURFACE VERTICAL MAGNETIC FIELD SIGNAL STRENGTH, H_z, VS DEPTH BY FREQUENCY loop antenna area with the available wire. Table VI-1 presents the loop impedance, current, and magnetic moment values calculated on the basis of this standard configuration for the GI transmitter. Although in some mines slightly larger or smaller loop areas, and thus magnetic moments, will be deployed, the tabulated values represent the most practical and realistic ones on which to base expected probabilities of signal detection on the surface.

Table VI-1

Loop Impedances and Magnetic Moments for the General Instruments Transmitter

	Loop Impedance		Transmitter Current/Moment		
Frequency (Hz)	R_L (Ohms) for 300 ft. #18 wire	X_L (Ohms) for L_L = 136 µH	$\lvert I\rvert$ Fund RMS (Amps)	$\lvert M\rvert$ Fund RMS (Amp-m^2)	$\lvert M\rvert$ Fund RMS (dB re 1 Amp-m^2)
630	1.92	0.737	1.272	665	56.5
1050	1.92	1.229	1.180	617	55.8
1950	1.92	2.282	0.953	498	54.0
3030	1.92	3.545	0.732	383	51.7

$V_s = \pm 3.45$ volts: (o-p square wave), $R_s = 0.312$ ohm

$|M|_{\text{Fund RMS}} = NA\,|I|_{\text{Fund RMS}}$, where N = 1, A = 523 m^2 (in a square)

Source: Arthur D. Little, Inc., and U.S. Bureau of Mines

VII. CHARACTERIZATION OF SURFACE NOISE ABOVE MINES

As discussed in Section IV-D, two independent sets of surface magnetic field noise measurements were obtained during the course of the measurement program. The Bureau of Mines tape recorded noise measurements, although far from comprehensive, were found to be more reliable, as well as representative, for the purpose of estimating signal-to-noise distributions on the surface and the corresponding probabilities of trapped miner signal detection. In this section we present the approach used to establish an appropriate probability distribution to characterize the noise data, together with the derived results.

As discussed in Section IV, atmospheric broadband noise, not discrete frequency man-made noise, will provide the main impediment to the detection of trapped miner signals. For the purpose of estimating signal detectability during a typical miner rescue operation, the RMS values of the vertical component of this atmospheric noise under non-extraordinary atmospheric noise conditions are the values of most interest. In practice, mine rescue signal detection efforts can be temporarily suspended during periods of severe local noise conditions. Furthermore, short instantaneous impulsive bursts of noise can be ignored without significant detection penalties during normal search and detection activities.

To investigate the behavior of the Bureau of Mines noise data, the convenient plotting technique described in Reference 12 was used. This procedure is computationally very simple and utilizes special probability graph paper that provides a convenient method of examining various theoretical probability distributions that might describe the data of interest. The procedure requires first ranking the data from lowest to highest value, assigning the lowest value the rank n (where n is the total number of observations), and then calculating H(x), where

$$H(x) = \sum_{(x)} \frac{1}{K(x)} , \qquad (13)$$

where K(x) equals the number of observations greater than or equal to x, the observed noise measurement.

As an illustration, some of the BOM noise data taken at 630 Hz yield the quantities given in Table VII-1. The cumulative conditional probability function H(x) is related to a probability law F(x), which is defined to be the probability of observing a noise value less than or equal to x. The theoretical properties are such that F(x) and H(x) are related as follows:

$$F(x) = 1 - e^{-H(x)} \qquad (14)$$

for <u>any</u> distributional form F(x). Probability paper is available for several different distributional forms; namely, the exponential, Weibull, normal, lognormal, and extreme value distributions. The paper is constructed so that the observed cumulative distribution values F(x) will tend to plot as a straight line if the underlying distribution form is appropriate.

For the BOM noise data, normal probability paper gave satisfactory results at each frequency. These plots of the RMS noise distribution are given in Figures VII-1 to VII-4. The mean value for each RMS noise distribution is located at the 50% point and is displayed on each graph. Examination of the graphs reveals that the RMS values decrease monotonically with increasing frequency by 20 dB over the 630 to 3030 Hz band. This behavior is consistent with that observed for atmospheric noise in this frequency band by other investigators,(6) as discussed in Section IV-D.

Table VII-1

Illustrative Example for Calculating Plot Points for Analysis of Noise Data

Noise (dB) (re 1 μA/m/ 30Hz) x	Rank (inverse order) K(x)	Cumulative conditional probability function H(x)	Cumulative distribution function F(x)
-15.2	27	0.0370	0.036
-8.2	26	0.0755	0.073
-7.2	25	0.1155	0.109
.	.	.	.
.	.	.	.
.	.	.	.
+29.8	2	2.8915	0.945
37.8	1	3.8915	0.980

Source: Arthur D. Little, Inc.

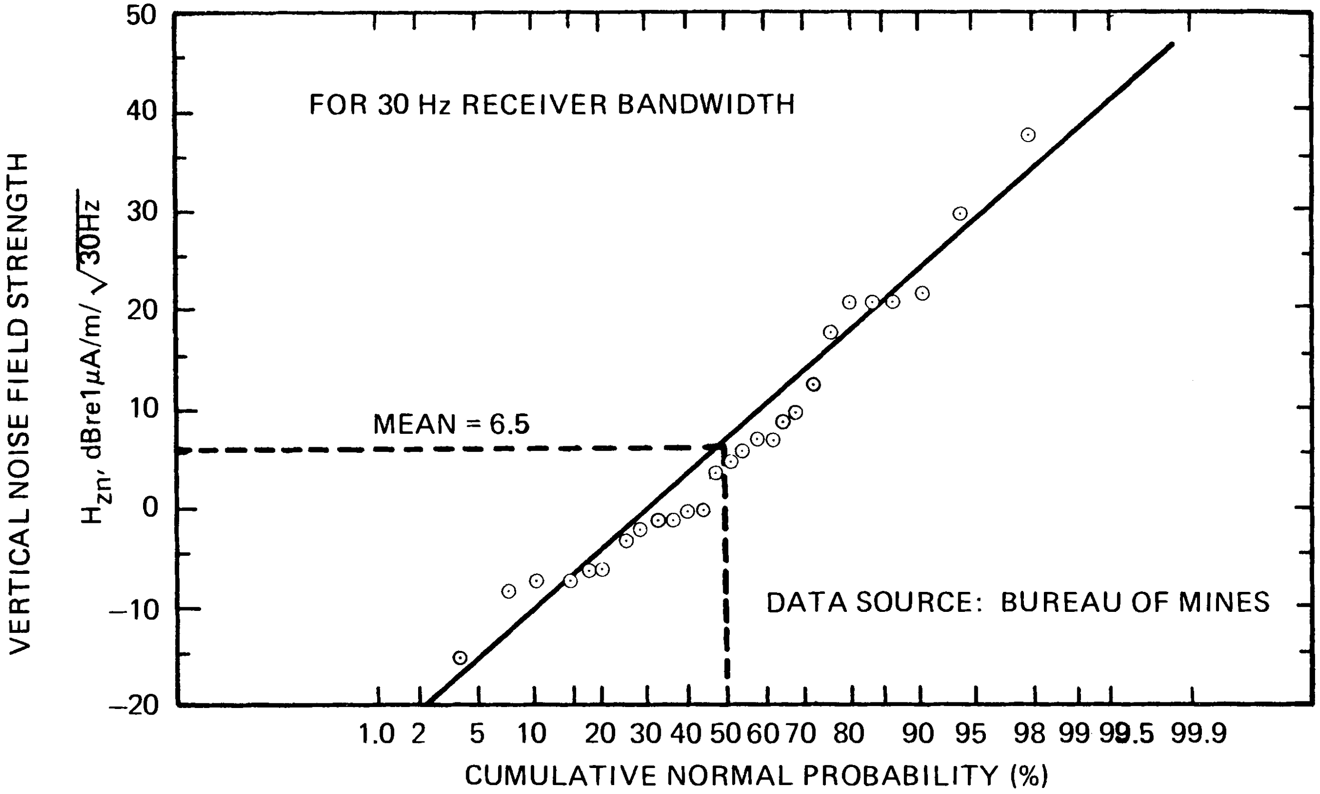


FIGURE VII-1 STATISTICAL DISTRIBUTION OF RMS SURFACE NOISE AT 630 Hz

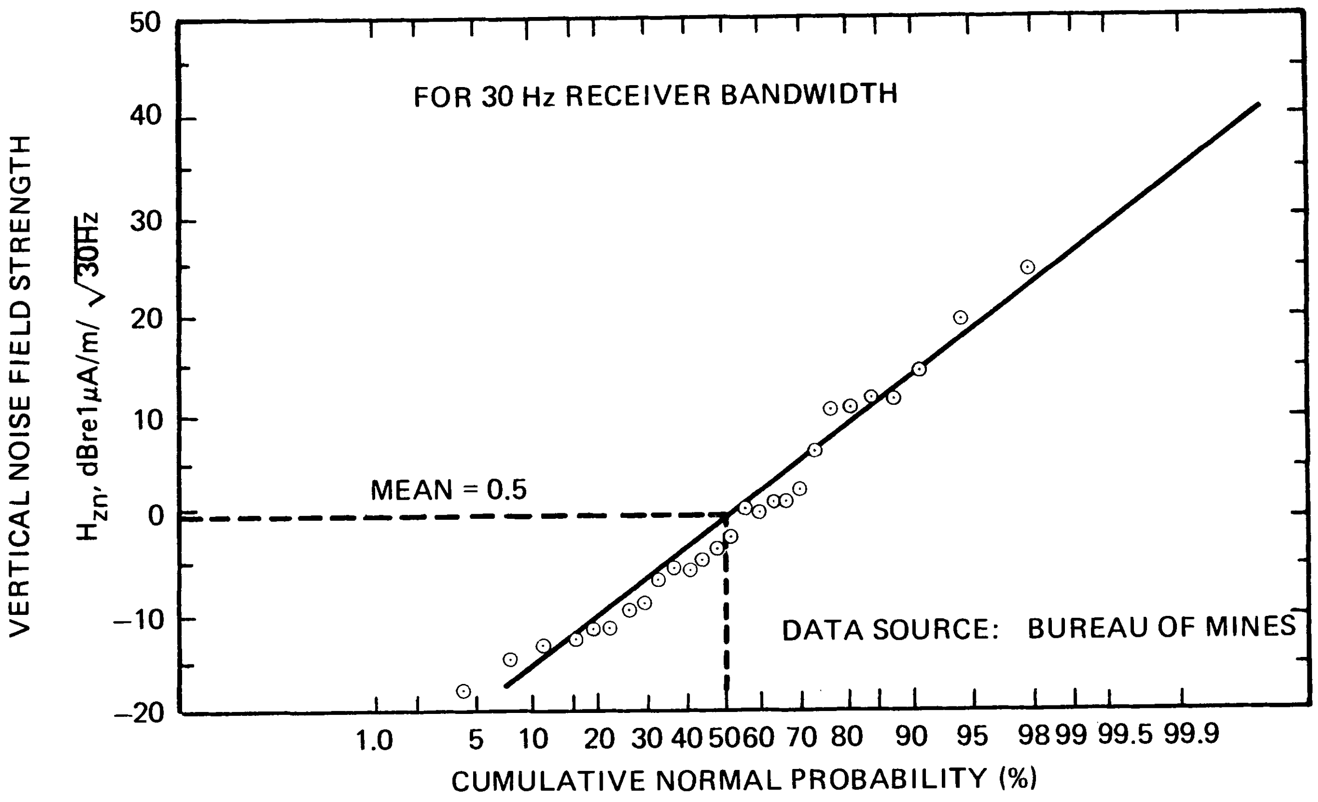


FIGURE VII-2 STATISTICAL DISTRIBUTION OF RMS SURFACE NOISE AT 1090 Hz

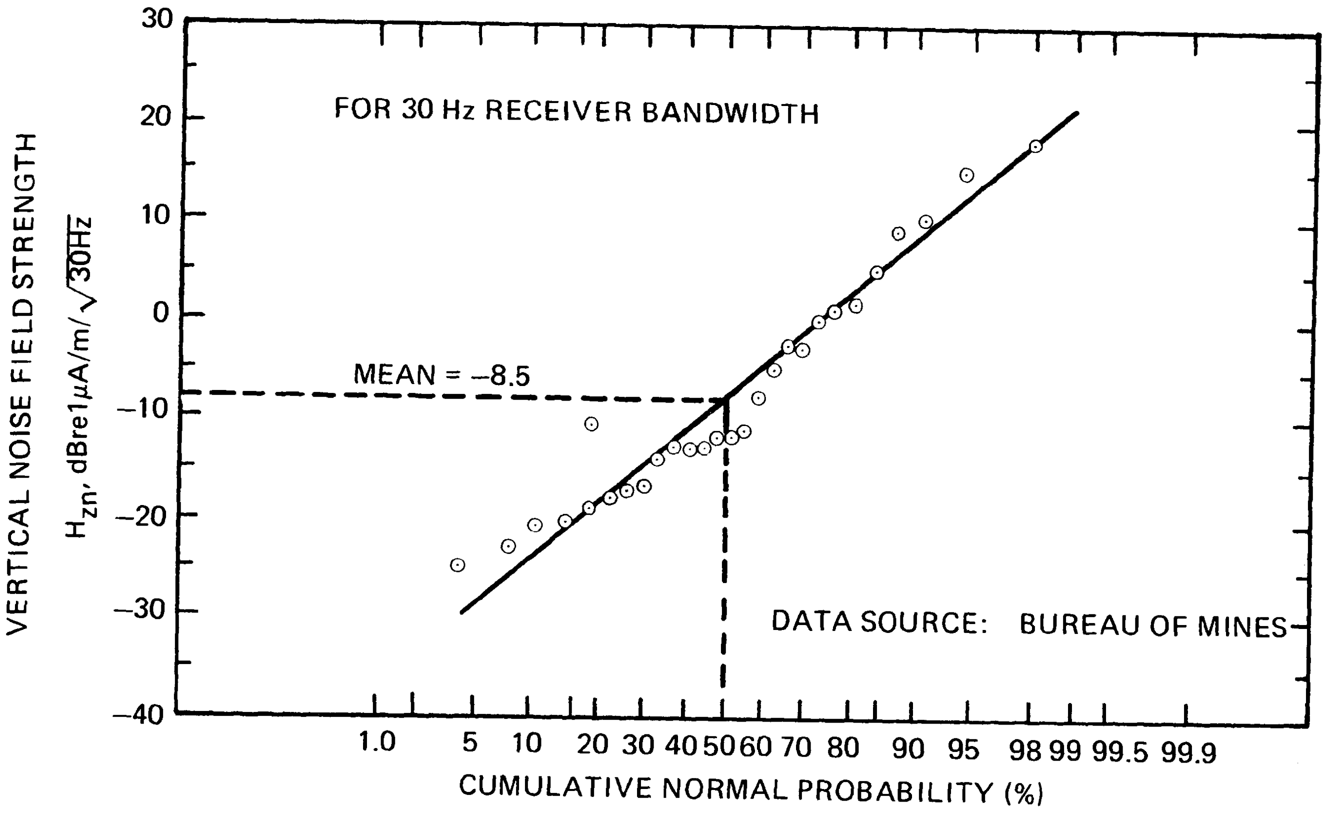


FIGURE VII-3 STATISTICAL DISTRIBUTION OF RMS SURFACE NOISE AT 1950 Hz

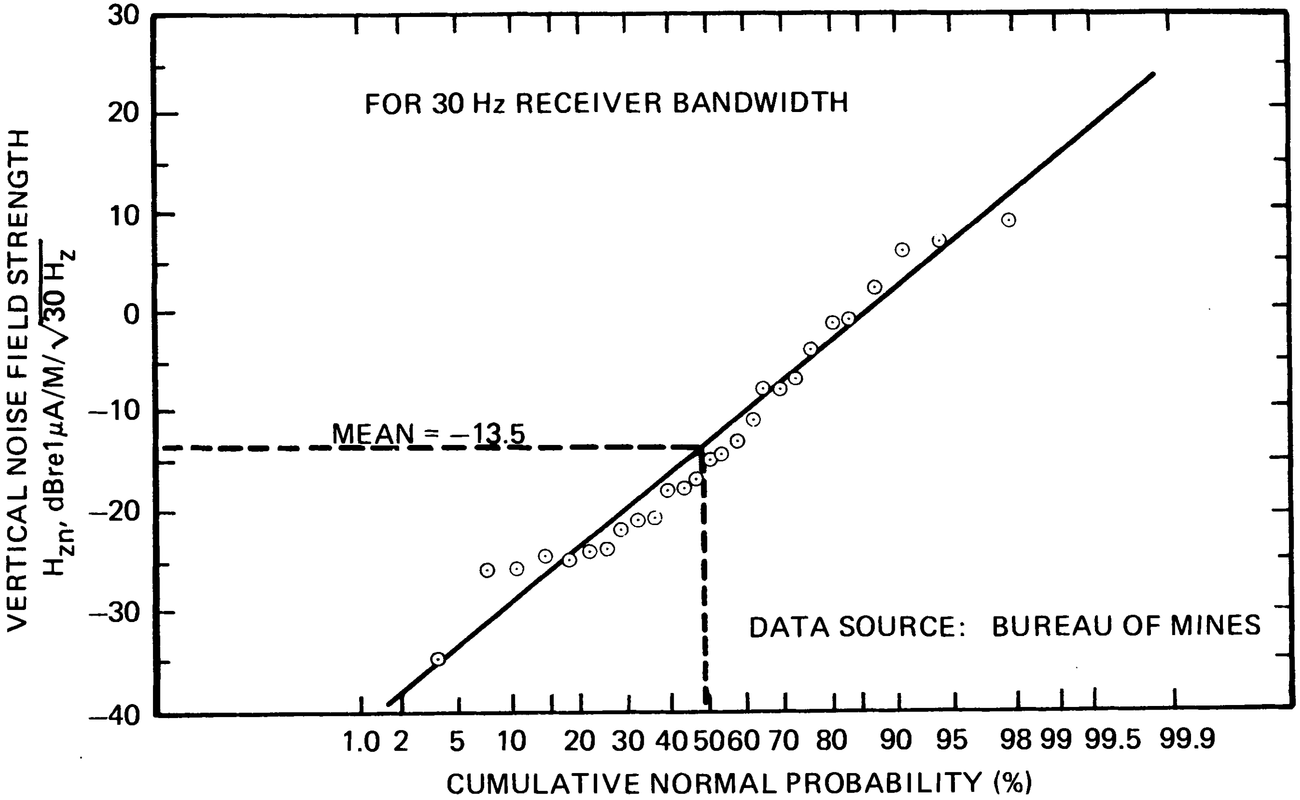


FIGURE VII-4 STATISTICAL DISTRIBUTION OF RMS SURFACE NOISE AT 3030 Hz

Figures IV-1 to IV-4 of Section IV-D indicate that the Westinghouse and Bureau of Mines noise data taken at the 27 mines jointly visited tend to agree on the average at the lower two frequencies, 630 and 1050 Hz, but depart significantly from each other at the upper two frequencies, 1950 and 3030 Hz. Westinghouse values consistently exceed BOM values at 1950 and 3030 Hz because of Collins receiver hardware problems. Figure VII-5 is a distribution plot at 630 Hz on normal probability paper comparing the BOM values at 27 mines with the 94 Westinghouse values measured at all mines. The excellent agreement between these two distributions at 630 Hz, together with the frequency dependence consistent with that of other investigators(6), lends added credence to using the Bureau of Mines data from 27 mines as descriptive of the expected surface noise to be found at mines in the U.S. coal fields.

The applicability of normal theory exhibited by the noise readings, coupled with the regression results which characterized signal strength in normal theory terms as well, permits a convenient analytical rather than empirical solution to the problem of characterizing signal-to-noise ratios on the surface. The approach and solution to estimating the behavior of signal-to-noise ratio at the surface as a function of overburden depth and frequency are described in the next section.

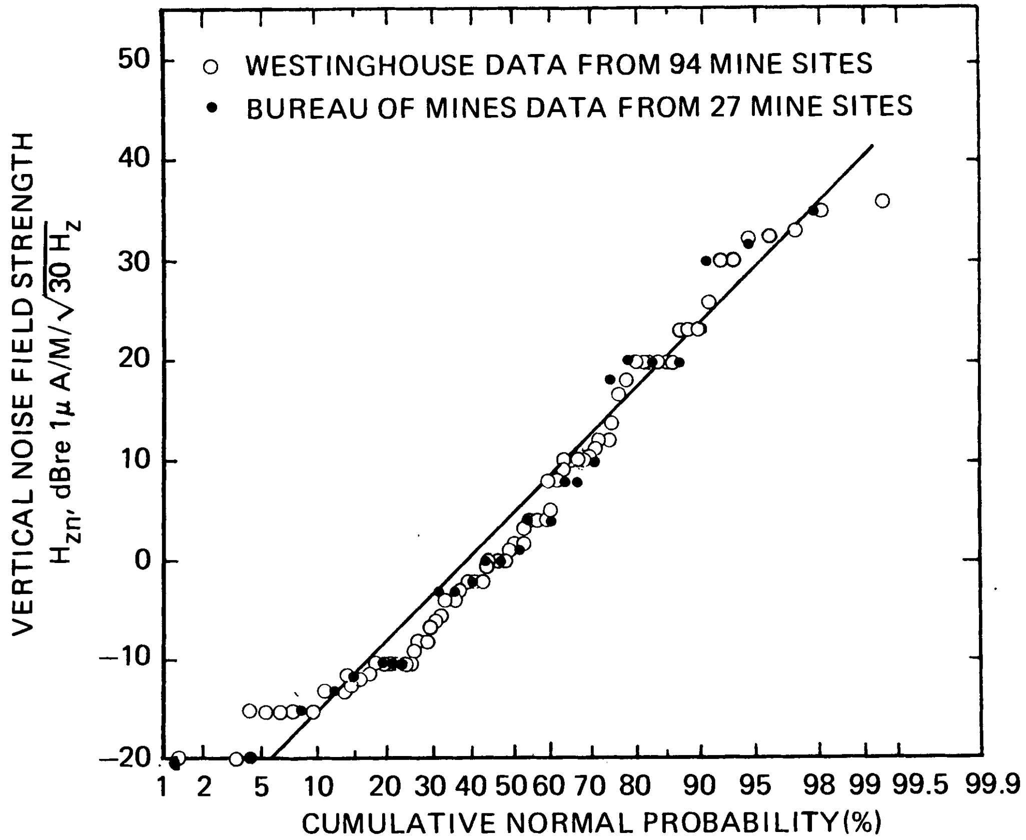


FIGURE VII-5 COMPARISON OF DISTRIBUTIONS OF WESTINGHOUSE AND BUREAU OF MINES NOISE DATA AT 630 Hz

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VIII. ESTIMATES OF SIGNAL-TO-NOISE RATIO ON THE SURFACE

In the three previous sections, the behavior of signal data and noise data obtained in this study have been characterized by statistical relationships. In particular, explanatory models have been derived from experimental data that portray the overburden signal transmission response as a linear function of log depth. It has been observed that the relationship differs somewhat over a range of four discrete frequencies considered in the test. The linear model actually expresses an average, or expected, signal strength that would be likely to occur if a very large number of tests were conducted at the same overburden depth level for widely varying mine sites and conditions in the U.S. coal fields. The variability about these average values is measured by the standard error of estimate, which is used to calculate confidence intervals and prediction intervals as described in Section V. Furthermore, probability distributions have been established for representing surface noise data. These noise distributions are independent of both transmitter signal strength and overburden depth.

The basic input for the derivation of RMS signal-to-noise ratio estimates on the surface is summarized in Table VIII-1, in which six overburden depth values are selected at 250-foot intervals for illustrative purposes. Mean RMS signal strength values at each frequency have been adjusted accordingly to pertain to the General Instruments transmitter, as discussed in Section VI and plotted in Figure VI-1. The objective is to obtain probability distributions of the RMS signal-to-noise ratio at each frequency above mines. These distributions can then be combined with probability of detection versus signal-to-noise ratio results for pulsed CW trapped miner signals, so that estimates of the probability of detecting trapped miner signals on the surface can be computed.

Table VIII-1

Estimated Parameters Characterizing Signal and Noise Distributions Above Coal Mines

Estimated Mean Signal in dB re 1 $\mu A/m$ for GI Transmitter

Overburden depth (ft.)	630 Hz	1050 Hz	1950 Hz	3030 Hz
250	39.71	39.77	37.28	35.83
500	21.05	19.57	16.71	12.74
750	10.14	7.75	4.68	-0.77
1000	2.40	-0.64	-3.85	-10.36
1250	-3.60	-7.14	-10.47	-17.79
1500	-8.51	-12.45	-15.88	-23.86
Standard Deviation	6.65	6.52	7.08	8.92

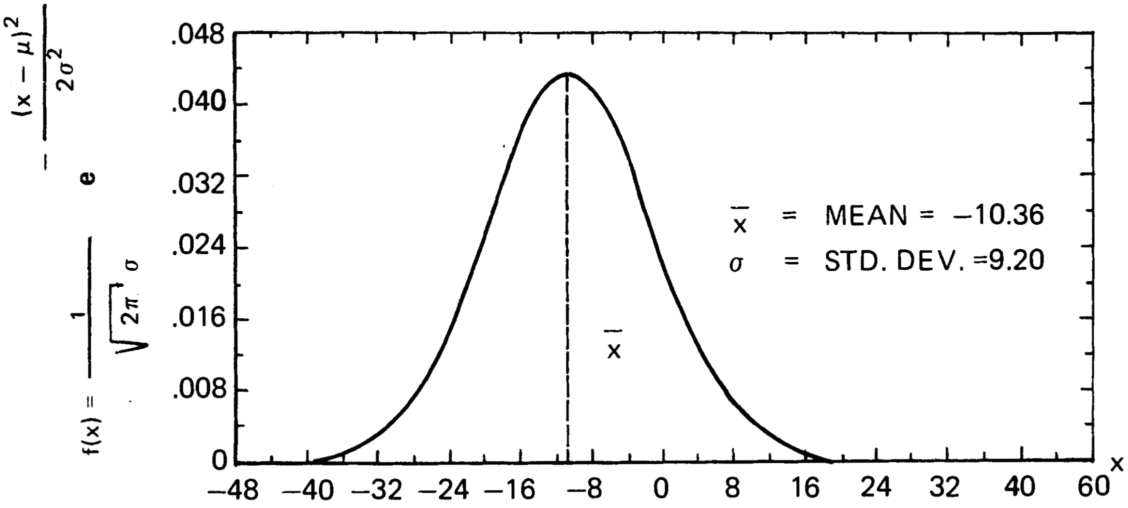
Estimated Mean Noise in dB re 1 $\mu A/m/\sqrt{30\ Hz}$

	630 Hz	1050 Hz	1950 Hz	3030 Hz
All Depths	6.5	-0.5	-8.5	-13.5
Standard Deviation	13.5	11.5	12.5	12.5

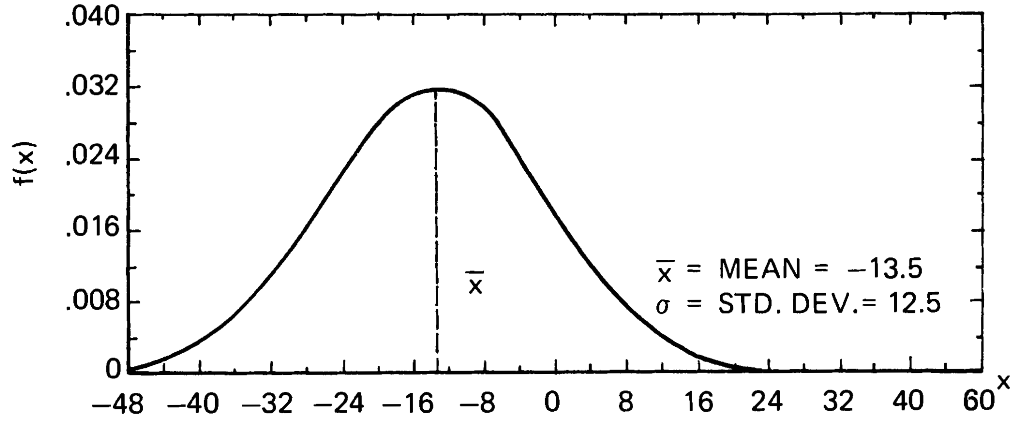
Source: Arthur D. Little, Inc.

The independence of signal and noise distributions, in addition to the property of normality exhibited by each distribution, permit straightforward combination of the two distributions to generate signal-to-noise probability estimates. This is due to the fact that the sum (or difference) of two normally and independently distributed variables is also normally distributed, with the mean equal to the sum (or difference) of the individual means, and the variance equal to the sum of the individual variances. This property is illustrated by the example portrayed in Figure VIII-1 for the expected performance of the GI transmitter at 1,000 feet and 3030 Hz. For the sake of completeness, it should be mentioned that the standard deviation given for signal strength (9.20 dB) in the figure is slightly higher than the tabular value given in Table VIII-1, since the actual 95% prediction interval width was used in the calculation to estimate signal strength variability.

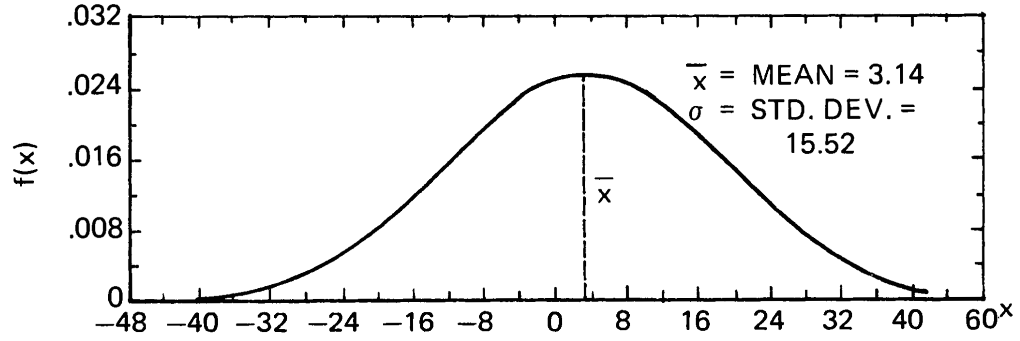
The signal-to-noise distribution appearing in Figure VIII-1 is more conveniently plotted using normal probability paper. This probability paper is designed so that only the two parameters needed to specify the normal curve (the mean and standard deviation) are required. Since one axis represents the cumulative probability under the normal curve, the mean is plotted at the 50 percentile point and the mean plus or minus one standard deviation is plotted at the 84 or 16 percentile point respectively. These points are then connected by a line which can be used to determine any percentile point for the specified normal curve. Such normal probability plots derived from the data in Table VIII-1 in the manner illustrated in Figure VIII-1 are given in Figures VIII-2 to VIII-5 for five different overburden depth configurations at each of the four frequencies. To illustrate the plotting technique, it can be seen in Figure VIII-5, at 1,000 feet, that the mean of 3.1 dB is found at the 50% point on the vertical axis, and 3.1 ± 15.5 = -12.4 and +18.6 are found at the 16% and 84% points, respectively.



a) NORMAL DISTRIBUTION CURVE, x = LOG SIGNAL (dB)



b) NORMAL DISTRIBUTION CURVE, x = LOG NOISE (dB)



c) NORMAL DISTRIBUTION CURVE, x = LOG(SIGNAL/NOISE)(dB)

FIGURE VIII-1 **DETERMINATION OF DISTRIBUTION OF SIGNAL-TO-NOISE RATIO ABOVE COAL MINES(Illustrative Example for 1000 Feet, 3030 Hz)**

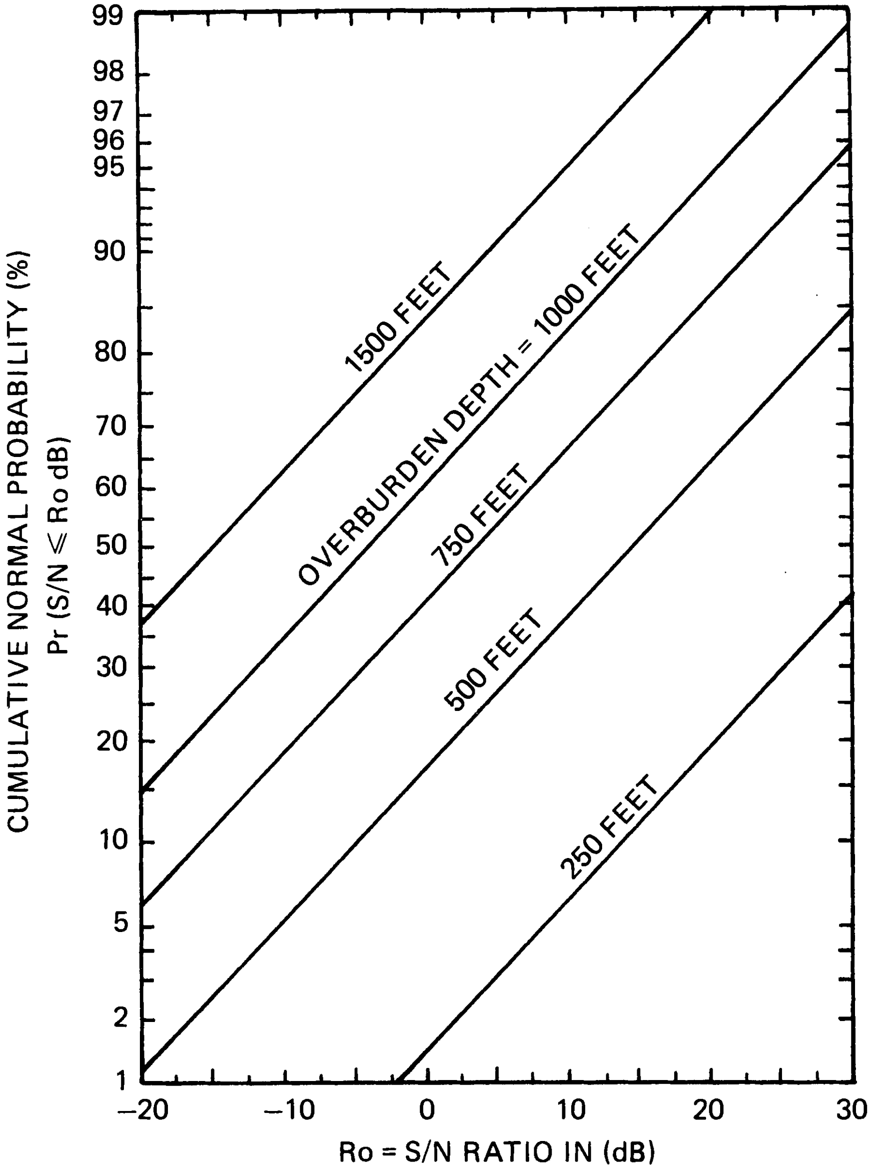


FIGURE VIII-2 CUMULATIVE PROBABILITY DISTRIBUTION OF S/N RATIOS EXPECTED ABOVE U.S. UNDERGROUND COAL MINES AT 630 Hz

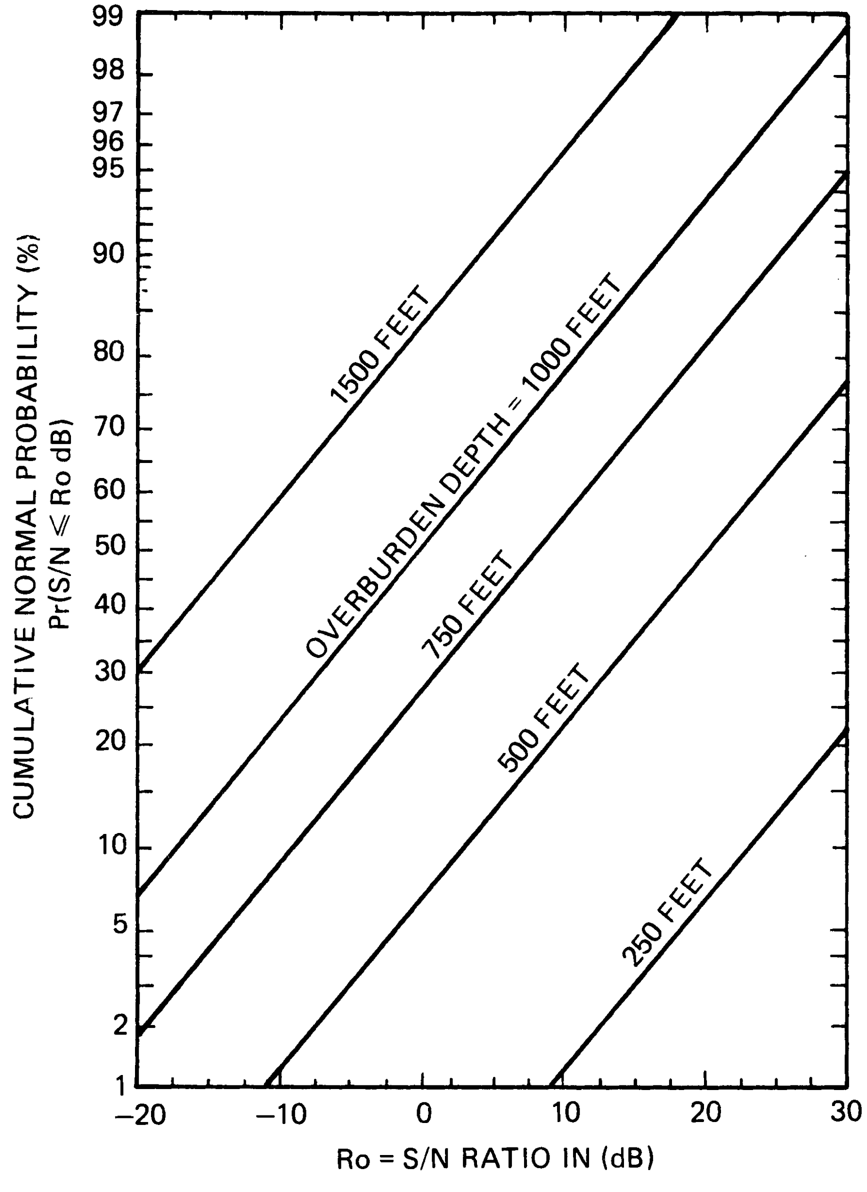


FIGURE VIII-3 CUMULATIVE PROBABILITY DISTRIBUTION OF S/N RATIOS EXPECTED ABOVE U.S. UNDERGROUND COAL MINES AT 1050 Hz

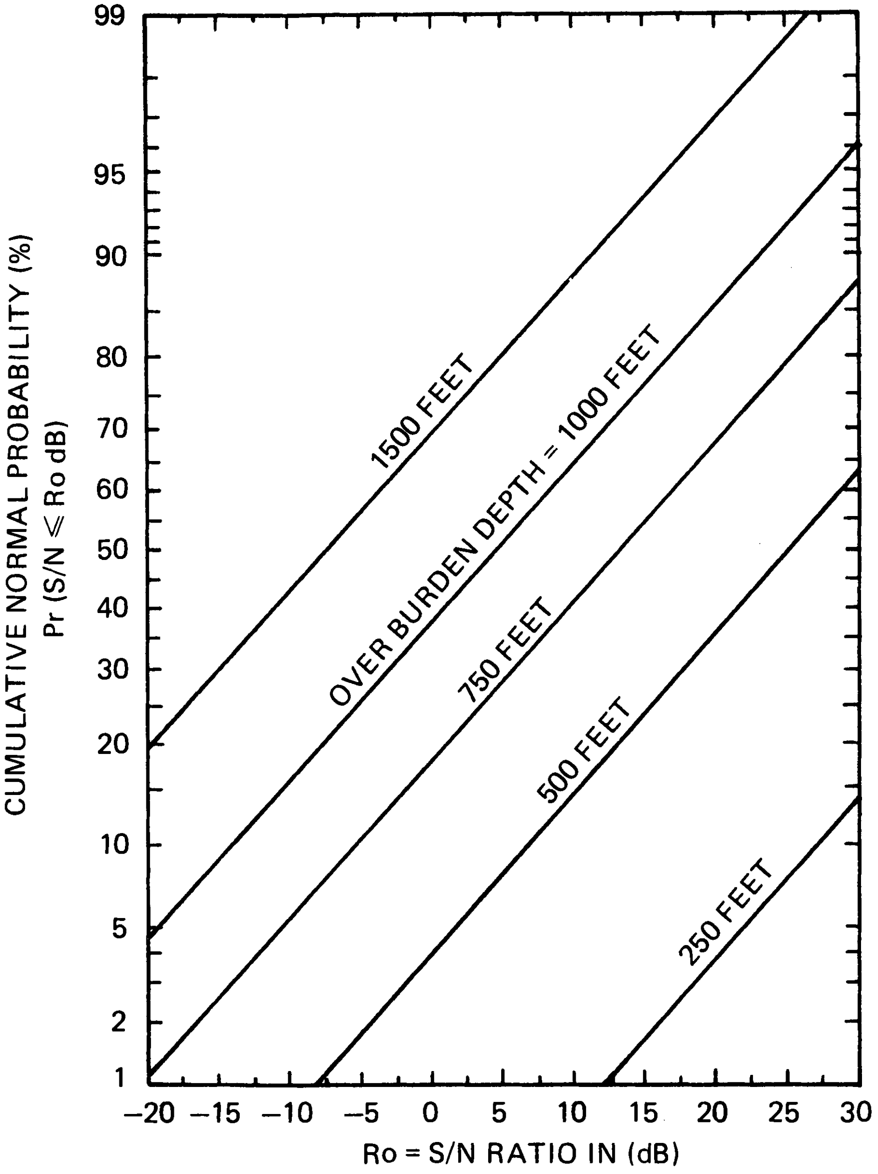


FIGURE VIII-4 CUMULATIVE PROBABILITY DISTRIBUTIONS OF S/N RATIOS EXPECTED ABOVE U.S. UNDERGROUND COAL MINES AT 1950 Hz

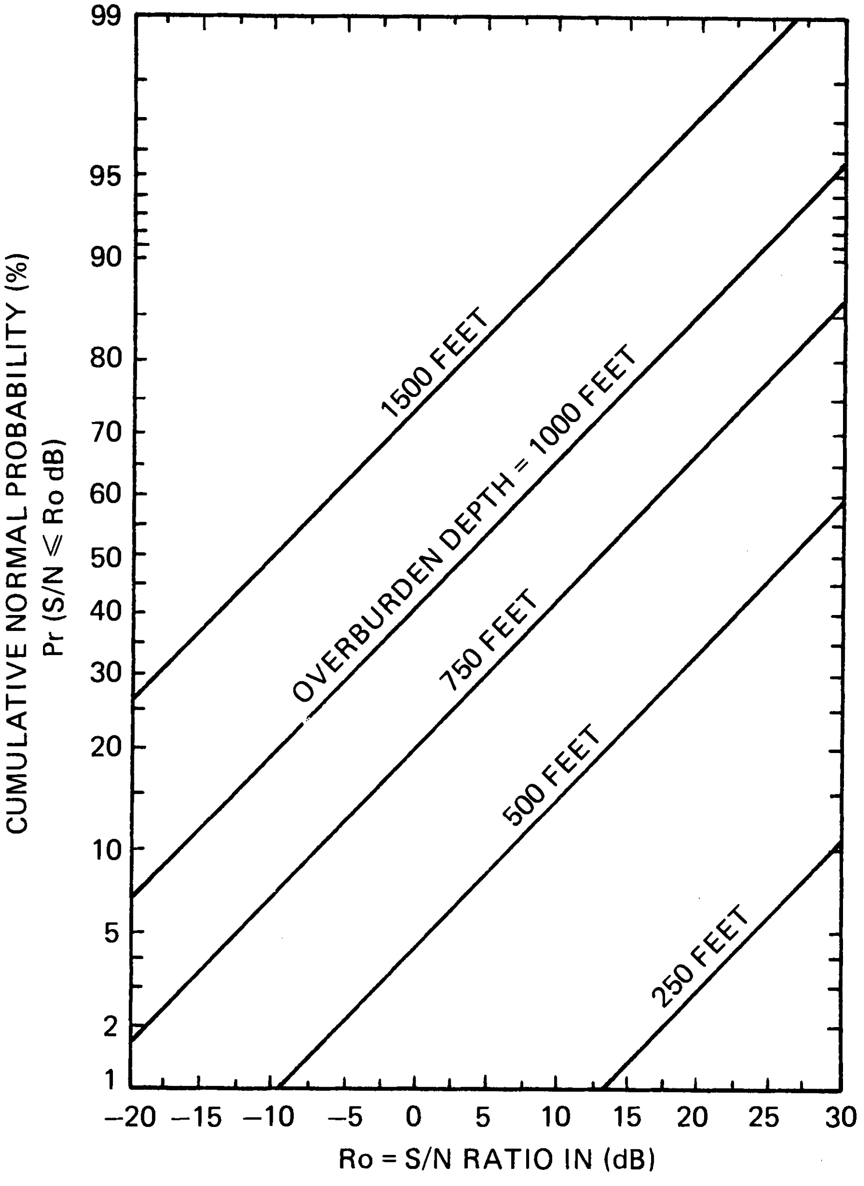


FIGURE VIII-5 CUMULATIVE PROBABILITY DISTRIBUTIONS OF S/N RATIOS EXPECTED ABOVE U.S. UNDERGROUND COAL MINES AT 3030 Hz

These four figures provide a simple method for determining estimates of achieving various signal-to-noise ratios in actual practice. Since the vertical axis represents the area under the normal curve from minus infinity to some signal-to-noise ratio R_o (measured in dB units) specified by the horizontal axis, this percentage is defined as the probability of achieving a signal-to-noise ratio less than or equal to R_o. By subtracting cumulative probabilities corresponding to two different ratios R_1 and R_2, these plots also yield direct probability estimates of observing signal-to-noise ratios in the interval represented by R_1 to R_2.

Some probability estimates for signal-to-noise ratios of interest have been read directly from the plots given in Figures VIII-2 to VIII-5 and are tabulated in Table VIII-2. These probabilities are subsequently used with the aural detection results of Section IX to derive signal detection probability estimates according to the method presented in Section X.

Prior to describing the analytical procedure used to determine overall signal detection probabilities over mines, it is also recognized that the data given in Table VIII-2 can be displayed in various ways. For example, it is possible to illustrate and compare the behavior of probability estimates associated with exceeding specified signal-to-noise ratio as a function of overburden depth and frequency. Two examples are given to illustrate such behavior; namely, Figure VIII-6 gives the probability of RMS signal being at least 9 dB greater than RMS noise, while Figure VIII-7 illustrates the probability of RMS signal simply exceeding RMS noise, as a function of overburden depth. The relative effect of frequency is also apparent in these figures. The figures reveal a relatively weak frequency dependence, and the somewhat surprising result of best predicted performance occurring in the upper part of the frequency band, and worst performance at the bottom of the band. This occurs because the measured RMS noise levels

Table VIII-2

Probability of Achieving Signal-to-Noise Ratios of Interest Above Coal Mines Using GI Transmitter

Signal-to-Noise Ratio (dB)	Overburden Depth (ft.)				Frequency (Hz)
	250 ft.	500 ft.	1000 ft.	1500 ft.	
<0	0.015	0.170	0.605	0.836	630 Hz
0 to 3	0.009	0.053	0.075	0.046	
3 to 6	0.013	0.055	0.067	0.034	
6 to 9	0.018	0.077	0.060	0.026	
9 to 12	0.025	0.078	0.050	0.020	
>12	0.920	0.567	0.143	0.038	
<0	0.01	0.065	0.500	0.834	1050 Hz
0 to 3		0.035	0.090	0.051	
3 to 6		0.044	0.087	0.037	
6 to 9		0.056	0.075	0.028	
9 to 12	0.008	0.070	0.068	0.020	
>12	0.982	0.730	0.180	0.030	
<0	0.01	0.039	0.374	0.692	1950 Hz
0 to 3		0.021	0.081	0.058	
3 to 6		0.030	0.088	0.060	
6 to 9		0.039	0.082	0.050	
9 to 12		0.050	0.075	0.039	
>12	0.99	0.821	0.305	0.091	
<0	0.01	0.045	0.420	0.745	3030 Hz
0 to 3		0.023	0.075	0.056	
3 to 6		0.030	0.075	0.049	
6 to 9		0.037	0.076	0.051	
9 to 12		0.045	0.069	0.031	
>12	0.99	0.820	0.285	0.078	

Source: Arthur D. Little, Inc.

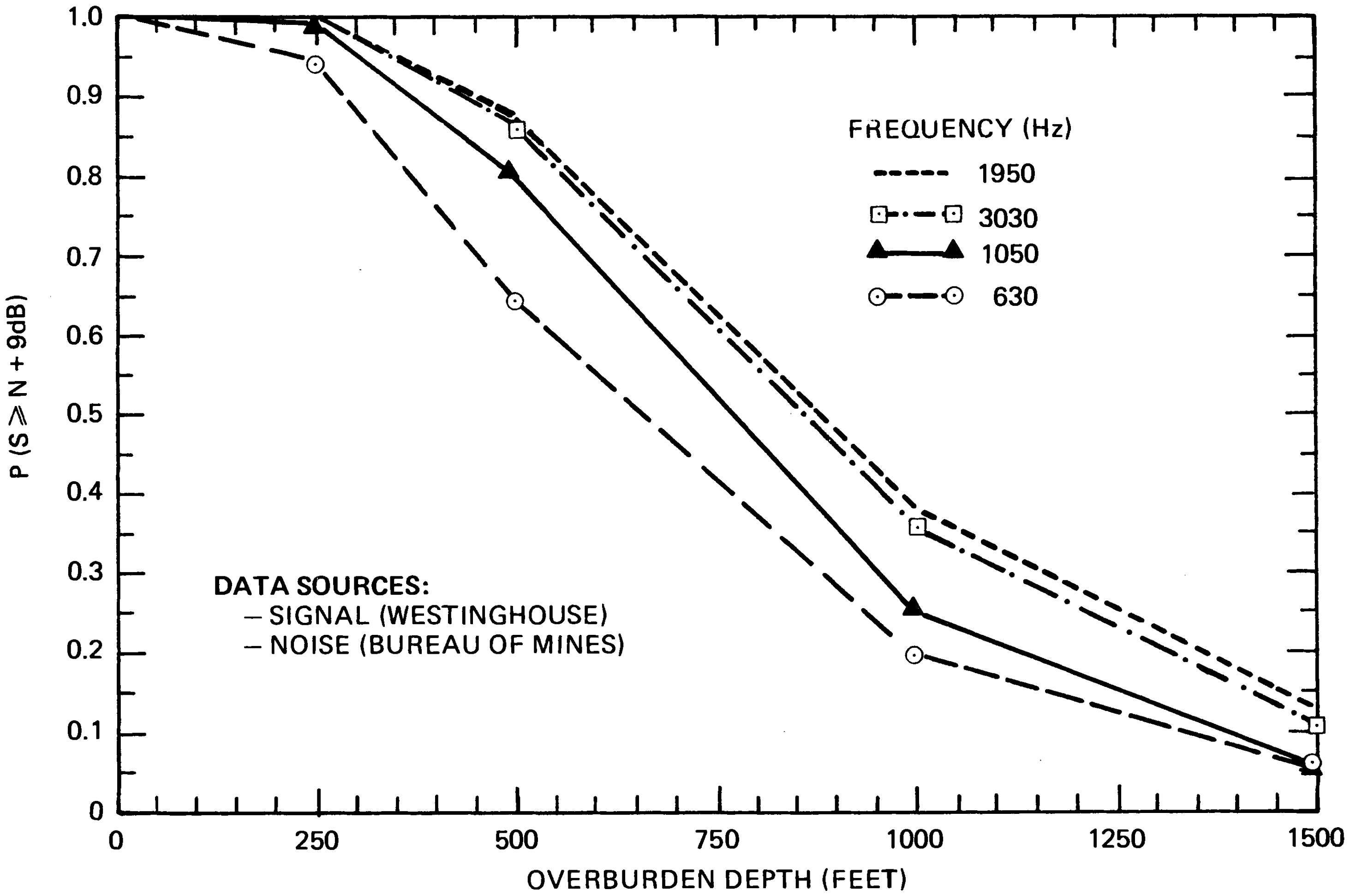


FIGURE VIII-6 PROBABILITY THAT MEAN RMS SIGNAL IS GREATER THAN OR EQUAL TO RMS NOISE + 9dB FOR THE GENERAL INSTRUMENTS TRANSMITTER

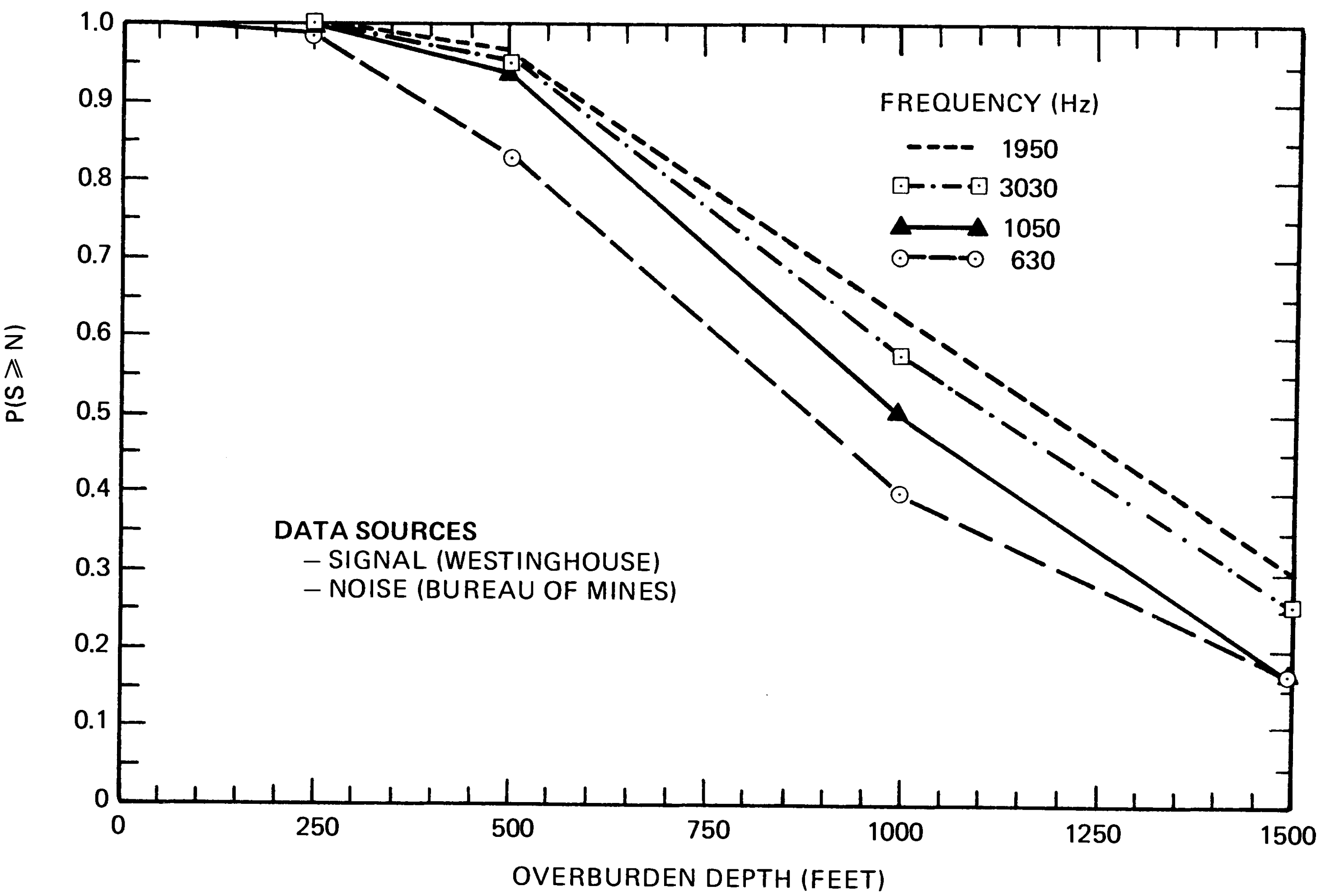


FIGURE VIII-7 PROBABILITY THAT MEAN RMS SIGNAL IS GREATER THAN OR EQUAL TO RMS NOISE FOR THE GENERAL INSTRUMENTS TRANSMITTER decrease faster with frequency than the mean RMS signal levels. A somewhat different method of presenting the same signal-to-noise data is shown in Figure VIII-8 for a frequency of 630 Hz. This figure illustrates the nature and approximate boundaries of the normal distributional characteristics of signal-to-noise ratio as a function of overburden depth.

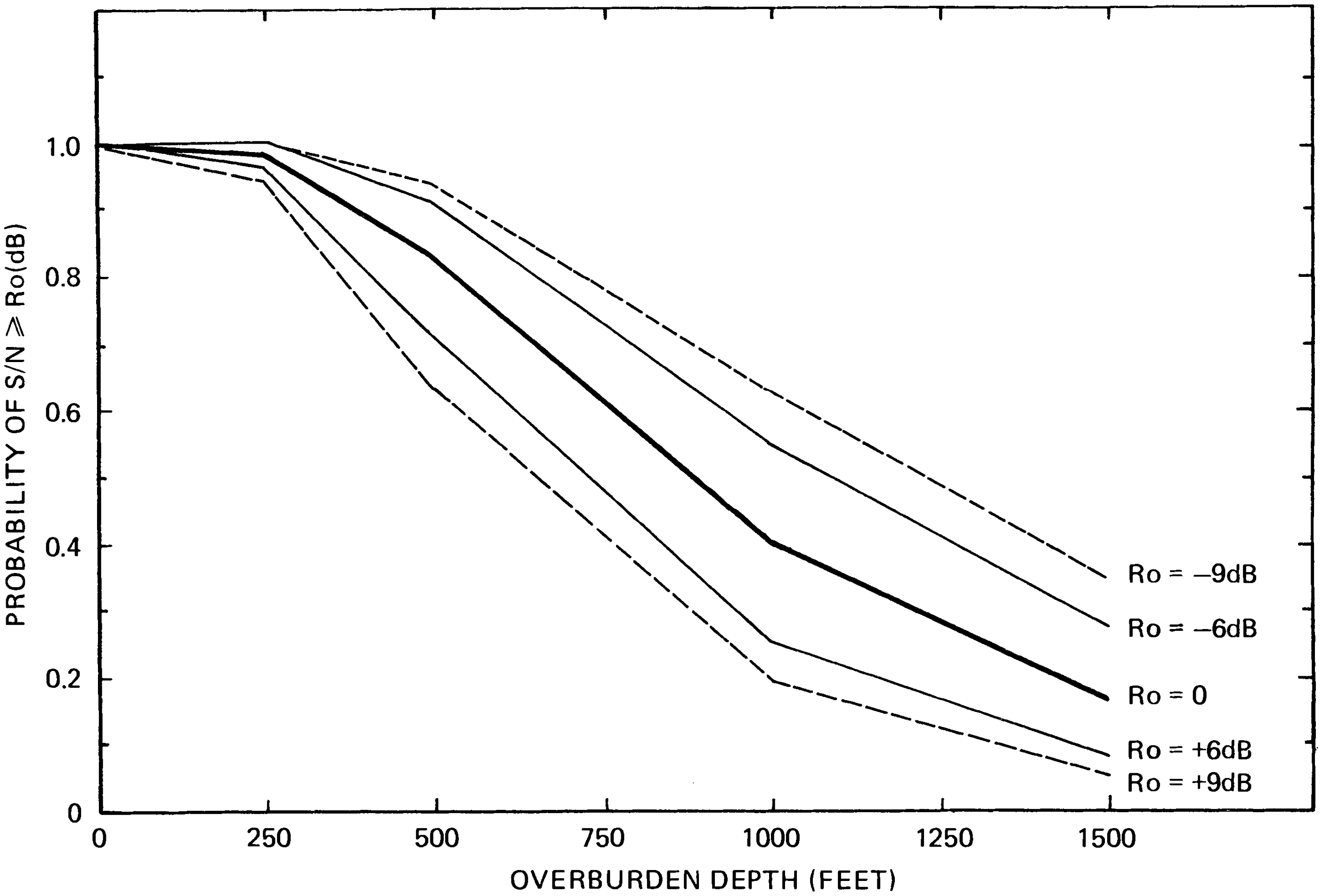


FIGURE VIII-8 RELATIONSHIP OF SIGNAL/NOISE RATIO PROBABILITIES VERSUS DEPTH FOR FREQUENCY = 630 Hz FOR THE GENERAL INSTRUMENTS TRANSMITTER

IX. AURAL DETECTION OF PULSED CW TONES IN NOISE

Trapped miner rescue operations based on the use of miner-carried ULF rescue transmitters will rely primarily on a surface search team to detect (and then locate the source of) signals generated by miners trapped underground. The pulsed CW signals generated by the transmitters will be detected by searchers carrying rescue receivers equipped with a hand-held loop antenna, headsets, and a meter indication as depicted in Figure III-4. Thus, the primary mode of detection will be aural, based on the headset signals perceived by the ear and brain. The objective of this section is to establish the signal-to-noise ratios required to achieve probabilities of aural signal detection in the broadband noise described in Section VII.

There is a wide body of theory and experimental data treating the ability of persons to detect audio frequency signals in background noise. Several parameters affect this ability to detect audio frequency tones in noise. They are:

- the listening frequency;
- the pulse length;
- the bandwidth of the noise; and
- the pulse repetition rate.

We have made use of this well-developed body of material from the literature to establish how each of these parameters affects pulse detection capability. We then combined the known results for each parameter to generate a probability of detection curve as a function of the RMS signal-to-noise ratio. This detection curve can then be applied to the signal-to-noise distributions of Section VIII to estimate probabilities of detecting trapped miner signals as a function of overburden depth.

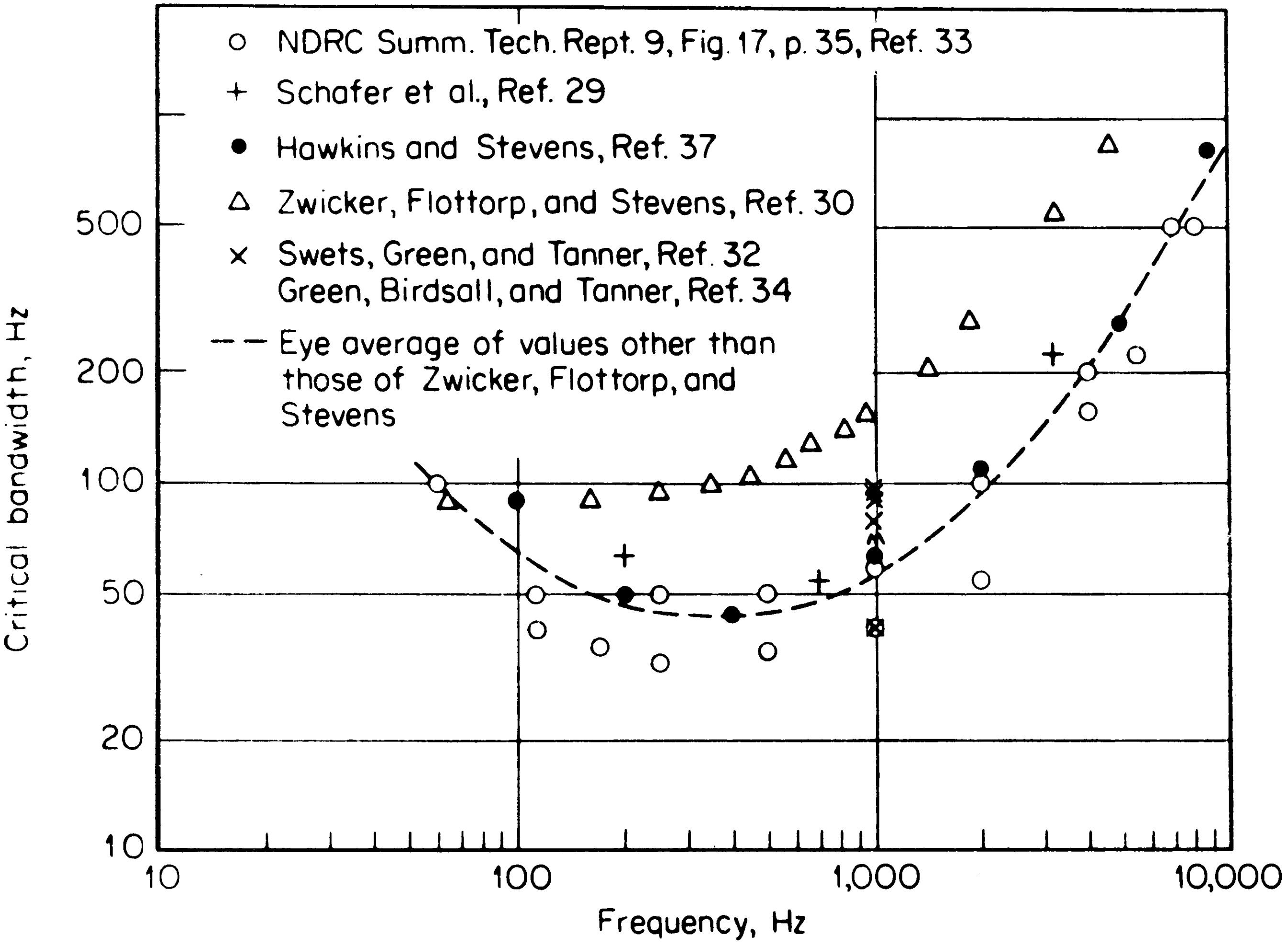
A. EFFECT OF LISTENING FREQUENCY

The present trapped-miner rescue receivers are designed so that all listening is done at 978 Hz, independent of the transmitted frequency. Namely, all receiver frequencies are heterodyned by the receiver to this relatively favorable frequency for aural detection. Figure IX-1(13) illustrates the auditory response to tones masked by broadband noise as a function of the frequency. This figure depicts the capability of the auditory response process to act as a filter to tune out competing background noise. In effect, the response can be considered as a relatively narrow bandpass filter centered at the listening frequency and of the bandwidth found on the plot, called the critical bandwidth. From this plot as a function of frequency, we find that the effective bandwidth, or the critical bandwidth, is approximately 60 Hz at the 978 Hz listening frequency of the rescue receivers.

B. EFFECT OF PULSE LENGTH

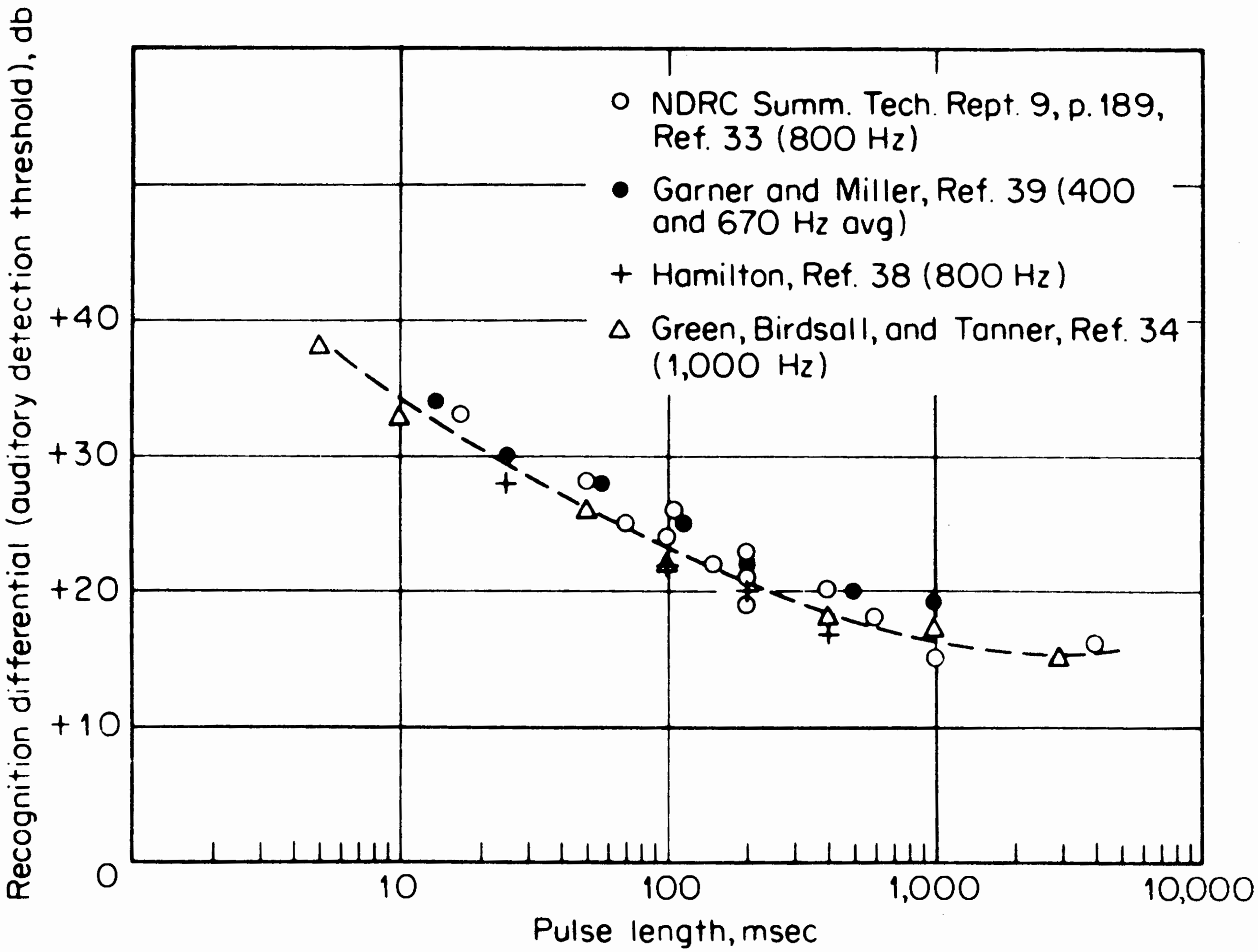
The effect of pulse length on aural detection capability is illustrated in Figure IX-2.(13) Psychoacoustic data taken by a number of investigators are combined in this figure to show the "recognition differential" required vs. pulse length for a 50 percent probability of detection. The recognition differential is the amount in dB by which the signal level needs to exceed the measured noise spectrum level within the listening bandwidth to provide a 50 percent probability of detection. The body of data comes from the investigators' psychoacoustic experiments on a number of subjects made under laboratory controlled conditions.

The rescue transmitters have a fixed pulse duration (length) of 100 ms. Therefore, this fixes the operating point of interest in Figure IX-2. The 100-ms pulse length prescribes a recognition



SOURCE: R.J. URICK, "PRINCIPLES OF UNDERWATER SOUND FOR ENGINEERS," McGRAW HILL – 1967, FIG. 12.10, REF. 13.

FIGURE IX-1 MEASURED VALUES OF THE CRITICAL BANDWIDTH OF THE EAR



SOURCE: R.J. URICK, "PRINCIPLES OF UNDERWATER SOUND FOR ENGINEERS" McGRAW HILL—1967, FIG. 12.11, REF. 13.

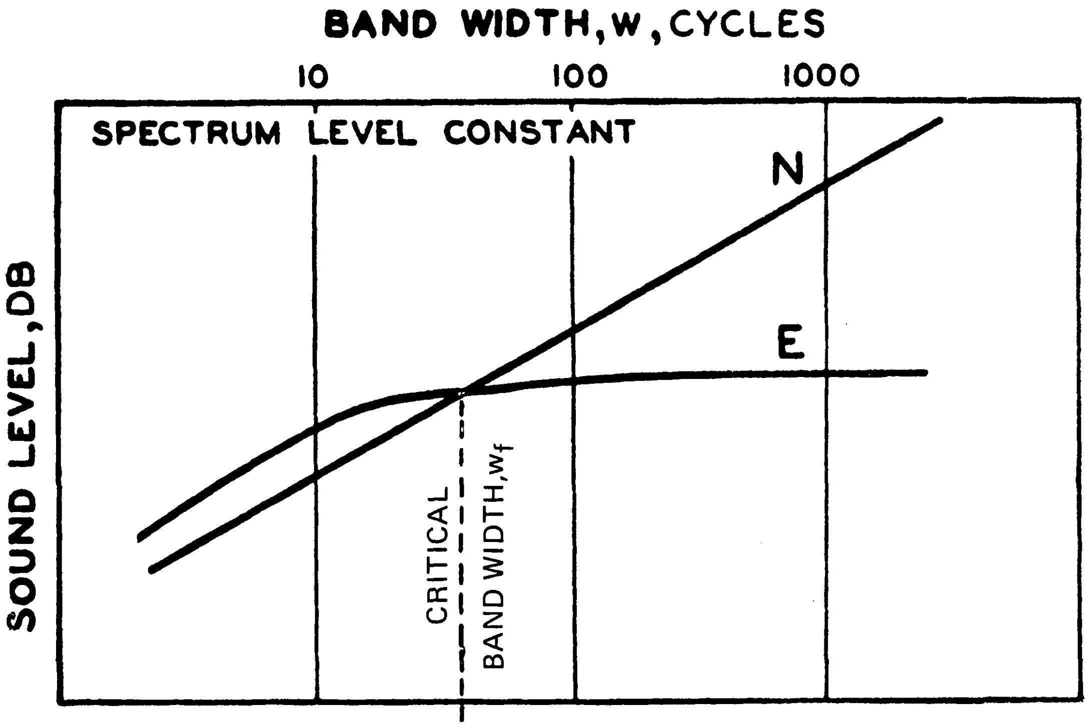
FIGURE IX-2 **RECOGNITION DIFFERENTIAL (AUDITORY DETECTION THRESHOLD, DT) FOR SINUSOIDAL PULSES IN BROADBAND NOISE REDUCED TO 1—Hz BANDS**

differential of 23 dB to achieve a 50 percent probability of detection. This is a fundamental number to the development of the detection capability that follows, and simply means that for a 50 percent probability of detection, the signal power level of a single tone burst needs to be 23 dB above the noise spectrum level in the listening bandwidth.

C. EFFECT OF BANDWIDTH

To determine the significance of the 23 dB recognition differential in terms of required signal-to-noise ratio, a bandwidth must be associated with the noise spectrum level. The electronic bandwidth used in the rescue receivers is 30 Hz, one-half the critical bandwidth of the ear at the receiver listening frequency. The effect of this reduced bandwidth can be estimated by using the data presented in Figure IX-3.(14) Figure IX-3 illustrates how the noise, N, and the required signal level, E, vary for a relatively long pulse when a 50 percent probability of detection is desired. The effect of the aural detection bandwidth, W_f, is clearly shown. As the electronic bandwidth is increased beyond W_f, the output noise level increases, while the signal level required remains fixed. It is as if a fixed bandpass filter were used; and indeed, the aural detection process works just that way with an effective filter bandwidth of W_f. Below the critical bandwidth, the signal level required remains constant with decreasing bandwidth until the bandwidth is reduced to less than about one-half of the critical bandwidth W_f.

The impact of this behavior on signal-to-noise ratio required for the trapped-miner detection hardware is as follows: The receiver has an electronic bandwidth of 30 Hz -- not small enough to provide any reduction from the signal level required for the 60 Hz critical bandwidth. Thus, from a detection standpoint,



SOURCE: PRINCIPLES AND APPLICATIONS OF UNDERWATER SOUND – SUMMARY TECHNICAL REPORT OF DIVISION 6, NDRC, VOL. 7, WASHINGTON, D.C., 1946 (REISSUED 1968), CHAP. 9, FIG. 7A., REF. 14.

FIGURE IX-3 DIAGRAM ILLUSTRATING RECOGNITION OF AN ECHO OF CONSTANT FREQUENCY AND RATHER LONG DURATION, WHEN THE NOISE LEVEL IS GREAT ENOUGH TO CAUSE MASKING LIMITED CONDITIONS FOR ALL BANDWIDTHS the system will behave as one having a noise bandwidth of 60 Hz and requiring a recognition differential of 23 dB. Therefore, a signal-to-noise ratio of 23 - 10 log 60 = 23 - 18 = 5 dB is needed for the 60Hz critical bandwidth to yield a 50 percent probability of detection.

The signal-to-noise ratios developed in Section VIII of this report have been based on the real 30 Hz electronic bandwidth of the receiver. Since we must account for the 60 Hz critical bandwidth effect of Figure IX-3, we have adopted the simple artifice of merely adding 3 dB to the 60 Hz 5 dB required signal-to-noise ratio criterion when using the signal-to-noise levels computed on the basis of the 30 Hz electronic bandwidth of the receiver. Thus, a 50 percent probability of detection will occur for the electronically-based signal-to-noise ratio of 8 dB. Alternatively, we could have chosen to reduce all of the computed electronically-based signal-to-noise ratios by 3 dB. We chose the easier path of altering the signal-to-noise criterion for 50 percent probability of detection to allow the use of the electronically-based signal-to-noise ratios.

The following quote, from Reference 14, page 197, describing some of the subjective effects of reduced bandwidth on the detection process, is also included for completeness:

> "When the bandwidth is less than W_f, echo and noise are heard as a single blended sound and recognition is caused almost entirely by a noticeable increase in loudness when the echo comes in. When the bandwidth is greater than W_f, echo and noise are heard as two distinct, though simultaneous, sounds, and the operator feels able to ignore the noise and concentrate on the echo. To a very considerable extent, this feeling is not an illusion."

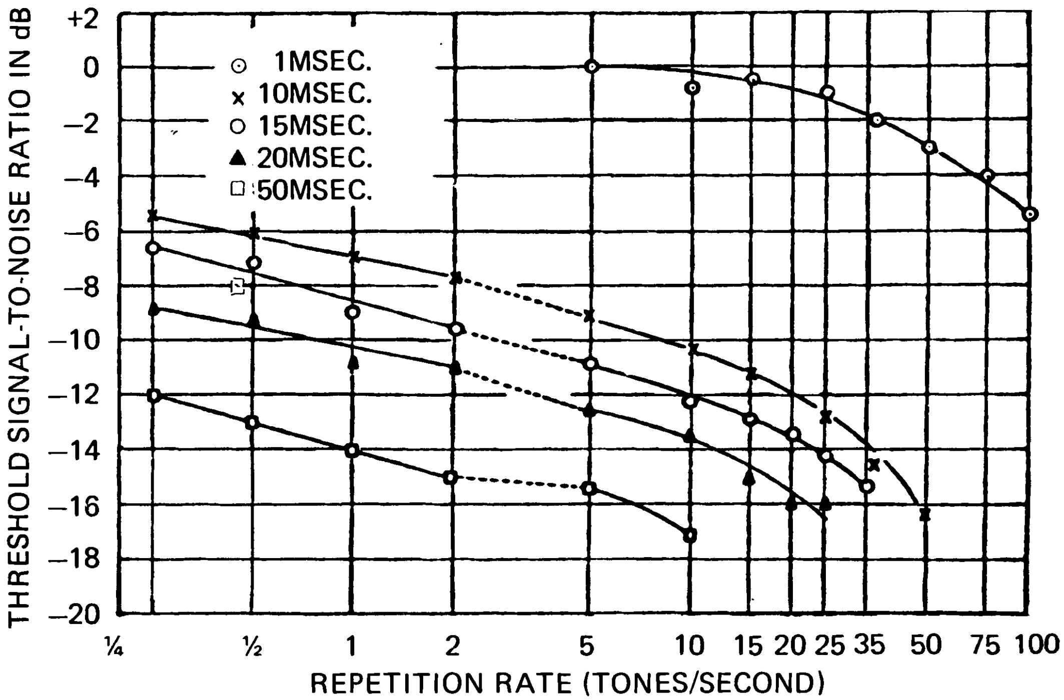
D. EFFECT OF PULSE REPETITION RATE

One more factor must be considered before arriving at a final value for the signal-to-noise ratio required to yield a 50 percent probability of detection. That factor is the continuously repeating nature of the transmitted signal. The data used above to arrive at the required signal-to-noise ratio are all based on the detection of a single tone burst in noise. Others(15,16) provide some data on continuously repeating tone bursts that enable us to take this repetition effect into account in setting the signal-to-noise 50 percent detection criterion. Figure IX-4 illustrates Garner's findings.(15) It shows that as the repetition rate of a 50 ms pulse is changed from one in four seconds to one per second, 2 dB less signal-to-noise ratio is required. From the nature of the Garner data, an even greater improvement might be expected, but the lack of data at repetition rates less than one per four seconds precludes a guarantee of this. Therefore, we use the 2 dB improvement value as a conservative estimate, and establish a 50 percent probability of detection signal-to-noise ratio criterion of (8-2) dB, or 6 dB.

We believe that a more reliable measure of detectability attainable through the use of repetitive pulse trains is still required. M. Ristenbatt of the University of Michigan is currently conducting laboratory experimental tests for the Bureau of Mines on this matter over a wide range of pulse repetition rates and observation intervals. The results of these tests should provide the information desired.

E. PROBABILITY OF DETECTION VS. S/N RATIO

Having established a basis for identifying the signal-to-noise ratio required for a 50 percent detection probability, we need a means for quantitively extending the signal-to-noise ratio



NOTE: EACH CURVE IS FOR A DIFFERENT TONAL DURATION. THE MASKING NOISE WAS FILTERED WITH A 5000 Hz LOW PASS FILTER, AND SIGNAL-TO-NOISE RATIOS ARE WITH RESPECT TO THE TOTAL NOISE ENERGY. THE INTENSITY OF THE MASKING NOISE WAS APPROXIMATELY 90 dB re 0.0002 dyne/cm^2. FREQUENCY IS 1000 Hz.

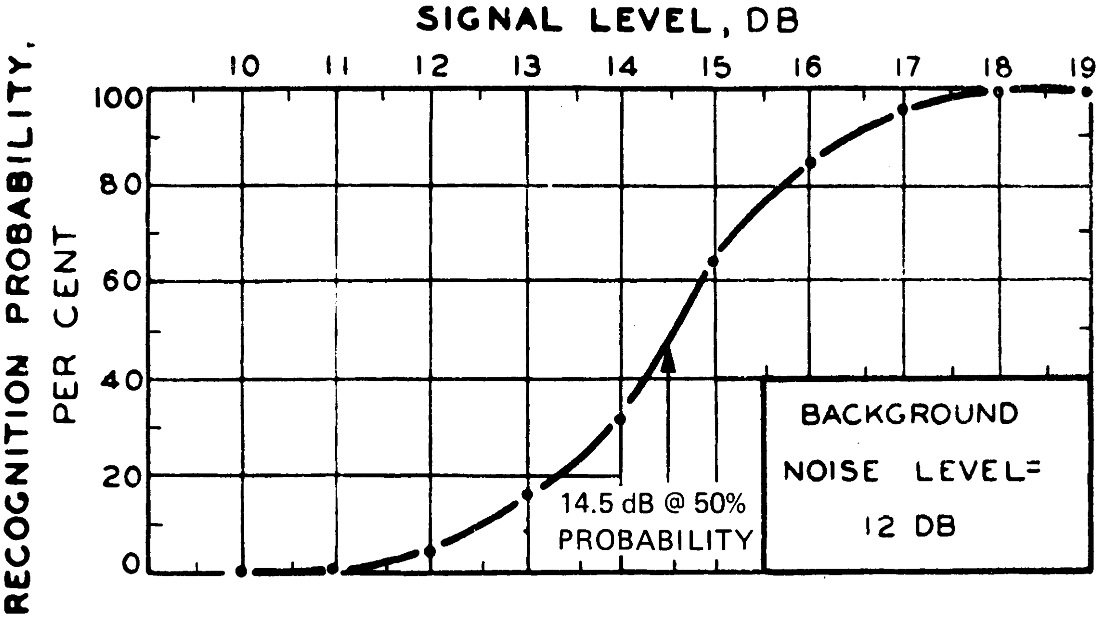
SOURCE: W.R. GARNER "AUDITORY THRESHOLDS OF SHORT TONES AS A FUNCTION OF REPETITION RATES", JASA VOL. 19, NO. 4, JULY 1947, PP. 600–608, FIG. 4, REF. 15.

FIGURE IX-4 THE EFFECT OF REPETITION RATE OF SHORT TONES ON THE MASKED THRESHOLD criterion to include higher and lower detection probabilities. We choose to stay with experimentally determined aural detection results for tones in noise such as that shown in Figure IX-5(14). Although this figure is strictly applicable to pure tones in noise, we believe that the shape of the response about the 50 percent probability value should be representative of the behavior expected for detecting pulsed CW tones in the field. Therefore, the probability of detection vs. signal-to-noise ratio curve for 100 ms repetitive CW audio pulses of Figure IX-6 has been constructed by relabeling the horizontal axis of Figure IX-5 so that the 50 percent probability of detection condition occurs for the signal-to-noise ratio of 6 dB derived above. This plot is used with the results of Section VIII to compute the trapped miner signal probability of detection estimates in Section X.

In conclusion, we make the following additional comments on the aural detection of pulsed tones noise:

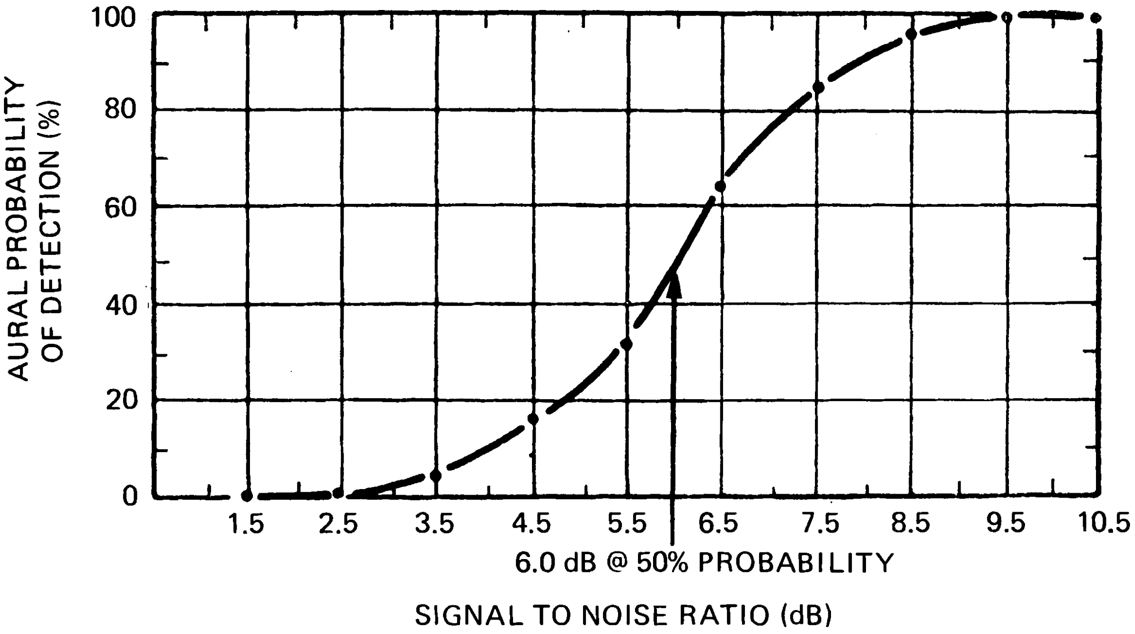
- Alerted vs. non-alerted detection. The probability of detection vs. signal-to-noise ratio is the product of psychoacoustic testing. These tests can readily be biased by alerting the listeners by such instructions as "Make sure you don't miss a signal," or "Be very sure you have a signal." Such instructions will alter the detection curve. We chose to use the non-alerted characteristic as being applicable to the trapped-miner detection problem.

- Modern treatments of detection disregard the recognition differential and adopt the detection index as a means of including false detections. We do not regard false detections as a problem. If a surface-based searcher thinks he has a detection while he is searching an area, he will stop and listen carefully. If he can't verify the



SOURCE: PRINCIPLES AND APPLICATIONS OF UNDERWATER SOUND – SUMMARY TECHNICAL REPORT OF DIVISION 6, NDRC, VOL. 7, WASHINGTON, D.C., 1946 (REISSUED 1968), CHAP. 14, FIG. 5, REF. 14.

FIGURE IX-5 PROBABILITY OF RECOGNITION OF A PURE TONE IN A BACKGROUND OF A NOISE AT A CONSTANT RMS LEVEL OF 12 dB



NOTE: FOR 100 MILLISECOND PULSES, 1 PER SECOND REPETITION RATE, 957 Hz LISTENING FREQUENCY, AND 30 Hz RECEIVER BANDWIDTH.

SOURCE: ARTHUR D. LITTLE, INC., AND REFS. 13, 14, 15.

FIGURE IX-6 AURAL PROBABILITY OF DETECTION VERSUS RMS SIGNAL-TO-NOISE RATIO FOR TRAPPED MINER PULSED CW SIGNALS IN BACKGROUND GAUSSIAN NOISE

detection, he will merely move on. Thus, we chose to use the recognition differential as a valid tool in the development of detection characteristics such as presented above.

- Additional detectability experiments should be performed, perhaps in conjunction with Ristenbatt's pulse repetition rate aural detection experiments, as a further check on the accuracy and applicability of the derived detection curve of Figure IX-6.

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X. PROBABILITY OF DETECTION ESTIMATES ON THE SURFACE ABOVE MINES

A. METHODOLOGY

In an actual mine emergency situation, the signal transmitted from a mine cannot always be expected to be detected at the surface. Several factors will influence the reception, detection and recognition of a true signal. As discussed throughout this report, the signal strength itself is known to vary, primarily as a function of overburden depth and transmitter frequency, but also according to overburden composition and other unknown and uncontrollable ancillary factors. The presence of these factors influencing the strength of signals transmitted through-the-earth has been acknowledged in this test program and is implicitly represented by the regression models derived from test data obtained by Westinghouse from the 94 mine sites. The noise level for any given emergency situation is also a random phenomenon, rather than a deterministic one, and has been characterized by a normal, or Gaussian, probability law from additional experimental data collected by the Bureau of Mines at 27 of the 94 mine sites.

Furthermore, for a known signal strength/background noise level combination, the actual detection of the signal by an observer at or above the surface cannot be treated deterministically; that is, signal detection must be considered a random event, the occurrence of which follows some probability law. In its simplest form, this law can be expressed in terms of signal-to-noise ratio. At extremely low ratios the chance of signal detection would be essentially zero, while at extremely high ratios detection would be close to certainty. At intermediate levels, the chance of detection would be expected to increase monotonically with increasing signal-to-noise ratio. Various studies have been conducted on hearing and aural detection of tones in noise to investigate properties of this relationship. Figure IX-6 of the previous section presents empirically derived probability of detection results that have been adapted for application to the trapped-miner detection problem.

The probability of detection curve in Figure IX-6 actually represents conditional probabilities; that is, the likelihood that detection will occur given the presence of a fixed, observable RMS signal-to-noise ratio. As a consequence, the chance of detecting a signal transmitted through the earth can be calculated according to the fundamental multiplication rule for probabilities:

$$P\left\{D \text{ and } R_k\right\} = P\left\{R_k\right\} \times P\left\{D \mid R_k\right\} \qquad (15)$$

where $P\left\{D \text{ and } R_k\right\}$ represents the probability of achieving a signal-to-noise ratio of size R_k and also detecting the signal embedded in this noise; $P\left\{R_k\right\}$ is the probability of the occurrence of a signal-to-noise ratio of size R_k, and $P\left\{D \mid R_k\right\}$ is the conditional probability of detecting a signal, given a signal-to-noise ratio of size R_k.

Probability distributions have been derived and presented in previous sections of this report for both factors on the right-hand side of the above equation. As mentioned above, Figure IX-6 gives $P\left\{D \mid R_k\right\}$; certain integral values of R_k and their associated probabilities of detection are also tabulated in Table X-1. Signal-to-noise probability distributions $P\left\{R_k\right\}$ are given in Figures VIII-2 to VIII-5. These figures emphasize the fact that these probabilities also depend on frequency and depth. Using additional subscripts to account for these dependencies, the probability of achieving a signal-to-noise ratio of size R_k (measured in dB) and detecting the signal transmitted from a depth i, at frequency j, can be denoted as follows:

TABLE X-1

PROBABILITY OF SIGNAL DETECTION VERSUS SIGNAL-TO-NOISE RATIO

Signal-to-Noise Ratio (dB)	Probability of Detection
2	0
3	0.02
4	0.10
5	0.22
6	0.50
7	0.78
8	0.90
9	0.98
10	1.00

Source: Arthur D. Little, Inc. (Figure IX-6)

$$P_{i,j,k} \left\{ D \text{ and } R_k \right\} = P_{i,j} \left\{ R_k \right\} \cdot P \left\{ D \middle| R_k \right\} \quad (16)$$

This is the probability associated with a specific R_k value. The analytical result that is of interest here is not simply $P_{i,j,k}$, but $P_{i,j} \{D\}$, the expected probability of detecting a signal transmitted at a specified overburden depth i,for a known transmission signal frequency j,summed over all possible R_k's. Since signal-to-noise ratio can take on any value R_k, and these values are mutually exclusive, the addition rule for probabilities applies; that is,

$$P_{j,1}\{D\} = \sum_{R_k} P_{j,1,k} \quad (17)$$

where the summation over all possible signal-to-noise ratios R_k is actually an approximation to the continuous integral over all R_k.

B. ILLUSTRATIVE EXAMPLE

These probability formulas and concepts can best be illustrated by a numerical example. For a transmission frequency of 3030 Hz at an overburden depth of 1,000 feet, the data from Table VIII-2 are as follows:

Signal-to-Noise Ratio (Interval)	Probability of Achieving Signal-to-Noise Ratio in Interval
(For depth of 1,000 feet at 3030 Hz)	
less than 0 dB	0.420
0 to 3 dB	0.075
3 to 6 dB	0.075
6 to 9 dB	0.076
9 to 12 dB	0.070
greater than 12 dB	0.285

It should be noted that the probabilities in this table sum to unity, since the table includes all possible signal-to-noise values. (Interval size could be made successively smaller to give closer approximations to the probability of detection integral actually being evaluated.)

Detection probabilities corresponding to the above signal-to-noise ratios can be obtained from Figure IX-6 using the midpoint of each interval, and these values are as follows:

Signal-to-Noise Ratio (Interval)	Interval Midpoint	Probability of Detection at Midpoint
less than 0 dB	less than 0 dB	0
0 to 3 dB	1.5 dB	0.01
3 to 6 dB	4.5 dB	0.15
6 to 9 dB	7.5 dB	0.85
9 to 12 dB	10.5 dB	0.99
greater than 12 dB	greater than 12 dB	1.00

Applying the summation formula, Eq. 17 , the expected probability of detection at 1,000 feet and 3030 Hz, is estimated to be:

$$
\begin{aligned}
P_{1000,3030} &= (0.42)(0) + (0.075)(0.01) + (0.075)(0.15) \qquad (18) \\
&+ (0.076)(0.85) + (0.070)(0.99) + (0.285)(1.0) \\
&= 0.43.
\end{aligned}
$$

The interpretation of this quantity is that, based on the results of this experimental program, a signal transmitted at 3030 Hz through an overburden depth of 1,000 feet can be expected to have a 43 percent chance of being detected by an observer at the surface.

C. FINAL DETECTABILITY RESULTS

Similar calculations were made for several other depth/-frequency combinations spanning the 630 Hz to 3030 Hz band and overburden depths down to 1,500 feet presently of interest to the detection of trapped miners. All data relevant to these calculations appear in Figures VIII-2 to VIII-5 and in Table VIII-2 of Section-VIII, and Figure IX-6 of Section IX. Final results representing the expected probabilities of detection are plotted in Figure X-1. These plots represent the likelihood, on the average, of trapped miner signals being detected on the surface above U.S. coal mines having the indicated overburden depths. The plots apply for the General Instruments transmitter and aural detection by a searcher using a Collins receiver and headset.

At any particular mine site with a given overburden depth, trapped-miner signals will either be detected or not detected. If such a detection experiment is repeated at several mines having the same overburden depth in the U.S. coal fields, the curves of Figure X-1 predict the expected percentage of experiments that will achieve signal detection at the indicated overburden depth and operating frequency. For example, if the device were tested at many locations having a 750-foot overburden, it is expected that the transmitted signal would be detected at about 68 percent of the locations for the operating frequency of 1950 Hz and at about 43 percent of the locations for 630 Hz.

Like the signal-to-noise ratio plots in Figures VII-6 and VIII-7 of Section VIII, the curves of Figure X-1 reveal that the chances for successful detection are significantly higher in the upper portion of the transmitter operating frequency band. This

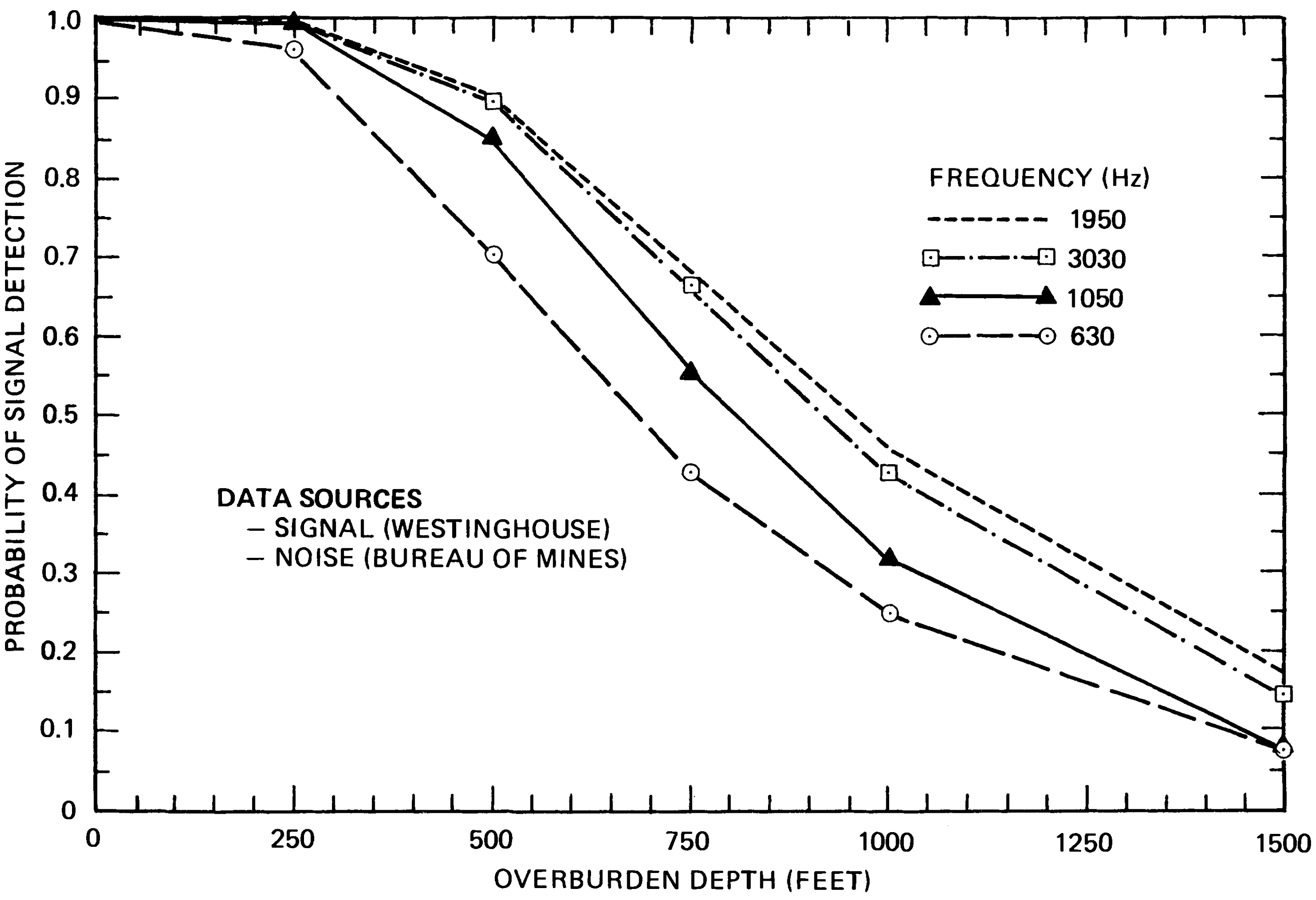

FIGURE X-1 PREDICTED PROBABILITY OF SIGNAL DETECTION VERSUS OVERBURDEN DEPTH BY FREQUENCY FOR THE GENERAL INSTRUMENTS TRANSMITTER occurs because, as shown in Section IV and Section VII, the background electromagnetic noise is lower and decreases faster than the signal, in this part of the band. Section IV-D also indicates that we can also expect somewhat worse signal detection conditions for certain geographical regions and times of day that have higher local thunderstorm activity. Under these conditions, the better detection results predicted at the higher frequencies will likely move downward towards the poorer results expected at the lower frequencies. As mentioned in Sections IV and VII, an acceptable solution for these situations may be the suspension of search activities until a more favorable time of day, such as the daylight morning hours.

XI. IMPLICATIONS OF RESULTS AND RECOMMENDATIONS

Quantitative results have been obtained related to the expected detectability of trapped miner signals above U.S. coal mines. This section is concerned with the need of the U.S. Bureau of Mines to assess the impact of these results on the trapped miner location program. The discussion centers on four areas: detectability vs. depth and altitude, sensitivity analyses, confirmatory tests, and operational utilization of the system.

A. DETECTABILITY VS. DEPTH AND ALTITUDE

The probability of detection vs. overburden depth curves of Section X depict a substantial departure from the intended performance goal for the equipment, namely to 1,000 feet. Even at the most favorable operating frequencies in the upper portion of the operating band, the expected probability of detection decreases from a highly satisfactory value of 90% for a 500 foot overburden to a value of about 45% for a 1,000 foot overburden. At the bottom of the operating frequency band these values decrease to about 70% at 500 feet and 35% at 1,000 feet, again a reduction by about a factor of two. These values of detection probability refer to the long-run, or limiting, frequency of occurrence of signal detection at mine sites throughout the U.S. coal fields having the indicated overburden depths.

However, this shortfall of the performance goal does not negate the value of the trapped miner transmitter and its potential to save lives. Several other factors need to be considered, including the distribution of miners throughout the U.S. coal fields vs. overburden depth, and the variability of overburden depth above each coal mine. For example, the device will provide very good protection to miners working in mines having overburdens shallower than 500 to 600 feet. In addition, consideration must be given to the fact that many mines, particularly in the Appalachian coal fields, will experience wide variations in overburden depth in different sections of the mine workings. Thus, many "deeper" mines will have areas with overburdens shallower than 500 to 600 feet. Therefore, the overall potential of the transmitter to save lives might be much more favorable than the raw detectability curves indicate at first glance when compared to the original performance goal.

On the other hand, the results of Section X apply to rescue teams searching on foot with hand-carried detection receivers. To speed up the search effort, helicopter-based detection receivers are desirable. To estimate how the detectability performance will behave as a function of altitude, compared with that experienced on the surface, requires that the behavior of both signal and noise be determined as a function of altitude above the surface. In addition, the results of Section X strictly apply only within horizontal distances of about several hundred feet from the point on the surface directly above the in-mine transmitter. Therefore, to obtain detectability estimates for greater horizontal ranges, the signal strength behavior as a function of horizontal offset must also be estimated both on the surface and as a function of altitude.

A convenient approximate method for extrapolating the overhead vertical signal strength results to off-axis and above the surface locations based on the homogeneous-earth radio propagation models developed by J. R. Wait[17] has been described in Reference 18 . To use these models, values of effective earth conductivity must be chosen. Two approaches have been suggested; one based on estimating overburden conductivities on a mine-by-mine basis from the individual field strength readings at each mine, and a second based on estimating an average overburden conductivity as a function of overburden depth from the transmission response regression lines derived from the normalized field strength data taken from all mines. We believe that the second approach based on the regression results may yield the most representative conductivity estimates and field strength extrapolations in the most systematic manner. These average extrapolated signal strength values can then be used with the Section VII surface noise distributions (assuming them to be independent of altitude to first approximation) to generate plots of approximate expected probabilities of detection as a function of altitude and horizontal offset. The specific applicability of these results to the development of practical search strategies needs to be assessed.

B. SENSITIVITY ANALYSES

A primary objective of this study was to quantify the likelihood, or chance, of detecting trapped miners over a wide range of actual operating conditions. Detection probability curves have been empirically derived from various transmit frequency/overburden depth combinations. These curves also depend on probability distributions which have been used to characterize the conditional behavior of signal strength, background noise, and aural detection levels. Although the analyses described in this report support the applicability of these distributions, some consideration should be given to investigating the effects of variations in their underlying form. For example, analytical studies can be performed to examine the effect of varying parameters, such as the following:

- estimated RMS signal strength mean
- estimated RMS signal strength variance
- estimated RMS noise mean
- estimated RMS noise variance

Variations can be considered independently or in combination. Since the relative behavior of the dependent variable (i.e., the probability of detection) is of primary interest, this type of study is generally referred to as a sensitivity analysis.

In addition to variations in the specific parameters, it might be of interest to consider deviations from normality as well. Other distributional forms could be assumed for characterizing RMS signal strength and noise; for example, a lognormal or exponential distribution might be more appropriate for characterizing transmitted signal strength at certain depths beyond, say, 1,500 feet.

Furthermore, the detectability results of Section X apply for basic aural detection, by a human operator with a headset, of the simple, pulsed CW signals produced by the General Instruments transmitter in the presence of background noise. Based on the literature, we estimate that a human cperator requires about a 6 dB signal-to-noise ratio to achieve a 50% probability of detection for this type of signal in random background noise. Additional experimental work needs to be conducted to check the validity of this 6 dB estimate, assess its sensitivity to pulse length and repetition rate, and to check the shape of the chosen detectability vs. signal-to-noise ratio curve above and below the 50% value. These experiments should also compare results obtained using random noise with those obtained using noise with characteristics similar to that recorded by the Bureau of Mines on the surface above mines. Finally, the Bureau of Mines noise recordings should be subjected to a more thorough analysis and comparison with other available results on atmospheric and cultural noise, to more firmly establish the characteristics and origin of this recorded noise.

To complement this experimental work, a parallel effort should be undertaken to analytically assess the sensitivity of the final probability of detection results to both the signal-to-noise ratio at the 50% detectability point and the shape of the probability of detection vs. signal-to-noise ratio curve, in addition to the variations in noise and signal levels recommended in the previous paragraph. The results of these sensitivity analyses should provide a means for deciding whether more sophisticated signalling and receiving systems are worth pursuing.

It may also be instructive, in light of the well-behaved regression models developed in Section V, to devote some additional effort to the possible extraction of quantitative, although perhaps weak, relationships between measured signal strengths on the surface and the distance to nearby electrical conductors, or the distance to receivers with large horizontal offsets, particularly for those situations that appear to represent pathological cases. Similarly, it may be instructive to better quantify the sensitivity of the regression results to random errors in reported parameter values such as overburden depth, transmit antenna dimensions, etc.

C. CONFIRMATORY TESTS

The program has yielded probability statements about the expected values of trapped miner signal strengths on the surface and their detectability as a function of overburden depth and frequency. Therefore, the results of several additional tests with pre-selected depth/frequency combinations at mine sites chosen at random from the U.S. coal field population would be expected to agree, on the average, with the results presented in this report. Oscar Kempthorne, in the introductory chapter of his classic text(19) on experiment design, emphasizes the circular nature of the experimental process; namely, that observations lead to the development of theory, which in turn leads to the prediction of new events, which then suggests the taking of new experimental observations, etc. Furthermore, it is well recognized as good scientific practice to experimentally verify deduced findings whenever possible.

The verification process assumes particular importance for this experimentally-based program with its potential regulatory implications. More specifically, we cite the following reasons for recommending verification tests:

- The experimental findings are important; it is clearly worth knowing with a high degree of certainty just how well the trapped miner detection system can be expected to perform under actual use conditions;
- The predicted performance is such that detection probability declines rather abruptly beyond overburden depths of 500 feet;
- There is a paucity of actual test data at mine sites having overburdens deeper than 700 feet; namely, only 15 tests were actually conducted at depths greater than 700 feet, although 43 were planned;
- The overburden and its transmission characteristics are known to be complex and variable between mine locations and between specific sites within the same mine.

Although there are many aspects to be considered during the actual planning of confirmatory tests, not the least of which is the need itself, we recommend for the sake of completeness that some additional testing be considered. For example, hypotheses could be tested, with relatively few additional test measurements, that address the validity of the probability estimates beyond certain overburden depths such as 700 feet. It is always possible that "unusual" site conditions could lead to unexpected outcomes. It is also recognized that agreement, based on a few additional tests, would not "prove" the theoretical relationships established by this study. Nevertheless, some additional results from tests designed on the basis of the models developed to date would increase our knowledge about the performance of the device, no matter what the outcomes might be.

D. OPERATIONAL UTILIZATION OF THE DETECTION SYSTEM

Given that a trapped miner detection system of specified performance is available, the question of its most effective utilization under mine emergency conditions needs to be addressed. This can be examined from two points of view; namely, the use of the in-mine transmitters by the trapped miners and the use of the detection equipment on the surface by the mine search and rescue team.

1. In-Mine Transmitters

The in-mine transmitters are presently designed to be carried on the miner's belt for use if the miner is unable to exit the mine during a mine emergency. In view of the above detectability findings and search strategy considerations discussed below, consideration should be given to the training of miners in the use of their transmitters. Namely, attention should be given to a number of psychological, operational and signal transmission factors that will tend to optimize the miner's probability of being detected and rescued. For example, if at all practical, provisions should be made to enable the miner to set up his transmitter and antenna at locations having signal transmission advantages,such as close to mine electrical conductors like power and communication cables, rails, etc., and in mine areas having shallower overburdens. Locations adjacent to mine conductors will also extend signal transmission ranges within the mine workings and increase the chances of being detected by the in-mine rescue crew. Underground areas having shallower overburdens could even be designated by color-coded signs to inform miners of locations having the most favorable transmission characteristics and, therefore, locations to which surface search teams will attach higher priorities. Practical operational procedures should also be developed to increase the chances that the in-mine transmitter's limited energy source will not be prematurely expended before at least the initial search efforts are substantially complete.

Consideration should also be given to another possible implementation of the rescue transmitter that has the advantages of being both more economical and more conveniently tested on a routine basis. This can be achieved by building the rescue transmitters into the mine pager phones located on each working section and at other strategic locations along mine haulageways and escapeways. Thus, during a mine disaster, miners could simply take one of the pager phones and carry it with them for use if they were not able to exit the mine. This would allow the use of a longer life energy source such as the pager phone lantern battery, provide routine inspection and testing during pager phone maintenance cycles, and not require the miner to carry another piece of equipment.

2. Surface Detection Receivers

Even more important consideration needs to be given to the problem of devising effective search plans and procedures for maximizing the number of rescuable miners detected per unit of search effort at a mine disaster site. Namely, how should the mine search and rescue team allocate its effort and resources to best accomplish the objective of finding and rescuing all trapped miners within the limited time constraints? This problem has been addressed in a preliminary manner in Appendix G, where we have formulated the search problem specifically for a rapid helicopter-based search effort backed up by man-carried surface-based receivers for pinpointing the underground transmitter locations. These plans and procedures can be modified accordingly to accommodate the situation in which the search must be conducted entirely by a large number of search team members carrying rescue receivers on the surface.

The appendix presents a methodology and mathematical representation to describe the important parameters, constraints, relationships and quantities to be optimized, together with key input information that must be obtained or estimated before "good," if not optimum, search patterns can be formulated and their effectiveness assessed. This key input information includes several important time intervals involved in post-disaster search and rescue operations, such as:

- The life expectancy of the trapped-miner transmitter as a function of the residual energy in the miner's cap lamp battery at the time of transmitter activation,
- The expected survival times of trapped miners for different mine disaster environmental conditions,
- Expected times required to rescue miners after detection for typical mine disaster conditions and mine configurations,
- Expected arrival and set-up times of ground and airborne search and rescue teams after a disaster has occurred.

The lengths of these times and their relationships to each cther will not only influence search and rescue team strategies, but may also have an impact on the training of miners regarding procedures for the activation and prolonged operation of their transmitters.

Another important input parameter will be the effective sweep width for the detection equipment used on the surface or in the air. The sweep width, W_f, (typically defined in terms of the horizontal offset for 50% signal detectability) will be a function of the mine overburden depth, altitude of the receive antenna above the surface, ambient noise conditions, and the actual signal detection process (i.e., aural or other). At mines with relatively flat surface topography, as in Illinois and Ohio, a constant sweep width can be assumed for the whole mine. In relatively mountainous areas such as West Virginia and eastern Kentucky, several sweep widths may be required to properly characterize different regions of a widely dispersed mine. The rescue team should take advantage of available topographic information in a practical manner that will minimize the number of different sweep widths required and simplify search operations and procedures as much as possible.

The signal detectability/sweep width information can be combined with mine map and operational information on the likely distribution and movement of miners in the mine. This combined information will enable the rescue team to quickly identify, in gross terms, high priority areas of the mine that have the highest likelihoods of both trapped miner presence and detectability, and those with proportionally smaller likelihoods. These priorities will then allow the efficient and systematic allocation of scarce search and rescue resources so as to increase the probable number of miners detected and rescued per unit of search effort.

The methodology and mathematical representations developed in Appendix G need to be refined and applied to several typical mine disaster operational scenarios for specific practical values of the key parameters. This should result in the formulation and assessment of a number of search strategies and lead to a better understanding of their practical application to real mine disaster situations.

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APPENDIX A

INFORMATION ON STATISTICALLY SELECTED MINES PLANNED FOR FIELD MEASUREMENT PROGRAM

This information was generated by the statistically based mine selection method described in Section IIIB. This method was applied to a consolidated Bureau of Mines computer data base of coal mines obtained by the merging of an MSHA mine data file containing the number of miners at each mine and a Bureau of Mines Eastern Field Operations Center data file containing the maximum overburden depth at each mine.

TABLE A1

LISTING OF SPECIFIC MINES SELECTED FOR FIELD MEASUREMENTS IN U.S. FIELDS (ORDERED BY DEPTH INTERVAL, DEPTH, AND NUMBER OF MINERS WITHIN EACH DEPTH INTERVAL)

Name/Location		MESA ID	Max. Depth	No. Men	Depth Interval
J & J Mining Co. #2 Mine Sewickley Route 8, Box 292C Morgantown, W.V. 26505	029	4602856	0100	12	<200
Peabody Coal Co. Baldwin Mine #1 No. 6, P.O. Box 67 Marissa, IL 62257	484	1101008	0138	478	<200
Consolidation Coal Co. Humphrey #7 UG Pittsburgh P.O. Box 100 Osage, WV 26543	036	4601453	0100	516	<200
Peggs Run Coal Co. Inc. Peggs Run #2 Upper Freeport P.O. Box 184 Shippingport, PA 15077	071	3601057	0250	68	200-299
Amherst Coal Co. MacGregor #8 UG, Coalburg Lundale, WV 25631	111	4603773	0250	81	200-299
Martin County Coal Corp. #1-S UG Stockton Route 40, Box 82A Inez, KY 41224	103	1504194	0260	84	200-299
Peabody Coal Co. Sinclair #1 UG Kentucky No. 9 301 No. Memorial Dr. St. Louis, MO 63102	489	1507165	0250	110	200-299

Name/Location		MESA ID	Max. Depth	No. Men	Depth Interval
Consl. Coal-Cen. Div. Franklin Highwall UG Pittsburgh (No. 8) Georgetown General Office Cadiz, OH 43907	036	3301065	0200	146	200-299
Republic Steel Corp. Banning #4 Pittsburgh 617 Fayette National Bank Bldg. Uniontown, PA 15401	036	3600973	0250	258	200-299
Ranger Fuel Corp. H Mine UG Peerless P. O. Box 966 Beckley, WV 25801	167	4603446	0300	34	300-399
Union Carbide Corp. Ferralloys #7C UG No. 5 Block Route 2, Box 224 Clendenin, WV 25045	084	4603226	0300	123	300-399
Shamrock Coal Company Shamrock #18 Hazard No. 4 Box 36A Beverly, KY 40913	135	1502502	0350	134	300-399
Badger Coal Co. Inc. Badger No. 14 UG Upper Kittanning P. O. Box 472 Clarksburg, WV 26301	076	4601254	0300	136	300-399
Bethlehem Mines Corp. #38 UG Lower Freeport Box 29 Ebensburg, PA 15931	074	3600852	0300	183	300-399

Name/Location		MESA ID	Max. Depth	No. Men	Depth Interval
Island Creek Coal Co. Fies Mine Kentucky No. 11 444 South Main Street Madisonville, KY 42431	484	1502018	0330	305	300-399
Peabody Coal Co. Alston #4 Mine UG Kentucky No. 9 301 No. Memorial Dr. St. Louis, MO 63102	489	1505047	0350	460	300-399
Peabody Coal Co. #10 Mine No. 6 P. O. Box H Pawnee, IL 62558	484	1100585	0375	658	300-399
Indian Ridge Coal Co. Indian Ridge #4 UG Gilbert Ottaway Trent Hanover, WV 24839	216	4602118	0400	15	400-499
Southeast Coal Co. #402 UG Hazard No. 4 Route 2, Box 60 Whitesburg, KY 41858	135	1506908	0400	29	400-499
Jumacris Mining Inc. #5 Mine UG Lower Cedar Grove P. O. Drawer D Gilbert, WV 25621	154	4604117	0400	32	400-499
Omar Mining Co. Chesterfield #1 UG Stockton P. O. Box 338 Madison, WV 25130	103	4601275	0400	66	400-499

Name/ Location		MESA ID	Max. Depth	No. Men	Depth Interval
Hawley Coal Mining Corp. Bottom Ck. #1 Mine Pocahontas No. 12 Drawer J Keystone, WV 24852	311	4600709	0400	90	400-499
United States Steel Corp. Mt. Braddock - Frick Coal Dist. Pittsburgh Fayette Bank Bldg. Uniontown, PA 15401	036	3602810	0400	92	400-499
Westmoreland Coal Co. Prescott #2 Mine UG Imboden Osaka Star Route Appalachia, VA 24216	168	4401689	0400	136	400-499
ARMCO Steel Corp. Robin Hood No. 8 UG Dorothy Montcoal, WV 25135	121	4601266	0400	189	400-499
National Mines Corp. Isabella Pittsburgh P. O. Box 431 Isabella, PA 15447	036	3600899	0400	221	400-499
Republic Steel Corp. Republic UG & Prep Plant Lower Elkhorn Route 1, Box 306 Elkhorn City, KY 41522	168	1502117	0420	222	400-499
Republic Steel Corp. Newfield Double Freeport 617 Fayette National Bank Bldg. Uniontown, PA 15401	071	3600809	0400	244	400-499

Name/Location		MESA ID	Max. Depth	No. Men	Depth Interval
Island Creek Coal/West KY Div. Providence #1 Kentucky No. 9 Drawer N Madisonville, KY 42431	489	1502156	0400	247	400-499
Alabama By-Products Corp. Gorgas Mine #7 America P. O. Box 158 Goodsprings, AL 35560	229	0100340	0400	380	400-499
United States Steel Corp. Robena #1 - Frick Coal Dist. Pittsburgh Fayette Bank Bldg. Uniontown, PA 15401	036	3600909	0450	443	400-499
Jones & Laughlin Steel Corp. Shannopin UG Pittsburgh Box 608 California, PA 15419	036	3600907	0450	445	400-499
Gateway Coal Co. Gateway Mine Pittsburgh P. O. Box 608 California, PA 15419	036	3600906	0400	564	400-499
Nacco Mining Co. Powhatan #6 UG Pittsburgh (No. 8) Powhatan PT, OH 43942	036	3301159	0450	613	400-499
Bill Branch Coal Co. Inc. #2 UG Blair Box 556 Vansant, VA 24656	177	4404134	0500	12	500-599

Name/Location		MESA ID	Max. Depth	No. Men	Depth Interval
Betty B Coal Co. Mine #3 Upper Banner Box 340 Clintwood, VA 24228	214	4401647	0500	14	500-599
White Peter Coal Mining Corp. War Eagle #1 Hawley Coal Lower War Eagle Gen. Delivery Isaban, WV 24846	195	4604338	0550	45	500-599
Bethlehem Mines Corp. Solomon Run #73 UG Upper Kittanning Box 29 Edensburg, PA 15931	076	3600844	0500	59	500-599
Southern Appalachian Coal Co. Bull Creek #2 No. 2 Gas 217 94th Street Marmet, WV 25315	168	4603471	0550	72	500-599
Bethlehem Mines Corp. #108 UG Redstone P. O. Box360 Bridgeport, WV 26330	033	4603887	0500	135	500-599
Webster City Coal Corp. Retiki Mine Kentucky No. 9 P. O. Box 45 Henderson, KY 42420	489	1500672	0500	138	500-599
Pocahontas Fuel Co. #7 UG Pocahontas No. 3 Horsepen, VA 24619	344	4601412	0500	162	500-599

Name/Location		MESA ID	Max. Depth	No. Men	Depth Interval
North Amer. Coal Corp. East.Div. Comemaugh #1 UG Lower Kittanning Seward, PA 15954	084	3600928	0565	169	500-599
Sewell Coal Co. Meadow River #1 UG Sewell Lookout, WV 25863	285	4603467	0500	190	500-599
Consl. Coal-Cen. Division Oak Park #7 UG Lower Freeport (No. 6A) Georgetown General Office Cadiz, OH 43907	074	3301158	0550	242	500-599
North American Coal Corp. Ohio Division Powhatan #5 UG Pittsburgh (No. 8) Powhatan PT, OH 43942	036	3300937	0580	258	500-599
Republic Steel Corp. North River #1 UG Pratt P. O. Box 268 Berry, AL 35546	227	0100759	0525	384	500-599
Alabama By-Products Corp. Segco #1 UG Mary Lee P. O. Box 127 Goodsprings, AL 35560	279	0100347	0500	423	500-599
Hatter Coal Co. Middle Split Slope Mammoth (Top Split) Hegins, PA 17938	400	3601852	0680	10	600-699
Calvert Coal Co. #7 UG Pocahontas No. 3 110 Harvey Street Beckley, WV 25801	344	4604219	0600	20	600-699

Name/Location		MESA ID	Max. Depth	No. Men	Depth Interval
Johnson Coal Co. #11 UG Hazard No. 4 Box 888 Martin, KY 41649	135	1507092	0600	32	600-699
Youngs Branch Coal Co. #14 UG Widow Kennedy Box 653 Vansant, VA 24656	252	4404039	0600	32	600-699
Barnes & Tucker Co. Lancashire #24 B UG Lower Kittanning 1912 Chestnut Avenue Barnesboro, PA 15714	084	3600837	0600	251	600-699
Affinity Mining Co. Keystone #5 UG Pocahontas No. 3 P. O. Box 948 Sophia, WV 25921	344	4602067	0650	327	600-699
Youghiogheny & Ohio Coal Co. Nelms #2 UG Lower Freeport (No. 6A) Hopedale, OH 43976	074	3300968	0600	368	600-699
Greenwich Collieries/PA Mines Greenwich Collieries #2 Lower Freeport P. O. Box 367 Ebensburg, PA 15931	074	3602404	0600	428	600-699
Consolidation Coal Co. Hillsboro Mine/Midwestern Reg. No. 6 P. O. Box 218 Pinckneyville, IL 62274	484	1100605	0600	458	600-699

Name/Location		MESA ID	Max. Depth	No. Men	Depth Interval
Peabody Coal Co. Camp #2 Kentucky No. 9 RR #5, Box 46-A Morganfield, KY 42437	489	1502705	0600	465	600-699
Peabody Coal Co. Camp #1 Kentucky No. 9 Morganfield, KY 42437	489	1502709	0600	465	600-699
Standard Sign & Signal Co. May Mine UG Elkhorn #2 Box 801 Pikeville, KY 41501	154	1502424	0775	31	700-799
Sewell Coal Co. Sewell #1 UG Sewell Nettie, WV 26681	285	4601478	0700	222	700-799
National Coal Mining Co. #25 UG Cedar Grove Box 461 Holden, WV 25625	151	4601450	0750	238	700-799
Kaiser Steel Corp. York Canyon #1 UG York Canyon P. O. Box 281 Raton, NM 87740	507	2900095	0750	255	700-799
Beth-Elkhorn Corp. Pike #26 UG & Prep Plant Elkhorn #2 Jenkins, KY 41537	154	1502092	0700	294	700-799

Name/Location		MESA ID	Max. Depth	No. Men	Depth Interval
U. S. Steel Corp. #9 Mine UG Pocahontas No. 3 Gary, WV 24836	344	4601418	0700	361	700-799
Southern Ohio Coal Co. Martinka #1 UG Lower Kittanning P. O. Box 552 Fairmont, WV 26554	084	4603805	0788	409	700-799
Valley Camp Coal Co. VC #1 Mine Pittsburgh 2971 E Dupont Avenue Shrewsbury, WV 25184	036	4601483	0700	486	700-799
Amigo Smokeless Coal Co. Amiga #2 UG Pocahontas No. 3 Box 966 Beckley, WV 25801	344	4604216	0800	37	800-899
Eastern Associated Coal Corp. Harris #2 UG Campbells Creek Star Route 2 Bald Knob, WV 25010	168	4601270	0800	281	800-899
Eastern Associated Coal Corp. Keystone #2 UG Pocahontas No. 3 Herndon, VA 24726	344	4601535	0800	356	800-899
Blue Diamond Mining Inc. Leatherwood Leatherwood Box 298 Leatherwood, KY 41756	111	1502082	0800	374	800-899

Name/Location		MESA ID	Max. Depth	No. Men	Depth Interval
North American Coal Corp. Ohio Division Powhatan #1 Pittsburgh (No. 8) Powhatan PT, OH 43942	036	3300938	0840	474	800-899
Freeman United Coal Mining Co. Orient #3 UG No. 6 300 W. Washington St. Chicago, IL 60606	484	1100600	0800	563	800-899
Consolidation Coal Co. Robinson Run #95 UG Pittsburgh P. O. Box 1632 Fairmont, WV 26554	036	4601318	0800	580	800-899
United States Steel Corp. Southern Mines Dist.- Concord #1 Pratt P. O. Box 599 Fairfield, AL 35064	227	0100329	0800	613	800-899
Consolidation Coal Co. Rowland #3 Mine/ S. Appalachia Upper Eagle Route 1, Box 169 Beckley, WV 25801	174	4601986	0900	93	900-999
Carbon Fuel Co. #36 UG Eagle Carbon, WV 25037	176	4601805	0950	106	900-999
Clinchfield Coal Co. Moss #3 Portal D Tiller Dante, VA 24237	269	4401644	0900	178	900-999

Name/Location		MESA ID	Max. Depth	No. Men	Depth Interval
Allied Chemical Corp.-Semet Sol Harewood UG Eagle Box 791 Montgomery, WV 25136	176	4601288	0950	208	900-999
Slab Fork Coal Co. #10 UG Pocahontas No. 4 Slab Fork, WV 25920	342	4601888	0950	222	900-999
Valley Camp Coal Co. VC #3 Mine Pittsburgh 2971 E. Dupont Avenue Shrewsbury, WV 25184	036	4601482	0900	342	900-999
Volunteer Mining Corp. #1 UG Dean Box 512 Lake City, TN 37769	134	4000255	1000	40	1000-1199
Eagle Coal & Dock Inc. #7-A UG No. 2 Gas P. O. Box 38 Stickney, WV 25188	168	4604578	1000	42	1000-1199
Ranger Fuel Corp. F Mine UG War Eagle P. O. Box 966 Beckley, WV 25801	168	4602165	1000	120	1000-1199
Eastern Associated Coal Corp. Harris #1 UG, Eagle Star Route 2 Baid Knob, WV 25010	176	4601271	1000	316	1000-1199

Name/Location		MESA ID	Max. Depth	No. Men	Depth Interval
Consolidation Coal Co. Blacksville #2 UG Pittsburgh Box 24 Wana, WV 26590	036	4601968	1000	435	1000-1199
Eastern Associated Coal Corp. Federal #2 UG Pittsburgh Miracle Run Fairview, WV 26570	036	4601456	1000	600	1000-1199
Bethlehem Mines Corp. #116 UG Eagle P. O. Box 4337 Charleston, WV 25304	176	4601496	1100	94	1000-1199
Jewell Ridge Coal Corp. Big Creek Seaboard #1 UG Lower Seaboard Jewell Valley, VA 24623	285	4402253	1100	136	1000-1199
Bethlehem Mines Corp. #131 UG Powellton P. O. Box 4337 Charleston, WV 25304	170	4601268	1200	207	1200-1399
U. S. Steel Corp. #2 UG Pocahontas No. 4 Gary, WV 24836	342	4601419	1200	304	1200-1399
CF & I Steel Corp. Allen Mine UG Allen P. O. Box 155 Weston, CO 81091	759	0500296	1200	350	1200-1399

Name/Location		MESA ID	Max. Depth	No. Men	Depth Interval
Consolidation Coal Co. Shoemaker UG Pittsburgh P. O. Drawer L Moundsville, WV 26041	036	4601436	1200	543	1200-1399
Clinchfield Coal Co. Chaney Creek #2 UG Jawbone Dante, VA 24237	266	4400279	1300	175	1200-1399
Youngstown Mines Corp. Dehue UG Eagle P. O. Box 900 Dehue, WV 25618	176	4601397	1400	200	1400-1599
U. S. Steel Corp. Pinnacle Creek #50 UG Pocahontas No. 3 Gary, WV 24836	344	4601816	1400	451	1400-1599
United States Fuel Co. King Mine Hiawatha A&B Box A Hiawatha, UT 84527	846	4200098	1800	113	1600-1999
Pocahontas Fuel Co. Matthews Mine Jellico P. O. Box 460 Middlesboro, KY 40965	151	4000520	1800	381	1600-1999
Westmoreland Coal Co. Stonega D Osaka #2 Mine UG Inboden Osaka Star Route Appalachia, VA 24216	168	4401688	2000	186	2000-2499

Name/Location		MESA ID	Max. Depth	No. Men	Depth Interval
Peabody Coal Co. Deer Creek UG Blind Canyon P. O. Box 588 Huntington, UT 84528	855	4200121	2000	295	2000-2499
Beatrice Pocahontas Co. Beatrice UG Pocahontas No. 3 Box F Keen Mountain, VA 24624	344	4400238	2500	496	≥2500
Island Creek Coal Co. VA Pocahontas #4 Pocahontas No. 3 Keen Mountain, VA 24624	344	4402134	2700	299	≥2500

APPENDIX B

INFORMATION ON ACTUAL MINES VISITED DURING FIELD MEASUREMENT PROGRAM

Source: Westinghouse(1,4)

TABLE B1

LISTING OF ACTUAL TEST SITE LOCATIONS IN U.S. COAL FIELDS AND SELECTED TEST SITE INFORMATION (ORDERED BY STATE AND COUNTY)

NORTHERN APPALACHIAN

PENNSYLVANIA

Mining Co., Mine Name, Town, County, State, *Seam Name*	Gateway Coal Co. – Gateway Mine Clarksville, Greene County, PA *Pittsburgh*	U.S. Steel Corp. – Robena Mine Greensboro, Greene County, PA *Pittsburgh*	Buckeye Coal Co. – Nemacolin Mine Nemacolin, Greene County, PA *Pittsburgh*	Duquesene Light – Warwich No. 2 Greensboro, Greene County, PA *Pittsburgh*	Duquesne Light – Warwich No. 3 Greensboro, Greene County, PA *Sewickley*	Eastern Associated Coal – Delmont Mine Hunker, Westmoreland County, PA *Upper Freeport*	North Amer. Coal Co. – Conemaugh No. 1 Seward, Westmoreland County, PA *N.E. Mains B*	Republic Steel – Newfield Mine New Kensington, Westmoreland County, PA *Upper & Lower Freeport*	Republic Steel – Banning No. 4 W. Newton, Westmoreland County, PA *Pittsburgh*	Helen Mining Co. – Homer City Mine Homer City, Indiana County, PA *Upper Freeport*	Greenwich Collieries – Mine No. 2 Spangler, Cambria County, PA *Lower Freeport*	Eastern Associated Coal – Colver Mine Colver, Cambria County, PA *Lower Kittanning*	Barnes & Tucker Coal – Lancashire No. 20 Bainsboro, Cambria County, PA *Lower Kittanning*	Barnes & Tucker Coal – Lancashire 25D Bainsboro, Cambria County, PA *Lower Freeport*	Barnes & Tucker Coal – Lancashire 24D Bainsboro, Cambria County, PA *Lower Freeport*
Mine Test No.	75	37	19	18	17	20	71	73	74	16	72	21	15	14	13
Field Report No.	14	7	4	4	4	4	14	14	14	4	14	4	4	4	4
Seam Thickness															
Feet	5.9	7.6	6.6	6.9	5.9	4.3	3.6	7.6	7.6	3.9	3.6	3.9	4.6	3.9	3.6
Meters	1.8	2.3	2.0	2.1	1.8	1.3	1.1	2.3	2.3	1.2	1.1	1.2	1.4	1.2	1.1
Number of Miners	570	443	600	160	400	94	174	297	324	400	465	230	380	320	300
Overburden Depth															
Feet	658	480	348	210	240	340	240	626	480	692	481	325	600	445	341
Meters	200	146	106	64	73	104	73	191	146	210	147	99	183	136	104
Offset Uplink															
Feet	0	61.7	59.7	34.8	0	19.7	0	0	0	49.9	0	9.8	6.6	4.9	6.9
Meters	0	18.8	18.2	10.6	0	6.0	0	0	0	15.2	0	3.0	2.0	1.5	2.1
Offset Downlink															
Feet	0	61.7	74.8	98.4	14.8	20	0	0	0	119.4	0	19.7	14.8	34.8	24.6
Meters	0	18.8	22.8	30	4.5	6.1	0	0	0	36.4	0	6.0	4.5	10.6	7.5
Month/Year of Test	7/78	10/77	4/77	4/77	4/77	4/77	7/78	7/78	7/78	4/77	7/78	4/77	4/77	4/77	4/77
Surface Noise Tape Recordings (BoM)	✓						✓	✓	✓		✓				

TABLE B1 (Continued)

NORTHERN APPALACHIAN

	OHIO							NORTHERN WEST VIRGINIA						
Mining Co., Mine Name, Town, County, State, *Seam Name*	Consol – Oak Park No. 7 Cadiz, Harrison County, OH *Lower Freeport 6A*	Youghiogheny & Ohio Coal – Nelm's 2 Hopedale, Harrison County, OH *Lower Freeport*	N. American Coal – Powhatan No. 1 Powhatan Point, Belmont County, OH *Pittsburgh No. 8*	N. American Coal – Powhatan No. 3 Powhatan Point, Belmont County, OH *Pittsburgh No. 8*	Youghiogheny & Ohio Coal – Allison Beallsville, Belmont County, OH *Pittsburgh No. 8*	Southern Ohio Coal Co. – Meigs No. 2 Athens, Meigs County, OH *Clarion 4A*	Southern Ohio Coal Co. – Meigs No. 2 Athens, Meigs County, OH *Clarion 4A*	Valley Camp Coal Co. – Mine No. 1 Short Creek, Ohio County, WV *Pittsburgh*	Consolidation Coal – Eastern Reg. (Shoemaker Mine) Moundsville, Marshall County, WV *Pittsburgh*	Southern Ohio Coal Co. – Martinka No. 1 Fairmont, Marion County, WV *Lower Kittanning*	Consolidation Coal – Loveridge Mine Fairview, Marion County, WV *Pittsburgh*	Badger Coal Co., Inc. – Mine No. 14 Philippi, Barbour County, WV *Kittanning*	Bethlehem Mines Corp., No. 108 Century, Barbour County, WV *Redstone*	Sewell Coal Company – Mine No. 1 Nettie, Nicholas County, WV *Sewell*
Mine Test No.	**84**	**83**	**81**	**80**	**82**	**9**	**10**	**39**	**38**	**11**	**34**	**35**	**36**	**58**
Field Report No.	**16**	**16**	**16**	**16**	**16**	**3**	**3**	**7**	**7**	**3**	**7**	**7**	**7**	**11**
Seam Thickness														
Feet	4.9	4.9	5.9	5.9	4.9	4.3	4.9	4.9	5.6	3.9	6.9	4.9	5.6	4.6
Meters	1.5	1.5	1.8	1.8	1.5	1.3	1.5	1.5	1.7	1.2	2.1	1.5	1.7	1.4
Number of Miners	269	450	570	570	527	635	635	550	600	425	580	120	80	200
Overburden Depth														
Feet	560	540	600	500	470	264	250	510	778	264	1343	324	215	580
Meters	171	165	183	152.5	143	80.5	77.4	155	238	80.5	409	99	66	177
Offset Uplink														
Feet	0	0	0	0	0	0	0	15.7	22.3	0	24.9	14.8	44.9	0
Meters	0	0	0	0	0	0	0	4.8	6.8	0	7.6	4.5	13.7	0
Offset Downlink														
Feet	0	0	0	0	0	0	0	61.3	40	0	61	59.7	74.8	0
Meters	0	0	0	0	0	0	0	18.7	12.2	0	18.6	18.2	22.8	0
Month/Year of Test	9/78	9/78	8/78	8/78	8/78	3/77	3/77	10/77	10/77	3/77	10/77	10/77	10/77	5/78
Surface Noise Tape Recordings (BoM)	✓	✓	✓	✓	✓									

TABLE B1 (Continued)

SOUTHERN APPALACHIAN
SOUTHERN WEST VIRGINIA

Mining Co., Mine Name, Town, County, State, *Seam Name*	Central Appalachian Coal – Five Block 1 Marmet, Kanawha County, WV *Lower Kittanning*	Sewell Coal Company – Meadow No. 1 Lookout, Fayette County, WV *Sewell*	Allied Chemical Corp. – Harewood Boomer, Fayette County, WV *Eagle*	Armco Coal Co. – Robinhood No. 8 Twilight, Boone County, WV *Dorothy*	Bethlehem Steel – Mine 131 Van, Boone County, WV *Powellton*	Omar Mining Company – Omar No. 4 Madison, Boone County, WV *Stockton*	Bethlehem Steel (downlink) – Mine 116 Eunice, Boone & Raleigh County, WV *Eagle*	Bethlehem Steel (uplink) – Mine 116 Eunice, Boone & Raleigh County, WV *Eagle*	Eagle Coal & Dock – Hope No. 10 Stickney, Boone & Raleigh County, WV *Stockton Lewiston*
Mine Test No.	12	59	67	56	63	64	61	62	66
Field Report No.	3	11	13	11	12	12	12	12	12
Seam Thickness									
Feet	3.9	4.9	4.6	7.9	5.9	4.3	3.9	3.9	7.2
Meters	1.2	1.5	1.4	2.4	1.8	1.3	1.2	1.2	2.2
Number of Miners	11	285	500	200	400	20	100	100	25
Overburden Depth									
Feet	250	388	420	421	485	347	845	645	250
Meters	76.2	118	128	129	148	108	258	209	78
Offset Uplink									
Feet	0	0	91.8	0	42.6	0	200	200	108.2
Meters	0	0	28	0	13	0	61	61	33
Offset Downlink									
Feet	7.2	0	131.2	0	0	0	400.2	400.2	108.2
Meters	2.2	0	40	0	0	0	122	122	33
Month/Year of Test	3/77	5/78	6/78	5/78	6/78	6/78	6/78	6/78	6/78
Surface Noise Tape Recordings (BoM)			√						

Mining Co., Mine Name, Town, County, State, *Seam Name*	Slab Fork Coal Co. – Mine 10 Slab Fork, Raleigh County, WV *Pocahontas No. 3*	Ranger Fuel – Mine F Bolt, Raleigh County, WV *Eagle*	Amherst Mining Co. – MacGregor No. 8 Lundale, Logan County, WV *Coalburg*	Eastern Associated Coal – Keystone Herndon, Wyoming County, WV *Pocahontas No. 3*	Jumacris Mining Inc. – Mine No. 4 Gilbert, Mingo County, WV *Lower Cedar Grove*	Hawley Mining Corp. – Bottom Creek No. 1 Keystone, McDowell County, WV *Pocahontas No. 12*	Petter White Coal Co. – Brushy No. 2 Isaban, McDowell County, WV *Lower War Eagle*	U.S. Steel – Gary No. 9 Filbert, McDowell County, WV *Pocahontas No. 3*	U.S. Steel – Gary No. 2 Wilcoe, McDowell County, WV *Pocahontas No. 4*
Mine Test No.	57	60	65	22	32	33	68	69	70
Field Report No.	11	11	12	5	6	6	13	13	13
Seam Thickness									
Feet	3.6	3.9	10.2	4.3	5.9	3.3	3.3	3.9	7.6
Meters	1.1	1.2	3.1	1.3	1.8	1	1.0	1.2	2.3
Number of Miners	275	39	77	648	22	90	70	350	300
Overburden Depth									
Feet	1050	350	227	569	330	230	450	430	915
Meters	320	107	71	173.5	101	70	137	131	279
Offset Uplink									
Feet	0	0	0	41.3	109.6	44.6	121.4	49.2	0
Meters	0	0	0	12.6	33.4	13.6	37	15	0
Offset Downlink									
Feet	0	0	0	41.3	109.6	54.8	0	49.2	0
Meters	0	0	0	12.6	33.4	16.7	0	15	0
Month/Year of Test	5/78	5/78	6/78	7/77	9/77	9/77	6/78	6/78	6/78
Surface Noise Tape Recordings (BoM)								√	√

TABLE B1 (Continued)

SOUTHERN APPALACHIAN

Mine Co., Mine Name, Town, County, State, *Seam Name*	VIRGINIA Island Creek – Virginia Pocahontas No. 3 Keen Mtn., Buchanan County, VA *Harlan*	Eastover Mining Co. – Virginia City Virginia City, Wise County, VA *Jaw Bone*	Jewell Ridge Coal Corp. – Seaboard No. 2 Tazewell County, VA *Lower Seaboard*	Clinchfield Coal Co. – Moss No. 2 Dante, Russell County, VA *Tiller*	Clinchfield Coal Co. – Moss No. 4 Dante, Russell County, VA *Tiller*	Westmoreland Coal – Prescott No. 2, Test 1 Big Stone Gap, Wise County, VA *Imboden*	Westmoreland Coal – Prescott No. 2, Test 2 Big Stone Gap, Wise County, VA *Imboden*	Westmoreland Coal Co. – Bullitt Mine Big Stone Gap, Wise County, VA *Dorchester*	TENNESSEE Volunteer Mining Corp. – No. 2 Mine Devonia, Anderson County, TN *Dean Big Mary*	Consolidation Coal Co – Mathews Arco, Claiborne County, TN *Jellico*
Mine Test No.	23	7	31	29	28	26	27	25	45	46
Field Report No.	5	2	6	6	6	5	5	5	9	9
Seam Thickness										
Feet	4.9	5.9	5.6	4.9	7.9	4.9	4.9	4.3	4.3	4.9
Meters	1.5	1.8	1.7	1.5	2.4	1.5	1.5	1.3	1.3	1.5
Number of Miners	496	200	114	275	170	136	136	300	87	340
Overburden Depth										
Feet	1200	512	620	580	519	690	690	426	946	1197
Meters	365.8	156	189	177	158	210	210	130	288	363
Offset Uplink										
Feet	79.7	0	9.8	79.7	49.9	99.7	44.6	109.6	843	49.2
Meters	24.3	0	3.0	24.3	15.2	30.4	13.6	33.4	257	15
Offset Downlink										
Feet	89.9	0	20	219.4	100	214.5	214.5	69.9	843	54.8
Meters	27.4	0	6.1	66.9	30.5	65.4	65.4	21.3	257	16.7
Month/Year of Test	7/77	11/76	9/77	9/77	9/77	7/77	7/77	7/77	3/78	3/78
Surface Noise Tape Recordings (BoM)										

TABLE B1 (Continued)

SOUTHERN APPALACHIAN
EASTERN KENTUCKY

Mining Co., Mine Name, Town, County, State *Seam Name*	Peter Cave – Mine No. 1 Lovely, Martin County, KY *Warfield*	Pontika – No. 1 Lovely, Martin County, KY *Pond Creek*	Standard Sign & Signal – No. 1 Mine Pikeville, Pike County, KY *Elkhorn*	Republic Steel Co. – Republic Elkhorn City, Pike County, KY *Lower Elkhorn*	South East Coal Co. – Mine No. 402 Irvine, Knott County, KY *Hazard No. 4*	Beth-Elkhorn Corp. – Pike No. 26 Shelby Gap, Pike County, KY *Elkhorn No. 3*	Beth-Elkhorn Corp. – Pike No. 25 Shelby Gap, Pike County, KY *Hazard No. 4*	Eastover Mining Co. – Highsplint (Harlan) Highsplint, Harlan County, KY *Harlan*	Eastover Mining Co. – Highsplint (Darby) Highsplint, Harlan County, KY *Darby*	Path Fork Harlan Coal Co. – FEE Alva, Harlan County, KY *Upper Harlan*	Eastover Mining Co. – Highsplint 4 Highsplint, Harlan County, KY *Harlan No. 4*	Cal Glo – No. 21 Siler, Knox County, KY *Blue Gem*
Mine Test No.	85	86	24	30	47	48	49	5	6	8	87	88
Field Report No.	17	17	5	6	9	9	9	2	2	2	17	17
Seam Thickness												
Feet	4.3	3.9	3.9	4.3	4.6	3.9	0	3.9	3.9-5.6	3.6	4.3	2.3
Meters	1.3	1.2	1.2	1.3	1.4	1.2	0	1.2	1.2-1.7	1.1	1.3	0.7
Number of Miners	130	184	30	156	13	300	173	185	185	100	300	40
Overburden Depth												
Feet	260	500	270	325	264	1010	478	1400	674	200	400	381
Meters	79.3	152	82.3	99	80	308	146	426	205	61	122	116
Offset Uplink												
Feet	0	0	209.3	44.6	0	0	0	0	0	0	0	0
Meters	0	0	63.8	13.6	0	0	0	0	0	0	0	0
Offset Downlink												
Feet	0	0	109.6	88.6	0	0	0	0	0	0	0	0
Meters	0	0	33.4	27	0	0	0	0	0	0	0	0
Month/Year of Test	9/78	9/78	7/77	9/77	3/78	3/78	3/78	11/76	11/76	11/76	9/78	9/78
Surface Noise Tape Recordings (BoM)	✓	✓									✓	✓

TABLE B1 (Continued)

CENTRAL

	WESTERN KENTUCKY							ILLINOIS						
Mining Co., Mine Name **Town, County, State,** *Seam Name*	**Island Creek – Hamilton No. 1** **Morganfield, Union County, KY** *No. 9*	**Peabody Coal Co. – Camp No. 1, Site No. 1** **Morganfield, Union County, KY** *No. 9*	**Peabody Coal Co. – Camp No. 1, Site No. 2** **Morganfield, Union County, KY** *No. 9*	**Pyro Mining Co. – Pyro Slope 6** **Sturgis, Union County, KY** *No. 6*	**Peabody Coal Co. – Alston No. 4** **Centertown, Ohio County, KY** *No. 9*	**Peabody Coal Co. – Sinclair No. 2** **Drakesboro, Butler County, KY** *No. 9*	**Owl Creek Corp. – Sue-Jan Coal Co.** **St. Charles, Hopkins County, KY** *No. 6*	**Amax Coal Co. – Wabash Mine** **Kennsburg, Wabash County, IL** *Harrisburg No. 5*	**Freeman United – Orient No. 4** **Marion, Williamson County, IL** *Herrin No. 6*	**Zeigler Coal Co. – Mine No. 4** **Johnston City, Williamson County, IL** *Herrin No. 6*	**Freeman United – Orient No. 6** **Waltonville, Jefferson County, IL** *Illinois No. 6*	**Old Ben Coal Co. – Old Ben No. 26** **Sesser, Franklin County, IL** *Herrin No. 6*	**Monterey Coal Co. – Monterey No. 1** **Carlinville, Macoupin County, IL** *Herrin No. 6*	**Peabody Coal Co. – Mine No. 10** **Pawnee, Christan County, IL** *Herrin No. 6*
Mine Test No.	1	2	3	94	91	92	93	50	51	52	4	53	55	54
Field Report No.	1	1	1	18	18	18	18	10	10	10	1	10	10	10
Seam Thickness														
Feet	4.0	5.3	5.3	3.6	3.6	4.9	4.6	6.9	5.9	5.9	7.6	6.9	6.9	6.9
Meters	1.21	1.62	1.62	1.1	1.1	1.5	1.4	2.1	1.8	1.8	2.3	2.1	2.1	2.1
Number of Miners	545	500	500	59	570	100	12	645	300	250	400	600	555	908
Overburden Depth														
Feet	600	400	400	340	190	260	70	746	280	460	800	650	289	308
Meters	183	123	123	100	58	80	21	227	85	140	244	198	88	94
Offset Uplink														
Feet	44.6	15.1	9.8	0	49.2	0	32.8	0	14.8	9.8	0	9.8	9.8	39.4
Meters	13.6	4.6	3.0	0	15	0	10	0	4.5	3	0	3	3	12
Offset Downlink														
Feet	120.1	39.7	29.9	–	98.4	0	0	59.7	24.6	9.8	0	65.6	29.5	0
Meters	36.6	12.1	8.1	–	30	0	0	18.2	7.5	3	0	20	9	0
Month/Year of Test	9/76	9/76	9/76	9/78	9/78	9/78	9/78	5/78	5/78	5/78	9/76	5/78	5/78	5/78
Surface Noise Tape Recordings (BoM)					√	√	√			√		√	√	

TABLE B1 (Continued)

	SOUTH							WEST			
	ALABAMA							UTAH			COLORADO
Mining Co., Mine Name **Town, County, State,** *Seam Name*	**Alabama By-Products – Segco No. 1** **Goodsprings, Walker County, AL** *Mary Lee*	**Alabama By-Products – Gorgas No. 7** **Goodsprings, Walker County, AL** *Mary Lee*	**Alabama By-Products, Corp-Mary Lee No. 1** **Goodsprings, Walker County, AL** *Mary Lee*	**Jim Walter Resources – Blue Creek No. 3** **Adger, Jefferson County, AL** *Blue Creek*	**The Mead Corp. – Mulga Mine** **Mulga, Jefferson County, AL** *Pratt*	**Republic Steel Corp. – North River** **Berry, Jefferson County, AL** *Pratt*	**Jim Walker Resources, Inc. – Bessie** **Birmingham, Jefferson County, AL** *Mary Lee*	**Kaiser Steel – Sunnyside No.1** **Sunnyside, Carbon County, UT** *Lower Sunnyside*	**Kaiser Steel – Sunnyside No. 3** **Sunnyside, Carbon County, UT** *Lower Sunnyside*	**Plateau Mining Co. – Star Point No. 2** **Wattis, Carbon County, UT (seam 3)** *3rd*	**Western Slope Carbon-Hawk's Next 3** **Somerset, Gunnison County, CO** *E*
Mine Test No.	**42**	**43**	**89**	**90**	**44**	**41**	**40**	**76**	**77**	**78**	**79**
Field Report No.	**8**	**8**	**18**	**18**	**8**	**8**	**8**	**15**	**15**	**15**	**15**
Seam Thickness											
Feet	4.6	3.9	3.3	13.5	5.9	5.6	4.9	5.9	4.6	7.9	5.9
Meters	1.4	1.2	1.0	4.1	1.8	1.7	1.5	1.8	1.4	2.4	1.8
Number of Miners	200	400	450	500	200	432	218	38	380	30	130
Overburden Depth											
Feet	385	296	650	1550	262	485	469	1200	1000	1200	1400
Meters	109	90	198	473	80	148	143	365	305	366	427
Offset Uplink											
Feet	0	0	65.6	0	0	77.7	22.3	0	0	0	0
Meters	0	0	20	0	0	23.7	6.8	0	0	0	0
Offset Downlink											
Feet	41.3	20	0	0	0	59.7	59.7	0	0	0	1499
Meters	12.6	6.1	0	0	0	18.2	18.2	0	0	0	457
Month/Year of Test	2/78	2/78	9/78	9/78	2/78	2/78	2/78	8/78	8/78	8/78	8/78
Surface Noise Tape Recordings (BoM)			√	√				√		√	

TABLE B-2

KEY TO FIELD EVALUATION REPORTS AND MINE TESTS

Field Report	Mine Test Number
1	1, 2, 3, 4
2	5, 6, 7, 8
3	9, 10, 11, 12
4	13, 14, 15, 16, 17, 18, 19, 20, 21
5	22, 23, 24, 25, 26, 27
6	28, 29, 30, 31, 32, 33
7	34, 35, 36, 37, 38, 39
8	40, 41, 42, 43, 44
9	45, 46, 47, 48, 49
10	50, 51, 52, 53, 54, 55
11 & 12*	56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66
13	67, 68, 69, 70
14	71, 72, 73, 74, 75
15 & 16*	76, 77, 78, 79, 80, 81, 82, 83, 84
17 & 18*	85, 86, 87, 88, 89, 90, 91, 92, 93, 94

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* Reports consolidating results of two consecutive field trips.

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APPENDIX C

DERIVATION OF FUNDAMENTAL CURRENT AND MAGNETIC MOMENT FOR THE IN-MINE TRANSMIT LOOP ANTENNA

The fundamental component of in-mine loop current (I_{FUND}) was calculated in a straightforward manner from a knowledge of the loop configuration and dimensions used at each mine, and the measured transmitter characteristics. Based on laboratory measurements by PMSRC, both the Collins Radio and the new General Instruments transmitters were shown to behave as square wave voltage sources having a peak-to-peak voltage swing of 6.9 volts ($\pm$3.45 volts) and a series source resistance of 0.312 ohms. The equivalent circuit of the transmitter and the associated loop antenna encircling one or two pillars is shown in Figure C-1. The 0.1-ohm precision resistor is the means used to monitor the loop current with the oscilloscope at each mine.

The values of loop resistance R_L and inductance L_L were calculated based on the loop dimensions and number of turns (usually one turn) for each mine, using the following equations:

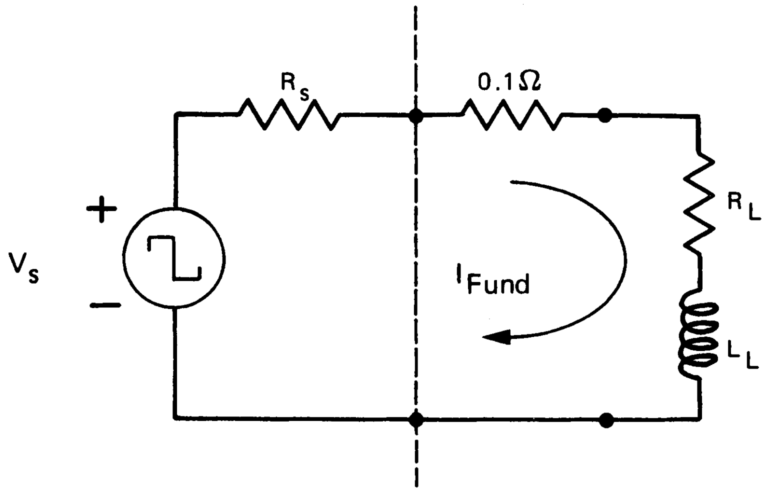
$$R_L = N\ p\ \rho \text{ ohms}, \qquad (1)$$

where N is the number of turns, p is the perimeter in feet, and ρ is the wire resistivity in ohms per foot; and the inductance formula[*] for a rectangular loop of wire

$$L_L = 0.12192\ N^2[a\ \ln(2a/r) + b\ \ln(2b/r) + 2\sqrt{a^2+b^2} - a\ \ln(a/b + \sqrt{1+(a/b)^2}) - b\ \ln(b/a + \sqrt{1+(b/a)^2}) -2(a+b) + 1/4(a+b)] \quad \text{(microhenries)} \qquad (2)$$

---

[*] Grover, F.W. Inductance Calculations - Working Formulas and Tables, Dover Publications, Inc., New York., p. 60, 1962.



V_s = 6.9 Volt p-p Square Wave* (±3.45 v)

R_s = 0.312 Ohm*

R_r = 0.1 Ohm Reference Resistor

R_L and L_L depend on loop configuration used in each mine test

*Derived from BOM PMSRC Laboratory Measurements

FIGURE C-1 EQUIVALENT CIRCUIT OF EM TRANSMITTER AND LOOP ANTENNA CONFIGURATION FOR COMPUTING I_{FUND}

where N is the number of turns, r is the wire radius in feet, and a and b are length and width, respectively, in feet. For the #12 and #19 wire used, ρ and r are:

	#12	#19	
ρ	1.588×10^{-3}	8.051×10^{-3}	ohm/ft
r	3.367×10^{-3}	1.495×10^{-3}	feet

The fundamental component of the loop current is simply the steady-state ac current flowing in the series R-L circuit of Figure C-1. The magnitude of its RMS value is given by Equation 3, from which can be calculated the fundamental component of magnetic moment, M_{FUND}, given by Equation 4:

$$I_{\substack{FUND\\RMS}} = \frac{4}{\sqrt{2}\pi}\left|\frac{V_s}{R_s+0.1+R_L+j\omega L_L}\right| \tag{3}$$

$$M_{\substack{FUND\\RMS}} = NAI_{\substack{FUND\\RMS}} \tag{4}$$

The area and linear dimensions of the loop antennas for each mine were obtained by PMSRC and ADL staff from the Westinghouse field reports, mine maps, and original data sheets. All areas were based on the geometrical shape (usually rectangular) described by the antenna deployed in the mine. The resistance, R_L, was based on the perimeter of the loop, as in Equation 1. The inductance, L_L, was based on the formula of Equation 2 for a rectangular-shaped loop. In the small number of cases where the loop was actually deployed in a trapezoidal, rhombic, L-shaped, or some other shape, an equivalent rectangle was selected for the purposes of estimating the inductance. Table C-1 provides a complete list of these in-mine loop dimensions, areas, number of turns, and wire size (usually #12). The data in this table were used to generate the RMS values of the in-mine fundamental loop currents and the corresponding magnetic moments listed in Table IV-1 in the body of this report for all mines at all frequencies.

Table C-1

Tabulation of In-Mine Transmit Loop Dimensions, Areas, Number of Turns, Wire Size Resistance, Inductance, and Time Constant for Total Transmitter Circuit

(all loops of #12 wire size except where indicated by *, #19 wire.)

LEGEND

MINE = Mine Number

LENGTH = Length of loop, long dimension in feet

WIDTH = Length of loop, short dimension in feet

PERIMETER = Length of loop perimeter in feet

TURNS = Number of turns in loop antenna

AREA (M**2) = Area enclosed by loop in square meters

RLOAD (OHM) = Resistance of loop antenna in ohms

LLOAD (μ H) = Inductance of loop antenna in microhenries

TC (SEC) = Time constant of total transmitter series R-L circuit, including source resistance of 0.312 ohm and reference resistor of 0.1 ohm, in seconds

NOTE = Number designation of notes describing source of antenna dimension information (Notes explained at end of table)

MINE	LENGTH	WIDTH	PERIMETER	TURNS	AREA(M**2)	RLOAD(OHM)	LLOAD(UH)	TC(SEC)	NOTES
1	135.0	55.0	380.0	1.0	690.0	0.603	221.072	2.177E-04	2
2	40.0	40.0	160.0	1.0	149.0	0.254	86.403	1.297E-04	2
3	40.0	40.0	160.0	1.0	149.0	0.254	86.403	1.297E-04	2
4	125.0	50.0	350.0	1.0	581.0	0.556	201.710	2.084E-04	2
5	125.0	55.0	360.0	1.0	639.0	0.572	208.886	2.124E-04	1
6	125.0	55.0	360.0	1.0	639.0	0.572	208.886	2.124E-04	1
7	113.0	57.0	340.0	1.0	639.0	0.540	197.040	2.070E-04	5
8	120.0	50.0	340.0	1.0	557.0	0.540	195.677	2.056E-04	2
9	50.0	50.0	200.0	1.0	232.0	0.318	110.724	1.518E-04	5
10	50.0	50.0	200.0	1.0	232.0	0.318	110.724	1.518E-04	5
11	68.0	48.0	236.0	1.0	232.0	0.375	130.148	1.654E-04	4
12	50.0	50.0	200.0	1.0	232.0	0.318	110.724	1.518E-04	5
13	60.0	70.0	260.0	1.0	390.0	0.413	148.014	1.794E-04	5
14	65.0	70.0	270.0	1.0	423.0	0.429	154.397	1.836E-04	1
15	53.7	53.7	215.0	1.0	267.0	0.341	119.853	1.591E-04	2
16	50.0	50.0	200.0	1.0	232.0	0.318	110.724	1.518E-04	5
17	65.0	60.0	250.0	1.0	362.0	0.397	141.784	1.753E-04	5
18	90.0	37.0	254.0	1.0	309.0	0.403	141.587	1.737E-04	2
19	116.0	12.0	256.0	1.0	129.0	0.407	129.585	1.583E-04	2,6
20	63.8	63.8	255.0	1.0	377.0	0.405	144.950	1.774E-04	3
21	54.0	40.0	184.0	1.0	199.0	0.292	103.136	1.465E-04	3
22	85.0	60.0	290.0	1.0	474.0	0.461	166.630	1.910E-04	2
23	104.0	70.0	340.0	1.0	678.0	0.540	203.654	2.139E-04	5,6

```
24      37.0     37.0    148.0      1.0    127.0     0.235     79.219   1.224E-04   2
25     100.0     45.0    290.0      1.0    418.0     0.461    164.589   1.886E-04   2
26      65.0     65.0    260.0      1.0    392.0     0.413    148.100   1.795E-04   2
27     170.0     80.0    400.0      1.0   1262.0     3.220    325.583   8.963E-05   2*
28      87.5     87.5    350.0      1.0    711.0     0.556    205.708   2.126E-04   2
29     200.0     50.0    500.0      1.0    929.0     0.794    292.055   2.422E-04   2
30      70.0     60.0    260.0      1.0    390.0     0.413    148.014   1.794E-04   5
31     120.0     50.0    340.0      1.0    557.0     0.540    195.677   2.056E-04   2
32      72.0     81.0    246.0      1.0    341.0     0.391    138.889   1.730E-04   2
33      30.0     20.0    100.0      1.0     56.0     0.805     55.856   4.589E-05   5*
34     100.0    100.0    400.0      1.0    928.0     0.635    238.350   2.276E-04   2
35      70.0     70.0    280.0      1.0    455.0     0.445    160.757   1.877E-04   2
36      75.0     65.0    280.0      1.0    450.0     0.445    160.677   1.876E-04   2
37      75.0     75.0    300.0      1.0    522.0     0.476    173.502   1.953E-04   2
38     115.0    100.0    430.0      1.0   1068.0     0.683    258.005   2.357E-04   2
39      70.0     60.0    260.0      1.0    390.0     0.413    148.014   1.794E-04   2
40      70.0     60.0    260.0      1.0    358.0     0.413    148.014   1.794E-04   5,6
41      50.0     50.0    200.0      1.0    232.0     0.318    110.724   1.518E-04   2
42      60.0     40.0    200.0      1.0    223.0     0.318    110.268   1.511E-04   2
43      40.0     40.0    160.0      1.0    149.0     0.254     86.403   1.297E-04   5
44      52.5     52.5    210.0      1.0    256.0     0.333    116.885   1.568E-04   2
45      98.4     49.2    295.2      1.0    450.0     0.469    168.486   1.513E-04   2
46      61.5     61.5    246.0      1.0    352.0     0.391    139.295   1.735E-04   2
47      41.0     41.0    164.0      1.0    156.0     0.260     88.810   1.321E-04   2
48     106.6     49.2    311.6      1.0    488.0     0.495    178.379   1.967E-04   5
```

49	53.3	53.3	213.2	1.0	264.0	0.339	118.863	1.584E-04	2
50	80.0	60.0	280.0	1.0	446.0	0.445	160.435	1.873E-04	2
51	56.0	36.0	184.0	1.0	187.0	0.292	100.433	1.426E-04	5
52	45.0	57.0	204.0	1.0	238.0	0.324	113.026	1.536E-04	2
53	77.9	77.9	311.6	1.0	564.0	0.495	180.931	1.995E-04	2
54	53.3	53.3	213.0	1.0	264.0	0.338	118.863	1.584E-04	5
55	75.0	75.0	300.0	1.0	522.0	0.476	173.502	1.953E-04	2
56	65.0	40.0	210.0	1.0	241.0	0.333	116.200	1.559E-04	2
57	120.0	50.0	340.0	1.0	558.0	0.540	195.677	2.056E-04	2
58	90.0	41.0	262.0	1.0	335.0	0.416	147.144	1.777E-04	5, 6
59	50.0	50.0	200.0	1.0	232.0	0.318	110.724	1.518E-04	2
60	60.0	55.0	230.0	1.0	307.0	0.365	129.268	1.663E-04	2
61	65.0	45.0	220.0	1.0	272.0	0.349	122.662	1.611E-04	2
62	65.0	45.0	220.0	1.0	272.0	0.349	122.662	1.611E-04	5
63	75.0	50.0	250.0	1.0	349.0	0.397	141.236	1.746E-04	5
64	70.0	50.0	240.0	1.0	325.0	0.381	135.159	1.704E-04	5
65	65.0	45.0	220.0	1.0	272.0	0.349	122.662	1.611E-04	5
66	65.0	45.0	220.0	1.0	272.0	0.349	122.662	1.611E-04	5
67	80.0	70.0	300.0	1.0	520.0	0.476	173.427	1.952E-04	5
68	50.0	50.0	200.0	1.0	232.0	0.318	110.724	1.518E-04	2
69	90.0	50.0	280.0	1.0	418.0	0.445	159.423	1.861E-04	5
70	90.0	65.0	310.0	1.0	543.0	0.452	179.449	1.984E-04	2
71	110.0	40.0	300.0	1.0	409.0	0.476	169.347	1.906E-04	2

```
72        63.0     43.0    212.0      1.0    252.0     0.337   117.692   1.572E-04   2
73       100.0    100.0    400.0      1.0    929.0     0.635   238.350   2.276E-04   2
74        70.0     70.0    280.0      1.0    455.0     0.445   160.757   1.877E-04   2
75        92.0     64.0    312.0      1.0    547.0     0.495   180.617   1.990E-04   2
76        90.0     40.0    260.0      1.0    334.0     0.413   145.762   1.767E-04   2
77        90.0     50.0    280.0      1.0    418.0     0.445   159.423   1.861E-04   2
78       100.0    100.0    400.0      1.0    929.0     0.635   238.350   2.276E-04   2
79       102.0     52.0    308.0      1.0    493.0     0.489   176.700   1.961E-04   2
80        50.0     50.0    200.0      1.0    232.0     0.318   110.724   1.518E-04   2
81        40.0     35.0    150.0      1.0    130.0     0.238    80.375   1.236E-04   2
82        60.0     50.0    220.0      1.0    279.0     0.349   122.973   1.615E-04   2
83        60.0     40.0    200.0      1.0    223.0     0.318   110.268   1.511E-04   2
84        60.5     50.2    222.5      1.0    282.0     0.353   123.836   1.618E-04   5,6
85        60.0     60.0    240.0      1.0    335.0     0.381   135.537   1.709E-04   2
86        70.0     70.0    280.0      1.0    455.0     0.445   160.757   1.877E-04   2
87        60.0     60.0    240.0      1.0    335.0     0.381   135.537   1.709E-04   2
88        52.0     26.0    156.0      1.0    126.0     0.248    82.972   1.258E-04   2
89        55.0     50.0    210.0      1.0    256.0     0.333   116.859   1.568E-04   2
90       100.0    100.0    400.0      1.0    929.0     0.635   238.350   2.276E-04   2
91        60.0     35.0    190.0      1.0    195.0     0.302   103.831   1.455E-04   2
92        70.0     70.0    280.0      1.0    455.0     0.445   160.757   1.877E-04   5
93        30.0     10.0     80.0      2.0     28.0     0.254   154.084   2.313E-04   2
94        35.0     30.0    130.0      2.0     98.0     0.413   274.055   3.322E-04   2
```

EXPLANATION OF NOTES

The in-mine antenna area for each mine test was recorded in the Westinghouse Field Reports prepared for each field trip. These reported areas were used unless, as for Mine Site 57, an obvious arithmetic error was made, or there were discrepancies between the reports and the original data sheets. The antenna lengths and widths, for the most part, had to be obtained or derived from information in the original data sheets. Whenever discrepancies occurred in the reocrded data that were not easily resolved, they were subjected to joint examination and consultation by Bureau of Mines (PMSRC) and Arthur D. Little, Inc., technical staff, to arrive at final agreed-upon values for length, width, perimeter, and area for the mines in question. The specific note explanations are listed below.

1. Antenna perimeter and area were given by Westinghouse in the field reports. The length and width dimensions of the antenna have been derived to agree with the given perimeter and area data, and to be consistent with the dimensional constraints of deployment around the coal pillar(s) used in the mine (as shown on either a mine map or hand drawing supplied in the field report or in the original data sheets from which the reports were prepared).

2. Length and width dimensions of the antenna were given by Westinghouse in the original data sheets. These values resulted in the same areas reported in the field reports.

3. Only antenna area was reported by Westinghouse. Length and width dimensions have been derived from this area information and the probable antenna shape as estimated from the mine map supplied. For example:

   - Mine 20 Square indicated, and side dimensions chosen to give the recorded area of 377 m^2.
   - Mine 21 Rectangle indicated, with a recorded area of 199 m^2. The rectangle aspect ratio of about 1.3-to-1 computed from the mine map was used to estimate the length and width dimensions of 54 ft. by 40 ft. tabulated.

4. Similar to Note (1), except the antenna perimeter was recorded by Westinghouse in the original data instead of in the field report.

5. Discrepancies in reported data. Antenna length, width, perimeter, and area tabulated are those resolved by telephone consultation between Arthur D. Little, Inc., and PMSRC staff on April 22, 1980.

6. The antenna was deployed in an irregular shape. For the purpose of estimating loop inductance, an "equivalent" rectangular shape was chosen to obtain the tabulated values for length and width.

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APPENDIX D.

Comprehensive Tabulations of Data Bases, Derived Parameters and Evaluation Indices

Table D-1

Comprehensive tabulations of screened but undeleted surface and in-mine signal strengths, key indices, and variables (ranked by depth)

Symbol Legend

MINE = Mine Number

ANTMIN = In-Mine Transit Antenna Area in Square Meters

IWEST = In-Mine "RMS" Transmit Loop Current in Amperes Recorded by Westinghouse (peak-to-peak value/ $2\sqrt{2}$)

SEMF = Surface Vertical Component of Magnetic Field Strength in dB re 1 μA/m

MEMF = In-Mine Vertical Component of Magnetic Field Strength in dB re 1 μA/m

DEPTHFT = Overburden Depth in Feet

MMFUND = In-Mine RMS Fundamental Component of Transmitter Magnetic Moment in Amp-turn-m^2

IFUND = In-Mine RMS Fundamental Component of Transmit Loop Current in Amperes

IEST = In-Mine "RMS" Value of Total Periodic Exponential Current in Transmit Loop in Amperes (peak-to-peak value/$2\sqrt{2}$) Based on Theoretical Calculation for Circuit of Figure C-1.

IDIFF = 20 Log (IFUND/IWEST) in dB

IDEL = IEST - IWEST in Amperes

IDIFF2 = 20 log (IEST/IWEST) in dB

TLU = Transmission Loss Uplink = $-20 \text{ Log } (2\pi D^3/M_m)$ - SEMF + 120 in dB

TLD = Transmission Loss Downlink = $20 \log (2\pi D^3/M_s)$ - MEMF + 120 in dB

DELTATL = TLU - TLD in dB

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                                               LISTING OF SELECTED VARIABLES                13:42 WEDNESDAY, MAY 14, 1980    1

                                                 IN ORDER OF INCREASING DEPTH

----------------------------------------------------------- FREQ=630 ------------------------------------------------------------

  MINE   ANTMIN   IWEST     SFMF    MEMF   DEPTHFT    MMFUND   IFUND     IEST     IDIFF      IDEL   IDIFF2      TLU       TLD   DELTATL

    93       28    3.18    57.00   67.50    68.880    192.59  3.4392   3.4329    0.6806    0.2529   0.6647  13.4005    22.598    -9.197
    91      195    3.68    44.00   52.50   190.240    735.41  3.7713   3.3889    0.2129   -0.2911  -0.7158  11.5657    11.292     0.274
     8      557    2.10    48.80     N     200.080   1409.75  2.5310   2.4571    1.6215    0.3571   1.3641  11.1038       .         .
    18      309    2.80    48.00   62.00   209.920    970.07  3.1394   2.9307    0.9938    0.1307   0.3963   7.4060     4.796     2.610
    36      450    2.82    53.00   64.00   216.480   1310.05  2.9112   2.7662    0.2765   -0.0538  -0.1673   4.2139     4.493    -0.279
    33       56    2.47    26.00   42.50   229.600    140.61  2.5109   2.0044    0.1426   -0.4656  -1.8143  10.2954    12.295    -1.999
    65      272    2.97    44.00   76.00   232.880    935.60  3.4397   3.1580    1.2753    0.1880   0.5331   8.3871    -4.004    12.391
    17      362    2.80    45.00   55.00   239.440   1141.97  3.1546   2.9511    1.0357    0.1511   0.4565   8.3946     8.367     0.027
    71      409    2.02    54.00   61.00   239.440   1141.48  2.7909   2.6619    2.8079    0.6419   2.3968  -0.6092    -2.009     1.400
    12      232    2.47      N     60.47   249.936    846.66  3.6494   3.3080    3.3905    0.8380   2.5374      .        11.127       .
    10      232    2.80    46.25   60.10   253.872    846.66  3.6494   3.3080    2.3013    0.5080   1.4481   3.0205     1.742     1.278
    66      272    2.97    16.00     F     255.840    935.60  3.4397   3.1580    1.2753    0.1880   0.5331  33.9370       .         .
    85      335    4.00    45.00   55.00   260.104   1086.68  3.2438   3.0173   -1.8201   -0.9827  -2.4488   5.8065     2.469     3.338
    44      256    2.50    48.00   39.00   262.400    906.28  3.5402   3.2312    3.0218    0.7312   2.2285   1.0006    11.238   -10.237
    47      156    3.18    43.00   48.50   262.400    638.59  4.0935   3.6101    2.1934    0.4301   1.1018   2.9599    -0.036     2.996
    92      455    2.97    47.50   -5.00   262.400   1324.37  2.9107   2.7660   -0.1752   -0.2040  -0.6181   4.7956    65.485   -60.689
     9      232    3.50    41.20   68.00   264.040    846.66  3.6494   3.3080    0.3631   -0.1920  -0.4901   7.0472     6.799     0.249
    11      232    2.83    44.00   32.90   264.040    766.26  3.3028   3.0500    1.3419    0.2200   0.6503   3.3805    16.953   -13.573
    24      127    2.44    39.00   56.00   269.944    548.64  4.3200   3.7588    4.9619    1.3188   3.7532   4.9025     8.385    -3.483
    51      187    2.82    26.00   71.00   278.800    718.27  3.8410   3.4378    2.6839    0.6178   1.7206  19.4014   -10.416    29.817
    55      522    2.12    44.00     N     285.640   1443.90  2.7661   2.6532    2.3106    0.5332   1.9487   6.5626       .         .
    43      149    3.20    43.00   61.00   295.200    618.10  4.1483   3.6464    2.2544    0.4464   1.1343  -0.3926     2.993    -3.386
    54      264    2.47    40.00   48.00   308.320    925.96  3.5074   3.2085    3.0458    0.7385   2.2721   4.9850     2.113     2.872
    21      199    2.80    30.00   60.00   324.720    759.37  3.8159   3.4337    2.6888    0.6337   1.7721  11.9118     5.777     6.135
    30      390    2.54    35.00   56.00   324.720   1197.27  3.0699   2.8873    1.6458    0.3473   1.1132  10.8665     4.798     6.068
    35      455    2.75    43.00   61.00   324.720   1324.37  2.9107   2.7660    0.4933    0.0160   0.0504   3.7429     2.948     0.795
    94       98    2.97    27.50     N     328.000    446.72  2.2792   2.4604   -2.2995   -0.5096  -1.6350   9.5415       .         .
    32      341    2.47    32.00   53.00   331.280   1088.70  3.1927   2.9780    2.2292    0.5080   1.6246  12.5197     7.988     4.531
    13      390    3.53    36.00   58.00   341.120   1197.27  3.0699   2.8873   -1.2130   -0.6427  -1.7457   8.5826     4.328     4.255
    20      377    2.80    35.00   47.00   341.120   1172.99  3.1114   2.9188    0.9160    0.1188   0.3609   9.4047    15.328    -5.923
    19      129    2.80    23.00   55.00   347.680    414.80  3.2155   2.9410    1.2018    0.1410   0.4267  11.8792     6.831     5.048
    60      307    2.80    40.00   53.00   350.960   1024.73  3.3379   3.0860    1.5263    0.2860   0.8448   2.4900    -0.481     2.971
    64      325    2.97    34.00   54.00   354.240   1055.16  3.2467   3.0180    0.7737    0.0480   0.1393   8.5018     0.963     7.538
    42      223    2.83    35.00   62.00   357.520    814.70  3.6534   3.3088    2.2182    0.4788   1.3577   5.0152     1.636     3.379
    86      126    3.60    29.00   35.00   380.480    531.06  4.2147   3.6844    1.3693    0.0844   0.2013   5.6761     3.628     2.048
    59      232    3.15    30.00   49.00   387.040    846.66  3.6494   3.3080    1.2782    0.1580   0.4251   8.2821     2.616     5.666
    87      335    2.70    30.00   52.00   400.160   1086.68  3.2438   3.0173    1.5938    0.3173   0.9651   9.5813     2.630     6.952
     2      149    3.50    32.30   33.30   403.440    618.10  4.1483   3.6464    1.4760    0.1464   0.3559   2.1677     1.671     0.496
     3      149    3.50    30.30   28.30   403.440    618.10  4.1483   3.6464    1.4760    0.1464   0.3559   4.1677     6.671    -2.504
    67      520    2.47    38.00   41.00   419.840   1438.60  2.7665   2.6534    0.9847    0.1834   0.6221   2.7670     4.445    -1.678
    56      241    3.01    35.00     N     423.120    854.57  3.5459   3.2324    1.4232    0.2224   0.6192   1.0403       .         .
    25      418    2.12    33.00   36.10   426.400   1192.32  2.8524   2.7139    2.5775    0.5939   2.1452   5.7321    19.895   -14.163
    69      418    2.69      F       F     429.680   1220.27  2.9193   2.7688    0.7105    0.0788   0.2508      .          .         .
    14      423    2.70    33.00   49.00   446.080   1264.04  2.9883   2.8255    0.8812    0.1255   0.3946   5.0637     6.337    -1.273
    68      232    1.69      F     27.00   449.360    846.66  3.6494   3.3080    6.6867    1.6180   5.8336      .        16.166       .
    52      238    2.40    29.00   38.00   459.200    858.32  3.6064   3.2772    3.5373    0.8772   2.7058   4.9461     5.370    -0.424
    40      358    2.80      N     56.00   469.040   1099.03  3.0699   2.8873    0.7993    0.0873   0.2667      .        -2.489       .
    82      279    3.18     8.00     N     469.040    958.98  3.4372   3.1574    0.6756   -0.0226  -0.0620  26.3568       .         .
    37      522    2.54    33.00   51.00   478.880   1443.90  2.7661   2.6532    0.7407    0.1132   0.3787   4.3704     2.825     1.545
    49      264    2.82    30.50   50.00   478.880    925.68  3.5064   3.2072    1.8922    0.3872   1.1175   3.0089     2.509     0.500
    74      455    2.83    28.00     N     476.880   1324.37  2.9107   2.7660    0.2442   -0.0640  -0.1987   8.6198       .         .
    72      252    2.96    26.00   53.00   482.160    887.68  3.5226   3.2170    1.5114    0.2570   0.7232   6.9669    -1.714     8.681
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                                         LISTING OF SELECTED VARIABLES                    13:42 WEDNESDAY, MAY 14, 1980   2

                                          IN ORDER OF INCREASING DEPTH

------------------------------------------------------------ FREQ=630 ------------------------------------------------------------

MINE  ANTMIN  IWEST   SEMF    MEMF    DEPTHFT   MMFUND   IFUND    IEST     IDIFF     IDEL     IDIFF2    TLU       TLD      DELTATL

 41    232    2.83   21.50   25.00    485.44    846.66  3.6494   3.3080   2.2087    0.4780    1.3556   10.8793   32.4411   -21.562
 63    349    2.97   30.00   54.00    485.44   1102.34  3.1586   2.9522   0.5348   -0.0178   -0.0522    4.6715   -5.4310    10.102
 86    455    3.90   26.00   41.50    498.56   1324.37  2.9107   2.7660  -2.5413   -1.1340   -2.9842    9.5704    4.4775     5.093
 80    232    3.18     N     36.00    500.20    846.66  3.6494   3.3080   1.1959    0.1280    0.3428     .        7.6793      .
 39    390    2.54   29.00   51.50    508.40   1197.27  3.0699   2.8873   1.6458    0.3473    1.1132    5.1847    2.1053     3.079
 28    711    2.26   14.00     F      518.24   1746.09  2.4558   2.4030   0.7217    0.1430    0.5329   22.9627     .          .
  7    639    2.00     S     48.70    519.88   1612.80  2.5239   2.4543   2.0208    0.4543    1.7780     .        5.0662      .
 83    223    2.69   15.00   39.00    541.20    814.70  3.6534   3.3088   2.6589    0.6188    1.7984   14.2117    7.7947     6.417
 84    282    2.69   13.00   37.00    560.88    963.76  3.4176   3.1406   2.0794    0.4506    1.3452   16.7404    4.1095    12.631
 22    474    2.12    8.00   51.00    569.08   1346.06  2.8398   2.7097   2.5390    0.5897    2.1317   24.2641   -0.0280    24.292
 29    929    2.10   28.00   42.00    580.56   1727.25  1.8593   1.8757  -1.0574   -0.2243   -0.9811    5.9095    1.2248     4.685
 56    335    2.45   27.00   48.00    580.56   1027.81  3.0681   2.8791   1.9541    0.4291    1.4018    2.4006    1.1832     1.217
  1    690    1.77   20.70   48.75    599.91   1598.82  2.3171   2.2802   2.3394    0.5102    2.2000   11.6840   -6.6825    18.367
 15    267    2.60   17.00   47.00    600.24    931.46  3.4886   3.1941   1.9099    0.3941    1.1438   10.6770    0.6025    10.075
 81    130    2.33   15.00   41.00    600.24    557.83  4.2910   3.7398   3.6154    0.9098    2.4212    8.2237    4.6219     3.602
 31    557    2.26   23.00   42.00    619.92   1409.75  2.5310   2.4571   0.9837    0.1971    0.7263    7.4359    3.9902     3.446
 73    929    1.20     F       F      626.48   2047.17  2.2036   2.1913   5.2790    0.9913    5.2304     .         .          .
 53    564    1.97   20.00   39.00    649.44   1516.04  2.6880   2.5913   2.6993    0.6213    2.3810    9.8551    5.7986     4.057
 89    256    2.76   22.00   41.50    649.44    906.34  3.5404   3.2313   2.1629    0.4713    1.3694    3.3867    4.3519    -0.965
 75    547    2.40   27.00     N      658.30   1470.69  2.6886   2.5904   0.9863    0.1904    0.6631    2.2384     .          .
  6    639    2.00   24.10     F      674.04   1544.54  2.4171   2.3646   1.6453    0.3646    1.4546    4.9481     .          .
 62    272    2.70    6.00     N      685.52    935.60  3.4397   3.1580   2.1031    0.4580    1.3610   18.2539     .          .
 16    232    2.80   10.00   41.00    688.80    846.66  3.6494   3.3080   2.3013    0.5080    1.4481   13.2618    6.1191     7.143
 26    392    2.12   19.00   40.00    688.80   1203.17  3.0693   2.8871   3.2141    0.7671    2.6825    7.3142    7.9350    -0.621
 27   1262    0.57   21.00     N      688.80   1017.03  0.8059   0.6714   3.0081    0.1014    1.4221    3.8543     .          .
 50    446    1.76    4.00   36.00    744.56   1299.10  2.9128   2.7667   4.3760    1.0067    3.9290   20.9521   10.7617    10.190
 38   1068    2.20   22.00   38.00    780.64   2215.63  2.0746   2.0797  -0.5098   -0.1203   -0.4884    6.3561    7.5286    -1.172
  4    581    3.50   -7.70   46.20    799.99   1438.36  2.4757   2.4112  -3.0074   -1.0888   -3.2367   31.6654   -8.1732    39.839
 61    272     .       N     18.00    846.24    935.60  3.4397   3.1580    .         .         .          .       26.3031      .
 70    543    2.62     F       N      915.12   1466.73  2.7012   2.6006   0.2651   -0.0194   -0.0646     .         .          .
 45    450    2.47   16.00   19.00    944.64   1265.16  2.8115   2.6837   1.1248    0.2137    0.7207    2.5202   22.0883   -19.568
 77    418    2.96     N     25.00   1000.40   1220.27  2.9193   2.7688  -0.1203   -0.1912   -0.5800     .       15.6667      .
 48    488    2.12   13.00   38.00   1010.24   1318.86  2.7026   2.5967   2.1089    0.4767    1.7617    4.1317    4.0000     0.132
 57    558    2.38   18.00   15.00   1049.60   1412.28  2.5310   2.4571   0.5343    0.0771    0.2769   -1.2698   21.0560   -22.326
 46    352    2.82    6.00   34.50   1190.64   1122.77  3.1897   2.9772   1.0700    0.1572    0.4712    5.4522    1.8797     3.573
 76    334    2.47     F     28.00   1197.20   1030.58  3.0856   2.8919   1.9329    0.4219    1.3697     .        8.1262      .
 23    678    1.27     F     15.00   1199.82   1688.25  2.4900   2.4402   5.8479    1.1702    5.6724     .       21.0802      .
 78    929    2.33   13.00   29.00   1200.48   2047.17  2.2036   2.1913  -0.4845   -0.1387   -0.5331    3.4550    0.2723     3.183
 34    928    2.00   -2.00     F     1341.52   2044.97  2.2036   2.1913   0.8421    0.1913    0.7934   15.5511     .          .
  5    639    2.00    3.26     F     1397.28   1544.54  2.4171   2.3646   1.6453    0.3646    1.4546    6.7922     .          .
 79    493    2.33   -1.60     F     1400.56   1342.41  2.7229   2.6143   1.3535    0.2843    1.0000   10.3729     .          .
 90    929    3.39   -2.00   -2.00   1551.44   2047.17  2.2036   2.1913  -3.7413   -1.1987   -3.7900   11.7722   32.8308   -21.059
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                                     IN ORDER OF INCREASING DEPTH

------------------------------------------------------------ FREQ=1050 -------------------------------------------------------------

MINE  ANTMIN  IWEST  SEMF  MEMF   DEPTHFT   MMFUND  IFUND   IEST    IDIFF    IDEL     IDIFF2   TLU      TLD      DELTATL

 93     28    3.04   56.0  67.0    68.880   143.12  2.5558  2.8333  -1.5069  -0.2067  -0.6116  11.8218  23.0979  -11.276
 91    195    3.54   41.0  53.0   190.240   612.26  3.1398  3.1685  -1.0420  -0.3715  -0.9630  12.9739  10.7919    2.182
  8    557    1.76   49.0    N    200.080  1078.64  1.9365  2.1027   0.8301   0.3427   1.5453   8.5785    .         .
 18    309    2.80   48.0  61.0   209.920   774.09  2.5051  2.6298  -0.9667  -0.1702  -0.5447   5.4458   5.7961   -0.350
 36    450    2.47   53.0  64.0   216.480  1025.56  2.2790  2.4310  -0.6991  -0.0390  -0.1382   2.0874   4.4930   -2.406
 33     56    2.47   29.0  42.5   229.600   136.78  2.4425  2.0042  -0.0972  -0.4658  -1.8151   7.0555  12.2946   -5.239
 65    272    2.83   44.0  69.0   232.880   760.38  2.7955  2.8872  -0.1065   0.0572   0.1738   6.5859   2.9959    3.590
 17    362    2.70   42.0  54.0   239.440   909.19  2.5116  2.6417  -0.6283  -0.0583  -0.1896   9.4145   9.3675    0.047
 71    409    2.02   52.0  62.0   239.440   890.00  2.1760  2.3286   0.6462   0.3086   1.2349  -0.7707  -3.0094    2.239
 12    232    2.41     N   56.4   249.936   697.97  3.0085  3.0656   1.9267   0.6556   2.0900    .       15.1968     .
 10    232    2.47   40.1  56.1   253.872   697.97  3.0085  3.0656   1.7131   0.5956   1.8764   7.4931   5.7424    1.751
 66    272    2.82   17.0    F    255.840   760.38  2.7955  2.8872  -0.0758   0.0672   0.2046  31.1357    .         .
 85    335    3.20   44.0  54.0   260.104   870.57  2.5987  2.7187  -1.8079  -0.4813  -1.4158   4.8805   3.4687    1.412
 44    256    2.10   47.0  47.0   262.400   741.37  2.8960  2.9728   2.7916   0.8728   3.0189   0.2561   3.2377   -2.982
 47    156    3.00   41.5  49.0   262.400   543.29  3.4826  3.4360   1.2956   0.4360   1.1786   3.0560  -0.5358    3.592
 92    455    2.76   46.5 -11.0   262.400  1036.64  2.2783  2.4305  -1.6660  -0.3295  -1.1043   3.6680  71.4850  -67.817
  9    232    3.20   41.4  64.1   264.040   697.97  3.0085  3.0656  -0.5360  -0.1344  -0.3727   5.1698  10.6985   -5.529
 11    232    2.54   45.0  28.4   264.040   618.77  2.6671  2.7707   0.4241   0.2307   0.7551   0.5237  21.4531  -20.929
 24    127    2.33   37.5  53.0   269.944   474.28  3.7345  3.6192   4.0975   1.2892   3.8251   5.1374  11.3854   -6.248
 51    187    2.65   33.0  71.0   278.800   600.72  3.2124  3.2269   1.6717   0.5769   1.7108  10.8491  -6.3334   17.183
 55    522    1.63   43.0    N    288.640  1119.00  2.1437  2.3050   1.3743   0.4750   2.0044   5.3484    .         .
 43    149    2.80   36.0  60.0   295.200   527.90  3.5429  3.4807   2.0440   0.6807   1.8902   5.2373   3.9930    1.244
 54    264    2.33   37.0  46.0   308.320   755.58  2.8621  2.9449   1.7866   0.6149   2.0343   6.2188   4.1127    2.106
 21    199    2.70   25.0  55.0   324.720   631.23  3.1720  3.2060   1.3994   0.5060   1.4920  15.3065   7.2552    8.051
 30    390    2.12   33.0  56.0   324.720   947.67  2.4299  2.5685   1.1851   0.4485   1.6669  10.8358   4.7982    6.038
 35    455    2.47   42.0  60.0   324.720  1036.64  2.2783  2.4305  -0.7017  -0.0395  -0.1400   2.6153   3.9481   -1.333
 94     98    2.69   20.0    N    328.000   306.34  1.5630  1.8183  -4.7159  -0.8717  -3.4017  13.7649    .         .
 32    341    2.30   31.0  53.0   331.280   869.51  2.5499  2.6748   0.8959   0.3748   1.3113  11.5670   7.9883    3.579
 13    390    3.18   36.0  57.0   341.120   947.67  2.4299  2.5685  -2.3368  -0.6115  -1.8550   6.5519   5.3275    1.224
 20    377    2.70   35.0  53.0   341.120   931.04  2.4696  2.6043  -0.7747  -0.0957  -0.3135   7.3982   9.3275   -1.929
 19    129    2.70   22.0  54.0   347.680   338.54  2.6243  2.6998  -0.2470  -0.0002  -0.0006  11.1145   7.8312    3.283
 60    307    2.66     S   50.0   350.960   826.41  2.6919  2.7997   0.1035   0.1397   0.4446    .        2.5195     .
 64    325    2.83   34.0  54.0   354.240   845.90  2.6028  2.7213  -0.7269  -0.1087  -0.3402   6.5818   0.9635    5.618
 42    223    2.65   36.0  61.0   357.520   672.28  3.0147  3.0690   1.1200   0.4190   1.2750   2.3462   2.6360   -0.290
 88    126    3.20   28.0  35.0   380.480   456.54  3.6233  3.5338   1.0791   0.3338   0.8618   5.3628   3.6278    1.735
 59    232    3.15   30.0  50.0   387.040   697.97  3.0085  3.0656  -0.3992  -0.0844  -0.2359   6.6047   1.6157    4.989
 87    335    2.50   28.0  52.0   400.160   870.57  2.5987  2.7187   0.3363   0.2187   0.7284   9.6553   2.6297    7.026
  2    149    3.50   29.3  30.3   403.440   527.90  3.5429  3.4807   0.1058  -0.0193  -0.0480   3.7975   4.6713   -0.874
  3    149    3.50   27.0  21.3   403.440   527.90  3.5429  3.4807   0.1058  -0.0193  -0.0480   6.0975  13.6713   -7.574
 67    520    2.12   36.0  48.0   419.840  1115.01  2.1442  2.3054   0.0986   0.1854   0.7282   2.5538  -2.5555    5.109
 56    241    2.80   33.0    N    423.120   700.04  2.9047  2.9779   0.3189   0.1779   0.5350   1.3079    .         .
 25    418    1.91   31.0  39.1   426.400   932.07  2.2298  2.3812   1.3447   0.4712   1.9153   5.5932  16.8946  -11.301
 69    418    1.77     F     F    429.680   957.14  2.2898  2.4386   2.2365   0.6686   2.7833    .        .         .
 14    423    2.50   30.0  49.0   446.080   994.78  2.3517  2.4978  -0.5312  -0.0022  -0.0076   5.9830   6.3372   -0.354
 68    232    0.99     F   28.0   449.360   697.97  3.0085  3.0656   9.6543   2.0756   9.8176    .       15.1660     .
 52    238    2.10   25.0  34.0   459.200   705.60  2.9647  3.0292   2.9952   0.9292   3.1822   7.2443   9.3698   -2.126
 40    358    2.60     N   53.0   469.040   869.91  2.4299  2.5685  -0.5877  -0.0315  -0.1059    .        0.5110     .
 82    279    3.11    8.0    N    469.040   778.90  2.7917  2.8849  -0.9378  -0.2251  -0.6526  24.5503    .         .
 37    522    2.30   32.0  50.0   478.880  1119.00  2.1437  2.3050  -0.6113   0.0050   0.0189   3.1562   3.8251   -0.669
 49    264    2.65   29.5  49.0   478.880   755.43  2.8615  2.9440   0.6670   0.2940   0.9138   2.2435   3.5087   -1.265
 74    455    2.55   25.0    N    478.880  1036.64  2.2783  2.4305  -0.9786  -0.1195  -0.4169   9.4922    .         .
 72    252    3.11   24.0  52.0   482.160   725.70  2.8799  2.9579  -0.6680  -0.1521  -0.4355   7.2169  -0.7139    7.931
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                                                      LISTING OF SELECTED VARIABLES                         13:42 WEDNESDAY, MAY 14, 1980    4

                                                       IN ORDER OF INCREASING DEPTH

-------------------------------------------------------------- FREQ=1050 ---------------------------------------------------------------

  MINE  ANTMIN  IWEST  SEMF   MEMF   DEPTHFT    MMFUND   IFUND     IEST     IDIFF      IDEL    IDIFF2       TLU       TLD    DELTATL

   41     232   2.65   21.5  36.00    485.44    697.97  3.0085   3.0656    1.1021    0.4156    1.2654     9.202   23.2440   -14.042
   63     349   2.47   26.0  46.00    485.44    878.48  2.5171   2.6454    0.1641    0.1754    0.5959     6.700    2.5690     4.131
   86     455   2.83   24.0    F      498.56   1036.64  2.2783   2.4305   -1.8835   -0.3995   -1.3218     9.443     .          .
   80     232   3.11    9.0  30.00    500.20    697.97  3.0085   3.0656   -0.2882   -0.0444   -0.1249    20.921   13.6793     7.242
   39     390   2.40   26.0  47.00    508.40    947.67  2.4299   2.5685    0.1075    0.1685    0.5894     6.154    6.6053    -0.451
   28     711   1.94   19.0    F      518.24   1324.91  1.8634   2.0358   -0.3499    0.0958    0.4187    15.565     .          .
    7     639   1.70   52.3  49.20    519.88   1231.86  1.9278   2.0959    1.0923    0.3959    1.8184   -18.450    4.5662   -23.016
   83     223   2.47   12.0  21.00    541.20    672.28  3.0147   3.0690    1.7309    0.5990    1.8860    15.543   25.7947   -10.252
   84     282   2.47   20.0  32.00    560.88    782.44  2.7746   2.8683    1.0101    0.3983    1.2986     7.930    9.1095    -1.179
   22     474   2.01   17.9  51.00    569.08   1049.02  2.2131   2.3692    0.8361    0.3592    1.4281    12.198   -0.0280    12.226
   29     929   1.80   25.0  40.00    580.56   1269.44  1.3665   1.5261   -2.3933   -0.2739   -1.4338     6.235    3.2248     3.010
   58     335   2.10   24.0  48.00    580.56    815.50  2.4343   2.5679    1.2831    0.4679    1.7472     3.391    1.1832     2.208
    1     690   1.70   14.3  43.76    599.91   1205.97  1.7478   1.9176    0.2409    0.2176    1.0462    15.635   -1.6925    17.327
   15     267   2.60   16.0  45.00    600.24    759.33  2.8439   2.9289    0.7788    0.3289    1.0346     9.902    2.6025     7.300
   81     130   2.69   11.0  38.00    600.24    481.27  3.7021   3.5959    2.7739    0.9059    2.5211    10.942    7.6219     3.320
   31     557   1.94   21.0  41.00    619.92   1078.64  1.9365   2.1027   -0.0157    0.1627    0.6995     7.111    4.9902     2.120
   73     929   0.91     F   33.00    626.48   1527.35  1.6441   1.8177    5.1377    0.9077    6.0096      .       4.8492      .
   53     564   1.69   10.0  35.00    649.44   1168.63  2.0720   2.2372    1.7701    0.5472    2.4364    17.594    9.7986     7.796
   89     256   2.26   20.0  40.50    649.44    741.45  2.8963   2.9730    2.1547    0.7130    2.3817     3.643    5.3519    -1.709
   75     547   2.12   15.0    N      658.30   1134.36  2.0738   2.2380   -0.1914    0.1180    0.4705    11.983     .          .
    6     639   1.70   20.7  -5.70    674.04   1172.25  1.8345   2.0038    0.6614    0.3038    1.4281     5.952   56.4599   -50.507
   62     272   2.80    4.0    N      685.52    760.38  2.7955   2.8872   -0.0140    0.0872    0.2664    18.453     .          .
   16     232   2.70    7.0  39.00    688.80    697.97  3.0085   3.0656    0.9397    0.3656    1.1030    14.584    8.1191     6.465
   26     392   2.01   17.0  52.00    688.80    952.20  2.4291   2.5679    1.6450    0.5579    2.1276     7.282   -4.0650    11.347
   27    1262   0.55   19.0    N      688.80    928.89  0.7360   0.6650    2.5303    0.1150    1.6492     5.067     .          .
   50     446   1.55   -7.0  33.00    744.56   1017.37  2.2811   2.4324    3.3563    0.8824    3.9141    29.829   13.7617    16.067
   38    1068   1.85   17.0  33.00    780.64   1639.10  1.5347   1.7066   -1.6230   -0.1434   -0.7008     8.738   12.5286    -3.790
    4     581   3.18   -8.9  22.20    799.99   1096.74  1.8877   2.0549   -4.5299   -1.1251   -3.7927    30.510   15.8268    14.683
   61     272    .       N   16.00    846.24    760.38  2.7955   2.8872      .         .         .          .      28.3031      .
   70     543   2.33     F     N      915.12   1132.16  2.0850   2.2488   -0.9650   -0.0812   -0.3081      .        .          .
   45     450   2.12    9.0    F      944.64    985.56  2.1901   2.3454    0.2826    0.2254    0.8776     7.351     .          .
   77     418   2.76     N   28.00   1000.40    957.14  2.2898   2.4386   -1.6222   -0.3214   -1.0754      .      14.9746      .
   48     488   2.00    8.0  37.00   1010.24   1020.25  2.0907   2.2511    0.3852    0.2511    1.0273     6.902    5.0000     1.902
   57     558   2.10   14.0   8.00   1049.60   1080.57  1.9365   2.1027   -0.7040    0.0027    0.0112     0.405   28.0560   -27.651
   46     352   2.47    1.0  32.00   1190.64    896.07  2.5457   2.6720    0.2622    0.2020    0.6828     8.493    4.3797     4.114
   76     334   2.47    2.0  26.00   1197.20    818.84  2.4516   2.5831   -0.0649    0.1131    0.3889     6.567   12.4340    -5.867
   23     678   1.20     F   14.00   1199.82   1278.95  1.8863   2.0632    3.9286    0.8632    4.7072      .      22.0802      .
   78     929   2.12    7.0  29.00   1200.48   1527.35  1.6441   1.8177   -2.2082   -0.3023   -1.3363     6.911    2.9663     3.944
   34     928   1.76   -8.0  15.00   1341.52   1525.70  1.6441   1.8177   -0.5917    0.0577    0.2802    19.007   18.1825     0.824
    5     639   1.70     F     F     1397.28   1172.25  1.8345   2.0038    0.6614    0.3038    1.4281      .        .          .
   79     493   2.19  -11.0    F     1400.56   1039.29  2.1081   2.2685   -0.3311    0.0785    0.3059    17.550     .          .
   90     929   3.18   -9.0  -6.00   1551.44   1527.35  1.6441   1.8177   -5.7300   -1.3623   -4.8581    16.228   38.4144   -22.187
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                                           LISTING OF SELECTED VARIABLES                    13:42 WEDNESDAY, MAY 14, 1980     5

                                            IN ORDER OF INCREASING DEPTH

----------------------------------------------------------- FREQ=1950 -----------------------------------------------------------

MINE  ANTMIN  IWEST   SEMF    MEMF   DEPTHFT   MMFUND  IFUND    IEST    IDIFF     IDEL     IDIFF2    TLU      TLD      DELTATL

 93     28    2.26   53.00   67.50    68.880   86.887  1.5515  1.8447  -3.2671  -0.4153  -1.7637  10.4867  22.5979  -12.111
 91    195    2.54   36.00   51.00   190.240  415.226  2.1294  2.4167  -1.5315  -0.1233  -0.4322  14.6008  12.7919    1.809
  8    557    1.27   44.10     N     200.080  670.698  1.2041  1.4190  -0.4628   0.1490   0.9636   9.3516     .         .
 18    309    2.10   42.00   61.00   209.920  500.719  1.6205  1.8793  -2.2514  -0.2207  -0.9645   7.6619   5.7961    1.866
 36    450    1.87   51.50   63.00   216.480  651.033  1.4467  1.6910  -2.2293  -0.1790  -0.8740  -0.3598   5.4930   -5.853
 33     56    2.29   32.00   43.00   229.600  124.572  2.2245  1.9894  -0.2521  -0.3006  -1.2223   3.2433  11.7946   -8.551
 65    272    2.12   40.00   70.00   232.880  501.478  1.8437  2.1201  -1.2129   0.0001   0.0004   6.9704   1.9959    4.974
 17    362    2.10   36.00   54.00   239.440  586.757  1.6209  1.8816  -2.2493  -0.2184  -0.9538  11.6106   9.3675    2.243
 71    409    1.41   43.00   61.00   239.440  562.851  1.3762  1.6110  -0.2108   0.2010   1.1575   4.2493  -2.0094    6.259
 12    232    1.41     N     57.50   249.936  467.820  2.0165  2.3015   3.1076   0.8915   4.2558     .      14.0968      .
 10    232    1.76   42.20   51.12   253.872  467.820  2.0165  2.3015   1.1817   0.5415   2.3300   1.9179  10.7224   -8.804
 66    272    2.12   15.00   36.00   255.840  501.478  1.8437  2.1201  -1.2129   0.0001   0.0004  29.5202  28.4806    1.040
 85    335    2.50   39.00   54.00   260.104  565.418  1.6878  1.9540  -3.4124  -0.5460  -2.1403   6.1318   3.4687    2.663
 44    256    1.70   44.00   50.00   262.400  492.507  1.9239  2.2050   1.0747   0.5050   2.2592  -0.2963   0.2377   -0.534
 47    156    2.30   40.00   51.00   262.400  378.814  2.4283  2.7174   0.4715   0.4174   1.4485   1.4239  -2.5358    3.960
 92    455    2.12   44.00  -11.00   262.400  657.992  1.4461  1.6904  -3.3228  -0.4296  -1.9669   2.2198  71.4850  -69.265
  9    232    2.80   37.45   60.70   264.040  467.820  2.0165  2.3015  -2.8512  -0.4985  -1.7029   5.6446  14.0985   -8.454
 11    232    1.76   42.00   34.40   264.040  405.263  1.7468  2.0149  -0.0654   0.2549   1.1748  -0.1522  15.4531  -15.605
 24    127    2.12   35.50   57.00   269.944  338.168  2.6627  2.9435   1.9797   0.8235   2.8506   4.1995   7.3854   -3.186
 51    187    2.12   29.00   66.00   278.800  409.683  2.1908  2.4796   0.2853   0.3596   1.3609  11.5246  -1.3334   12.858
 55    522    1.13   37.00     N     288.640  703.739  1.3482  1.5817   1.5335   0.4517   2.9209   7.3201     .         .
 43    149    2.40   34.00   60.00   295.200  370.027  2.4834  2.7712   0.2967   0.3712   1.2491   4.1509   3.9930    0.158
 54    264    1.55   26.00     F     308.320  500.548  1.8960  2.1758   1.7501   0.6258   2.9457  13.6421     .         .
 21    199    2.10   17.00   55.00   324.720  427.281  2.1471  2.4391   0.1927   0.3391   1.3002  19.9170   9.5341   10.383
 30    390    1.76   32.00   56.00   324.720  608.033  1.5591  1.8143  -1.0528   0.0543   0.2639   7.9812   4.7982    3.183
 35    455    1.76   37.00   60.00   324.720  657.992  1.4461  1.6904  -1.7063  -0.0696  -0.3505   3.6671   3.9481   -0.281
 94     98    1.94    7.00     N     328.000  176.073  0.8983  1.0878  -6.6876  -0.8522  -5.0251  21.9547     .         .
 32    341    1.70   24.00   53.00   331.280  562.944  1.6509  1.9138  -0.2546   0.2138   1.0290  14.7908   7.9883    6.803
 13    390    2.68   36.00   56.00   341.120  608.033  1.5591  1.8143  -4.7052  -0.8657  -3.3885   2.6974   6.3275   -3.630
 20    377    2.10   30.00   52.00   341.120  599.022  1.5889  1.8469  -2.4225  -0.2531  -1.1155   8.5677  10.3275   -1.760
 19    129    2.10   18.00   53.00   347.680  224.313  1.7389  1.9953  -1.6389  -0.1047  -0.4442  11.5395   8.8312    2.708
 60    307    1.75   37.00   51.00   350.960  540.495  1.7606  2.0321   0.0525   0.2821   1.2981  -0.0664   1.5195   -1.586
 64    325    2.33   31.00   54.00   354.240  549.787  1.6917  1.9579  -2.7807  -0.3721  -1.5113   5.8393   0.9635    4.876
 42    223    1.76   31.00   60.50   357.520  451.112  2.0229  2.3077   1.2092   0.5477   2.3533   3.8809   3.1360    0.745
 88    126    2.80   26.00   32.00   380.480  322.938  2.5630  2.8459  -0.7682   0.0459   0.1412   4.3557   6.6278   -2.272
 59    232    2.03   23.00   48.00   387.040  467.820  2.0165  2.3015  -0.0580   0.2715   1.0903  10.1295   3.6157    6.514
 87    335    1.76   24.00   52.00   400.160  565.418  1.6878  1.9540  -0.3638   0.1940   0.9082   9.9066   2.6297    7.277
  2    149    3.20   23.60   27.30   403.440  370.027  2.4834  2.7712  -2.2021  -0.4288  -1.2496   6.4112   7.6713   -1.260
  3    149    3.20   20.80   15.30   403.440  370.027  2.4834  2.7712  -2.2021  -0.4288  -1.2496   9.2112  19.6713  -10.460
 67    520    1.24   31.00     F     419.840  701.299  1.3487  1.5822   0.7299   0.3422   2.1168   3.5263     .         .
 56    241    2.10   29.00     N     423.120  465.796  1.9328  2.2135  -0.7206   0.1135   0.4572   1.7693     .         .
 25    418    1.37   20.00   47.10   426.400  590.898  1.4136  1.6532   0.2721   0.2832   1.6321  12.6345   8.8946    3.740
 69    418    1.45   32.00   30.00   429.680  608.732  1.4563  1.7009   0.0377   0.2509   1.3862   0.6931  17.2422  -16.549
 14    423    1.80   19.00   46.00   446.080  634.685  1.5004  1.7502  -1.5813  -0.0498  -0.2437  13.0796   9.3372    3.742
 68    232    0.77     F     26.00   449.360  467.820  2.0165  2.3015   8.3622   1.5315   9.5104     .      17.1660      .
 52    238    1.76   20.00   31.00   459.200  471.389  1.9806  2.2641   1.0257   0.5041   2.1877   8.7407  12.3698   -3.629
 40    358    1.70     N     50.00   469.040  558.143  1.5591  1.8143  -0.7515   0.1143   0.5652     .       3.5110      .
 82    279    2.55    1.00     N     469.040  513.348  1.8400  2.1164  -2.8344  -0.4336  -1.6188  27.9289     .         .
 37    522    1.77   26.00   48.00   478.880  703.739  1.3482  1.5817  -2.3644  -0.1883  -0.9770   5.1279   5.8251   -0.697
 49    264    1.94   27.00   49.00   478.880  500.504  1.8958  2.1755  -0.2002   0.2355   0.9951   1.1678   3.5087   -2.341
 74    455    2.69     F       N     478.880  657.992  1.4461  1.6904  -5.3911  -0.9996  -4.0353     .        .         .
 72    252    2.40   18.00   51.00   482.160  481.758  1.9117  2.1918  -1.9758  -0.2082  -0.7882   9.6584   0.2861    9.372
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                                      LISTING OF SELECTED VARIABLES                    13:42 WEDNESDAY, MAY 14, 1980     6

                                       IN ORDER OF INCREASING DEPTH

------------------------------------------------------------------- FREQ=1950 -------------------------------------------------------------------

 MINE  ANTMIN  IWEST    SEMF    MEMF   DEPTHFT   MMFUND   IFUND    IEST     IDIFF    IDEL     IDIFF2     TLU      TLD      DELTATL

  41    232    1.760   15.50   32.00    485.44   467.820  2.0165  2.3015   1.1817   0.5415   2.3300    11.727  25.4411   -13.714
  63    349    1.700   16.00   46.00    485.44   567.486  1.6260  1.8869  -0.3866   0.1869   0.9060    12.904   2.5690    10.335
  86    455    2.000   18.00   37.00    498.56   657.992  1.4461  1.6904  -2.8166  -0.3096  -1.4608    11.495   8.9775     2.517
  80    232    2.540    7.00     F      500.20   467.820  2.0165  2.3015  -2.0047  -0.2385  -0.8565    19.446    .           .
  39    390    1.620   18.00   45.00    508.40   608.033  1.5591  1.8143  -0.3328   0.1943   0.9839    10.299   8.6053     1.694
  28    711    1.340    8.50     F      518.24   817.998  1.1505  1.3594  -1.3244   0.0194   0.1248    21.876    .           .
   7    639    1.240   47.40   48.70    519.88   764.831  1.1969  1.4113  -0.3073   0.1713   1.1240   -17.690   5.0662   -22.756
  83    223    1.780    6.00   32.00    541.20   451.112  2.0229  2.3077   1.1111   0.5277   2.2552    18.077  14.7947     3.283
  84    282    1.870   12.00   20.00    560.88   515.439  1.8278  2.1029  -0.1983   0.2329   1.0195    12.305  21.1095    -8.805
  22    474    1.800   21.60   50.00    569.08   663.126  1.3990  1.6380  -2.1891  -0.1620  -0.8192     4.515   0.9720     3.543
  29    929    1.250   22.00   37.00    580.56   764.167  0.8226  0.9809  -3.6344  -0.2691  -2.1057     4.826   6.2248    -1.399
  58    335    1.575   19.00   45.00    580.56   524.488  1.5656  1.8202  -0.0520   0.2452   1.2568     4.557   4.1832     0.374
   1    690    1.270    5.85   33.75    599.91   740.899  1.0738  1.2711  -1.4576   0.0011   0.0075    19.853   8.3175    11.536
  15    267    2.100   12.00   44.00    600.24   502.482  1.8820  2.1608  -0.9520   0.0608   0.2479    10.316   3.6025     6.714
  81    130    1.840    2.00   32.00    600.24   342.179  2.6321  2.9143   3.1097   1.0743   3.9943    16.979  13.6219     3.357
  31    557    1.340   17.00   41.00    619.92   670.698  1.2041  1.4190  -0.9288   0.0790   0.4976     6.984   4.9902     1.993
  73    929    2.120     F     33.00    626.48   930.105  1.0012  1.1890  -6.5163  -0.9310  -5.0231      .      4.8492      .
  53    564    1.090   10.00   27.00    649.44   731.422  1.2968  1.5244   1.5089   0.4344   2.9134    13.524  17.7986    -4.274
  89    256    1.980   16.00   38.50    649.44   492.595  1.9242  2.2053  -0.2483   0.2253   0.9360     4.091   7.3519    -3.261
  75    547    1.480   12.00     N      658.30   710.359  1.2986  1.5262  -1.1357   0.0462   0.2670    10.918    .           .
   6    639    1.240   13.00     F      674.04   723.888  1.1328  1.3385  -0.7854   0.0985   0.6639     9.466    .           .
  62    272    2.120    0.00     N      685.52   501.478  1.8437  2.1201  -1.2129   0.0001   0.0004    18.837    .           .
  16    232    2.100    5.00   36.00    688.80   467.820  2.0165  2.3015  -0.3524   0.2015   0.7958    13.109  11.1191     1.990
  26    392    1.800   14.00   49.00    688.80   610.857  1.5583  1.8136  -1.2524   0.0136   0.0654     6.426  -1.0650     7.491
  27   1262    0.530   17.00     N      688.80   726.563  0.5757  0.5989   0.7184   0.0689   1.0616     4.933    .           .
  50    446    1.410    0.00   23.50    744.56   646.066  1.4486  1.6929   0.2346   0.2829   1.5882    18.885  23.2617    -4.377
  38   1068    1.300    5.00   27.00    780.64   991.614  0.9285  1.1053  -2.9232  -0.1947  -1.4093    16.373  18.5286    -2.156
   4    581      .       F      4.70    799.99   679.936  1.1703  1.3806     .        .        .          .     33.3268      .
  61    272      .       N     18.00    846.24   501.478  1.8437  2.1201     .        .        .          .     26.3031      .
  70    543    1.520   -6.00     N      915.12   709.451  1.3065  1.5350  -1.3147   0.0150   0.0853    20.323    .           .
  45    450    1.410   10.00   13.00    944.64   622.775  1.3839  1.6206  -0.1623   0.2106   1.2091     2.364  28.0883   -25.724
  77    418    1.980     N     21.00   1000.40   608.732  1.4563  1.7009  -2.6683  -0.2791  -1.3197      .     19.2806      .
  48    488    1.240    4.00   36.00   1010.24   640.593  1.3127  1.5411   0.4349   0.3011   1.8882     6.859   6.0000     0.859
  57    558    1.645    7.00    0.00   1049.60   671.902  1.2041  1.4190  -2.7101  -0.2260  -1.2837     3.278  32.5342   -29.256
  46    352    1.980     F     27.50   1190.64   579.717  1.6469  1.9099  -1.6000  -0.0701  -0.3131      .      8.8797      .
  76    334    1.700     F     17.00   1197.20   527.365  1.5789  1.8345  -0.6419   0.1345   0.6614      .     18.7401      .
  23    678    1.060     F     15.00   1199.82   788.553  1.1631  1.3750   0.8062   0.3150   2.2599      .     21.0802      .
  78    929    1.480    2.00   25.00   1200.48   930.105  1.0012  1.1890  -3.3948  -0.2910  -1.9016     7.603   5.0281     2.575
  34    928    1.130  -20.00    3.00   1341.52   929.104  1.0012  1.1890  -1.0512   0.0590   0.4421    26.699  30.1825    -3.484
   5    639    1.240   -0.02     F     1397.28   723.888  1.1328  1.3385  -0.7854   0.0985   0.6639     3.490    .           .
  79    493    1.560     F       F     1400.56   653.007  1.3246  1.5546  -1.4208  -0.0054  -0.0301      .       .           .
  90    929    1.700  -12.00     F     1551.44   930.105  1.0012  1.1890  -4.5986  -0.5110  -3.1053    14.920    .           .
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                                             LISTING OF SELECTED VARIABLES                    13:42 WEDNESDAY, MAY 14, 1980    7

                                             IN ORDER OF INCREASING DEPTH

--------------------------------------------------------------- FREQ=3030 --------------------------------------------------------------

  MINE  ANTMIN   IWEST   SEMF    MEMF    DEPTHFT    MMFUND   IFUND    IEST     IDIFF     IDEL    IDIFF2      TLU      TLD     DELTATL

   93     28     1.590   52.0    68.00    68.880    57.824  1.0326  1.2536  -3.7493  -0.3364  -2.0648     7.950  22.0979   -14.148
   91    195     2.121   33.0    51.00   190.240   288.197  1.4779  1.7543  -3.1379  -0.3667  -1.6487    14.429  12.7919     1.637
    8    557     0.880   45.8      N     200.080   449.959  0.8078  0.9767  -0.7436   0.0967   0.9056     4.184     .           .
   18    309     1.400   44.0    60.00   209.920   340.813  1.1030  1.3235  -2.0711  -0.0765  -0.4881     2.320   6.7961    -4.476
   36    450     1.410   49.0    64.00   216.480   440.002  0.9778  1.1777  -3.1794  -0.2323  -1.5637    -1.263   4.4930    -5.756
   33     56     2.190   31.0    42.50   229.600   107.623  1.9218  1.8973  -1.1347  -0.2927  -1.2462     2.973  12.2946    -9.322
   65    272     1.770   40.0    70.00   232.880   343.965  1.2646  1.5111  -2.9204  -0.2589  -1.3736     3.696   1.9959     1.700
   17    362     1.400   34.0    51.00   239.440   399.020  1.1023  1.3233  -2.0766  -0.0767  -0.4894    10.261  12.3675    -2.106
   71    409     1.060   39.0    60.00   239.440   379.880  0.9288  1.1195  -1.1477   0.0595   0.4744     4.834  -1.0094     5.844
   12    232     1.060     N     56.47   249.936   323.048  1.3925  1.6577   2.3698   0.5977   3.8840      .     15.1268       .
   10    232     1.414   40.3    50.90   253.872   323.048  1.3925  1.6577  -0.1331   0.2437   1.3811     0.602  10.9424   -10.341
   66    272     1.560   16.0    40.00   255.840   343.965  1.2646  1.5111  -1.8234  -0.0489  -0.2766    25.245  24.4806     0.765
   85    335     1.750   40.0    54.00   260.104   385.458  1.1506  1.3795  -3.6423  -0.3705  -2.0663     1.804   3.4687    -1.665
   44    256     1.300   41.0    50.00   262.400   338.825  1.3235  1.5789   0.1556   0.2789   1.6882    -0.545   0.2377    -0.783
   47    156     1.760   33.0    49.00   262.400   266.298  1.7070  2.0113  -0.2656   0.2513   1.1593     5.363  -0.5358     5.899
   92    455     1.560   38.0   -16.00   262.400   444.686  0.9773  1.1772  -4.0619  -0.3828  -2.4455     4.816  76.4850   -71.669
    9    232     2.100   34.7    60.10   264.040   323.048  1.3925  1.6577  -3.5685  -0.4423  -2.0543     5.178  14.6985    -9.520
   11    232     1.410   43.0    35.60   264.040   277.192  1.1948  1.4299  -1.4385   0.0199   0.1217    -4.451  11.4871   -15.938
   24    127     1.800   36.0    55.00   269.944   240.370  1.8927  2.2152   0.4362   0.4152   1.8028     0.734   9.3854    -8.651
   51    187     1.600   30.0    65.00   276.800   285.059  1.5244  1.8069  -0.4204   0.2069   1.0563     7.374  -0.3334     7.708
   55    522     0.840   34.0      N     288.640   474.016  0.9081  1.0957   0.6771   0.2557   2.3082     6.888     .           .
   43    149     1.700   41.0    58.00   295.200   260.783  1.7502  2.0591   0.2528   0.3591   1.6646    -5.888   5.9930   -11.881
   54    264     1.060   23.0    40.00   308.320   343.957  1.3029  1.5553   1.7921   0.4953   3.3302    13.383  10.1127     3.271
   21    199     1.800    5.0    59.00   324.720   296.318  1.4890  1.7684  -1.6476  -0.0316  -0.1538    28.738   3.2552    25.483
   30    390     1.200   33.0    56.00   324.720   412.573  1.0579  1.2715  -1.0947   0.0715   0.5027     3.613   4.7982    -1.186
   35    455     1.340   35.5    60.00   324.720   444.686  0.9773  1.1772  -2.7415  -0.1628  -1.1251     1.764   3.9481    -2.184
   94     98     1.480   -4.0      N     326.000   115.252  0.5880  0.7197  -8.0177  -0.7603  -6.2622    29.274     .           .
   32    341     1.340   31.0    52.00   331.280   383.299  1.1240  1.3485  -1.5268   0.0085   0.0549     4.452   8.9883    -4.536
   13    390     2.120   31.0    52.00   341.120   412.573  1.0579  1.2715  -6.0378  -0.8485  -4.4404     4.329  10.3275    -5.999
   20    377     1.400   28.0    52.00   341.120   406.885  1.0793  1.2965  -2.2597  -0.1035  -0.6671     7.208  10.3275    -3.119
   19    129     1.400   14.0    52.00   347.680   154.152  1.1950  1.4264  -1.3752   0.0264   0.1623    12.281   9.8312     2.450
   60    307     1.400   35.0    50.00   350.960   369.481  1.2035  1.4408  -1.3136   0.0408   0.2495    -1.370   2.5195    -3.890
   64    325     1.630   31.0    54.00   354.240   374.905  1.1536  1.3828  -3.0026  -0.2472  -1.4286     2.514   0.9635     1.550
   42    223     1.340   29.0    60.50   357.520   311.662  1.3976  1.6633   0.3656   0.3233   1.8773     2.669   3.1360    -0.467
   88    126     2.200   23.0    33.00   380.480   228.621  1.8145  2.1289  -1.6733  -0.0711  -0.2853     4.356   5.6278    -1.272
   59    232     1.650   21.0    45.00   387.040   323.048  1.3925  1.6577  -1.4738   0.0077   0.0404     8.913   6.6157     2.297
   87    335     1.240   24.0    52.00   400.160   385.458  1.1506  1.3795  -0.6499   0.1395   0.9260     6.579   2.6297     3.949
    2    149     2.100   17.9    21.80   403.440   260.783  1.7502  2.0591  -1.5826  -0.0409  -0.1708     9.072  13.1713    -4.099
    3    149     2.100   10.9    10.80   403.440   260.783  1.7502  2.0591  -1.5826  -0.0409  -0.1708    16.072  24.1713    -8.099
   67    520     1.000   29.0    54.00   419.840   472.389  0.9084  1.0961  -0.8345   0.0961   0.7970     2.094  -8.5555    10.650
   56    241     1.470   27.0      N     423.120   320.661  1.3305  1.5867  -0.8660   0.1167   0.6635     0.526     .           .
   25    418     1.270   43.0    45.30   426.400   399.164  0.9549  1.1505  -2.4769  -0.1195  -0.8583   -13.773  10.6946   -24.467
   69    418     1.060   25.0    32.00   429.680   411.694  0.9849  1.1859  -0.6383   0.1259   0.9748     4.296  15.2422   -10.946
   14    423     1.300    9.0    46.00   446.080   429.752  1.0160  1.2225  -2.1410  -0.0775  -0.5339    19.693   9.3372    10.356
   68    232     0.530     F     25.00   449.360   323.048  1.3925  1.6577   8.3904   1.1277   9.9046      .     18.1660       .
   52    238     1.230   14.0    31.00   459.200   325.062  1.3658  1.6272   0.9096   0.3972   2.4307    11.512  12.3698    -0.857
   40    358     1.300     N     48.00   469.040   378.721  1.0579  1.2715  -1.7900  -0.0285  -0.1925      .      5.5110       .
   82    279     1.910   -9.0      N     469.040   352.010  1.2617  1.5079  -3.6015  -0.4021  -2.0532    34.652     .           .
   37    522     1.240   21.0    45.00   478.880   474.016  0.9081  1.0957  -2.7058  -0.1443  -1.0746     6.695   8.8251    -2.130
   49    264     1.410   24.0    49.00   478.880   343.943  1.3028  1.5552  -0.6868   0.1452   0.8513     0.909   3.5087    -2.599
   74    455     1.410   15.0      N     478.880   444.686  0.9773  1.1772  -3.1838  -0.2328  -1.5674    12.141     .           .
   72    252     1.630   16.0    49.00   482.160   331.332  1.3148  1.5688  -1.8666  -0.0612  -0.3324     8.407   2.2861     6.121
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                                                     LISTING OF SELECTED VARIABLES                  13:42 WEDNESDAY, MAY 14, 1980   8

                                                       IN ORDER OF INCREASING DEPTH

----------------------------------------------------------------------- FREQ=3030 -----------------------------------------------------------------------

MINE  ANTMIN  IWEST     SEMF      MEMF    DEPTHFT  MMFUND   IFUND    IEST     IDIFF     IDEL     IDIFF2     TLU      TLD      DELTATL

 41     232   1.340   13.500    36.000   485.44  323.048  1.3925  1.6577   0.3338   0.3177   1.8480   10.510  21.4411   -10.931
 63     349   1.400   18.000    48.000   485.44  386.059  1.1062  1.3277  -2.0459  -0.0723  -0.4606    7.558   0.5690     6.989
 86     455   1.410   14.000    35.000   498.56  444.686  0.9773  1.1772  -3.1838  -0.2328  -1.5674   12.091  10.9775     1.114
 80     232   1.910   -7.000    24.000   500.20  323.048  1.3925  1.6577  -2.7448  -0.2523  -1.2305   30.230  19.6793    10.551
 39     390   1.240   13.000    42.500   508.40  412.573  1.0579  1.2715  -1.3795   0.0315   0.2179   11.931  11.1053     0.826
 28     711   1.000    8.000    10.000   518.24  547.443  0.7700  0.9321  -2.2702  -0.0679  -0.6107   18.888  31.9822   -13.094
  7     639   1.000   43.100    51.200   519.88  512.846  0.8026  0.9706  -1.9100  -0.0294  -0.2592  -16.861   2.5662   -19.427
 83     223   1.410   -3.000    25.000   541.20  311.662  1.3976  1.6633  -0.0767   0.2533   1.4350   23.865  21.7947     2.071
 84     282   1.340    5.000    24.000   560.86  353.375  1.2531  1.4978  -0.5824   0.1578   0.9670   16.026  17.1095    -1.084
 22     474   1.370    6.600    52.200   569.06  447.487  0.9441  1.1380  -3.2341  -0.2320  -1.6116   16.098  -1.2280    17.326
 29     929   0.900   19.500    36.000   580.56  507.177  0.5459  0.6637  -4.3426  -0.2363  -2.6454    3.766   7.2248    -3.459
 58     335   1.225   15.000    44.000   580.56  356.208  1.0633  1.2774  -1.2296   0.0524   0.3638    5.196   5.1832     0.013
  1     690   0.770    0.506    30.750   599.91  495.018  0.7174  0.8693  -0.6146   0.0993   1.0536   21.694  11.3175    10.377
 15     267   1.400   10.000    44.000   600.24  345.131  1.2926  1.5434  -0.6933   0.1434   0.8470    9.053   3.6025     5.451
 81     130   1.410  -11.000    26.000   600.24  242.868  1.8682  2.1885   2.4441   0.7785   3.8185   27.001  19.6219     7.379
 31     557   1.000   17.000    41.000   619.92  449.959  0.8078  0.9767  -1.8539  -0.0233  -0.2048    3.517   4.9902    -1.474
 73     929   1.840      F         F     626.48  619.620  0.6670  0.8093  -8.8138  -1.0307  -7.1342      .        .          .
 53     564     .        S      20.000   649.44  491.821  0.8720  1.0531      .        .        .          .     24.7986       .
 89     256   1.340   10.000    38.000   649.44  338.894  1.3238  1.5792  -0.1056   0.2392   1.4266    6.842   7.8519    -1.010
 75     547   1.060    3.000       N     658.30  477.749  0.8734  1.0547  -1.6819  -0.0053  -0.0435   16.472      .          .
  6     639   1.000   -9.890       F     674.04  484.493  0.7582  0.9179  -2.4043  -0.0821  -0.7441   28.868      .          .
 62     272   2.120   -6.000       N     685.52  343.965  1.2646  1.5111  -4.4877  -0.6089  -2.9409   21.562      .          .
 16     232   1.400   -3.000    33.000   688.80  323.048  1.3925  1.6577  -0.0467   0.2577   1.4676   17.893  14.1191     3.774
 26     392   1.370    9.000    52.000   688.80  414.467  1.0573  1.2709  -2.2504  -0.0991  -0.6522    8.057  -4.0650    12.122
 27    1262   0.460   16.000       N     688.80  545.613  0.4323  0.4877  -0.5395   0.0277   0.5079    3.445      .          .
 50     446   1.060  -16.000    18.000   744.56  436.702  0.9792  1.1793  -0.6887   0.1193   0.9264   31.483  28.7617     2.721
 38    1068   0.950  -11.500    20.500   780.64  659.183  0.6172  0.7498  -3.7460  -0.2002  -2.0556   29.326  25.0286     4.298
  4     581     .        F      -0.781   799.99  455.690  0.7843  0.9488      .        .        .          .     38.8078       .
 61     272     .        N      16.000   846.24  343.965  1.2646  1.5111      .        .        .          .     28.3031       .
 70     543   1.000      F         N     915.12  477.251  0.8789  1.0612  -1.1212   0.0612   0.5159      .        .          .
 45     450   1.000   -6.000     4.000   944.64  420.200  0.9338  1.1257  -0.5949   0.1257   1.0285   14.946  37.0883   -22.142
 77     418   1.520      N      20.000  1000.40  411.694  0.9849  1.1859  -3.7690  -0.3341  -2.1559      .     21.0364       .
 48     488   0.880    0.000    34.000  1010.24  431.232  0.8837  1.0666   0.0364   0.1866   1.6704    7.422   8.0000    -0.578
 57     558   1.050    3.000    -1.000  1049.60  450.767  0.8078  0.9767  -2.2777  -0.0733  -0.6286    3.811  37.0560   -33.245
 46     352   1.700  -17.000    23.000  1190.64  394.606  1.1210  1.3451  -3.6169  -0.3549  -2.0339   19.370  13.3797     5.990
 76     334   1.270      F      11.000  1197.20  358.351  1.0729  1.2886  -1.4649   0.0186   0.1263      .     25.4958       .
 23     678   0.780      F      18.000  1199.82  527.496  0.7780  0.9421  -0.0223   0.1621   1.6400      .     18.0802       .
 78     929   1.060   -5.000    22.000  1200.48  619.620  0.6670  0.8093  -4.0236  -0.2507  -2.3439   11.074   8.0281     3.046
 34     928   0.880  -24.000       F    1341.52  618.953  0.6670  0.8093  -2.4071  -0.0707  -0.7275   27.171      .          .
  5     639   1.000   -7.000       F    1397.28  484.493  0.7582  0.9179  -2.4043  -0.0821  -0.7441    6.982      .          .
 79     493   1.100      F         F    1400.56  439.699  0.8919  1.0763  -1.8215  -0.0237  -0.1892      .        .          .
 90     929   1.130  -16.000   -26.000  1551.44  619.620  0.6670  0.8093  -4.5791  -0.3207  -2.8994   15.392  56.8308   -41.439
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Table D-2

Comprehensive tabulations of surface and in-mine data bases with key indices and variables (rank ordered by depth)

Symbol Legend

MINE = Mine Number

SEMF = Surface Vertical Component of Magnetic Field Strength in dB re 1 μA/m

MEMF = In-Mine Vertical Component of Magnetic Field Strength in dB re 1 μA/m

DEPTHFT = Overburden Depth in Feet

MMFUND = In-Mine RMS Fundamental Component of Transmitter Magnetic Moment in Amp-turn-m^2

IFUND = In-Mine RMS Fundamental Component of Transmit Loop Current in Amperes

IDIFF = 20 Log (IFUND/IWEST) in dB

IDIFF2 = 20 log (IEST/IWEST) in dB

MMDN = Surface RMS Fundamental Component of Transmit Magnetic Moment in Amp-Turn-m^2

MMUP = In-Mine "RMS" Transmit Magnetic Moment in Amp-Turn-m^2 Based on IWEST

TLU = Transmission Loss Uplink = $-20 \text{ Log } (2\pi D^3/M_m)$ - SEMF + 120 in dB

TLD = Transmission Loss Downlink = $20 \log (2\pi D^3/M_s)$ - MEMF + 120 in dB

DELTATL = TLU - TLD in dB

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                                        SCREENED DATA WITH OUTLIERS FLAGGED                 13:42 WEDNESDAY, MAY 14, 1980   16

                                           IN ORDER OF INCREASING DEPTH

-------------------------------------------------------------- FREQ=630 ------------------------------------------------------------

MINE     SEMF     MEMF     DEPTHFT     MMFUND     IFUND       IDIFF     IDIFF2     MMDN        MMUP     TLU          TLD      DELTATL

 93     57.00    67.50      68.880     192.59     3.4392     0.6806     0.6647    1860.0     178.08   13.4005     22.598     -9.197
 91     44.00    52.50     190.240     735.41     3.7713     0.2129    -0.7158    1896.0     717.60   11.5657     11.292      0.274
  8     48.80      N       200.080    1409.75     2.5310     1.6215     1.3641       .      1169.70   11.1038        .          .
 18     48.00    62.00     209.920     970.07     3.1394     0.9938     0.3963    3600.0     865.20    7.4060      4.796      2.610
 36     53.00    64.00     216.480    1310.05     2.9112     0.2765    -0.1673    4800.0    1269.00    4.2139      4.493     -0.279
 33     26.00    42.50     229.600     140.61     2.5109     0.1426    -1.8143    1183.0     138.32   10.2954     12.295     -1.999
 65     44.00      D       232.880     935.60     3.4397     1.2753     0.5331    8944.0     807.84    8.3871     -4.004     12.391
 17     45.00    55.00     239.440    1141.97     3.1546     1.0357     0.4565    3600.0    1013.60    8.3946      8.367      0.027
 71     54.00    61.00     239.440    1141.48     2.7909     2.8079     2.3968    2175.0     826.18   -0.6092     -2.009      1.400
 12     38.55    60.47     249.936     846.66     3.6494     3.3905     2.5374   10560.0     573.04      .        11.127        .
 10     46.25    60.10     253.872     846.66     3.6494     2.3013     1.4481    3600.0     649.60    3.0205      1.742      1.278
 66     16.00      F       255.840     935.60     3.4397     1.2753     0.5331    4992.0     807.84   33.9370        .          .
 85     45.00    55.00     260.104    1086.68     3.2438    -1.8201    -2.4488    2340.0    1340.00    5.8065      2.469      3.338
 44     48.00    39.00     262.400     906.28     3.5402     3.0218     2.2285    1045.0     640.00    1.0006     11.238    -10.237
 47     43.00    48.50     262.400     638.59     4.0935     2.1934     1.1018     852.0     496.08    2.9599     -0.036      2.996
 92     47.50      D       262.400    1324.37     2.9107    -0.1752    -0.6181    3400.0    1351.35    4.7956     65.485    -60.689
  9     41.20    68.00     264.040     846.66     3.6494     0.3631    -0.4901   18000.0     812.00    7.0472      6.799      0.249
 11     44.00    32.90     264.040     766.26     3.3028     1.3419     0.6503    1018.6     656.56    3.3805     16.953    -13.573
 24     39.00    56.00     269.944     548.64     4.3200     4.9619     3.7532    5800.0     309.88    4.9025      8.385     -3.483
 51     26.00      D       278.800     718.27     3.8410     2.6839     1.7206    4125.0     527.34   19.4014    -10.416     29.817
 55     44.00      N       288.640    1443.90     2.7661     2.3106     1.9487       .      1106.64    6.5626        .          .
 43     43.00    61.00     295.200     618.10     4.1483     2.2544     1.1343    7250.0     476.80   -0.3926      2.993     -3.386
 54     40.00    48.00     308.320     925.96     3.5074     3.0458     2.2721    1671.0     652.08    4.9850      2.113      2.872
 21     30.00    60.00     324.720     759.37     3.8159     2.6888     1.7721   11850.0     557.20   11.9118      5.777      6.135
 30     35.00    56.00     324.720    1197.27     3.0699     1.6458     1.1132    6680.0     990.60   10.8665      4.798      6.068
 35     43.00    61.00     324.720    1324.37     2.9107     0.4933     0.0504    9600.0    1251.25    3.7429      2.948      0.795
 94     27.50      N       328.000     446.72     2.2792    -2.2995    -1.6350       .       582.12    9.5415        .          .
 32     32.00    53.00     331.280    1088.70     3.1927     2.2292     1.6246    7250.0     842.27   12.5197      7.988      4.531
 13     36.00    58.00     341.120    1197.27     3.0699    -1.2130    -1.7457    9235.0    1376.70    8.5826      4.328      4.255
 20     35.00    47.00     341.120    1172.99     3.1114     0.9160     0.3609    9235.0    1055.60    9.4047     15.328     -5.923
 19     23.00    55.00     347.680     414.80     3.2155     1.2018     0.4267    9235.0     361.20   11.8792      6.831      5.048
 60     40.00    53.00     350.960    1024.73     3.3379     1.5263     0.8448    3251.5     859.60    2.4900     -0.481      2.971
 64     34.00    54.00     354.240    1055.16     3.2467     0.7737     0.1393    4430.0     965.25    8.5018      0.963      7.538
 42     35.00    62.00     357.520     814.70     3.6534     2.2182     1.3577   12360.5     631.09    5.0152      1.636      3.379
 88     29.00    35.00     380.480     531.06     4.2147     1.3693     0.2013     837.0     453.60    5.6761      3.628      2.048
 59     30.00    49.00     387.040     846.66     3.6494     1.2782     0.4251    3930.0     730.80    8.2821      2.616      5.666
 87     30.00    52.00     400.160    1086.68     3.2438     1.5938     0.9651    6145.0     904.50    9.5813      2.630      6.952
  2     32.30    33.30     403.440     618.10     4.1483     1.4760     0.3559     655.0     521.50    2.1677      1.671      0.496
  3     30.30    28.30     403.440     618.10     4.1483     1.4760     0.3559     655.0     521.50    4.1677      6.671     -2.504
 67     38.00    41.00     419.840    1438.60     2.7665     0.9847     0.6221    2465.0    1284.40    2.7670      4.445     -1.678
 56     35.00      N       423.120     854.57     3.5459     1.4232     0.6192    2032.8     725.41    1.0403        .          .
 25     33.00    36.10     426.400    1192.32     2.8524     2.5775     2.1452    8700.0     886.16    5.7321     19.895    -14.163
 69       F        F       429.680    1220.27     2.9193     0.7105     0.2508    3250.0    1124.42      .           .          .
 14     33.00    49.00     446.080    1264.04     2.9883     0.8812     0.3946    9235.0    1142.10    5.0637      6.337     -1.273
 68     18.23    27.00     449.360     846.66     3.6494     6.6867     5.8336    2325.0     392.08      .        16.166        .
 52     29.00    38.00     459.200     858.32     3.6064     3.5373     2.7058    2540.0     571.20    4.9461      5.370     -0.424
 40     38.03    56.00     469.040    1099.03     3.0699     0.7993     0.2667    8700.0    1002.40      .        -2.489        .
 82      8.00      N       469.040     958.98     3.4372     0.6756    -0.0620       .       887.22   26.3568        .          .
 37     33.00    51.00     478.880    1443.90     2.7661     0.7407     0.3787    9600.0    1325.88    4.3704      2.825      1.545
 49     30.50    50.00     478.880     925.68     3.5064     1.8922     1.1175    6250.0     744.48    3.0089      2.509      0.500
 74     28.00      N       478.880    1324.37     2.9107     0.2442    -0.1987       .      1287.65    8.6198        .          .
 72     26.00    53.00     482.160     887.68     3.5226     1.5114     0.7232    7315.0     745.92    6.9669     -1.714      8.681
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                                   SCREENED DATA WITH OUTLIERS FLAGGED                    13:42 WEDNESDAY, MAY 14, 1980   17

                                      IN ORDER OF INCREASING DEPTH

----------------------------------------------------------------- FREQ=630 --------------------------------------------------------------

 MINE      SEMF     MEMF     DEPTHFT      MMFUND      IFUND      IDIFF     IDIFF2       MMDN       MMUP        TLU        TLD    DELTATL

   41     21.50     25.0      485.44      846.66     3.6494     2.2087     1.3556    15163.5     656.56    10.8793    32.4411    -21.562
   63     30.00      D        485.44     1102.34     3.1586     0.5348    -0.0522     5460.0    1036.53     4.6715    -5.4310     10.102
   86     26.00     41.5      498.56     1324.37     2.9107    -2.5413    -2.9842     4389.0    1774.50     9.5704     4.4775      5.093
   80     23.92     36.0      500.20      846.66     3.6494     1.1959     0.3428     3402.0     737.76       .        7.6793        .
   39     29.00     51.5      508.40     1197.27     3.0699     1.6458     1.1132    11200.0     990.60     5.1847     2.1053      3.079
   28     14.00      F        518.24     1746.09     2.4558     0.7217     0.5329     3112.0    1606.86    22.9627       .            .
    7     31.12     48.7      519.88     1612.80     2.5239     2.0208     1.7780    12200.0    1278.00       .        5.0662        .
   83     15.00     39.0      541.20      814.70     3.6534     2.6589     1.7984     6168.0     599.87    14.2117     7.7947      6.417
   84     13.00     37.0      560.88      963.76     3.4176     2.0794     1.3452     3568.0     758.58    16.7404     4.1095     12.631
   22     32.29     51.0      569.08     1346.06     2.8398     2.5390     2.1317    11600.0    1004.88    24.2641    -0.0280     24.292
   29     28.00     42.0      580.56     1727.25     1.8593    -1.0574    -0.9811     5048.0    1950.90     5.9095     1.2248      4.685
   58     27.00     48.0      580.56     1027.81     3.0681     1.9541     1.4018    10024.0     820.75     2.4006     1.1832      1.217
    1     20.70      D        599.91     1598.82     2.3171     2.3394     2.2000     4875.0    1221.30    11.6840    -6.6825     18.367
   15     17.00     47.0      600.24      931.46     3.4886     1.9099     1.1438     9235.0     747.60    10.6770     0.6025     10.075
   81     15.00     41.0      600.24      557.83     4.2910     3.6154     2.4212     7352.0     367.90     8.2237     4.6219      3.602
   31     23.00     42.0      619.92     1409.75     2.5310     0.9837     0.7263     8450.0    1258.82     7.4359     3.9902      3.446
   73       F        F        626.48     2047.17     2.2036     5.2790     5.2304     3416.0    1114.80       .          .            .
   53     20.00     39.0      649.44     1516.04     2.6880     2.6993     2.3810     8470.0    1111.08     9.8551     5.7986      4.057
   89     22.00     41.5      649.44      906.34     3.5404     2.1629     1.3694     9562.0     706.56     3.3867     4.3519     -0.965
   75     27.00      N        658.30     1470.69     2.6886     0.9863     0.6631        .       1312.80     2.2384       .            .
    6     24.10      F        674.04     1544.54     2.4171     1.6453     1.4546    18810.0    1278.00     4.9481       .            .
   62      6.00      N        685.52      935.60     3.4397     2.1031     1.3610        .        734.40    18.2539       .            .
   16     10.00     41.0      688.80      846.66     3.6494     2.3013     1.4481    13200.0     649.60    13.2618     6.1191      7.143
   26     19.00     40.0      688.80     1203.17     3.0693     3.2141     2.6825    14500.0     831.04     7.3142     7.9350     -0.621
   27     21.00      N        688.80     1017.03     0.8059     3.0081     1.4221        .        719.34     3.8543       .            .
   50      4.00     36.0      744.56     1299.10     2.9128     4.3760     3.9290    16000.0     784.96    20.9521    10.7617     10.190
   38     22.00     38.0      780.64     2215.63     2.0746    -0.5098    -0.4884    16000.0    2349.60     6.3561     7.5286     -1.172
    4     -7.70      D        799.99     1438.36     2.4757    -3.0074    -3.2367     7260.0    2033.50    31.6654    -8.1732     39.839
   61       N        D        846.24      935.60     3.4397       .          .       17700.0       .          .       26.3031        .
   70       F        N        915.12     1466.73     2.7012     0.2651    -0.0646     4008.0    1422.66       .          .            .
   45     16.00      D        944.64     1265.16     2.8115     1.1248     0.7207    17004.0    1111.50     2.5202    22.0883    -19.568
   77      1.05     25.0     1000.40     1220.27     2.9193    -0.1203    -0.5800    19239.5    1237.28       .       15.6667        .
   48     13.00     38.0     1010.24     1318.86     2.7026     2.1089     1.7617    23100.0    1034.56     4.1317     4.0000      0.132
   57     18.00     15.0     1049.60     1412.28     2.5310     0.5343     0.2769    13068.0    1328.04    -1.2698    21.0560    -22.326
   46      6.00     34.5     1190.64     1122.77     3.1897     1.0700     0.4712    19800.0     992.64     5.4522     1.8797      3.573
   76      2.44     28.0     1197.20     1030.58     3.0856     1.9329     1.3697    19550.0     824.98       .        8.1262        .
   23     -6.29     15.0     1199.92     1688.25     2.4900     5.8479     5.6724    19575.0     861.06       .       21.0802        .
   78     13.00     29.0     1200.48     2047.17     2.2036    -0.4845    -0.5331     8954.0    2164.57     3.4550     0.2723      3.183
   34     -2.00      F       1341.52     2044.97     2.2036     0.8421     0.7934    19600.0    1856.00    15.5511       .            .
    5      3.26      F       1397.28     1544.54     2.4171     1.6453     1.4546    15700.0    1278.00     6.7922       .            .
   79     -1.60      F       1400.56     1342.41     2.7229     1.3535     1.0000    22200.0    1148.69    10.3729       .            .
   90     -2.00     -2.0     1551.44     2047.17     2.2036    -3.7413    -3.7900    23125.0    3149.31    11.7722    32.8308    -21.059
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                                   SCREENED DATA WITH OUTLIERS FLAGGED                 13:42 WEDNESDAY, MAY 14, 1980   18

                                        IN ORDER OF INCREASING DEPTH

------------------------------------------------------------ FREQ=1050 ------------------------------------------------------------

MINE     SEMF     MEMF    DEPTHFT     MMFUND      IFUND      IDIFF     IDIFF2      MMDN       MMUP       TLU        TLD      DELTATL

 93     56.00     67.0     68.880     143.12     2.5558    -1.5069    -0.6116     1860.0     170.24    11.8218    23.0979    -11.276
 91     41.00     53.0    190.240     612.26     3.1398    -1.0420    -0.9630     1896.0     690.30    12.9739    10.7919      2.182
  8     49.00      N      200.080    1078.64     1.9365     0.8301     1.5453         .       980.32     8.5785       .          .
 18     48.00     61.0    209.920     774.09     2.5051    -0.9667    -0.5447     3600.0     865.20     5.4458     5.7961     -0.350
 36     53.00     64.0    216.480    1025.56     2.2790    -0.6991    -0.1382     4800.0    1111.50     2.0874     4.4930     -2.406
 33     29.00     42.5    229.600     136.78     2.4425    -0.0972    -1.8151     1183.0     138.32     7.0555    12.2946     -5.239
 65     44.00      D      232.880     760.38     2.7955    -0.1065     0.1738     8944.0     769.76     6.5859     2.9959      3.590
 17     42.00     54.0    239.440     909.19     2.5116    -0.6283    -0.1896     3600.0     977.40     9.4145     9.3675      0.047
 71     52.00     62.0    239.440     890.00     2.1760     0.6462     1.2349     2175.0     826.18    -0.7707    -3.0094      2.239
 12     32.80     56.4    249.936     697.97     3.0085     1.9267     2.0900    10560.0     559.12       .       15.1968        .
 10     40.10     56.1    253.872     697.97     3.0085     1.7131     1.8764     3600.0     573.04     7.4931     5.7424      1.751
 66     17.00      F      255.840     760.38     2.7955    -0.0758     0.2046     4992.0     767.04    31.1357       .          .
 85     44.00     54.0    260.104     870.57     2.5987    -1.8079    -1.4158     2340.0    1072.00     4.8805     3.4687      1.412
 44     47.00     47.0    262.400     741.37     2.8960     2.7916     3.0189     1045.0     537.60     0.2561     3.2377     -2.982
 47     41.50     49.0    262.400     543.29     3.4826     1.2956     1.1786      852.0     468.00     3.0560    -0.5358      3.592
 92     46.50      D      262.400    1036.64     2.2783    -1.6660    -1.1043     3400.0    1255.80     3.6680    71.4850    -67.817
  9     41.40     64.1    264.040     697.97     3.0085    -0.5360    -0.3727    18000.0     742.40     5.1698    10.6985     -5.529
 11     45.00     28.4    264.040     618.77     2.6671     0.4241     0.7551     1018.6     589.28     0.5237    21.4531    -20.929
 24     37.50     53.0    269.944     474.28     3.7345     4.0975     3.8251     5800.0     295.91     5.1374    11.3854     -6.248
 51     33.00      D      278.800     600.72     3.2124     1.6717     1.7108     6600.0     495.55    10.8491    -6.3334     17.183
 55     43.00      N      288.640    1119.00     2.1437     1.3743     2.0044         .       955.26     5.3484       .          .
 43     36.00     60.0    295.200     527.90     3.5429     2.0440     1.8902     7250.0     417.20     5.2373     3.9930      1.244
 54     37.00     46.0    308.320     755.58     2.8621     1.7866     2.0343     1671.0     615.12     6.2188     4.1127      2.106
 21     25.00     55.0    324.720     631.23     3.1720     1.3994     1.4920     7900.0     537.30    15.3065     7.2552      8.051
 30     33.00     56.0    324.720     947.67     2.4299     1.1851     1.6669     6680.0     826.80    10.8358     4.7982      6.038
 35     42.00     60.0    324.720    1036.64     2.2783    -0.7017    -0.1400     9600.0    1123.85     2.6153     3.9481     -1.333
 94     20.00      N      328.000     306.34     1.5630    -4.7159    -3.4017         .       527.24    13.7649       .          .
 32     31.00     53.0    331.280     869.51     2.5499     0.8959     1.3113     7250.0     784.30    11.5670     7.9883      3.579
 13     36.00     57.0    341.120     947.67     2.4299    -2.3368    -1.8550     9235.0    1240.20     6.5519     5.3275      1.224
 20     35.00     53.0    341.120     931.04     2.4696    -0.7747    -0.3135     9235.0    1017.90     7.3982     9.3275     -1.929
 19     22.00     54.0    347.680     338.54     2.6243    -0.2470    -0.0006     9235.0     348.30    11.1145     7.8312      3.283
 60     38.10     50.0    350.960     826.41     2.6919     0.1035     0.4446     3251.5     816.62       .        2.5195        .
 64     34.00     54.0    354.240     845.90     2.6026    -0.7269    -0.3402     4430.0     919.75     6.5818     0.9635      5.618
 42     36.00     61.0    357.520     672.28     3.0147     1.1200     1.2750    12360.5     590.95     2.3462     2.6360     -0.290
 88     28.00     35.0    380.480     456.54     3.6233     1.0791     0.8618      837.0     403.20     5.3628     3.6278      1.735
 59     30.00     50.0    387.040     697.97     3.0085    -0.3992    -0.2359     3930.0     730.80     6.6047     1.6157      4.989
 87     28.00     52.0    400.160     870.57     2.5987     0.3363     0.7284     6145.0     837.50     9.6553     2.6297      7.026
  2     29.30     30.3    403.440     527.90     3.5429     0.1058    -0.0480      655.0     521.50     3.7975     4.6713     -0.874
  3     27.00     21.3    403.440     527.90     3.5429     0.1058    -0.0480      655.0     521.50     6.0975    13.6713     -7.574
 67     36.00     48.0    419.840    1115.01     2.1442     0.0986     0.7282     2465.0    1102.40     2.5538    -2.5555      5.109
 56     33.00      N      423.120     700.04     2.9047     0.3189     0.5350     2032.8     674.80     1.3079       .          .
 25     31.00     39.1    426.400     932.07     2.2298     1.3447     1.9153     8700.0     798.38     5.5932    16.8946    -11.301
 69       F        F      429.680     957.14     2.2898     2.2365     2.7833     3250.0     739.86       .          .          .
 14     30.00     49.0    446.080     994.78     2.3517    -0.5312    -0.0076     9235.0    1057.50     5.9830     6.3372     -0.354
 68     17.55     28.0    449.360     697.97     3.0085     9.6543     9.8176     2325.0     229.68       .       15.1660        .
 52     25.00     34.0    459.200     705.60     2.9647     2.9952     3.1822     2540.0     499.80     7.2443     9.3698     -2.126
 40     33.00     53.0    469.040     869.91     2.4299    -0.5877    -0.1059     8700.0     930.80       .        0.5110        .
 82      8.00      N      469.040     778.90     2.7917    -0.9378    -0.6526         .       867.69    24.5503       .          .
 37     32.00     50.0    478.880    1119.00     2.1437    -0.6113     0.0189     9600.0    1200.60     3.1562     3.8251     -0.669
 49     29.50     49.0    478.880     755.43     2.8615     0.6670     0.9138     8250.0     699.60     2.2435     3.5087     -1.265
 74     25.00      N      478.880    1036.64     2.2783    -0.9786    -0.4169         .      1160.25     9.4922       .          .
 72     24.00     52.0    482.160     725.70     2.8798    -0.6680    -0.4355     7315.0     783.72     7.2169    -0.7139      7.931
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                       SCREENED DATA WITH OUTLIERS FLAGGED                13:42 WEDNESDAY, MAY 14, 1980   19

                                   IN ORDER OF INCREASING DEPTH

------------------------------------------------------------ FREQ=1050 ------------------------------------------------------------

 MINE      SEMF      MEMF    DEPTHFT     MMFUND     IFUND      IDIFF     IDIFF2       MMDN       MMUP       TLU        TLD    DELTATL

   41     21.50     36.00     485.44     697.97    3.0085     1.1021     1.2654    18661.5     614.80     9.202    23.2440    -14.042
   63     26.00     46.00     485.44     878.48    2.5171     0.1641     0.5959     5460.0     862.03     6.700     2.5690      4.131
   86     24.00       F       498.56    1036.64    2.2783    -1.8835    -1.3218     4389.0    1287.65     9.443      .           .
   80      9.00     30.00     500.20     697.97    3.0085    -0.2882    -0.1249     3402.0     721.52    20.921    13.6793      7.242
   39     26.00     47.00     508.40     947.67    2.4299     0.1075     0.5894    11200.0     936.00     6.154     6.6053     -0.451
   28     19.00       F       518.24    1324.91    1.8634    -0.3499     0.4187     3112.0    1379.34    15.565      .           .
    7     29.28     49.20     519.88    1231.86    1.9278     1.0923     1.8184    12200.0    1086.30   -18.450     4.5662    -23.016
   83     12.00     21.00     541.20     672.28    3.0147     1.7309     1.8860     6168.0     550.81    15.543    25.7947    -10.252
   84     20.00     32.00     560.88     782.44    2.7746     1.0101     1.2986     3568.0     696.54     7.930     9.1095     -1.179
   22     30.13     51.00     569.08    1049.02    2.2131     0.8361     1.4281    11600.0     952.74    12.198    -0.0280     12.226
   29     25.00     40.00     580.56    1269.44    1.3665    -2.3933    -1.4338     5048.0    1672.20     6.235     3.2248      3.010
   58     24.00     48.00     580.56     815.50    2.4343     1.2831     1.7472    10024.0     703.50     3.391     1.1832      2.208
    1     14.30     43.76     599.91    1205.97    1.7478     0.2409     1.0462     4875.0    1173.00    15.635    -1.6925     17.327
   15     16.00     45.00     600.24     759.33    2.8439     0.7788     1.0346     9235.0     694.20     9.902     2.6025      7.300
   81     11.00     38.00     600.24     481.27    3.7021     2.7739     2.5211     7352.0     349.70    10.942     7.6219      3.320
   31     21.00     41.00     619.92    1078.64    1.9365    -0.0157     0.6995     8450.0    1080.58     7.111     4.9902      2.120
   73     26.01     33.00     626.48    1527.35    1.6441     5.1377     6.0096     3416.0     845.39      .        4.8492       .
   53     10.00     35.00     649.44    1168.63    2.0720     1.7701     2.4364     8470.0     953.16    17.594     9.7986      7.796
   89     20.00     40.50     649.44     741.45    2.8963     2.1547     2.3817     9562.0     578.56     3.643     5.3519     -1.709
   75     15.00       N       658.30    1134.36    2.0738    -0.1914     0.4705         .     1159.64    11.983      .           .
    6     20.70     -5.70     674.04    1172.25    1.8345     0.6614     1.4281    18810.0    1086.30     5.952    56.4599    -50.507
   62      4.00       N       685.52     760.38    2.7955    -0.0140     0.2664         .      761.60    18.453      .           .
   16      7.00     39.00     688.80     697.97    3.0085     0.9397     1.1030    13200.0     626.40    14.584     8.1191      6.465
   26     17.00       D       688.80     952.20    2.4291     1.6450     2.1276    14500.0     787.92     7.282    -4.0650     11.347
   27     19.00       N       688.80     928.89    0.7360     2.5303     1.6492         .      694.10     5.067      .           .
   50     -7.00     33.00     744.56    1017.37    2.2811     3.3563     3.9141    16000.0     691.30    29.829    13.7617     16.067
   38     17.00     33.00     780.64    1639.10    1.5347    -1.6230    -0.7008    16000.0    1975.80     8.738    12.5286     -3.790
    4     -8.90     22.20     799.99    1096.74    1.8877    -4.5299    -3.7927     7260.0    1847.58    30.510    15.8268     14.683
   61       N         D       846.24     760.38    2.7955      .          .        17700.0        .        .       28.3031       .
   70       F         N       915.12    1132.16    2.0850    -0.9650    -0.3081     4008.0    1265.19      .          .           .
   45      9.00       F       944.64     985.56    2.1901     0.2826     0.8776    17004.0     954.00     7.351      .           .
   77     -0.37     28.00    1000.40     957.14    2.2898    -1.6222    -1.0754    25095.0    1153.68      .       14.9746       .
   48      8.00     37.00    1010.24    1020.25    2.0907     0.3852     1.0273    23100.0     976.00     6.902     5.0000      1.902
   57     14.00      8.00    1049.60    1080.57    1.9365    -0.7040     0.0112    13068.0    1171.80     0.405    28.0560    -27.651
   46      1.00     32.00    1190.64     896.07    2.5457     0.2622     0.6828    19800.0     869.44     8.493     4.3797      4.114
   76      2.00     26.00    1197.20     818.84    2.4516    -0.0649     0.3889    25500.0     824.98     6.567    12.4340     -5.867
   23     -9.70     14.00    1199.82    1278.95    1.8863     3.9286     4.7072    19575.0     813.60      .       22.0802       .
   78      7.00     29.00    1200.48    1527.35    1.6441    -2.2082    -1.3363    12210.0    1969.48     6.911     2.9663      3.944
   34     -8.00     15.00    1341.52    1525.70    1.6441    -0.5917     0.2802    19600.0    1633.28    19.007    18.1825      0.824
    5       F         F      1397.28    1172.25    1.8345     0.6614     1.4281    15700.0    1086.30      .          .           .
   79    -11.00       F      1400.56    1039.29    2.1081    -0.3311     0.3059    27750.0    1079.67    17.550      .           .
   90     -9.00     -6.00    1551.44    1527.35    1.6441    -5.7300    -4.8581    27750.0    2954.22    16.228    38.4144    -22.187
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                                  SCREENED DATA WITH OUTLIERS FLAGGED              13:42 WEDNESDAY, MAY 14, 1980   20

                                     IN ORDER OF INCREASING DEPTH

------------------------------------------------------------ FREQ=1950 ------------------------------------------------------------

MINE    SEMF     MEMF    DEPTHFT    MMFUND    IFUND     IDIFF     IDIFF2      MMDN       MMUP      TLU       TLD     DELTATL

 93    53.00    67.50     68.880    86.887   1.5515   -3.2671   -1.7637     1860.0     126.56   10.4867   22.5979   -12.111
 91    36.00    51.00    190.240   415.226   2.1294   -1.5315   -0.4322     1896.0     495.30   14.6008   12.7919     1.809
  8    44.10      N      200.080   670.698   1.2041   -0.4628    0.9636        .       707.39    9.3516      .          .
 18    42.00    61.00    209.920   500.719   1.6205   -2.2514   -0.9645     3600.0     648.90    7.6619    5.7961     1.866
 36    51.50    63.00    216.480   651.033   1.4467   -2.2293   -0.8740     4800.0     841.50   -0.3598    5.4930    -5.853
 33    32.00    43.00    229.600   124.572   2.2245   -0.2521   -1.2223     1183.0     128.24    3.2433   11.7946    -8.551
 65    40.00      D      232.880   501.478   1.8437   -1.2129    0.0004     8944.0     576.64    6.9704    1.9959     4.974
 17    36.00    54.00    239.440   586.757   1.6209   -2.2493   -0.9538     3600.0     760.20   11.6106    9.3675     2.243
 71    43.00    61.00    239.440   562.851   1.3762   -0.2108    1.1575     2175.0     576.69    4.2493   -2.0094     6.259
 12    30.43    57.50    249.936   467.820   2.0165    3.1076    4.2558    10560.0     327.12      .       14.0968       .
 10    42.20    51.12    253.872   467.820   2.0165    1.1817    2.3300     3600.0     408.32    1.9179   10.7224    -8.804
 66    15.00    36.00    255.840   501.478   1.8437   -1.2129    0.0004     4992.0     576.64   29.5202   28.4806     1.040
 85    39.00    54.00    260.104   565.418   1.6878   -3.4124   -2.1403     2340.0     837.50    6.1318    3.4687     2.663
 44    44.00    50.00    262.400   492.507   1.9239    1.0747    2.2592     1045.0     435.20   -0.2963    0.2377    -0.534
 47    40.00    51.00    262.400   378.814   2.4283    0.4715    1.4485      852.0     358.80    1.4239   -2.5358     3.960
 92    44.00      D      262.400   657.992   1.4461   -3.3228   -1.9669     3400.0     964.60    2.2198   71.4850   -69.265
  9    37.45    60.70    264.040   467.820   2.0165   -2.8512   -1.7029    18000.0     649.60    5.6446   14.0985    -8.454
 11    42.00    34.40    264.040   405.263   1.7468   -0.0654    1.1748     1018.6     408.32   -0.1522   15.4531   -15.605
 24    35.50    57.00    269.944   338.168   2.6627    1.9797    2.8506     5800.0     269.24    4.1995    7.3854    -3.186
 51    29.00    66.00    278.800   409.683   2.1908    0.2853    1.3609     6600.0     396.44   11.5246   -1.3334    12.858
 55    37.00      N      288.640   703.739   1.3482    1.5335    2.9209        .       589.86    7.3201      .          .
 43    34.00    60.00    295.200   370.027   2.4834    0.2967    1.2491     7250.0     357.60    4.1509    3.9930     0.158
 54    26.00      F      308.320   500.548   1.8960    1.7501    2.9457     1671.0     409.20   13.6421      .          .
 21    17.00    55.00    324.720   427.281   2.1471    0.1927    1.3002    10270.0     417.90   19.9170    9.5341    10.383
 30    32.00    56.00    324.720   608.033   1.5591   -1.0528    0.2639     6680.0     686.40    7.9812    4.7982     3.183
 35    37.00    60.00    324.720   657.992   1.4461   -1.7063   -0.3505     9600.0     800.80    3.6671    3.9481    -0.281
 94     7.00      N      328.000   176.073   0.8983   -6.6876   -5.0251        .       380.24   21.9547      .          .
 32    24.00    53.00    331.280   562.944   1.6509   -0.2546    1.0290     7250.0     579.70   14.7908    7.9883     6.803
 13    36.00    56.00    341.120   608.033   1.5591   -4.7052   -3.3885     9235.0    1045.20    2.6974    6.3275    -3.630
 20    30.00    52.00    341.120   599.022   1.5889   -2.4225   -1.1155     9235.0     791.70    8.5677   10.3275    -1.760
 19    18.00    53.00    347.680   224.313   1.7389   -1.6389   -0.4442     9235.0     270.90   11.5395    8.8312     2.708
 60    37.00    51.00    350.960   540.495   1.7606    0.0525    1.2981     3251.5     537.25   -0.0664    1.5195    -1.586
 64    31.00    54.00    354.240   549.787   1.6917   -2.7807   -1.5113     4430.0     757.25    5.8393    0.9635     4.876
 42    31.00    60.50    357.520   451.112   2.0229    1.2092    2.3533    12360.5     392.48    3.8809    3.1360     0.745
 88    26.00    32.00    380.480   322.938   2.5630   -0.7682    0.1412      837.0     352.80    4.3557    6.6278    -2.272
 59    23.00    48.00    387.040   467.820   2.0165   -0.0580    1.0903     3930.0     470.96   10.1295    3.6157     6.514
 87    24.00    52.00    400.160   565.418   1.6878   -0.3638    0.9082     6145.0     589.60    9.9066    2.6297     7.277
  2    23.60    27.30    403.440   370.027   2.4834   -2.2021   -1.2496      655.0     476.80    6.4112    7.6713    -1.260
  3    20.80    15.30    403.440   370.027   2.4834   -2.2021   -1.2496      655.0     476.80    9.2112   19.6713   -10.460
 67    31.00      F      419.840   701.299   1.3487    0.7299    2.1168     2465.0     644.80    3.5263      .          .
 56    29.00      N      423.120   465.796   1.9328   -0.7206    0.4572     2032.8     506.10    1.7693      .          .
 25    20.00    47.10    426.400   590.898   1.4136    0.2721    1.6321     8700.0     572.66   12.6345    8.8946     3.740
 69    32.00    30.00    429.680   608.732   1.4563    0.0377    1.3862     3250.0     606.10    0.6931   17.2422   -16.549
 14    19.00    46.00    446.080   634.685   1.5004   -1.5813   -0.2437     9235.0     761.40   13.0796    9.3372     3.742
 68    12.07    26.00    449.360   467.820   2.0165    8.3622    9.5104     2325.0     178.64      .       17.1660       .
 52    20.00    31.00    459.200   471.389   1.9806    1.0257    2.1877     2540.0     418.88    8.7407   12.3698    -3.629
 40    26.14    50.00    469.040   558.143   1.5591   -0.7515    0.5652     8700.0     608.60      .        3.5110       .
 82     1.00      N      469.040   513.348   1.8400   -2.8344   -1.6188        .       711.45   27.9289      .          .
 37    26.00    48.00    478.880   703.739   1.3482   -2.3644   -0.9770     9600.0     923.94    5.1279    5.8251    -0.697
 49    27.00    49.00    478.880   500.504   1.8958   -0.2002    0.9951     8250.0     512.16    1.1678    3.5087    -2.341
 74      F        N      478.880   657.992   1.4461   -5.3911   -4.0353        .      1223.95      .         .          .
 72    18.00    51.00    482.160   481.758   1.9117   -1.9758   -0.7882     7315.0     604.80    9.6584    0.2861     9.372
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                                   SCREENED DATA WITH OUTLIERS FLAGGED                    13:42 WEDNESDAY, MAY 14, 1980   21

                                         IN ORDER OF INCREASING DEPTH

------------------------------------------------------------- FREQ=1950 -------------------------------------------------------------

MINE    SEMF      MEMF     DEPTHFT    HMFUND     IFUND      IDIFF      IDIFF2      MMDN        MMUP       TLU       TLD        DELTATL

 41     15.50     32.00     485.44    467.820    2.0165     1.1817     2.3300    15163.5      408.32    11.727    25.4411     -13.714
 63     16.00     46.00     485.44    567.486    1.6260    -0.3866     0.9060     5460.0      593.30    12.904     2.5690      10.335
 86     18.00     37.00     498.56    657.992    1.4461    -2.8166    -1.4608     4389.0      910.00    11.495     8.9775       2.517
 80      7.00       F       500.20    467.820    2.0165    -2.0047    -0.8565     3402.0      589.28    19.446       .            .
 39     18.00     45.00     508.40    608.033    1.5591    -0.3328     0.9839    11200.0      631.80    10.299     8.6053       1.694
 28      8.50       F       518.24    817.998    1.1505    -1.3244     0.1248     3112.0      952.74    21.876       .            .
  7     24.64     48.70     519.88    764.831    1.1969    -0.3073     1.1240    12200.0      792.36   -17.690     5.0662     -22.756
 83      6.00     32.00     541.20    451.112    2.0229     1.1111     2.2552     6168.0      396.94    18.077    14.7947       3.283
 84     12.00     26.00     560.88    515.439    1.8278    -0.1983     1.0195     3568.0      527.34    12.305    21.1095      -8.805
 22     25.14     50.00     569.08    663.126    1.3990    -2.1891    -0.8192    11600.0      853.20     4.515     0.9720       3.543
 29     22.00     37.00     580.56    764.167    0.8226    -3.6344    -2.1057     5048.0     1161.25     4.826     6.2248      -1.399
 58     19.00     45.00     580.56    524.488    1.5656    -0.0520     1.2568    10024.0      527.62     4.557     4.1832       0.374
  1      5.85     33.75     599.91    740.899    1.0738    -1.4576     0.0075     4875.0      876.30    19.853     8.3175      11.536
 15     12.00     44.00     600.24    502.482    1.8820    -0.9520     0.2479     9235.0      560.70    10.316     3.6025       6.714
 81      2.00     32.00     600.24    342.179    2.6321     3.1097     3.9943     7352.0      239.20    16.979    13.6219       3.357
 31     17.00     41.00     619.92    670.698    1.2041    -0.9288     0.4976     8450.0      746.38     6.984     4.9902       1.993
 73     21.70     33.00     626.48    930.105    1.0012    -6.5163    -5.0231     3416.0     1969.48       .        4.8492        .
 53     10.00     27.00     649.44    731.422    1.2968     1.5089     2.9134     8470.0      614.76    13.524    17.7986      -4.274
 89     16.00     38.50     649.44    492.595    1.9242    -0.2483     0.9360     9562.0      506.88     4.091     7.3519      -3.261
 75     12.00       N       658.30    710.359    1.2986    -1.1357     0.2670        .        809.56    10.918       .            .
  6     13.00       F       674.04    723.888    1.1328    -0.7854     0.6639    18810.0      792.36     9.466       .            .
 62      0.00       N       685.52    501.478    1.8437    -1.2129     0.0004        .        576.64    18.837       .            .
 16      5.00     36.00     688.80    467.820    2.0165    -0.3524     0.7958    13200.0      487.20    13.109    11.1191       1.990
 26     14.00     49.00     688.80    610.857    1.5583    -1.2524     0.0654    14500.0      705.60     6.426    -1.0650       7.491
 27     17.00       N       688.80    726.563    0.5757     0.7184     1.0616        .        668.86     4.933       .            .
 50      0.00     23.50     744.56    646.066    1.4486     0.2346     1.5882    16000.0      628.86    18.885    23.2617      -4.377
 38      5.00     27.00     780.64    991.614    0.9285    -2.9232    -1.4093    16000.0     1388.40    16.373    18.5286      -2.156
  4    -15.87      4.70     799.99    679.936    1.1703       .          .        7260.0         .         .       33.3268        .
 61       N         D       846.24    501.478    1.8437       .          .       17700.0         .         .       26.3031        .
 70     -6.00       N       915.12    709.451    1.3065    -1.3147     0.0853     4008.0      825.36    20.323       .            .
 45     10.00       D       944.64    622.775    1.3839    -0.1623     1.2091    17004.0      634.50     2.364    28.0883     -25.724
 77     -8.61     21.00    1000.40    608.732    1.4563    -2.6683    -1.3197    18403.0      827.64       .       19.2806        .
 48      4.00     36.00    1010.24    640.593    1.3127     0.4949     1.8852    23100.0      605.12     6.859     6.0000       0.859
 57      7.00      0.00    1049.60    671.902    1.2041    -2.7101    -1.2837     8712.0      917.91     3.278    32.5342     -29.256
 46     -3.17     27.50    1190.64    579.717    1.6469    -1.6000    -0.3131    19800.0      696.96       .        8.8797        .
 76    -13.99     17.00    1197.20    527.365    1.5789    -0.6419     0.6614    18700.0      567.80       .       18.7401        .
 23    -12.90     15.00    1199.82    788.553    1.1631     0.8062     2.2599    19575.0      718.68       .       21.0802        .
 78      2.00     25.00    1200.48    930.105    1.0012    -3.3948    -1.9016     9768.0     1374.92     7.603     5.0281       2.575
 34    -20.00      3.00    1341.52    929.104    1.0012    -1.0512     0.4421    19600.0     1048.64    26.699    30.1825      -3.484
  5     -0.02       F      1397.28    723.888    1.1328    -0.7854     0.6639    15700.0      792.36     3.490       .            .
 79       F         F      1400.56    653.007    1.3246    -1.4208    -0.0301    24050.0      769.08       .          .            .
 90    -12.00       F      1551.44    930.105    1.0012    -4.5986    -3.1053    22200.0     1579.30    14.920       .            .
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                                SCREENED DATA WITH OUTLIERS FLAGGED                   13:42 WEDNESDAY, MAY 14, 1980   22

                                  IN ORDER OF INCREASING DEPTH

------------------------------------------------------------ FREQ=3030 ------------------------------------------------------------

MINE    SEMF     MEMF    DEPTHFT    MMFUND    IFUND     IDIFF     IDIFF2      MMDN        MMUP       TLU        TLD     DELTATL

  93    52.00    68.00    68.880    57.824   1.0326   -3.7493   -2.0648    1860.0      89.040     7.950    22.0979    -14.148
  91    33.00    51.00   190.240   288.197   1.4779   -3.1379   -1.6487    1896.0     413.595    14.429    12.7919      1.637
   8    45.80      N     200.080   449.959   0.8078   -0.7436    0.9056       .        490.160     4.184       .           .
  18    44.00    60.00   209.920   340.813   1.1030   -2.0711   -0.4881    3600.0     432.600     2.320     6.7961     -4.476
  36    49.00    64.00   216.480   440.002   0.9778   -3.1794   -1.5637    4800.0     634.500    -1.263     4.4930     -5.756
  33    31.00    42.50   229.600   107.623   1.9218   -1.1347   -1.2462    1183.0     122.640     2.973    12.2946     -9.322
  65    40.00      D     232.880   343.965   1.2646   -2.9204   -1.3736    8944.0     481.440     3.696     1.9959      1.700
  17    34.00    51.00   239.440   399.020   1.1023   -2.0766   -0.4894    3600.0     506.800    10.261    12.3675     -2.106
  71    39.00    60.00   239.440   379.880   0.9288   -1.1477    0.4744    2175.0     433.540     4.834    -1.0094      5.844
  12    26.18    56.47   249.936   323.046   1.3925    2.3698    3.8840   10560.0     245.920       .       15.1268        .
  10    40.30    50.90   253.872   323.048   1.3925   -0.1331    1.3811    3600.0     328.048     0.602    10.9424    -10.341
  66    16.00    40.00   255.840   343.965   1.2646   -1.8234   -0.2766    4992.0     424.320    25.245    24.4806      0.765
  85    40.00    54.00   260.104   385.458   1.1506   -3.6423   -2.0663    2340.0     586.250     1.804     3.4687     -1.665
  44    41.00    50.00   262.400   338.825   1.3235    0.1556    1.6882    1045.0     332.800    -0.545     0.2377     -0.783
  47    33.00    49.00   262.400   266.298   1.7070   -0.2656    1.1593     852.0     274.560     5.363    -0.5358      5.899
  92    38.00      D     262.400   444.686   0.9773   -4.0619   -2.4455    3400.0     709.800     4.816    76.4850    -71.669
   9    34.70    60.10   264.040   323.048   1.3925   -3.5685   -2.0543   18000.0     487.200     5.178    14.6985     -9.520
  11    43.00    35.60   264.040   277.192   1.1948   -1.4385    0.1217     740.8     327.120    -4.451    11.4871    -15.938
  24    36.00    55.00   269.944   240.370   1.8927    0.4362    1.8028    5800.0     228.600     0.734     9.3854     -8.651
  51    30.00    65.00   278.800   285.059   1.5244   -0.4204    1.0563    6600.0     299.200     7.374    -0.3334      7.708
  55    34.00      N     288.640   474.016   0.9081    0.6771    2.3082       .        438.480     6.888       .           .
  43    29.12    58.00   295.200   260.753   1.7502    0.2528    1.6646    7250.0     253.300    -5.888     5.9930    -11.881
  54    23.00    40.00   308.320   343.957   1.3029    1.7921    3.3302    1671.0     279.840    13.383    10.1127      3.271
  21     5.00    59.00   324.720   296.318   1.4890   -1.6476   -0.1538    7900.0     358.200    28.738     3.2552     25.483
  30    33.00    56.00   324.720   412.573   1.0579   -1.0947    0.5027    6680.0     468.000     3.613     4.7982     -1.186
  35    35.50    60.00   324.720   444.686   0.9773   -2.7415   -1.1251    9600.0     609.700     1.764     3.9481     -2.184
  94    -4.00      N     328.000   115.252   0.5880   -8.0177   -6.2622       .        290.080    29.274       .           .
  32    31.00    52.00   331.280   383.299   1.1240   -1.5268    0.0549    7250.0     456.940     4.452     8.9883     -4.536
  13    31.00    52.00   341.120   412.573   1.0579   -6.0378   -4.4404    9235.0     826.800     4.329    10.3275     -5.999
  20    28.00    52.00   341.120   406.885   1.0793   -2.2597   -0.6671    9235.0     527.800     7.208    10.3275     -3.119
  19    14.00    52.00   347.680   154.152   1.1950   -1.3752    0.1623    9235.0     180.600    12.281     9.8312      2.450
  60    35.00    50.00   350.960   369.481   1.2035   -1.3136    0.2495    3251.5     429.800    -1.370     2.5195     -3.890
  64    31.00    54.00   354.240   374.965   1.1536   -3.0026   -1.4286    4430.0     529.750     2.514     0.9635      1.550
  42    29.00    60.50   357.520   311.662   1.3976    0.3656    1.8773   12360.5     298.820     2.669     3.1360     -0.467
  88    23.00    33.00   380.480   228.621   1.8145   -1.6733   -0.2853     837.0     277.200     4.356     5.6278     -1.272
  59    21.00    45.00   387.040   323.048   1.3925   -1.4738    0.0404    3930.0     382.800     8.913     6.6157      2.297
  87    24.00    52.00   400.160   385.458   1.1506   -0.6499    0.9260    6145.0     415.400     6.579     2.6297      3.949
   2    17.90    21.80   403.440   260.783   1.7502   -1.5826   -0.1708     655.0     312.900     9.072    13.1713     -4.099
   3    10.90    10.80   403.440   260.783   1.7502   -1.5826   -0.1708     655.0     312.900    16.072    24.1713     -8.099
  67    29.00      D     419.840   472.389   0.9084   -0.8345    0.7970    2465.0     520.000     2.094    -8.5555     10.650
  56    27.00      N     423.120   320.661   1.3305   -0.8660    0.6635    2032.8     354.270     0.526       .           .
  25    18.53    45.30   426.400   399.164   0.9549   -2.4769   -0.8583    8700.0     530.860   -13.773    10.6946    -24.467
  69    25.00    32.00   429.680   411.644   0.9849   -0.6383    0.9748    3250.0     443.080     4.296    15.2422    -10.946
  14     9.00    46.00   446.080   429.752   1.0160   -2.1410   -0.5339    9235.0     549.900    19.693     9.3372     10.356
  68     7.86    25.00   449.360   323.048   1.3925    8.3904    9.9046    2325.0     122.960       .       18.1660        .
  52    14.00    31.00   459.200   325.062   1.3658    0.9096    2.4307    2540.0     292.740    11.512    12.3698     -0.857
  40    20.78    48.00   469.040   378.721   1.0579   -1.7900   -0.1925    8700.0     465.400       .        5.5110        .
  82    -9.00      N     469.040   352.010   1.2617   -3.6015   -2.0532       .        532.890    34.652       .           .
  37    21.00    45.00   478.880   474.016   0.9081   -2.7058   -1.0746    9600.0     647.280     6.695     8.8251     -2.130
  49    24.00    49.00   478.880   343.943   1.3028   -0.6868    0.8513    8250.0     372.240     0.909     3.5087     -2.599
  74    15.00      N     478.880   444.686   0.9773   -3.1838   -1.5674       .        641.550    12.141       .           .
  72    16.00    49.00   482.160   331.332   1.3148   -1.8666   -0.3324    7315.0     410.760     8.407     2.2861      6.121
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                       SCREENED DATA WITH OUTLIERS FLAGGED                  13:42 WEDNESDAY, MAY 14, 1980   23

                            IN ORDER OF INCREASING DEPTH

--------------------------------------------------------- FREQ=3030 -------------------------------------------------------------

 MINE      SEMF      MEMF   DEPTHFT    MMFUND    IFUND     IDIFF    IDIFF2      MMDN      MMUP       TLU       TLD   DELTATL

   41    13.500    36.000    485.44   323.048   1.3925    0.3338    1.8480   15163.5    310.88    10.510   21.4411   -10.931
   63    18.000    48.000    485.44   386.059   1.1062   -2.0459   -0.4606    5460.0    488.60     7.558    0.5690     6.989
   86    14.000    35.000    498.56   444.686   0.9773   -3.1838   -1.5674    4389.0    641.55    12.091   10.9775     1.114
   80    -7.000    24.000    500.20   323.048   1.3925   -2.7448   -1.2305    3402.0    443.12    30.230   19.6793    10.551
   39    13.000    42.500    508.40   412.573   1.0579   -1.3795    0.2179   11200.0    483.60    11.931   11.1053     0.826
   28     8.000    10.000    518.24   547.443   0.7700   -2.2702   -0.6107    3112.0    711.00    18.888   31.9822   -13.094
    7    23.670    51.200    519.88   512.846   0.8026   -1.9100   -0.2592   12200.0    639.00   -16.861    2.5662   -19.427
   83    -3.000    25.000    541.20   311.662   1.3976   -0.0767    1.4350    6168.0    314.43    23.865   21.7947     2.071
   84     5.000    24.000    560.88   353.375   1.2531   -0.5824    0.9670    3568.0    377.88    16.026   17.1095    -1.084
   22    23.930    52.200    569.08   447.487   0.9441   -3.2341   -1.6116   11600.0    649.38    16.098   -1.2280    17.326
   29    19.500    36.000    580.56   507.177   0.5459   -4.3426   -2.6454    5048.0    836.10     3.766    7.2248    -3.459
   58    15.000    44.000    580.56   356.208   1.0633   -1.2296    0.3638   10024.0    410.37     5.196    5.1832     0.013
    1     0.506    30.750    599.91   495.018   0.7174   -0.6146    1.0536    4875.0    531.30    21.694   11.3175    10.377
   15    10.000    44.000    600.24   345.131   1.2926   -0.6933    0.8470    9235.0    373.80     9.053    3.6025     5.451
   81   -11.000    26.000    600.24   242.868   1.8682    2.4441    3.8185    7352.0    183.30    27.001   19.6219     7.379
   31    17.000    41.000    619.92   449.959   0.8078   -1.8539   -0.2048    8450.0    557.00     3.517    4.9902    -1.474
   73       F         F      626.48   619.620   0.6670   -8.8138   -7.1342    3416.0   1709.36        .         .         .
   53    -4.720    20.000    649.44   491.821   0.8720        .         .     8470.0        .         .    24.7986        .
   89    10.000    38.000    649.44   338.894   1.3238   -0.1056    1.4266    9562.0    343.04     6.842    7.8519    -1.010
   75     3.000       N      658.30   477.749   0.8734   -1.6819   -0.0435        .     579.82    16.472        .         .
    6    -9.890       F      674.04   484.493   0.7582   -2.4043   -0.7441   18810.0    639.00    28.868        .         .
   62    -6.000       N      685.52   343.965   1.2646   -4.4877   -2.9409        .     576.64    21.562        .         .
   16    -3.000    33.000    688.80   323.048   1.3925   -0.0467    1.4676   13200.0    324.80    17.893   14.1191     3.774
   26     9.000       D      688.80   414.467   1.0573   -2.2504   -0.6522   14500.0    537.04     8.057   -4.0650    12.122
   27    16.000       N      688.80   545.613   0.4323   -0.5395    0.5079        .     580.52     3.445        .         .
   50   -16.000    18.000    744.56   436.702   0.9792   -0.6887    0.9264   16000.0    472.76    31.483   28.7617     2.721
   38   -11.500    20.500    780.64   659.183   0.6172   -3.7460   -2.0556   16000.0   1014.60    29.326   25.0286     4.298
    4   -24.830    -0.781    799.99   455.690   0.7843        .         .     7260.0        .         .    38.8078        .
   61       N         D      846.24   343.965   1.2646        .         .    17700.0        .         .    28.3031        .
   70       F         N      915.12   477.251   0.8789   -1.1212    0.5159    4008.0    543.00        .         .         .
   45    -6.000       D      944.64   420.200   0.9338   -0.5949    1.0285   17004.0    450.00    14.946   37.0883   -22.142
   77   -13.760    20.000   1000.40   411.694   0.9849   -3.7690   -2.1559   20076.0    635.36        .    21.0364        .
   48     0.000    34.000   1010.24   431.232   0.8837    0.0364    1.6704   23100.0    429.44     7.422    8.0000    -0.578
   57     3.000    -1.000   1049.60   450.767   0.8078   -2.2777   -0.6286   13068.0    585.90     3.811   37.0560   -33.245
   46   -17.000    23.000   1190.64   394.606   1.1210   -3.6169   -2.0339   19800.0    598.40    19.370   13.3797     5.990
   76   -24.110    11.000   1197.20   358.351   1.0729   -1.4649    0.1263   20400.0    424.18        .    25.4958        .
   23   -13.390    18.000   1199.82   527.496   0.7780   -0.0223    1.6400   19575.0    528.84        .    18.0802        .
   78    -5.000    22.000   1200.48   619.620   0.6670   -4.0236   -2.3439    9768.0    984.74    11.074    8.0281     3.046
   34   -24.000       F     1341.52   618.953   0.6670   -2.4071   -0.7275   19600.0    816.64    27.171        .         .
    5    -7.000       F     1397.28   484.493   0.7582   -2.4043   -0.7441   15700.0    639.00     6.982        .         .
   79       F         F     1400.56   439.699   0.8919   -1.8215   -0.1892   24050.0    542.30        .         .         .
   90   -16.000   -26.000   1551.44   619.620   0.6670   -4.5791   -2.8994   23125.0   1049.77    15.392   56.8308   -41.439
```

Table D-3

Summary table of statistics for selected variables by frequency (for final data base of Table D-2)

Symbol Legend

IFUND = In-Mine RMS Fundamental Component of Transmit Loop Current in Amperes

IWEST = In-Mine "RMS" Transmit Loop Current in Amperes Recorded by Westinghouse (peak-to-peak value/ $2\sqrt{2}$)

IDIFF = 20 Log (IFUND/IWEST) in dB

IDIFF2 = 20 log (IEST/IWEST) in dB

IDEL = IEST - IWEST in Amperes

MMUP = In-Mine "RMS" Transmit Magnetic Moment in Amp-Turn-m^2 Based on IWEST

MMDN = Surface RMS Fundamental Component of Transmit Magnetic Moment in Amp-Turn-m^2

FREQ = Frequency

N = Number of data values

MEAN = $(\Sigma X_i)/N$

STANDARD DEVIATION = $\sqrt{\dfrac{\Sigma (Xi - \overline{X})^2}{N-1}}$

VARIANCE = $(\text{STD. DEV.})^2$

MINIMUM VAlUE = Min. Data Value

MAXIMUM VALUE = Max. Data Value

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                                     STATISTICS FOR SELECTED VARIABLES                    13:42 WEDNESDAY, MAY 14, 1980   24
                                                  FREQ=630

VARIABLE      N           MEAN       STANDARD         VARIANCE       MINIMUM        MAXIMUM
                                     DEVIATION                        VALUE          VALUE

IFUND        94     3.10711489     0.59850690           0.3582    0.80590000      4.3200000
IWEST        93     2.64043011     0.56492961           0.3191    0.57000000      4.0000000
IDIFF        93     1.45891672     1.66872366           2.7846   -3.74133869      6.6866953
IDIFF2       93     0.87458753     1.58396507           2.5089   -3.78995719      5.8335759
IDEL         93     0.24937097     0.46838426           0.2194   -1.19870000      1.6180000
MMUP         93   978.01301075   473.93765320      224616.8991  138.32000000   3149.3100000
MMDN         86  8413.50523256  6084.91585538    37026200.9671  655.00000000  23125.0000000

------------------------------------------- FREQ=1050 -----------------------------------------

IFUND        94     2.49370638     0.56156181           0.3154    0.73600000      3.7345000
IWEST        93     2.40892473     0.56757773           0.3221    0.55000000      3.5400000
IDIFF        93     0.34652953     1.97763203           3.9110   -5.72997781      9.6542964
IDIFF2       93     0.74143050     1.88253606           3.5439   -4.85809826      9.8176059
IDEL         93     0.18436129     0.47482183           0.2255   -1.36230000      2.0756000
MMUP         93   880.49064516   414.51445088      171822.2300  138.32000000   2954.2200000
MMDN         86  8730.47616279  6735.17541595    45362587.8836  655.00000000  27750.0000000

------------------------------------------- FREQ=1950 -----------------------------------------

IFUND        94     1.63474468     0.43142649           0.1861    0.57570000      2.6627000
IWEST        92     1.82717391     0.49367333           0.2437    0.53000000      3.2000000
IDIFF        92    -0.93287634     2.06705625           4.2727   -6.68760660      8.3621500
IDIFF2       92     0.31256360     2.00223979           4.0090   -5.02505351      9.5104051
IDEL         92     0.05523913     0.40871998           0.1671   -0.99960000      1.5315000
MMUP         92   656.77961957   296.04737380       87644.0475  126.56000000   1969.4800000
MMDN         86  8373.87151163  6035.23388365    36424048.0304  655.00000000  24050.0000000

------------------------------------------- FREQ=3030 -----------------------------------------

IFUND        94     1.12270638     0.32032752           0.1026    0.43230000      1.9218000
IWEST        91     1.36626374     0.37637735           0.1417    0.46000000      2.2000000
IDIFF        91    -1.68296734     2.12693442           4.5239   -8.81383978      8.3903867
IDIFF2       91    -0.13016099     2.09182541           4.3757   -7.13416565      9.9046014
IDEL         91    -0.02199780     0.30942568           0.0957   -1.03070000      1.1277000
MMUP         91   487.22898901   224.72331158       50500.5668   89.04000000   1709.3600000
MMDN         86  8443.71104651  6154.03007974    37872086.2224  655.00000000  24050.0000000
```

Table D-4

Summary table of statistics for set of key variables by frequency and depth interval (For final data base of Table D-2)

Symbol Legend

DEPTHFT = Depth in feet

MMFUND = In-Mine RMS Fundamental Component of Transmitter Magnetic Moment in A/p-turn-m^2

MMDN = Surface RMS Fundamental Component of Transmit Magnetic Moment in Amp-Turn-m^2

SEMF = Surface Vertical Component of Magnetic Field Strength in dB re 1 μA/m

MEMF = In-Mine Vertical Component of Magnetic Field Strength in dB re 1 μA/m

TLU = Transmission Loss Uplink = $-20 \text{ Log } (2\pi D^3/M_m)$ - SEMF + 120 in dB

TLD = Transmission Loss Downlink = $20 \log (2 \pi D^3/M_s)$ - MEMF + 120 in dB

DELTATL = TLU - TLD in dB

FREQ = Frequency in Hz

DEPTHINT = Depth Interval in Feet (8 total)

1 = less than 300
2 = 300-399
3 = 400-499
4 = 500-599
5 = 600-699
6 = 700-999
7 = 1000-1199
8 = 1200 or more

```
                          STATISTICS FOR DEPTH INTERVALS                    13:42 WEDNESDAY, MAY 14, 1980     9
                               FREQ=630   DEPTHINT=1

VARIABLE     N         MEAN          STANDARD        MINIMUM         MAXIMUM
                                     DEVIATION        VALUE           VALUE

DEPTHFT     22    240.66254545    46.99638708     68.88000000     295.2000000
MMFUND      22    886.55473182   344.61939392    140.61310000    1443.9045000
MMDN        20   4552.03000000  4130.90398888    652.00000000   18000.0000000
SEMF        22     42.78636364     9.48304479     16.00000000      57.0000000
MEMF        16     55.34187500    10.10435828     32.90000000      68.0000000
TLU         21      7.93237003     7.63913725     -0.60917096      33.9369584
TLD         19      9.18771267    15.61273527    -10.41584936      65.4849862
DELTATL     18     -2.69241128    17.19654822    -60.68939755      29.8172791

------------------------- FREQ=630   DEPTHINT=2 -------------------------

DEPTHFT     14    342.99428571    22.08603517    308.32000000     387.0400000
MMFUND      14    914.26854286   292.37962725    414.79960000    1324.3691000
MMDN        13   6889.61923077  3769.08524123    637.00000000   12360.5500000
SEMF        14     33.53571429     5.41530696     23.00000000      43.0000000
MEMF        13     53.15384615     7.26689014     35.00000000      62.0000000
TLU         14      8.09993205     3.23155656      2.48997965      12.5196828
TLD         13      4.49793073     4.02618778     -0.48054437      15.3275448
DELTATL     13      3.49111331     3.38468651     -5.92285402       7.5383330

------------------------- FREQ=630   DEPTHINT=3 -------------------------

DEPTHFT     19    451.94947368    32.12947374    400.16000000     498.5600000
MMFUND      19   1047.93041579   251.54983653    618.10030000    1443.9045000
MMDN        17   5698.84117647  3941.33116203    655.00000000   15163.5000000
SEMF        18     28.88111111     7.25728590      8.00000000      38.0300000
MEMF        14     41.51428571    10.51422898     25.00000000      56.0000000
TLU         16      6.86936201     5.93299653      1.04034077      26.3568069
TLD         15      6.38686008     9.68649880     -5.43104294      32.4410933
DELTATL     13     -0.63330854     8.78314668    -21.56182468      10.1024939

------------------------- FREQ=630   DEPTHINT=4 -------------------------

DEPTHFT     10    547.89120000    34.96178449    500.20000000     599.9120000
MMFUND      10   1288.12180000   366.38283464    814.70210000    1746.0933000
MMDN        10   7119.70000000  3707.35335516   3112.00000000   12200.0000000
SEMF        10     23.40300000     7.29345833     13.00000000      32.2900000
MEMF         8     44.15000000     6.38256554     36.00000000      51.5000000
TLU          8     12.91973310     8.16766339      2.40063327      24.2641003
TLD          9      2.49472412     4.44775106     -6.68252280       7.7946578
DELTATL      7     10.09830962     8.63359688      1.21740097      24.2921021

------------------------- FREQ=630   DEPTHINT=5 -------------------------

DEPTHFT     12     652.5013333    34.05929962    600.24000000     688.8000000
MMFUND      12    1198.8557250   410.37858376    557.82520000    2047.1689000
MMDN         9   10332.7777778  4513.74095894   3416.00000000   18810.0000000
SEMF        11      18.5545455     6.22757796      6.00000000      27.0000000
MEMF         7      41.6428571     2.56115673     39.00000000      47.0000000
TLU         11       8.1317375     4.74408945      2.23835981      18.2538574
TLD          7       4.7741624     2.27553275      0.60247974       7.9350095
DELTATL      7       3.8193357     3.93747238     -0.96518634      10.0745686
```

```
                     STATISTICS FOR DEPTH INTERVALS               13:42 WEDNESDAY, MAY 14, 1980   10
                         FREQ=630   DEPTHINT=6

VARIABLE       N          MEAN      STANDARD       MINIMUM       MAXIMUM
                                   DEVIATION         VALUE         VALUE

DEPTHFT        6   838.5320000   78.55137773  744.56000000   944.6400000
MMFUND         6  1436.7616500  425.93194936  935.60250000  2215.6260000
MMDN           6 12995.3333333 5829.67493662 4008.00000000 17700.0000000
SEMF           4     8.5750000   13.18038315   -7.70000000    22.0000000
MEMF           2    37.0000000    1.41421356   36.00000000    38.0000000
TLU            4    15.3734472   13.45448204    2.52015318    31.6654281
TLD            5    11.7016892   13.54982072   -8.17316848    26.3030901
DELTATL        4     7.3221082   24.90509922  -19.56812661    39.8385966

------------------------- FREQ=630   DEPTHINT=7 -------------------------

DEPTHFT        5  1107.9840000   97.73739575  1000.4000000  1199.8240000
MMFUND         6  1298.8345167  234.11259939  1030.5842000  1688.2476000
MMDN           6 19055.4166667 3265.29273445 13068.0000000 23100.0000000
SEMF           6     5.7000000    8.72559683    -6.2900000    18.0000000
MEMF           6    25.9166667    9.62505411    15.0000000    38.0000000
TLU            3     2.7713958    3.56149597    -1.2697828     5.4522202
TLD            6    11.9681319    8.47734169     1.8797134    21.0802205
DELTATL        3    -6.2071736   14.06473111   -22.3257737     3.5725068

------------------------- FREQ=630   DEPTHINT=8 -------------------------

DEPTHFT        5  1378.2560000  126.29916738 1200.48000000  1551.4400000
MMFUND         5  1805.2517800  337.89752244 1342.41380000  2047.1689000
MMDN           5 17915.8000000 5778.19809283 8954.00000000 23125.0000000
SEMF           5     2.1320000    6.47032611   -2.00000000    13.0000000
MEMF           2    13.5000000   21.92031022   -2.00000000    29.0000000
TLU            5     9.5886887    4.64692191    3.45501551    15.5511275
TLD            2    16.5515287   23.02232886    0.27228380    32.8307735
DELTATL        2    -8.9379148   17.14118268  -21.05856132     3.1827317

------------------------- FREQ=1050   DEPTHINT=1 -------------------------

DEPTHFT       22  240.66254545   46.99638708   68.88000000   295.2000000
MMFUND        22  714.40212727  259.46312500  136.78260000  1118.9980000
MMDN          20 4675.78000000 4154.44297864  852.00000000 18000.0000000
SEMF          22   41.76363636    8.68806217   17.00000000    56.0000000
MEMF          16   54.46875000    9.62730275   28.40000000    67.0000000
TLU           21    6.94989268    6.64504621   -0.77073312    31.1357207
TLD           19   10.82204949   16.48683299   -6.33344971    71.4849862
DELTATL       18   -4.97428274   17.43596215  -67.81701993    17.1825067

------------------------- FREQ=1050   DEPTHINT=2 -------------------------

DEPTHFT       14  342.99428571   22.08603517  308.32000000   387.0400000
MMFUND        14  733.09416429  230.97489549  306.33980000  1036.6399000
MMDN          13 6585.77307692 3484.33808017  837.00000000 12360.5500000
SEMF          14   31.93571429    6.33762964   20.00000000    42.0000000
MEMF          13   52.61538462    6.66506391   35.00000000    61.0000000
TLU           13    8.17449031    4.02278250    2.34623658    15.3064577
TLD           13    4.76548264    2.63719462    0.96345632     9.3275448
DELTATL       12    2.75597332    3.08515910   -1.92933668     8.0512204
```

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                         STATISTICS FOR DEPTH INTERVALS                13:42 WEDNESDAY, MAY 14, 1980   11
                            FREQ=1050    DEPTHINT=3

VARIABLE       N         MEAN         STANDARD         MINIMUM          MAXIMUM
                                      DEVIATION         VALUE            VALUE

DEPTHFT       19    451.94947368    32.12947374    400.16000000      498.5600000
MMFUND        19    838.29780526   179.03650255    527.89920000     1118.9980000
MMDN          17   5904.60588235  4515.78103329    655.00000000    18661.5000000
SEMF          18     26.65833333     6.51239203      8.00000000       36.0000000
MEMF          14     41.97857143    10.39520441     21.30000000       53.0000000
TLU           16      7.13975107     5.38902507      1.30793622       24.5502589
TLD           14      7.08059568     7.53591940     -2.55545258       23.2440352
DELTATL       12     -1.16736665     6.93340760    -14.04215106        7.9308559

------------------------- FREQ=1050    DEPTHINT=4 -------------------------

DEPTHFT       10    547.89120000    34.96178449    500.20000000      599.9120000
MMFUND        10    999.70641000   249.32774137    672.28120000     1324.9055000
MMDN          10   7119.70000000  3707.35335516   3112.00000000    12200.0000000
SEMF          10     20.87100000     7.27735369      9.00000000       30.1300000
MEMF           9     40.21777778    10.35223862     21.00000000       51.0000000
TLU           10      8.51224557    10.96325972    -18.44968866       20.9213964
TLD            9      6.93805745     8.52486455     -1.69252280       25.7946578
DELTATL        9      0.79053985    11.97343717    -23.01593641       17.3272377

------------------------- FREQ=1050    DEPTHINT=5 -------------------------

DEPTHFT       12     652.5013333    34.05929962    600.24000000      688.8000000
MMFUND        12     950.2267167   282.92870308    481.27100000     1527.3469000
MMDN           9   10332.7777778  4513.74095894   3416.00000000    18810.0000000
SEMF          12      15.5591667     6.45232933      4.00000000       26.0100000
MEMF           8      33.2250000    16.15343838     -5.70000000       45.0000000
TLU           11      10.2284727     5.01260765      3.64257293       18.4526197
TLD            9      10.6364636    17.64188617     -4.06499051       56.4598735
DELTATL        8      -1.7335442    20.10692042    -50.50739998       11.3472409

------------------------- FREQ=1050    DEPTHINT=6 -------------------------

DEPTHFT        6     838.5320000    78.55137773    744.56000000      944.6400000
MMFUND         6    1105.2185833   292.15814958    760.37790000     1639.1047000
MMDN           6   12995.3333333  5829.67493662   4008.00000000    17700.0000000
SEMF           4       2.5250000    12.55265576     -8.90000000       17.0000000
MEMF           3      29.4000000     6.23538291     22.20000000       33.0000000
TLU            4      19.1070697    12.78937239      7.35095185       30.5101847
TLD            4      17.6050416     7.26067623     12.52858935       28.3030901
DELTATL        3       8.9867503    11.08683170     -3.79026574       16.0671635

------------------------- FREQ=1050    DEPTHINT=7 -------------------------

DEPTHFT        6    1107.9840000    97.73739575   1000.4000000     1199.8240000
MMFUND         6    1008.6382000   161.07247569    818.8394000     1278.9451000
MMDN           6   21023.0000000  4643.55682640  13068.0000000    25500.0000000
SEMF           6       2.4883333     8.02590909     -9.7000000       14.0000000
MEMF           6      24.1666667    11.03479346      8.0000000       37.0000000
TLU            4       5.5918311     3.55857641      0.4049003        8.4932823
TLD            6      14.4874214     9.36362340      4.3797134       28.0559909
DELTATL        4      -6.8756056    14.49649917    -27.6510906        4.1135689
```

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                    STATISTICS FOR DEPTH INTERVALS                      13:42 WEDNESDAY, MAY 14, 1980   12
                       FREQ=1050    DEPTHINT=8

VARIABLE      N         MEAN         STANDARD         MINIMUM         MAXIMUM
                                     DEVIATION          VALUE           VALUE

DEPTHFT       5    1378.2560000   126.29916738   1200.4800000    1551.4400000
MMFUND        5    1358.3861200   235.35183675   1039.2881000    1527.3469000
MMDN          5   20602.0000000  7029.35061012  12210.0000000   27750.0000000
SEMF          4      -5.2500000     8.26135582    -11.0000000       7.0000000
MEMF          3      12.6666667    17.61628035     -6.0000000      29.0000000
TLU           4      14.9238121     5.46130619      0.9106958      19.0068064
TLD           3      19.8543946    17.78311169      2.9662553      38.4143984
DELTATL       3      -5.8059297    14.27152112    -22.1865060       3.9444405

------------------------ FREQ=1950    DEPTHINT=1 ------------------------

DEPTHFT      22    240.66254545    46.99638708    68.88000000     295.2000000
MMFUND       22    469.39860000   155.90582214    86.88680000     703.7388000
MMDN         20   4675.78000000  4154.44297864   852.00000000   18000.0000000
SEMF         22     38.50818182     7.95605767    15.00000000      53.0000000
MEMF         18     54.34555556     9.32010807    34.40000000      67.5000000
TLU          21      6.73426746     6.71551742    -0.35976361      29.5201773
TLD          20     11.66897814    16.24311815    -2.53580020      71.4849862
DELTATL      19     -4.97551555    17.07698459   -69.26516739      12.8580780

------------------------ FREQ=1950    DEPTHINT=2 ------------------------

DEPTHFT      14    342.99428571    22.08603517   308.32000000     387.0400000
MMFUND       14    478.31364286   146.91769481   176.07310000     657.9919000
MMDN         13   6768.08076923  3618.25934979   837.00000000   12360.5500000
SEMF         14     26.78571429     8.56808543     7.00000000      37.0000000
MEMF         12     52.54166667     7.36533136    32.00000000      60.5000000
TLU          14      9.20688383     6.55488245    -0.06639235      21.9546673
TLD          12      5.63478970     3.11989615     0.96345632      10.3275448
DELTATL      12      2.14018146     4.34186669    -3.63019213      10.3828729

------------------------ FREQ=1950    DEPTHINT=3 ------------------------

DEPTHFT      19    451.94947368    32.12947374   400.16000000     498.5600000
MMFUND       19    544.99327368   100.63324665   370.02660000     703.7398000
MMDN         17   5698.84117647  3941.33116203   655.00000000   15163.5000000
SEMF         18     21.06166667     7.46421285     1.00000000      32.0000000
MEMF         15     39.18000000    11.47576328    15.30000000      52.0000000
TLU          16      9.12379869     6.59528445     0.69305061      27.9288807
TLD          15      9.67337002     7.33623688     0.28605365      25.4410933
DELTATL      13     -0.89747680     8.48315831   -16.54914600      10.3352548

------------------------ FREQ=1950    DEPTHINT=4 ------------------------

DEPTHFT      10    547.89120000    34.96178449   500.20000000     599.9120000
MMFUND       10    631.79122000   136.59767671   451.11180000     817.9980000
MMDN         10   7119.70000000  3707.35335516  3112.00000000   12200.0000000
SEMF         10     14.81300000     7.81289539     5.85000000      25.1400000
MEMF          8     38.93125000    10.20234348    20.00000000      50.0000000
TLU          10      9.80656809    11.78904425   -17.68964149      21.8764267
TLD           6      8.65915179     6.44468114     0.97199816      21.1095374
DELTATL       6     -1.56626812    10.26156738   -22.75588924      11.5356866
```

```
                    STATISTICS FOR DEPTH INTERVALS                13:42 WEDNESDAY, MAY 14, 1980   13
                       FREQ=1950    DEPTHINT=5

VARIABLE       N        MEAN          STANDARD        MINIMUM         MAXIMUM
                                      DEVIATION        VALUE           VALUE

DEPTHFT       12     652.5013333    34.05929962    600.24000000     688.8000000
MMFUND        12     617.5371667   161.21912725    342.17870000     930.1055000
MMDN           9   10332.7777778  4513.74095894   3416.00000000   18810.0000000
SEMF          12      11.6416667     6.47055686      0.00000000      21.7000000
MEMF           8      37.5625000     7.07832456     27.00000000      49.0000000
TLU           11      10.5074945     4.79313655      4.09069922      18.8370763
TLD            8       7.7835373     6.06971366     -1.06499051      17.7985639
DELTATL        7       2.0014390     4.49560625     -4.27430901       7.4914296

------------------------ FREQ=1950    DEPTHINT=6 ------------------------

DEPTHFT        6     838.5320000    78.55137773    744.56000000     944.6400000
MMFUND         5     691.8868333   163.35194697    501.47850000     991.6145000
MMDN           6   12995.3333333  5829.67493662   4008.00000000   17700.0000000
SEMF           5      -1.3740000    10.04262814    -15.87000000      10.0000000
MEMF           3      18.4000000    11.99291457      4.70000000      27.0000000
TLU            4      14.4861813     8.24472583      2.36388685      20.3230018
TLD            5      25.9016892     5.50925176     18.52858935      33.3268315
DELTATL        3     -10.7522671    13.01372294    -25.72439294      -2.1555423

------------------------ FREQ=1950    DEPTHINT=7 ------------------------

DEPTHFT        6    1107.9840000    97.73739575   1000.40000000    1199.8240000
MMFUND         6     636.1437833    89.77236186    527.36520000     788.5535000
MMDN           6   18048.3333333  4871.05658627   8712.00000000   23100.0000000
SEMF           6      -4.6116667     8.76020871    -13.99000000       7.0000000
MEMF           6      19.4166667    12.20826223      0.00000000      36.0000000
TLU            2       5.0686694     2.53248662      3.27793098       6.8594079
TLD            6      17.7524600     9.48397831      6.00000373      32.5341658
DELTATL        2     -14.1984153    21.29497253    -29.25623478       0.8594042

------------------------ FREQ=1950    DEPTHINT=8 ------------------------

DEPTHFT        5    1378.2560000   126.29916738   1200.48000000    1551.4400000
MMFUND         5     833.2419600   134.53424890    653.00660000     930.1055000
MMDN           5   18263.6000000  5690.14277501   9768.00000000   24050.0000000
SEMF           4      -7.5050000    10.37143995    -20.00000000       2.0000000
MEMF           2      14.0000000    15.55634919      3.00000000      25.0000000
TLU            4      13.1776811    10.17828405      3.48965513      26.6986999
TLD            2      17.6052925    17.78689989      5.02805502      30.1825201
DELTATL        2      -0.4546495     4.28390842     -3.48383016       2.5745312

------------------------ FREQ=3030    DEPTHINT=1 ------------------------

DEPTHFT       22    240.66254545    46.99638708     68.88000000     295.2000000
MMFUND        22    322.41277273   101.68694279     57.82360000     474.0159000
MMDN          20   4661.89000000  4167.75704034    740.80000000   18000.0000000
SEMF          22     36.77727273     7.99313824     16.00000000      52.0000000
MEMF          18     53.92055556     8.69285472     35.60000000      68.0000000
TLU           21      4.59551012     6.63481034     -5.88615790      25.2454236
TLD           20     12.16317544    16.78169262     -1.00937926      76.4849862
DELTATL       19     -7.51069421    17.02077327    -71.66850334       7.7078256
```

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                 STATISTICS FOR DEPTH INTERVALS              13:42 WEDNESDAY, MAY 14, 1980   14
                     FREQ=3030    DEPTHINT=2

VARIABLE      N        MEAN         STANDARD         MINIMUM         MAXIMUM
                                    DEVIATION          VALUE           VALUE

DEPTHFT      14    342.99428571    22.08603517    308.32000000     387.0400000
MMFUND       14    326.95818571    99.23481308    115.25200000     444.6863000
MMDN         13   6585.77307692  3484.33808017    837.00000000   12360.5500000
SEMF         14     23.96428571    11.69560122     -4.00000000      35.5000000
MEMF         13     51.19230769     7.93079037     33.00000000      60.5000000
TLU          14      8.72309826     9.47827414     -1.37036793      29.2737765
TLD          13      6.18855956     3.37767700      0.96345632      10.3275448
DELTATL      13      0.95371730     7.91284031     -5.99872615      25.4826306

------------------------- FREQ=3030    DEPTHINT=3 ------------------------

DEPTHFT      19    451.94947368    32.12947374    400.16000000     498.5600000
MMFUND       19    371.96291053    64.26287370    260.78300000     474.0159000
MMDN         17   5698.84117647  3941.33116203    655.00000000   15163.5000000
SEMF         19     16.65631579     8.60940907     -9.00000000      29.0000000
MEMF         15     38.26000000    12.16715720     10.80000000      52.0000000
TLU          17      8.76683854     9.96474797    -13.77276452      34.6517449
TLD          16      9.39656861     8.36005873     -8.55545258      24.1713264
DELTATL      14     -1.78218472     9.65447831    -24.46735556      10.6496515

------------------------- FREQ=3030    DEPTHINT=4 ------------------------

DEPTHFT      10    547.89120000    34.96178449    500.20000000     599.9120000
MMFUND       10    426.68384000    86.98577983    311.66210000     547.4434000
MMDN         10   7119.70000000  3707.35335516   3112.00000000   12200.0000000
SEMF         10      9.86060000    10.96512407     -7.00000000      23.9300000
MEMF         10     33.96500000    13.62546737     10.00000000      52.2000000
TLU          10     13.08340020    13.26182143    -16.86121450      30.2299657
TLD          10     12.67346907    10.05694353     -1.22800184      31.9821737
DELTATL      10      0.40993113    10.97731374    -19.42746224      17.3264545

------------------------- FREQ=3030    DEPTHINT=5 ------------------------

DEPTHFT      12     652.5013333    34.05929962    600.24000000     688.8000000
MMFUND       12     423.1356250   107.80017640    242.86760000     619.6196000
MMDN          9   10332.7777778  4513.74095894   3416.00000000   18810.0000000
SEMF         11       2.7627273    10.18396395    -11.00000000      17.0000000
MEMF          6      33.6666667     9.22315926     20.00000000      44.0000000
TLU          10      14.2711205     9.42881208      3.44534363      28.8678459
TLD           7      10.1313052     9.97403714     -4.06499051      24.7985639
DELTATL       6       4.3738591     5.17241456     -1.47367532      12.1224307

------------------------- FREQ=3030    DEPTHINT=6 ------------------------

DEPTHFT       6     838.5320000    78.55137773    744.56000000     944.6400000
MMFUND        6     465.4985667   105.26127256    343.96530000     659.1833000
MMDN          6   12995.3333333  5829.67493662   4008.00000000   17700.0000000
SEMF          4     -14.5825000     7.96202811    -24.83000000      -6.0000000
MEMF          3      12.5730000    11.63226061     -0.78100000      20.5000000
TLU           3      25.2518799     8.98973767     14.94637262      31.4829533
TLD           5      31.5978892     6.00381714     25.02858935      38.8078315
DELTATL       3      -5.0409616    14.83081365    -22.14190717       4.2977243
```

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                       STATISTICS FOR DEPTH INTERVALS                 13:42 WEDNESDAY, MAY 14, 1980   15
                          FREQ=3030   DEPTHINT=7

VARIABLE       N         MEAN          STANDARD         MINIMUM          MAXIMUM
                                       DEVIATION          VALUE            VALUE

DEPTHFT        6    1107.9840000     97.73739575    1000.4000000     1199.8240000
MMFUND         6     429.0241833     57.71293905     358.3506000      527.4956000
MMDN           6   19336.5000000   3328.89265372   13068.0000000    23100.0000000
SEMF           6     -10.8766667     10.37410751     -24.1100000        3.0000000
MEMF           6      17.5000000     11.77709642      -1.0000000       34.0000000
TLU            3      10.2008402      8.14315402       3.8108469       19.3696921
TLD            6      20.5080213     10.12077326       8.0000037       37.0559909
DELTATL        3      -9.2777291     21.01457572     -33.2451441        5.9899787

------------------------- FREQ=3030   DEPTHINT=8 -------------------------

DEPTHFT        5    1378.2560000    126.29916738   1200.48000000     1551.4400000
MMFUND         5     556.4768400     87.60118667    439.69950000      619.6196000
MMDN           5   18448.6000000   5862.54507872   9768.00000000    24050.0000000
SEMF           4     -13.0000000      8.75595036    -24.00000000       -5.0000000
MEMF           2      -2.0000000     33.94112550    -26.00000000       22.0000000
TLU            4      15.1546556      8.71548028      6.98197952       27.1705565
TLD            2      32.4294143     34.50873318      8.02805502       56.8307735
DELTATL        2     -19.1963710     31.45601414    -41.43913189        3.0463899
```

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APPENDIX E

COMPLETE COMPUTER OUTPUT OF REGRESSION ANALYSES FOR SIGNAL VERSUS LOG DEPTH MODELS AT EACH OF FOUR FREQUENCIES

Standard output of regression analyses produced by SAS sub-routine GLM (General Linear Models) Procedure is given. Computational details and definition of terms are given in "A User's Guide to SAS 76", SAS Institute, Inc., Cary, North Carolina, pages 127 to 144.

Observation number refers to mine position in listing when ranked by increasing depth. All signal field strength values SEMFNORM are expressed in dB re 1 μA/m. SEMFNORM = Surface Vertical Component of Magnetic Field Strength for a Transmit Magnetic Moment of 1 A-m^2.

Table E-1

Statistical Analysis of Uplink Data

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                                  ANALYSIS OF UPLINK DATA                        10:30 WEDNESDAY, MAY 14, 1980    6
                                         FREQ=630

                                GENERAL LINEAR MODELS PROCEDURE

                                 DEPENDENT VARIABLE INFORMATION

                             NUMBER OF OBSERVATIONS IN BY GROUP = 94

NOTE: ALL DEPENDENT VARIABLES ARE CONSISTENT WITH RESPECT TO THE PRESENCE OR ABSENCE OF MISSING VALUES. HOWEVER, ONLY    90
      OBSERVATIONS IN BY GROUP CAN BE USED IN THIS ANALYSIS.
```

```
                                    ANALYSIS OF UPLINK DATA                       10:30 WEDNESDAY, MAY 14, 1980     7
                                           FREQ=630

                                  GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: SEMFNORM

SOURCE                  DF        SUM OF SQUARES         MEAN SQUARE        F VALUE          PR > F        R-SQUARE           C.V.

MODEL                    1        19592.77611750      19592.77611750         442.89          0.0001        0.834240        20.1692

ERROR                   88         3893.00746003         44.23872114                         STD DEV                 SEMFNORM MEAN

CORRECTED TOTAL         89        23485.78357754                                          6.65121952                  -32.97706128

SOURCE                  DF             TYPE I SS      F VALUE      PR > F         DF          TYPE IV SS      F VALUE      PR > F

LOGDEPTH                 1        19592.77611750       442.89      0.0001          1      19592.77611750       442.89      0.0001

                                       T FOR H0:      PR > |T|          STD ERROR OF
PARAMETER                ESTIMATE    PARAMETER=0                          ESTIMATE

INTERCEPT             99.82861848          15.72        0.0001            6.34941600
LOGDEPTH             -61.96740938         -21.04        0.0001            2.94453441

OBSERVATION              OBSERVED           PREDICTED            RESIDUAL          LOWER 95% CL          UPPER 95% CL
                            VALUE               VALUE                                INDIVIDUAL            INDIVIDUAL

          1           11.30711788         17.89411415         -6.58699628            3.76143952           32.02678879
          2          -13.33061542         -9.44644591         -3.88416952          -22.92209315            4.02920133
          3          -14.18282851        -10.80364628         -3.37918223          -24.25875437            2.65146180
          4          -11.73602298        -12.09567538          0.35965240          -25.53233725            1.34098649
          5           -9.34573489        -12.92380546          3.57807057          -26.34921396            0.50160304
          6          -16.96051566        -14.50732711         -2.45318855          -27.91246125           -1.10219298
          7          -15.42182747        -14.88906548         -0.53276199          -28.28955712           -1.48857385
          8          -16.15311748        -15.63667200         -0.51644548          -29.02834809           -2.24499591
          9           -7.14939352        -15.63667200          8.48727847          -29.02834809           -2.24499591
         10          -20.00416443        -16.79125566         -3.21290877          -30.17003778           -3.41247354
         11          -12.30416443        -17.21176584          4.90760141          -30.58606958           -3.83746210
         12          -43.42182747        -17.41958235        -26.00224512          -30.79171585           -4.04744885
         13          -15.72205027        -17.86442064          2.14237038          -31.23200433           -4.49683695
         14          -11.14523642        -18.10093783          6.95570141          -31.46615555           -4.73572011
         15          -13.10444635        -18.10093783          4.99649148          -31.46615555           -4.73572011
         16          -14.94018079        -18.10093783          3.16075704          -31.46615555           -4.73572011
         17          -17.35416443        -18.26861503          0.91445060          -31.63217777           -4.90505229
         18          -13.68748457        -18.26861503          4.58113047          -31.63217777           -4.90505229
         19          -15.78567495        -18.86374723          3.07807229          -32.22158587           -5.50590860
         20          -31.12575818        -19.73247395        -11.39328423          -33.08237732           -6.38257058
         21          -19.19076940        -20.66593530          1.47516590          -34.00786903           -7.32400156
         22          -12.82117909        -21.27072713          8.44954804          -34.60780579           -7.93364847
         23          -19.33185578        -22.44100298          3.10914720          -35.76937695           -9.11262902
         24          -27.60909845        -23.83572460         -3.77337386          -37.15491459          -10.51653460
         25          -26.56383330        -23.83572460         -2.72810871          -37.15491459          -10.51653460
         26          -19.44018079        -23.83572460          4.39554381          -37.15491459          -10.51653460
         27          -25.50066904        -24.10620028         -1.39446877          -37.42375931          -10.78864125
         28          -28.73815808        -24.37398462         -4.36417346          -37.68997697          -11.05799227
         29          -25.56383330        -25.16171219         -0.40212112          -38.47337335          -11.85005103
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                                        ANALYSIS OF UPLINK DATA                      10:30 WEDNESDAY, MAY 14, 1980     8
                                               FREQ=630

                                     GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: SEMFNORM

OBSERVATION        OBSERVED           PREDICTED           RESIDUAL        LOWER 95% CL       UPPER 95% CL
                     VALUE              VALUE                              INDIVIDUAL         INDIVIDUAL

     30          -26.38588397       -25.16171219       -1.22417178       -38.47337335       -11.85005103
     31          -29.35676658       -25.67433919       -3.68242739       -38.98340431       -12.36527407
     32          -20.21219919       -25.92703686        5.71483767       -39.23488688       -12.61918684
     33          -26.46640754       -26.17738382       -0.28902372       -39.48407214       -12.87069550
     34          -23.21997672       -26.42542340        3.20544668       -39.73100204       -13.11984476
     35          -25.50280476       -28.10049489        2.59769012       -41.39965722       -14.80133255
     36          -28.55416443       -28.56054205        0.00637762       -41.85827100       -15.26281311
     37          -30.72205027       -29.45769526       -1.26435501       -42.75303680       -16.16235372
     38          -23.52117909       -29.67738713        6.15620804       -42.97222627       -16.38254798
     39          -25.52117909       -29.67738713        4.15620804       -42.97222627       -16.38254798
     40          -25.15882225       -30.74972436        5.59090211       -44.04257570       -17.45687302
     41          -23.63491626       -30.95915813        7.32424187       -44.25171125       -17.66660501
     42          -28.52785731       -31.16697464        2.63911733       -44.45926092       -17.87468836
     43 *              .            -31.37319867             .            -44.66524879       -18.08114855
     44          -29.03524314       -32.38126048        3.34601734       -45.67256679       -19.08995418
     45          -40.32416443       -32.57841964       -7.74574480       -45.86966017       -19.28717910
     46          -29.67297756       -33.16137609        3.48839853       -46.45257471       -19.87017747
     47          -22.79020280       -33.73197210       10.94176930       -47.02335050       -20.44059371
     48          -51.63616201       -33.73197210      -17.90418991       -47.02335050       -20.44059371
     49          -30.19076940       -34.29072098        4.09995158       -47.58248709       -20.99895487
     50          -28.82921949       -34.29072098        5.46150149       -47.58248709       -20.99895487
     51          -34.44018079       -34.29072098       -0.14945981       -47.58248709       -20.99895487
     52          -32.96516882       -34.47442206        1.50925324       -47.76636139       -21.18248273
     53          -37.05416443       -34.65687770       -2.39728673       -47.94901148       -21.36474392
     54          -30.84634679       -34.65687770        3.81053091       -47.94901148       -21.36474392
     55          -36.44018079       -35.37457634       -1.06560445       -48.66769166       -22.08146101
     56          -34.63416443       -35.46295771        0.82879328       -48.75621780       -22.16969762
     57          -32.56383330       -35.90056254        3.33672923       -49.19461657       -22.60650851
     58          -50.84134892       -36.41646531      -14.42488360       -49.71162025       -23.12131038
     59          -33.03161730       -36.50149573        3.46987843       -49.79684924       -23.20614221
     60          -43.21997672       -37.58311688       -5.63685983       -50.88141921       -24.28481456
     61          -46.67935812       -38.54436564       -8.13499248       -51.84594629       -25.24278498
     62          -30.29126192       -38.93496907        8.64370715       -52.23805862       -25.63187951
     63          -36.74710151       -39.47246119        2.72535968       -52.77779396       -26.16712843
     64          -33.23822213       -39.47246119        6.23423906       -52.77779396       -26.16712843
     65          -43.37601861       -40.35490431       -3.02111430       -53.66433888       -27.04546974
     66          -42.38330657       -40.36961440       -2.01369217       -53.67912175       -27.06010704
     67          -39.92996260       -40.36961440        0.43965180       -53.67912175       -27.06010704
     68          -39.98282851       -41.23782208        1.25499357       -54.55188137       -27.92376278
     69 *              .            -41.52111000             .            -54.83676344       -28.20545656
     70          -43.61419372       -42.48977357       -1.12442015       -55.81128243       -29.16826472
     71          -37.14578845       -42.48977357        5.34398513       -55.81128243       -29.16826472
     72          -36.35039503       -42.85427717        6.50388214       -56.17815133       -29.53040300
     73          -39.67599445       -43.49033877        3.81434433       -56.81855233       -30.16212522
     74          -53.42182747       -43.94483625       -9.47699122       -57.27631542       -30.61335709
     75          -48.55416443       -44.07329523       -4.48086920       -57.40572228       -30.74086817
     76          -42.60656949       -44.07329523        1.46672574       -57.40572228       -30.74086817
     77          -39.14666759       -44.07329523        4.92662764       -57.40572228       -30.74086817
     78          -58.27283293       -46.16820032      -12.10463261       -59.51763179       -32.81876886
     79          -44.90992906       -47.44169874        2.53176968       -60.80288819       -34.08050929
```

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                                                  ANALYSIS OF UPLINK DATA                          10:30 WEDNESDAY, MAY 14, 1980     9
                                                         FREQ=630

                                               GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: SEMFNORM

OBSERVATION              OBSERVED            PREDICTED              RESIDUAL          LOWER 95% CL        UPPER 95% CL
                           VALUE               VALUE                                    INDIVIDUAL          INDIVIDUAL

     80                -70.85732899        -48.10071243          -22.75661657        -61.46840716        -34.73301770
     81 *                    .             -49.61320711                .             -62.99691429        -36.22949993
     82 *                    .             -51.71913837                .             -65.12764284        -38.31063389
     83                -46.04289532        -52.57356264            6.53066731        -65.99295530        -39.15416997
     84                -60.67908594        -54.11700669           -6.56207926        -67.55727338        -40.67674000
     85                -49.40398579        -54.38042253            4.97643675        -67.82440635        -40.93643871
     86                -44.99840880        -55.40903579           10.41062699        -68.86796509        -41.95010648
     87                -55.00581058        -58.80216333            3.79635275        -72.31522796        -45.28909869
     88                -57.82166960        -58.95003240            1.12836280        -72.46562400        -45.43444080
     89                -70.83872282        -59.00895329          -11.82976953        -72.52555569        -45.49235089
     90                -53.22307351        -59.02366338            5.80058987        -72.54051848        -45.50680828
     91                -68.21371886        -62.01310894           -6.20060993        -75.58417193        -48.44204594
     92                -60.51599445        -63.10908258            2.59308813        -76.70143362        -49.51673153
     93                -64.15772816        -63.17218250           -0.98554566        -76.76578216        -49.57858284
     94                -68.22307351        -65.92559686           -2.29747664        -79.57610297        -52.27509076

* OBSERVATION WAS NOT USED IN THIS ANALYSIS

           SUM OF RESIDUALS                                        0.00000000
           SUM OF SQUARED RESIDUALS                             3893.00746003
           SUM OF SQUARED RESIDUALS - ERROR SS                    -0.00000000
           PRESS STATISTIC                                      4076.28377669
           FIRST ORDER AUTOCORRELATION                            -0.20074851
           DURBIN-WATSON D                                         2.38899590
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                                          ANALYSIS OF UPLINK DATA                    10:30 WEDNESDAY, MAY 14, 1980   10
                                                 FREQ=1050

                                       GENERAL LINEAR MODELS PROCEDURE

                                        DEPENDENT VARIABLE INFORMATION

                                    NUMBER OF OBSERVATIONS IN BY GROUP = 94

NOTE: ALL DEPENDENT VARIABLES ARE CONSISTENT WITH RESPECT TO THE PRESENCE OR ABSENCE OF MISSING VALUES. HOWEVER, ONLY     90
      OBSERVATIONS IN BY GROUP CAN BE USED IN THIS ANALYSIS.
```

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                                      ANALYSIS OF UPLINK DATA                    10:30 WEDNESDAY, MAY 14, 1980   11
                                            FREQ=1050

                                  GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: SEMFNORM

SOURCE                 DF      SUM OF SQUARES        MEAN SQUARE      F VALUE         PR > F      R-SQUARE          C.V.

MODEL                   1      21995.63617793     21995.63617793       518.09         0.0001      0.854808       19.5660

ERROR                  88       3736.04471417        42.45505357                     STD DEV                SEMFNORM MEAN

CORRECTED TOTAL        89      25731.68089211                                     6.51575426                 -33.30136397


SOURCE                 DF          TYPE I SS     F VALUE      PR > F        DF        TYPE IV SS      F VALUE      PR > F

LOGDEPTH                1      21995.63617793     518.09      0.0001         1    21995.63617793      518.09      0.0001


                                  T FOR H0:      PR > |T|          STD ERROR OF
PARAMETER              ESTIMATE  PARAMETER=0                        ESTIMATE

INTERCEPT          110.27017823        17.38      0.0001             6.34489246
LOGDEPTH           -67.11199745       -22.76      0.0001             2.94846922


OBSERVATION          OBSERVED          PREDICTED          RESIDUAL       LOWER 95% CL       UPPER 95% CL
                       VALUE              VALUE                          INDIVIDUAL         INDIVIDUAL

      1           12.88583566        21.53340029       -8.64756464        7.66062432        35.40617627
      2          -14.73876598        -8.07699678       -6.66176920      -21.28242183         5.12842827
      3          -11.65751191        -9.54687311       -2.11063880      -22.73150272         3.63775650
      4           -9.77577528       -10.94616758        1.17039230      -24.11213211         2.21979695
      5           -7.21919522       -11.84304973        4.62385452      -24.99763360         1.31153413
      6          -13.72061709       -13.55803673       -0.16258036      -26.69213137        -0.42394209
      7          -13.62058972       -13.97146735        0.35087763      -27.10087334        -0.84206136
      8          -17.17310925       -14.78114081       -2.39196844      -27.90164724        -1.66063438
      9           -6.98783136       -14.78114081        7.79330945      -27.90164724        -1.66063438
     10          -24.07677993       -16.03157901       -8.04520092      -29.13907843        -2.92407959
     11          -16.77677993       -16.48700031       -0.28977962      -29.58998523        -3.38401539
     12          -40.62058972       -16.71206992      -23.90851979      -29.81286775        -3.61127209
     13          -14.79606995       -17.19383908        2.39776912      -30.29005325        -4.09762490
     14          -10.40065915       -17.44999213        7.04933297      -30.54382358        -4.35616068
     15          -13.20061984       -17.44999213        4.24937229      -30.54382358        -4.35616068
     16          -13.81255841       -17.44999213        3.63743371      -30.54382358        -4.35616068
     17          -15.47677993       -17.63159004        2.15481011      -30.72375515        -4.53942492
     18          -10.83062570       -17.63159004        6.80096434      -30.72375515        -4.53942492
     19          -16.02061564       -18.27613063        2.25551499      -31.36253483        -5.18972642
     20          -22.57338544       -19.21697980       -3.35640564      -32.29540483        -6.13855476
     21          -17.97658621       -20.22793791        2.25135170      -33.29835918        -7.15751664
     22          -18.45102008       -20.88294008        2.43192001      -33.94849141        -7.81738876
     23          -20.56564356       -22.15037325        1.58472969      -35.20720732        -9.09353919
     24          -31.00376225       -23.66088586       -7.34287639      -36.70854900       -10.61322273
     25          -26.53311699       -23.66088586       -2.87223112      -36.70854900       -10.61322273
     26          -18.31255841       -23.66088586        5.34832745      -36.70854900       -10.61322273
     27          -29.72406849       -23.95381667       -5.77025182      -36.99985491       -10.90777844
     28          -27.78547664       -24.24383270       -3.54164394      -37.28831139       -11.19935401
     29          -23.53311699       -25.09695810        1.56384111      -38.13713315       -12.05678305
```

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                                     ANALYSIS OF UPLINK DATA                        10:30 WEDNESDAY, MAY 14, 1980   12
                                           FREQ=1050

                                  GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: SEMFNORM

OBSERVATION          OBSERVED           PREDICTED            RESIDUAL         LOWER 95% CL        UPPER 95% CL
                       VALUE              VALUE                                INDIVIDUAL          INDIVIDUAL

     30            -24.37940132       -25.09695810         0.71755678       -38.13713315        -12.05678305
     31            -28.59209460       -25.65214384        -2.93995077       -38.68974603        -12.61454164
     32            -20.24391758       -25.92582069         5.68190311       -38.96222074        -12.88942064
     33            -24.54638153       -26.19695167         1.65057014       -39.23220384        -13.16169950
     34            -20.55101933       -26.46558371         5.91456438       -39.49974088        -13.43142654
     35            -25.18951771       -28.27972108         3.09020337       -41.30758650        -15.25185566
     36            -26.87677993       -28.77796176         1.90118184       -41.80443577        -15.75148776
     37            -30.79606995       -29.74959741        -1.04647254       -42.77377550        -16.72541931
     38            -25.15102008       -29.98752828         4.83650821       -43.01122832        -16.96382824
     39            -27.45102008       -29.98752828         2.53650821       -43.01122832        -16.96382824
     40            -24.94556590       -31.14889188         6.20332598       -44.17073392        -18.12704985
     41            -23.90251172       -31.37571303         7.47320131       -44.39728431        -18.35414174
     42            -28.38899203       -31.60078264         3.21179061       -44.62211504        -18.57945025
     43 *                .            -31.82412757              .             -44.84525221        -18.80300293
     44            -29.95453305       -32.91587955         2.96134651       -45.93640891        -19.89535019
     45            -39.32677993       -33.12940703        -6.19737290       -46.14990155        -20.10891251
     46            -31.97116652       -33.76076103         1.78959451       -46.78130867        -20.74021339
     47            -25.78948547       -34.37872842         8.58924296       -47.39955405        -21.35790279
     48            -49.82961400       -34.37872842       -15.45088558       -47.39955405        -21.35790279
     49            -28.97658621       -34.98386511         6.00727891       -48.00517960        -21.96255062
     50            -28.06388111       -34.98386511         6.91998401       -48.00517960        -21.96255062
     51            -35.31255841       -34.98386511        -0.32869330       -48.00517960        -21.96255062
     52            -33.21514246       -35.18281722         1.96767475       -48.20433925        -22.16129518
     53            -35.37677993       -35.38042048         0.00364056       -48.40217159        -22.35866938
     54            -32.87464251       -35.38042048         2.50577797       -48.40217159        -22.35866938
     55            -36.31255841       -36.15770308        -0.15485533       -49.18057699        -23.13482918
     56            -47.87677993       -36.25342196       -11.62335797       -49.27645857        -23.23038534
     57            -33.53311699       -36.72735712         3.19424013       -49.75127838        -23.70343585
     58            -43.44369806       -37.28609059        -6.15760747       -50.31122354        -24.26095763
     59            -32.53126021       -37.37818030         4.84692009       -50.40353049        -24.35283011
     60            -44.55101933       -38.54959858        -6.00142075       -51.57814479        -25.52105237
     61            -37.86904198       -39.59065104         1.72160906       -52.62271059        -26.55859149
     62            -30.28565135       -40.01368271         9.72803135       -53.04735075        -26.98001467
     63            -37.07225658       -40.59579789         3.52354132       -53.63185006        -27.55974573
     64            -34.22848996       -40.59579789         6.36730793       -53.63185006        -27.55974573
     65            -47.32673009       -41.55150221        -5.77522788       -54.59189720        -28.51110721
     66            -41.60860888       -41.56743354        -0.04117534       -54.60790544        -28.52696164
     67            -42.64779386       -41.56743354        -1.08036032       -54.60790544        -28.52696164
     68            -39.65751191       -42.50772057         2.85020866       -55.55299344        -29.46244770
     69            -37.66875376       -42.81452730         5.14577354       -55.86147808        -29.76757652
     70            -51.35353765       -43.86361017        -7.48992748       -56.91671203        -30.81050830
     71            -37.40167722       -43.86361017         6.46193295       -56.91671203        -30.81050830
     72            -46.09501502       -44.25837516        -1.83663985       -57.31395731        -31.20279302
     73            -40.68037593       -44.94724316         4.26686723       -58.00737012        -31.88711619
     74            -53.62058972       -45.43947341        -8.18111631       -58.50301653        -32.37593029
     75            -49.87677993       -45.57859716        -4.29818276       -58.64313129        -32.51406303
     76            -42.57460094       -45.57859716         3.00399622       -58.64313129        -32.51406303
     77            -40.35929417       -45.57859716         5.21930299       -58.64313129        -32.51406303
     78            -67.14956317       -47.84742309       -19.30214008       -60.92969967        -34.76514652
     79            -47.29213391       -49.22664846         1.93451454       -62.32116356        -36.13213335
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                                          GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: SEMFNORM

OBSERVATION            OBSERVED             PREDICTED               RESIDUAL          LOWER 95% CL         UPPER 95% CL
                         VALUE                VALUE                                    INDIVIDUAL           INDIVIDUAL

     80             -69.70208554         -49.94037403           -19.76171151         -63.04165246         -36.83909560
     81 *                 .              -51.57843733                 .              -64.69634438         -38.46053029
     82 *                 .              -53.85920483                 .              -67.00282189         -40.71558776
     83             -50.87369399         -54.78456414             3.91087016         -67.93945764         -41.62967065
     84             -59.98953474         -56.45614626            -3.53338848         -69.63264093         -43.27965158
     85             -52.17416783         -56.74143111             4.56726329         -69.92177031         -43.56109192
     86             -46.67309188         -57.85544073            11.18234885         -71.05123194         -44.65964952
     87             -58.04687268         -61.53026867             3.48339599         -74.78196678         -48.27857055
     88             -56.26397463         -61.69041396             5.42643933         -74.94471969         -48.43610823
     89             -71.83703805         -61.75422651           -10.08281154         -75.00957525         -48.49887777
     90             -56.67875376         -61.77015784             5.09140409         -75.02576733         -48.51454835
     91             -71.66939773         -65.00778976            -6.66160796         -78.31930026         -51.69627926
     92 *                 .              -66.19475208                 .              -79.52819933         -52.86130484
     93             -71.33471909         -66.26309062            -5.07162848         -79.59782427         -52.92835696
     94             -72.67875376         -69.24509583            -3.43365792         -82.63843162         -55.85176004

* OBSERVATION WAS NOT USED IN THIS ANALYSIS

           SUM OF RESIDUALS                                  0.00000000
           SUM OF SQUARED RESIDUALS                       3736.04471417
           SUM OF SQUARED RESIDUALS - ERROR SS               0.00000000
           PRESS STATISTIC                                3930.57150390
           FIRST ORDER AUTOCORRELATION                      -0.13425666
           DURBIN-WATSON D                                   2.24534165
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                                         ANALYSIS OF UPLINK DATA                     10:30 WEDNESDAY, MAY 14, 1980   14
                                                FREQ=1950

                                      GENERAL LINEAR MODELS PROCEDURE

                                       DEPENDENT VARIABLE INFORMATION


                                  NUMBER OF OBSERVATIONS IN BY GROUP = 94

NOTE: ALL DEPENDENT VARIABLES ARE CONSISTENT WITH RESPECT TO THE PRESENCE OR ABSENCE OF MISSING VALUES. HOWEVER, ONLY     91
      OBSERVATIONS IN BY GROUP CAN BE USED IN THIS ANALYSIS.
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                                         ANALYSIS OF UPLINK DATA                     10:30 WEDNESDAY, MAY 14, 1980   15
                                               FREQ=1950

                                      GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: SEMFNORM

SOURCE                    DF        SUM OF SQUARES         MEAN SQUARE      F VALUE          PR > F       R-SQUARE            C.V.

MODEL                      1        23217.54635251      23217.54635251       462.77          0.0001       0.838700         20.5331

ERROR                     89         4465.23042402         50.17112836                       STD DEV                 SEMFNORM MEAN

CORRECTED TOTAL           90        27682.77677653                                        7.08315808                  -34.49624909

SOURCE                    DF             TYPE I SS     F VALUE     PR > F          DF         TYPE IV SS     F VALUE     PR > F

LOGDEPTH                   1        23217.54635251      462.77     0.0001           1     23217.54635251      462.77     0.0001

                                         T FOR H0:      PR > |T|          STD ERROR OF
PARAMETER                 ESTIMATE     PARAMETER=0                           ESTIMATE

INTERCEPT             111.83365893           16.34      0.0001            6.84264449
LOGDEPTH              -68.31077640          -21.51      0.0001            3.17546986

OBSERVATION              OBSERVED            PREDICTED            RESIDUAL        LOWER 95% CL         UPPER 95% CL
                           VALUE               VALUE                                INDIVIDUAL           INDIVIDUAL

      1                14.22092395         21.51183233         -7.29090839          6.44461826          36.57904641
      2               -16.36568661         -8.62747644         -7.73821017        -22.97904580           5.72409292
      3               -12.43054282        -10.12360823         -2.30693459        -24.45281776           4.20560130
      4               -11.99188142        -11.54789741         -0.44398401        -25.85702841           2.76123359
      5                -4.77206540        -12.46080000          7.68873461        -26.75768340           1.83608340
      6                -9.90840177        -14.20642072          4.29801895        -28.48124230           0.06840086
      7               -14.00504636        -14.62723619          0.62218983        -28.89700678          -0.35746560
      8               -19.36916707        -15.45137233         -3.91779474        -29.71155266          -1.19119200
      9               -12.00787038        -15.45137233          3.44350195        -29.71155266          -1.19119200
     10               -22.97156827        -16.72414631         -6.24742195        -30.97030220          -2.47799043
     11               -11.20156827        -17.18770251          5.98613425        -31.42898822          -2.94641680
     12               -39.00504636        -17.41679240        -21.58825396        -31.65571819          -3.17786661
     13               -16.04740028        -17.90716709          1.85976681        -32.14114581          -3.67318837
     14                -9.84824991        -18.16789564          8.31964573        -32.39930204          -3.93648925
     15               -11.56851354        -18.16789564          6.59938210        -32.39930204          -3.93648925
     16               -12.36441095        -18.16789564          5.80348469        -32.39930204          -3.93648925
     17               -15.95156827        -18.35273732          2.40116905        -32.58234449          -4.12313014
     18               -10.15473696        -18.35273732          8.19800036        -32.58234449          -4.12313014
     19               -15.08264247        -19.00879093          3.92614846        -33.23217579          -4.78540607
     20               -23.24895674        -19.96644589         -3.28251085        -34.18120679          -5.75168498
     21               -19.94822992        -20.99546210          1.04723218        -35.20156446          -6.78935974
     22               -17.36465890        -21.66216416          4.29750526        -35.86299342          -7.46133491
     23               -27.98891634        -22.95223669         -5.03667966        -37.14361571          -8.76085766
     24               -35.61428179        -24.48973062        -11.12455117        -38.67114649         -10.30831476
     25               -23.67854587        -24.48973062          0.81118476        -38.67114649         -10.30831476
     26               -19.36441095        -24.48973062          5.12531968        -38.67114649         -10.30831476
     27               -37.91386021        -24.78789387        -13.12596634        -38.96754145         -10.60824629
     28               -31.00930852        -25.08309027         -5.92621825        -39.26103963         -10.90514090
     29               -19.67854587        -25.95145450          6.27290863        -40.12471125         -11.77819775
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                              ANALYSIS OF UPLINK DATA                    10:30 WEDNESDAY, MAY 14, 1980   16
                                    FREQ=1950

                              GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: SEMFNORM

OBSERVATION       OBSERVED          PREDICTED          RESIDUAL         LOWER 95% CL       UPPER 95% CL
                   VALUE              VALUE                              INDIVIDUAL         INDIVIDUAL

     30         -25.54886271       -25.95145450        0.40259180       -40.12471125       -11.77819775
     31         -29.01709275       -26.51655717       -2.50053557       -40.68700315       -12.34611120
     32         -17.65582719       -26.79512254        9.13929535       -40.96425350       -12.62599158
     33         -23.80388301       -27.07109656        3.26721355       -41.23897069       -12.90322242
     34         -22.08568375       -27.34452700        5.25884326       -41.51120102       -13.17785298
     35         -24.18236958       -29.19106916        5.00869958       -43.35081522       -15.03132310
     36         -30.40156827       -29.69820960       -0.70335867       -43.85641199       -15.54000720
     37         -31.04740028       -30.68720095       -0.36019933       -44.84283840       -16.53156350
     38         -27.76465890       -30.92938183        3.16472293       -45.08448098       -16.77428269
     39         -30.56465890       -30.92938183        0.36472293       -45.08448098       -16.77428269
     40         -25.91806192       -32.11149013        6.19342822       -46.26446891       -17.95851136
     41         -24.36391323       -32.34236284        7.97844961       -46.49502579       -18.18969989
     42         -35.43024599       -32.57145273       -2.85879326       -46.72383404       -18.41907142
     43         -23.68852122       -32.79878713        9.11026590       -46.95092023       -18.64665402
     44         -37.05117153       -33.91004038       -3.14113115       -48.06140853       -19.75867223
     45         -41.33156827       -34.12738196       -7.20418630       -48.27868754       -19.97607638
     46         -33.46759625       -34.77001344        1.30241719       -48.92130060       -20.61872629
     47         -28.79491432       -35.39901919        6.60410488       -49.55052943       -21.24750896
     48         -53.20823580       -35.39901919      -17.80921660       -49.55052943       -21.24750896
     49         -30.94822992       -36.01496505        5.06673513       -50.16692487       -21.86300523
     50         -26.98814585       -36.01496505        9.02681920       -50.16692487       -21.86300523
     51 *             .            -36.01496505             .            -50.16692487       -21.86300523
     52         -35.65658411       -36.21747091        0.56088680       -50.36962850       -22.06531333
     53         -37.90156827       -36.41860384       -1.48296443       -50.57098232       -22.26622536
     54         -39.07910763       -36.41860384       -2.66050379       -50.57098232       -22.26622536
     55         -38.36441095       -37.20977055       -1.15464040       -51.36325451       -23.05628659
     56         -46.40156827       -37.30719918       -9.09436908       -51.46084536       -23.15355300
     57         -37.67854587       -37.78959995        0.11105408       -51.94413361       -23.63506628
     58         -49.75504484       -38.35831372      -11.39673112       -52.51407372       -24.20255371
     59         -33.03130738       -38.45204837        5.42074099       -52.60802920       -24.29606754
     60         -47.08568375       -39.64439095       -7.44129279       -53.80364247       -25.48513944
     61         -42.24354046       -40.70403907       -1.53950139       -54.86691540       -26.54116274
     62         -31.29192112       -41.13462708        9.84270596       -55.29916934       -26.97008482
     63         -35.66376785       -41.72714022        6.06337237       -55.89415710       -27.56012334
     64         -35.39471112       -41.72714022        6.33242910       -55.89415710       -27.56012334
     65         -51.54517900       -42.69991567       -8.84526333       -56.87145275       -28.52837860
     66         -42.02241364       -42.71613158        0.69371794       -56.88774882       -28.54451434
     67         -48.68505944       -42.71613158       -5.96892786       -56.88774882       -28.54451434
     68         -39.53054282       -43.67321436        4.14267154       -57.84984257       -29.49658615
     69         -37.67064425       -43.98550138        6.31485713       -58.16388350       -29.80711926
     70         -47.28335919       -45.05332335       -2.23003585       -59.23814429       -30.86850241
     71         -37.84980351       -45.05332335        7.20351983       -59.23814429       -30.86850241
     72         -45.02955897       -45.45513978        0.42558082       -59.64256042       -31.26771915
     73         -44.19342395       -46.15631259        1.96288864       -60.34850103       -31.96412414
     74         -54.00504636       -46.65733524       -7.34771113       -60.85311053       -32.46155994
     75         -48.40156827       -46.79894406       -1.60262420       -60.99576033       -32.60212780
     76         -41.71878968       -46.79894406        5.08015439       -60.99576033       -32.60212780
     77         -40.22545958       -46.79894406        6.57348449       -60.99576033       -32.60212780
     78         -56.20553369       -49.10829659       -7.09723710       -63.32377673       -34.89281645
     79         -54.92685737       -50.51215818       -4.41469919       -64.74053511       -36.28378125
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                                                       ANALYSIS OF UPLINK DATA                      10:30 WEDNESDAY, MAY 14, 1980   17
                                                              FREQ=1950

                                                   GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: SEMFNORM

OBSERVATION            OBSERVED           PREDICTED             RESIDUAL        LOWER 95% CL        UPPER 95% CL
                        VALUE               VALUE                                INDIVIDUAL          INDIVIDUAL

     80            -72.51936072        -51.23863258         -21.28072814        -65.47414256        -37.00312260
     81 *             .                -52.90595557            .                -67.15901760        -38.65289353
     82            -63.01844688        -55.22746296          -7.79098392        -69.50769420        -40.94723172
     83            -45.88662899        -56.16935138          10.28272239        -70.46150851        -41.87719426
     84            -64.29852122        -57.87079191          -6.42772932        -72.18580721        -43.55577660
     85            -52.13164377        -58.16117262           6.02952885        -72.48025774        -43.84208751
     86            -49.54612255        -59.29508109           9.74895853        -73.63052795        -44.95963423
     87            -58.43431773        -63.03555014           4.60123241        -77.43024229        -48.64085798
     88            -68.43222936        -63.19855600          -5.23367336        -77.59601299        -48.80109902
     89            -70.83662327        -63.26350840          -7.57311488        -77.66207132        -48.86494548
     90            -57.37064425        -63.27972430           5.90908005        -77.67856370        -48.88088490
     91            -79.36129127        -66.57518798         -12.78610329        -81.03332573        -52.11705023
     92            -57.21342395        -67.78335226          10.56992831        -82.26477168        -53.30193284
     93 *             .                -67.85291148            .                -82.33569636        -53.37012659
     94            -71.37064425        -70.88818235          -0.48246190        -85.43318962        -56.34317509

* OBSERVATION WAS NOT USED IN THIS ANALYSIS

           SUM OF RESIDUALS                                   0.00000000
           SUM OF SQUARED RESIDUALS                        4465.23042402
           SUM OF SQUARED RESIDUALS - ERROR SS                0.00000000
           PRESS STATISTIC                                 4689.73608807
           FIRST ORDER AUTOCORRELATION                       -0.05084358
           DURBIN-WATSON D                                    2.08973031
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                              ANALYSIS OF UPLINK DATA                      10:30 WEDNESDAY, MAY 14, 1980   18
                                     FREQ=3030

                            GENERAL LINEAR MODELS PROCEDURE

                             DEPENDENT VARIABLE INFORMATION

                          NUMBER OF OBSERVATIONS IN BY GROUP = 94

NOTE: ALL DEPENDENT VARIABLES ARE CONSISTENT WITH RESPECT TO THE PRESENCE OR ABSENCE OF MISSING VALUES. HOWEVER, ONLY    90
      OBSERVATIONS IN BY GROUP CAN BE USED IN THIS ANALYSIS.
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                                        ANALYSIS OF UPLINK DATA                    10:30 WEDNESDAY, MAY 14, 1980   19
                                              FREQ=3030

                                     GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: SEMFNORM

SOURCE                  DF        SUM OF SQUARES          MEAN SQUARE       F VALUE          PR > F         R-SQUARE            C.V.

MODEL                    1        28617.01524838       28617.01524838        360.01          0.0001         0.803575         25.1365

ERROR                   88         6995.09942717          79.48976622                       STD DEV                    SEMFNORM MEAN

CORRECTED TOTAL         89        35612.11467555                                        8.91570335                    -35.46918468


SOURCE                  DF             TYPE I SS      F VALUE      PR > F         DF          TYPE IV SS     F VALUE        PR > F

LOGDEPTH                 1        28617.01524838       360.01      0.0001          1      28617.01524838      360.01        0.0001


                                        T FOR H0:       PR > |T|          STD ERROR OF
PARAMETER                ESTIMATE     PARAMETER=0                           ESTIMATE

INTERCEPT            128.50374772           14.78        0.0001            8.69297681
LOGDEPTH             -76.71420882          -18.97        0.0001            4.04314440


OBSERVATION           OBSERVED            PREDICTED             RESIDUAL         LOWER 95% CL          UPPER 95% CL
                        VALUE               VALUE                                  INDIVIDUAL            INDIVIDUAL

     1             16.75789747         27.07074063         -10.31284316           8.08842361           46.05305764
     2            -16.19378309         -6.77623563          -9.41754746         -24.84424535           11.29177410
     3             -7.26345886         -8.45641807           1.19295921         -26.49599164            9.58315551
     4             -6.65033579        -10.05591998           3.40558419         -28.06997855            7.95813859
     5             -3.86909696        -11.08112572           7.21202876         -29.07963141            6.91737997
     6             -9.63807767        -13.04148862           3.40341096         -31.01200367            4.92902642
     7            -10.73029264        -13.51407183           2.73377919         -31.47818374            4.45004007
     8            -18.01989982        -14.43959128          -3.58030854         -32.39155186            3.51236930
     9            -12.59292630        -14.43959128           1.84666498         -32.39155186            3.51236930
    10            -24.00534920        -15.86893895          -8.13641025         -33.80314665            2.06526875
    11             -9.88534920        -16.38952075           6.50417156         -34.31756889            1.53852738
    12            -34.73029264        -16.64679275         -18.08349990         -34.57185728            1.27827178
    13            -11.71953677        -17.19749219           5.47795542         -35.11630474            0.72132037
    14             -9.59950894        -17.49029496           7.89078602         -35.40585811            0.42526820
    15            -15.50736788        -17.49029496           1.98292708         -35.40585811            0.42526820
    16            -14.96107500        -17.49029496           2.52921996         -35.40585811            0.42526820
    17            -15.48534920        -17.69787542           2.21252623         -35.61116639            0.21541554
    18             -5.85561697        -17.69787542          11.84225845         -35.61116639            0.21541554
    19            -11.61759804        -18.43463522           6.81703718         -36.34007236           -0.52919808
    20            -19.09870429        -19.51009866           0.41139437         -37.40466264           -1.61553468
    21            -19.51585819        -20.66570205           1.14984386         -38.54936605           -2.78203805
    22            -19.20558554        -21.41442024           2.20883470         -39.29145605           -3.53738444
    23            -27.73009062        -22.86319448          -4.86689614         -40.72837520           -4.99801376
    24            -44.43517240        -24.58982734         -19.84534506         -42.44255363           -6.73710105
    25            -19.31001185        -24.58982734           5.27981549         -42.44255363           -6.73710105
    26            -17.46107500        -24.58982734           7.12875234         -42.44255363           -6.73710105
    27            -45.23296941        -24.92466993         -20.30829948         -42.77519206           -7.07414781
    28            -20.67075599        -25.25618070           4.58542471         -43.10458821           -7.40777319
    29            -21.31001185        -26.23136908           4.92135723         -44.07394643           -8.38879173
```

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                                        ANALYSIS OF UPLINK DATA                            10:30 WEDNESDAY, MAY 14, 1980   20
                                              FREQ=3030

                                    GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: SEMFNORM

OBSERVATION          OBSERVED           PREDICTED             RESIDUAL          LOWER 95% CL        UPPER 95% CL
                       VALUE              VALUE                                  INDIVIDUAL          INDIVIDUAL

    30            -24.18944427       -26.23136908          2.04192481        -44.07394643         -8.38879173
    31            -29.75897764       -26.86598936         -2.89298828        -44.70508573         -9.02689299
    32            -16.35185161       -27.17882319         10.82697158        -45.01629451         -9.34135186
    33            -20.47843160       -27.48874689          7.01031529        -45.32466750         -9.65282628
    34            -20.87367985       -27.79581411          6.92213426        -45.63025643         -9.96137179
    35            -24.18233760       -29.86951358          5.68717598        -47.69548864        -12.04353851
    36            -29.18534920       -30.43904125          1.25369205        -48.26315340        -12.61492910
    37            -27.71953677       -31.54969601          3.83015925        -49.37074904        -13.72864299
    38            -30.42558554       -31.82166942          1.39608388        -49.64208901        -14.00124984
    39            -37.42558554       -31.82166942         -5.60391612        -49.64208901        -14.00124984
    40            -24.48599001       -33.14919793          8.66320792        -50.96717897        -15.33121689
    41            -23.12092556       -33.40847206         10.28754650        -51.22610345        -15.59084067
    42            -33.49302950       -33.66574405          0.17271456        -51.48306940        -15.84841871
    43            -27.29148653       -33.92104459          6.62955806        -51.73810652        -16.10398267
    44            -43.66435813       -35.16900163         -8.49535650        -52.98535344        -17.35264983
    45            -42.32534920       -35.41308007         -6.91226913        -53.22940510        -17.59675504
    46            -36.23933208       -36.13476657         -0.10456550        -53.95122702        -18.31830612
    47            -30.78638087       -36.84115115          6.05477028        -54.65805470        -19.02424759
    48            -59.93110002       -36.84115115        -23.08994888        -54.65805470        -19.02424759
    49            -32.51585819       -37.53286923          5.01701104        -55.35050439        -19.71523407
    50            -26.72971940       -37.53286923         10.80314983        -55.35050439        -19.71523407
    51            -37.96107500       -37.53286923         -0.42820577        -55.35050439        -19.71523407
    52            -34.40527550       -37.76028689          3.35501138        -55.57822693        -19.94234685
    53            -36.68534920       -37.98616272          1.30081352        -55.80443708        -20.16788836
    54            -33.73306913       -37.98616272          4.25309359        -55.80443708        -20.16788836
    55            -38.96107500       -38.87465691         -0.08641809        -56.69455104        -21.05476278
    56            -57.18534920       -38.98407099        -18.20127821        -56.80419818        -21.16394380
    57            -39.31001185       -39.52581557          0.21580372        -57.34720527        -21.70442587
    58            -46.76678449       -40.16449118         -6.60229330        -57.98760119        -22.34138118
    59            -30.52973437       -40.26975686          9.74002249        -58.09317448        -22.44633923
    60            -52.87367985       -41.60877864        -11.26490121        -59.43670390        -23.78085338
    61            -45.96472872       -42.79878220         -3.16594652        -60.63163820        -24.96592620
    62            -29.08561428       -43.28234014         14.19672586        -61.11744825        -25.44723204
    63            -34.60319443       -43.94774287          9.34454843        -61.78618461        -26.10930113
    64            -36.03406850       -43.94774287          7.91367437        -61.78618461        -26.10930113
    65            -53.38642509       -45.04018689         -8.34623820        -62.88469066        -27.19568312
    66            -40.75968191       -45.05839763          4.29871572        -62.90300865        -27.21378661
    67            -58.70739162       -45.05839763        -13.64899399        -62.90300865        -27.21378661
    68            -36.06345886       -46.13321851         10.06975965        -63.98451951        -28.28191750
    69 *                .            -46.48392235               .            -64.33755929        -28.63028542
    70            -58.55613784       -47.68310529        -10.87303255        -65.54529805        -29.82091253
    71            -40.60127760       -47.68310529          7.08182769        -65.54529805        -29.82091253
    72            -50.58400119       -48.13435224         -2.44964895        -65.99999211        -30.26871237
    73            -63.59574834       -48.92178169        -14.67396665        -66.79373455        -31.04982883
    74            -56.73029264       -49.48443898         -7.24585367        -67.36113450        -31.60774345
    75            -53.18534920       -49.64346819         -3.54188101        -67.52153916        -31.76539722
    76            -43.34979077       -49.64346819          6.29367742        -67.52153916        -31.76539722
    77            -38.73769419       -49.64346819         10.90577400        -67.52153916        -31.76539722
    78            -68.80369765       -52.23691169        -16.56678577        -70.13958591        -34.33423786
    79            -67.88012392       -53.81347325        -14.06665067        -71.73309948        -35.89384703
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                                                      ANALYSIS OF UPLINK DATA                     10:30 WEDNESDAY, MAY 14, 1980   21
                                                             FREQ=3030

                                                  GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: SEMFNORM

OBSERVATION            OBSERVED           PREDICTED            RESIDUAL        LOWER 95% CL        UPPER 95% CL
                        VALUE               VALUE                               INDIVIDUAL          INDIVIDUAL

     80            -78.00339759        -54.62931684        -23.37408075        -72.55830638        -36.70032729
     81 *             .                -56.50175001           .                -74.45374879        -38.54975123
     82 *             .                -59.10884383           .                -77.09639220        -41.12129546
     83            -58.46911476        -60.16660117          1.69748641        -78.16973391        -42.16346843
     84            -66.05148653        -62.07734894         -3.97413759        -80.11032472        -44.04437316
     85            -52.69421760        -62.40345162          9.70923402        -80.44173752        -44.36516572
     86            -50.07903844        -63.67685085         13.59781242        -81.73647592        -45.61722579
     87            -68.92328249        -67.87746368         -1.04581881        -86.01425847        -49.74066890
     88            -75.19616272        -68.06052215         -7.13564057        -86.20091510        -49.92012921
     89            -67.83437683        -68.13346484          0.29908801        -86.27529697        -49.99163270
     90            -60.84250294        -68.15167558          7.30917264        -86.29386751        -50.00948366
     91            -79.83314783        -71.85253952         -7.98060831        -90.07184623        -53.63323281
     92            -60.70574834        -73.20932935         12.50358101        -91.45888842        -54.95977028
     93 *             .                -73.28744558           .                -91.53877857        -55.03611260
     94            -71.84250294        -76.69610841          4.85360547        -95.02823698        -58.36397983

* OBSERVATION WAS NOT USED IN THIS ANALYSIS

           SUM OF RESIDUALS                                  0.00000000
           SUM OF SQUARED RESIDUALS                       6995.09942717
           SUM OF SQUARED RESIDUALS - ERROR SS              -0.00000000
           PRESS STATISTIC                                7319.96004574
           FIRST ORDER AUTOCORRELATION                      -0.01673112
           DURBIN-WATSON D                                   2.01489035
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APPENDIX F

PROBABILITY OF DETECTION BASED ON PROBIT ANALYSIS OF SUCCESS/FAIL FIELD TEST DATA

In the most fundamental sense, the outcome of each transmission test conducted at a mine site could be described in terms of whether the signal transmitted from the in-mine transmitter was actually detected (success) or not detected (failure) on the surface. It should be recognized that the experiment was conducted under "ideal" rather than "real" conditions, i.e.:

- the observer knew that a signal was being sent, when it had been sent, and approximately where it had been sent from,
- the observer functioned in a more favorable "alerted" state of mind and static measurement conditions,
- the Collins transmit moments were generally stronger than the GI operational ones because of the larger loop areas used in the deep mines and the larger #12 wire size that would not be permissible under emergency mine conditions.

Nevertheless, it is of interest to analyze test results according to this most fundamental success/failure property. The purpose of this Appendix is to present the results of a statistical technique which expresses the likelihood of successful signal detection as a function of depth under the exact, but optimistic and impractical, transmitter and test conditions experienced in this field test program.

The basic data for this analysis are given in Table F-1. Although a total of 94 tests was conducted, equipment malfunctions and other circumstances resulted in a few inadmissible data points for this analysis. All remaining "valid" tests (i.e., those in which a signal could have been received at the surface) were recorded as a success if the signal was actually observed, and a failure if it was not. The specific "failure" and "no-test" results are summarized by mine in Table F-2. Test outcomes at each frequency are given in Table F-1 for various depth intervals, pre-chosen to include a sufficient number of data points within each interval.

A statistical analysis of these data began by formulating the following three hypotheses of interest:

Hypothesis 1: There is no difference in the probability of failure to detect signals among the four frequency levels tested.

Hypothesis 2: There is no difference in the probability of failure to detect signals at the various depths tested.

Hypothesis 3: There is no frequency/depth interaction; i.e., the probability of failure to detect does not vary with depth differently, depending on which frequency is used.

The underlying theory and computational details required to test the hypotheses stated above are described in Reference F-1, Chapter 16, and will not be repeated here.

The results indicate that the data in Table F-1 lead to rejection of Hypothesis 2 only. Thus, there appears to be a direct relationship between failure to detect and depth. On the other

TABLE F-1

SUMMARY OF TEST OUTCOMES — FAILURE TO DETECT UPLINK SIGNALS

Tests conducted within depth interval (ft.)	630 Hz		1050 Hz		1950 Hz		3030 Hz	
	No. of tests uplink	No. of failures	No. of tests uplink	No. of failures	No. of tests uplink	No. of failures	No. of tests uplink	No. of failures
< 300	21	0	21	0	21	0	21	0
300 – 399	14	0	14	0	14	0	14	0
400 – 499	18	2	18	2	17	2	17	1
500 – 599	8	0	9	0	9	0	9	0
600 – 699	13	1	13	1	13	1	13	1
700 – 999	5	1	5	1	5	1	5	2
1000 – 1199	4	1	4	0	4	2	4	1
≥ 1200	6	1	6	2	6	3	6	3
Total	89	6	90	6	89	9	89	8

Source: Arthur D. Little, Inc.

TABLE F-2

SUMMARY OF SPECIFIC FAILURE TO DETECT AND TEST UPLINK TEST RESULTS

Symbols:

N = No valid test measurement performed
F = Failure to detect transmitted signal
T = Valid test performed

Mine No.	County/State	Depth (ft.)	630	1050	1950	3030
12	Kanawha, WV	250	N[1]	N[1]	N[1]	N[1]
69	McDowell, WV	430	F[1,2]	F[1,2]	N[1]	N[1]
68	McDowell, WV	449	F	F	F	F
40	Jefferson, AL	469	N[1]	N[1]	N[1]	N[1]
74	Westmoreland, PA	479			F	
80	Belmont, OH	500	N[3]			
73	Westmoreland, PA	626	F	F	F	F
4	Jefferson, IL	800			F	F
61	Boone & Raleigh, WV	846	N[4]	N[4]	N[4]	N[4]
70	McDowell, WV	915	F[5]	F[5]		F[5]
77	Carbon, UT	1000	N[1]	N[1]	N[1]	N[1]
46	Claiborne, TN	1191			F	
76	Carbon, UT	1197	F[5]		F	F[5]
23	Buchanon, WV	1200	F	F	F	F
34	Marion, WV	1342			F[6]	F[6]
5	Harlan, KY	1397		F		
79	Garrison, CO	1401			F	F
		TOTALS	5N 6F 89T	4N 6F 90T	5N 9F 89T	5N 8F 89T

Notes:

1. Defective surface receiver
2. Based on fail to detect, even on more sensitive BOM tape recording
3. Receiver not set up in time to detect valid transmission
4. Uplink tests not performed
5. Based on BOM tape data, Westinghouse data judged not valid
6. Based on original receive loop, signal level data based on tuned receive loop

Source: Arthur D. Little, Inc.

hand, there is no evidence from this experiment that the probability of a successful signal detection differs among the four frequencies used in this test program. Therefore, the outcomes were combined over all four frequencies prior to conducting the next stage of the analysis.

Since failure to detect was observed to be related in some way to depth, the next step involved the attempt to quantify this relationship. A technique frequently used in the analysis of proportions, known as Probit Analysis, was then used for this purpose. This technique, described in Reference F-2, Chapter 10, regards the probability of failure p_j as a normally distributed variable across the depth interval classifications. The Exact Probit Solution technique described in detail in Reference 2 is an iterative one and takes into account the different sample sizes within depth intervals. The relevant calculations are summarized in Table F-3, and the resulting Probit regression equation is plotted in Figure F-1.

The interpretation of Figure F-1 is that if the linear relationship as derived from experimental data is truly representative, then it is possible to determine the probability of successful signal detection at the surface as a function of depth. The expression should apply for all mine locations and conditions; however, it is crucial to recognize that the estimated probabilities are quite optimistic in terms of real trapped miner scenarios, due to the nature of the experimental test, as described in the initial paragraph.

Although the details will not be presented here, a test for linearity was conducted for these data. The results indicated that the probit regression model, as derived, fits or "explains" the data extremely well, and therefore can be used for inferential purposes. Consequently, the results are re-plotted on a more

TABLE F-3

EXACT PROBIT SOLUTIONS
(Second Iteration)

Avg. Depth (x)	Log (depth) (log x)	No. of Tests[1] (n)	Proportion of Failures[1] (p)	Expected Probit[2] (Y)	Weighting Factor (W)	Working Probit[2] (y)
250	2.40	21	0	2.47	0.047	2.12
350	2.54	14	0	2.90	0.110	2.49
450	2.65	17.5	0.100	3.24	0.191	3.96
550	2.74	8.75	0	3.52	0.276	3.00
650	2.81	13	0.077	3.73	0.346	3.59
800	2.90	5	0.250	4.01	0.442	4.38
1100	3.04	4	0.250	4.44	0.567	4.34
1350	3.13	6	0.375	4.71	0.617	4.68

Estimated Probit Regression Equation:

$Y = -4.935 + 3.085 \log x$

[1] = Averaged over all four frequencies.

[2] = Value of a normally distributed variate with mean of zero and unit variance (with 5 units added).

Source: Arthur D. Little, Inc.

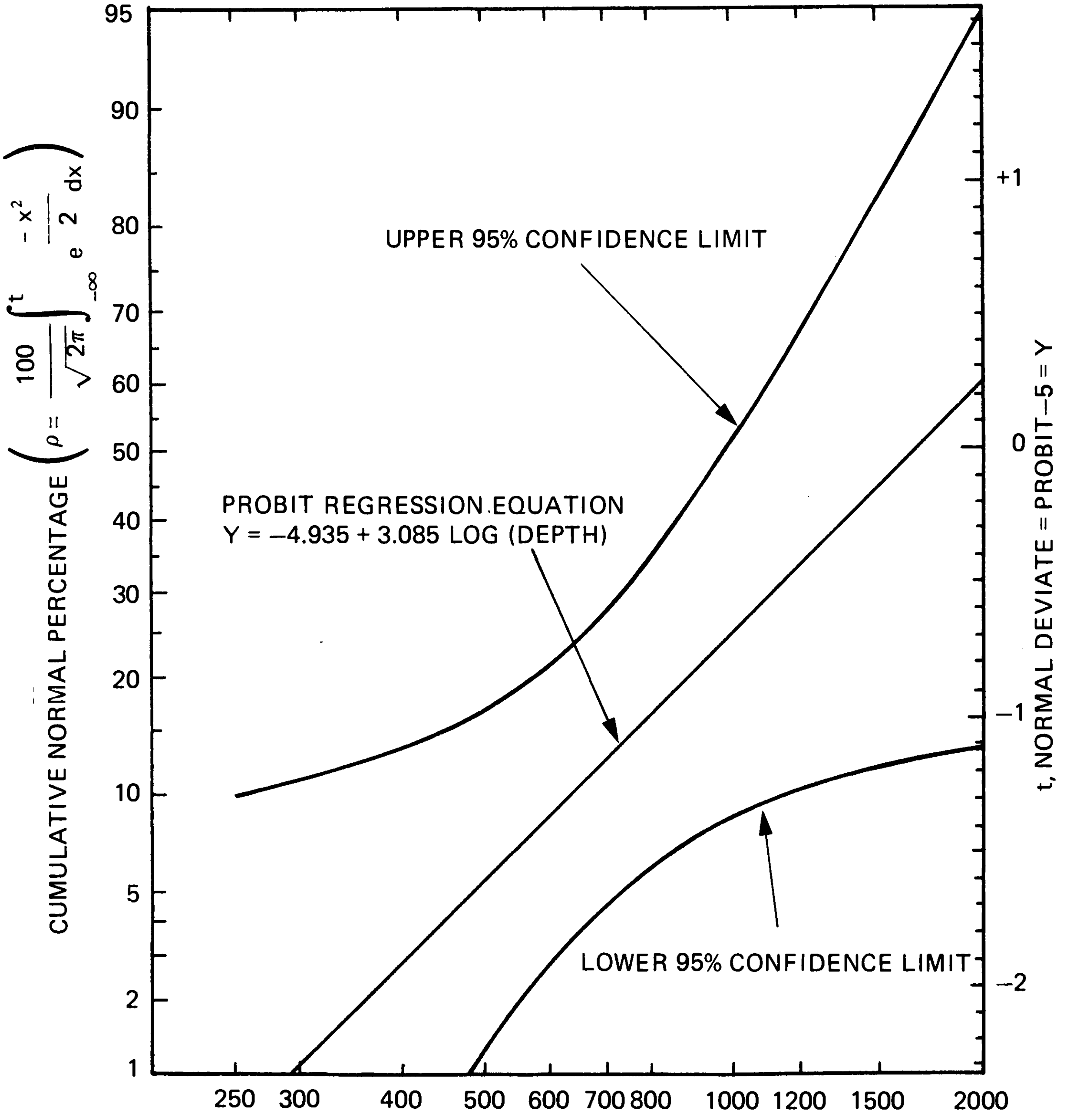

FIGURE F–1 RESULTS OF PROBIT ANALYSIS

convenient scale in Figure F-2. This figure illustrates the behavior of the uplink probability of successful detection with increasing depth, and the corresponding expansion of the interval estimates expressed in terms of upper and lower bounds. For example, at 1,200 feet, the figure indicates that we are 95 percent confident that the interval (0.34 to 0.90) includes the true (unknown) probability that a signal will be detected uplink for this type of experiment. In other words, it is highly unlikely that the chance of detection is lower than 0.34 or higher than 0.90, if repeated tests had been carried out at this depth. The graph also indicates that a signal detection could be expected to occur about two-thirds of the time at this depth.

It is interesting to note that the optimum allocation formulas mentioned in Section III-B of this report, which were used to determine sampling fractions, made use of assumed probabilities of successful detection, as follows:

Depth Interval	Assumed Probability of Success
< 400 ft.	0.98
400 - 1000 ft.	0.85
> 1000 ft.	0.50

The comparison to the observed outcome as illustrated in Figure F-2 reveals a remarkable, fortuitous agreement between the two independent measures.

References

(F-1) Statistical Methods, G.W. Snedecor and W.G. Cochran, Iowa State University Press, 6th Edition (1974).

(F-2) Experimental Statistics, M.G. Natrella, National Bureau of Standards Handbook 91, August 1, 1963.

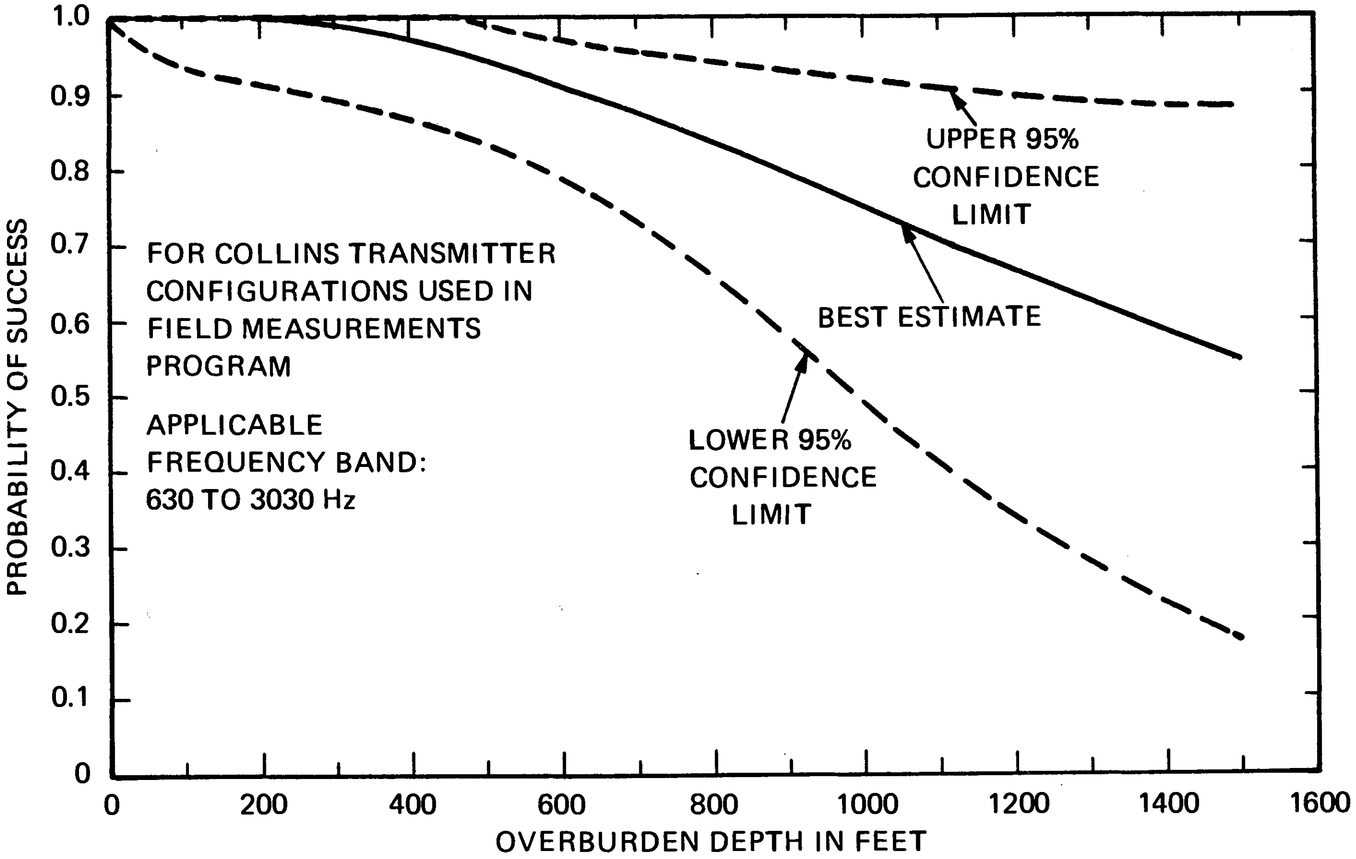

FIGURE F–2 ESTIMATED UPLINK PROBABILITY OF SUCCESSFUL DETECTION VS OVERBURDEN DEPTH (BASED ON SUCCESS/FAIL DATA FROM 94 MINE FIELD TESTS)

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APPENDIX G

APPLICATION OF SEARCH THEORY TO THE DETECTION OF TRAPPED MINERS

A. INTRODUCTION

This Appendix applies the principles of search theory to the problem of devising effective and practical search plans and procedures for maximizing the number of rescuable miners detected per unit of search effort at a mine disaster site. Given that a mine disaster has occured, and that one or more miners may have survived and activated their EM rescue transmitters somewhere within the mine, how should the mine search and rescue team allocate its effort and resources to best accomplish the objective of finding and rescuing these miners? The question is obviously important, because the amount of time available to rescue live miners is unknown but finite, and the roughly circular area of signal detectability above a trapped miner is quite small, compared to the extensive area of the mine workings. Since time is a critical factor, whenever trapped miner signals can be detected from the air, a helicopter-carried receiver will most likely be used to rapidly survey the large areas involved. Therefore, we have formulated the search problem specifically for a helicopter-based rapid survey effort, backed up by surface-based receivers for pin-pointing, or localizing, the underground transmitters. The problem and associated search plan and procedures can be modified to accomodate the situation in which the search must be conducted by a large number of search team members carrying rescue receivers on the surface.

B. SEARCH OBJECTIVES

The objective of the helicopter search is to "detect" signals from any transmitters that have been put into operation by the trapped miners, and to report their approximate locations to searchers on the surface. Hence, in laying out a search plan for the helicopter pilot, consideration should be given to the areas in which detectable signals are likely to be present at the time of the search, and the likelihood that the signals can be detected. Consideration also should be given to the likelihood that miners at the source of a detected signal can be rescued before they succumb, and to the number of miners involved.

The expected number of miners that can be rescued alive after their presence has been detected and their approximate location has been ascertained by the helicopter search, is one measure of search plan effectiveness that takes these factors into account. We assume for the purpose of this initial study that the objective of the helicopter search is to maximize the expected number of rescuable miners who have been found by the searching effort available from the helicopter. Some of the parameters on which the search plan is based will not be known accurately. The search plan that we seek is the plan that is "best," given the information available.

C. ESTIMATION OF PARAMETERS

With the EM receiver antenna suspended below the helicopter, the pilot will fly over the region covered by the underground mine, and use landmarks with known locations relative to the mine map to locate and orient his search. The search plan consists of instructions to the pilot as to where and how to search, in what sequence, and how to change the search procedure when a detection is made.

If nothing is known or can be estimated about the locations and survival probabilities of the trapped miners, or of the effectiveness of the EM receivers in detecting EM signals from various parts of the mine, the best that can be done is to instruct the helicopter pilot to fly "at random" over the mine. The pilot would then attempt to "cover" the entire region of the mine while taking care to stay within its boundaries. If we have an estimate of the horizontal range from the helicopter at which the EM signal from an underground transmitter can be detected versus helicopter altitude, a "regular" pattern, such as parallel sweeps, will be an improvement over a random search. Estimates of the probable locations of trapped miners can also be used to concentrate the searching effort in particular regions, rather than spreading the effort uniformly over the entire mine. In addition, estimates of survival times and rescue times for miners in various parts of the mine can be used to determine the sequence for searching various areas above the mine and for modifying the search plan with time.

We therefore construct a procedure for finding a "good" search plan in the general case. We assume that the expected numbers of trapped miners, and the conditions that affect the search and rescue operations, vary sufficiently from one region of the mine to another to justify different concentrations of effort from region to region. For this purpose, we divide the mine into a number of regions. The division lines are somewhat arbitrary, but should take into account the extent and structure of the mine, the work schedule for the day, and other factors. The regions need not have the same size or shape. They should be large enough that the helicopter pilot can achieve a desired distribution of search effort within his accuracy limitations in location and navigation. On the other hand, the regions should be small enough to permit significant differences in numbers and conditions to be specified.

For the $i^{\underline{th}}$ region, $i = 1, 2, \ldots, k$, the following quantities are estimated:

n_i = expected number of trapped miners in the i^{th} region;

A_i = area of the i^{th} region;

W_i = sweep width of the helicopter receiver in detecting a signal in the i^{th} region;

$p_{si}(t)$ = the probability that a signal is being transmitted from the i^{th} region at time t after the disaster;

$p_{ri}(t)$ = probability that a miner in the i^{th} region will survive until rescued, given a helicopter detection at time t.

The sweep width, W_i, is the equivalent width of a strip in the horizontal plane that is "swept" by the helicopter. If $p_i(x)$ is the probability of detecting a signal at horizontal distance x from the helicopter path, then

$$W_i = 2 \int_0^\infty x \, p_i(x) dx, \qquad (1)$$

assuming the same function on both sides of the path. A simpler estimate than Eq. (1) is twice the distance at which the probability of detection is 0.5. This estimate is sufficient, since the distribution of searching effort depends primarily on the ratios of the sweep widths rather than the absolute values. Furthermore, 0.5 provides a practical balance between the overly conservative narrow lane widths and overlapping areas of detectability imposed by a high probability such as 0.9, and the wider lanes but higher chances of not detecting valid signals offered by a lower probability such as 0.3.

It is unlikely that $p_{si}(t)$ and $p_{ri}(t)$ can be estimated with precision. Perhaps the only estimates available will be the expected times, as follows:

s_i = expected duration of a detectable signal transmission from the $i^{\underline{th}}$ region;

v_i = expected survival time for a miner trapped in the $i^{\underline{th}}$ region;

r_i = expected time required to rescue a miner from the $i^{\underline{th}}$ region.

To a first approximation, s_i is proportional to the expected number n_i of miners trapped in the $i^{\underline{th}}$ region, on the assumption that they are in one group and can pool their batteries to power one transmitter.

If we can estimate only the expected times, we will use an assumed shape for the functions $p_{si}(t)$ and $p_{ri}(t)$, with the expected times as parameters. For example, let v_i and r_i be the times at which the survival and rescue probabilities change abruptly from 1 to 0. This results in the following uniform distribution for $p_{ri}(t)$:

$$p_{ri}(t) = \begin{cases} 1, \text{ if } 0 \le t \le v_i - r_i; \\ 0, \text{ if } t > v_i - r_i. \end{cases} \tag{2}$$

A second example is the case of an exponential distribution. If v_i and r_i are the expected survival and rescue times used in exponential functions, then

$$p_{ri}(t) = \frac{v_i e^{-t/v_i}}{v_i + r_i} \quad , \tag{3}$$

as will be shown later. In (3), the exponential factor is the probability that a miner will survive to time t, while the factor $v_i/(v_i + r_i)$ is the probability that he will survive until rescued, given that he has survived to time t.

D. OPTIMIZATION PROBLEM

We want to construct a search plan that maximizes the expected number of miners rescued alive with a given amount of searching effort. We will measure the amount of searching effort in time t by the length L(t) of the horizontal component of the helicopter flight path while searching over the regions of the mine. Let $L_i(t)$ = length of path flown over the $i^{\underline{th}}$ region by time t. Then

$$\sum_{i=1}^{k} L_i(t) = L(t). \tag{4}$$

The probability $P_i(t)$ that a signal has been detected in the $i^{\underline{th}}$ region by time t, with a random distribution of effort in the region, is

$$P_i(t) = 1 - \exp\left[-c(W_i/A_i)\int_0^t p_{si}(x)\,\lambda_i(x)dx\right] , \tag{5}$$

where $\lambda_i(t)$ is the search rate (miles of search track per hour) in the $i^{\underline{th}}$ region at time t:

$$\lambda_i(t) = L_i'(t). \tag{6}$$

The derivation of (5) is given below.

The probability that a signal will be detected in the interval (t, t + dt), given that a detectable signal is present at time t, is $c(W_i/A_i)\ \lambda_i(t)dt$, where c is a constant that depends on the efficiency of the helicopter searcher in scanning the frequency bands and becoming aware of a signal indication on his receiver. For an efficient searcher, c = 1. Let

$$Q_i = 1 - P_i(t). \tag{7}$$

Then

$$Q_i(t + dt) = Q_i(t) \left[1 - p_{si}(t)c(W_i/A_i)\ \lambda_i(t)dt\right]. \tag{8}$$

Equation (8) is obtained by elementary arguments, as follows: The probability $Q_i(t + dt)$ that no signal will be detected by time t + dt is equal to the probability $Q_i(t)$ of failure by time t multiplied by the probability that no signal will be detected in the interval (t, t + dt). The latter probability is the quantity in brackets in Equation (8). The solution of Equation (8) with the condition $Q_i(0) = 1$ yields Equation (5), when (7) is used.

From Equation (6) and the condition that $L_i(0) = 0$, we have

$$L_i(t) = \int_0^t \lambda_i(x)dx. \tag{9}$$

The condition expressed by Equation (4) then becomes

$$\sum_{i=1}^{k} \int_0^t \lambda_i(x)dx = L(t) \tag{10}$$

in terms of the search rates.

The overall search plan will consist of a sequence of search plans for various time intervals called stages. Stage 1 extends from the start of search to the first detection, Stage 2 extends from the first detection to the second detection, etc. The optimal search in Stage 2 will be contingent upon the time t_1 at which the first detection occurred, the region in which it occurred, and the search policy concerning further helicopter search in a region in which a detection has been made. If it is reasonable to expect that all the miners in the region in question are in one group, or are separated but are likely to be found by a rescue team, further helicopter search in that region may not be justified. In that case, the helicopter search in the region is terminated and the surface searchers take over to pinpoint the source of the signal detected by the helicopter.

If the search policy is to include the possibility of search in the region in question in later stages, an estimate of the expected number n_1' of miners not at the location of the detected transmission is needed for Stage 2. Then the optimization problem for Stage 2 is essentially the same problem as that for Stage 1, except for the change in the expected number of trapped miners in the region in which the detection was made. Thus, we proceed from stage to stage. The search plan in each stage is contingent on the previous detections -- their times, regions, and revised estimates of the expected number of trapped miners remaining.

E. OPTIMIZATION IN THE FIRST STAGE

We limit further consideration of the optimal problem to the first stage. The solution for that stage can be modified easily to apply to the later stages. The time t_1 of the first detection will not be known in advance, of course. Our objective in the first stage is to construct a search plan that is optimal, if possible, whatever the value of t_1. If this can't be done, then we must use a compromise plan. For this reason, we referred earlier to the desired plan as a "good" plan, rather than an optimal plan.

We construct the search plan under the condition that the first detection occurs at $t = t_1$, even though the value of t_1 will not be known until the first detection occurs. Hence, we replace the detection probability $P_i(t)$ from Equation (5) by the conditional detection probability $P_i(t_1 \mid \text{first detection at } t = t_1)$. For the first detection to occur in the $i^{\underline{th}}$ region at time $t = t_1$, a detectable signal must be present at $t = t_1$; and detection must be made, given that a signal is present. Hence

$$P_i(t_1 \mid \text{first detection at } t = t_1) =$$

$$p_{si}(t_1)[1 - \exp(-cL_i(t_1)/b_i)], \qquad (11)$$

where

$$b_i = A_i/W_i. \qquad (12)$$

The expected number of miners rescued alive, given that the first detection occurs in the $i^{\underline{th}}$ region at $t = t_1$, is $n_i p_{ri}(t_1)$. Hence, the expected number N_1 of miners rescued alive as the result of the search in the first stage is

$$N_1 = \sum_{i=1}^{k} n_i p_{ri}(t_1) p_{si}(t_1)[1 - \exp(-cL_i(t)/b_i)]. \qquad (13)$$

We want to maximize N_1, subject to condition of Equation (4) for $t = t_1$, and the conditions

$$L_i(t_1) \geq 0, \; i = 1, 2, \ldots, k. \qquad (14)$$

First, we find the solution without using conditions of Equation (14). By elementary calculus, the solution is

$$L_i(t_1) = (b_i/cB) \left[cL(t_1 + Bh_i(t_1) - \sum_{i=1}^{k} b_i h_i(t_i) \right], \qquad (15)$$

where

$$B = \sum_{i=1}^{k} b_i, \tag{16}$$

$$h_i(t_1) = \ln \left[L_o n_i p_{ri}(t_1) p_{si}(t_1)/b_i \right], \tag{17}$$

and L_o is an arbitrary unit of length, say, one mile, that has been inserted to make the bracketed quantity in Equation (17) dimensionless instead of appearing to have dimension of (1/length). In computations, we can put $L_o = 1$.

The distribution given by $L_i(t_1)$ in Equation (15) is the optimal solution for any value of t_1 for which conditions of Equation (14) are satisfied. If some of the $L_i(t_1)$ in Equation (15) are negative, a modification is required. We want to find the "largest" subset $\{J\}$ of the set $\{1, 2, \ldots, k\}$ for which $L_j^*(t_1) > 0$ for $j \epsilon \{J\}$ when computed from Equations (15), (16), and (17) by limiting the summations in Equation (15) and (16) to the subset $\{J\}$. The desired subset can usually be obtained by starting with the index i_1 for which h_{i_1} is maximum, and adding indices in the order of decreasing values of h_i until a negative value of $L_i(t_1)$ is obtained for the index last added; then dropping the last index and putting $L_j^*(t_1) = 0$ for the dropped index and the remaining indices. Or we can proceed by dropping indices that produce negative values when the entire set is used, recompute with summations over the reduced set, and continue to drop indices that produce negative values until a set $\{J\}$ is obtained for which $L_j(t_1) > 0$, $j \epsilon \{J\}$.

If the optimal values $L_i^*(t_1)$ of $L_i(t_1)$ found in this way are monotonic nondecreasing functions of t_1, it is possible -- at least in theory -- to construct a search plan that is optimal for all $t_1 > 0$. In fact, we can proceed step by step in arbitrary increments of time, optimizing in each step, and the overall distribution will be optimal. If at least one of the $L_i^*(t_1)$ is not monotonic nondecreasing, the optimal solution cannot be attained for all t_1. If we proceed step by step, the distribution obtained may be optimal for small values of t_1, but not for large values of t_1.

F. SOLUTION FOR EXPONENTIAL PROBABILITY FUNCTIONS

If s_i is the expected duration of a detectable signal transmission from the $i^{\underline{th}}$ region, the corresponding exponential function for $p_{si}(t)$ is

$$p_{si}(t) = \exp[-(t - t_o)/s_i], \quad t \geq t_o \ , \tag{18}$$

where t_o is the time after the disaster occurred at which signal transmissions start. For $t < t_o$, $p_{si}(t) = 0$. The expected duration in the exponential function can be obtained from an estimate of the 50% value by the equation

$$\text{expected value} = (50\% \text{ value})/\ell n2 \ . \tag{19}$$

If $t_o \ll s_i$, we use the approximation

$$p_{si}(t) = \begin{cases} 0, & t < t_o; \\ \exp(-t/s_i), & t \geq t_o. \end{cases} \tag{20}$$

To derive Equation (3), we suppress the index i and let v and r be the expected survival and rescue times, respectively. For exponential functions, the probability that a miner will survive no longer than time t_v is $1 - \exp(-t_v/v)$, and the density function $f(t_v)$ of the survival time t_v is

$$f(t_v) = (1/v)\exp(-t_v/v). \tag{21}$$

The probability that the rescue time t_r does not exceed x is

$$P\left\{t_r \leq x\right\} = 1 - \exp(-x/r) \; . \tag{22}$$

For a given survival time t_v and helicopter detection time t, the probability of making a live rescue is zero if $t_v \leq t$, and is $P\left\{t_r \leq t_v - t\right\}$ if $t_v > t$. Hence, the probability $p_r(t_v, t)$ of making a live rescue, given t_v and t, is

$$p_r(t_v, t) = \begin{cases} 0, \; t_v \leq t; \\ 1 - \exp[-(t_v - t)/r], \; t_v > t \; . \end{cases} \tag{23}$$

The probability $p_r(t)$ of making a live rescue, given that a helicopter detection occurs at time t, is

$$p_r(t) = \int_0^\infty p_r(t_v, t) f(t_v) dt_v = ve^{-t/v} \Big/ (v + r) \; . \tag{24}$$

Restoring the index i, we obtain

$$p_{ri}(t) = \frac{v_i e^{-t/v_i}}{v_i + r_i} \tag{25}$$

as stated earlier in Equation (3).

We now use Equations (18) and (25) in Equation (15). Assuming that the total distance $L(t_1)$ is

$$L(t_1) = ut_1 \; , \tag{26}$$

where u is the effective helicopter speed over the ground in the horizontal plane while searching, $L_i(t_1)$ in (15) becomes the linear functions

$$L_i(t_1) = (b_i/cB) \left[t_1(cu + \sum_{i=1}^{k} a_i b_i - a_i B) + Bg_i - \sum b_i g_i \right] , \tag{27}$$

where

$$a_i = (1/v_i) + (1/s_i) \ , \tag{28}$$

and

$$g_i = \ln \left[n_i v_i e^{t_o/s_i} \Big/ b_i(v_i + r_i) \right] \ . \tag{29}$$

If the coefficients of t_i in (27) are non-negative for all i, the optimal solution can be attained, or closely approximated, by the step-by-step procedure described earlier. If some of the coefficients are negative, the optimal solution may be impossible to attain if the first detection occurs late.

G. COMPARISON WITH THE CLASSICAL SEARCH PROBLEM

The optimization problem described above differs in several respects from the classical search problem associated with detecting a submerged submarine first formulated and solved by Koopman (G-1,2,3). It differs in the following ways:

1) Koopman assumes there is one and only one "target"; hence, search stops when the target is found. In the search for miners there are multiple "targets," and search continues after a detection is made. The searching conditions after a detection are not the same as the conditions that are applied before the detection. Hence, after detections have been made, the additional search is conditional on the detections that have been made.

2) Koopman assumes that the "visibility" of the target remains constant throughout the search. In our problem, the signal that is the object of the search may disappear at any time; namely, the transmitter may cease to operate.

3) Koopman assumes that the objective of the operation is detection. In the search-and-rescue operation for trapped miners, a helicopter detection is a first step only; our overall objective is to rescue as many live miners as possible.

These differences make the mine search-and-rescue problem more difficult than the classical search problem.

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