DETECTION OF TRAPPED MINER ELECTROMAGNETIC SIGNALS ABOVE COAL MINES

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prepared for

UNITED STATES DEPARTMENT OF THE INTERIOR
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by

ARTHUR D. LITTLE, INC.
Cambridge, Massachusetts

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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

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FINAL REPORT

July 1980

United States
Department of the Interior
Bureau of Mines

FOREWORD

This report was prepared by Arthur D. Little, Inc., Cambridge, Massachusetts, under USBM Contract No. J0188037. 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 H0346045, 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.

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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

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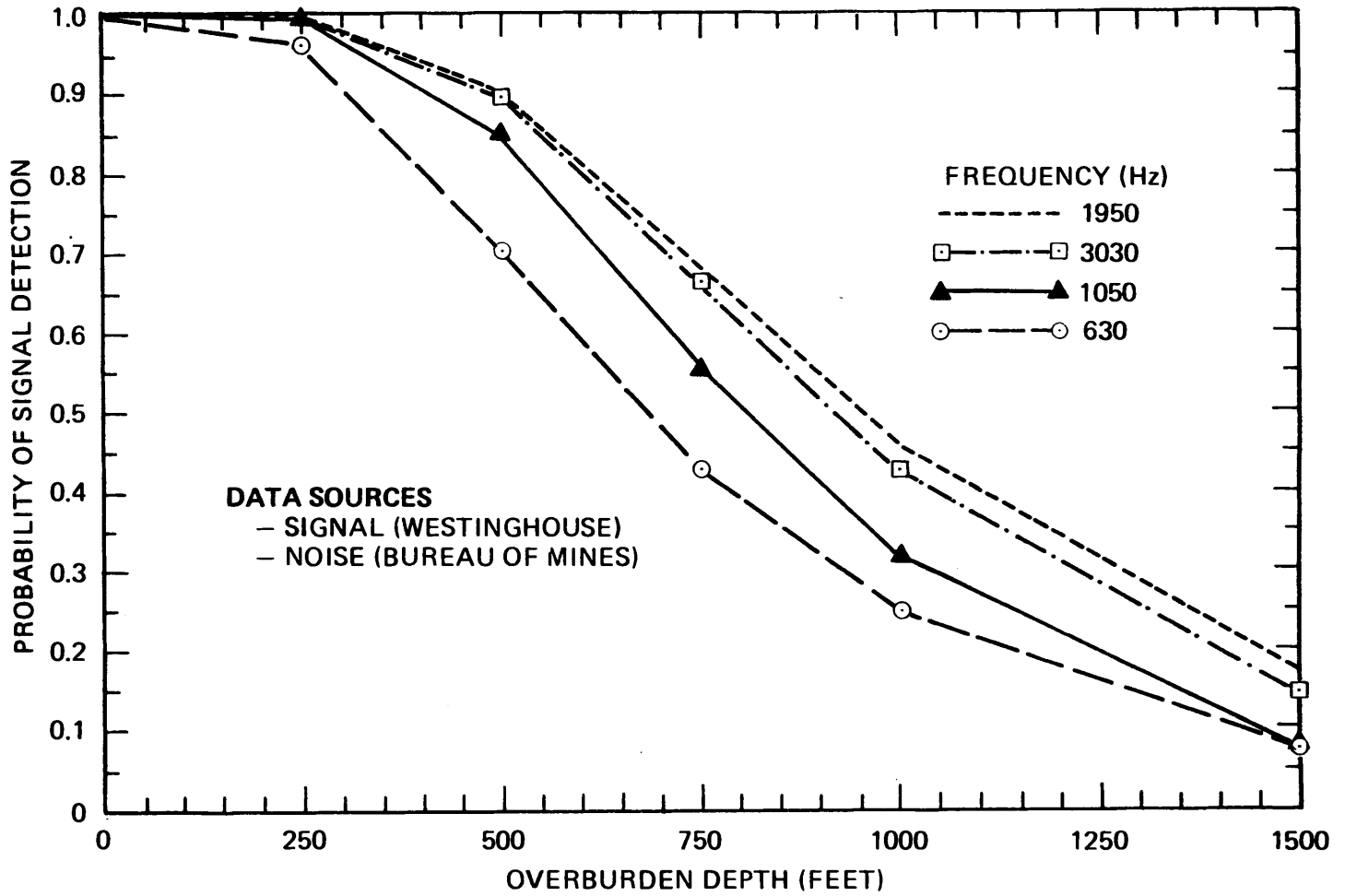
FIGURE I-1   PREDICTED PROBABILITY OF SIGNAL DETECTION VERSUS OVERBURDEN DEPTH BY FREQUENCY FOR THE GENERAL INSTRUMENTS TRANSMITTER

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 Instru-
ments transmitter. Section VII characterizes the statistical distri-
bution 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

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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.

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RECEIVING LOOP ANTENNA

SURFACE

MAGNETIC FIELD LINES

OVERBURDEN

Coal Seam

MINE

TRANSMITTING LOOP ANTENNA
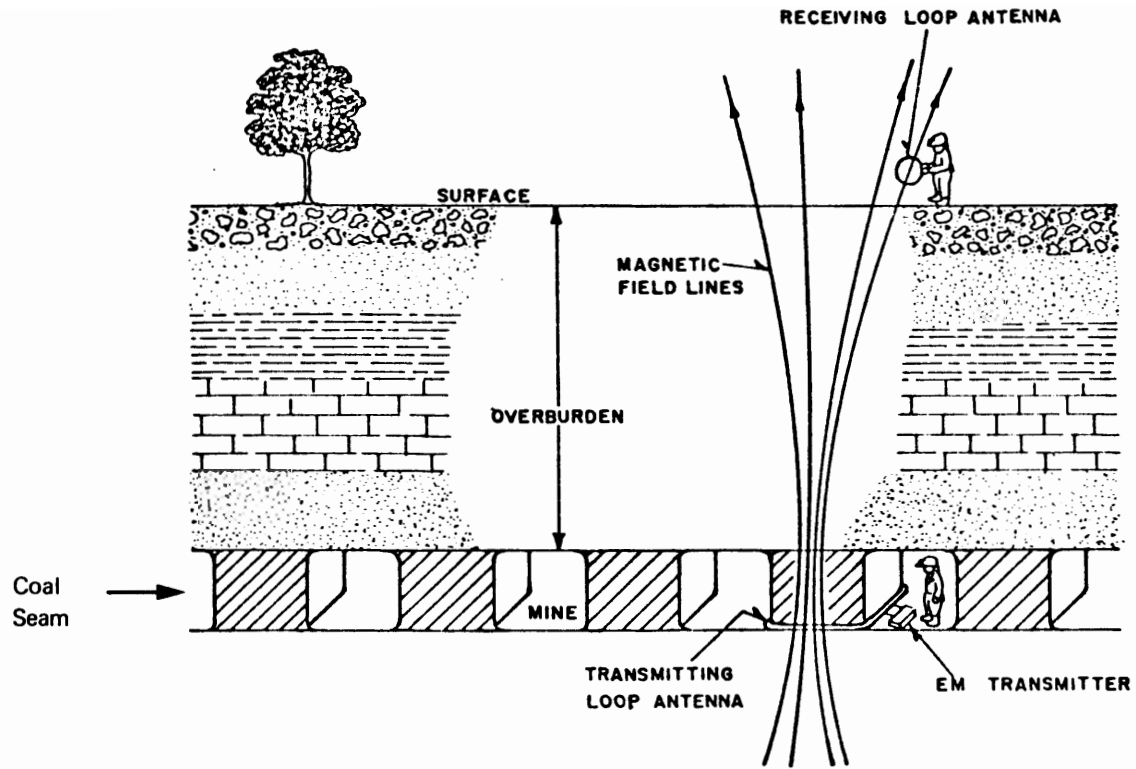
EM TRANSMITTER

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

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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 success-
ful performance of the EM trapped-miner signaling system. A trans-
mission 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 pre-
designated 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: Westing-
house 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 represen-
tative 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

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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 over-burden 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:

$$n_h = n \frac{N_h S_h}{\sum N_h S_h} \tag{1}$$

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).

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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		3,359
201 – 300	166	6	} 4%	7,669
301 – 400	203	8		10,837
401 – 500	169	17		13,093
501 – 600	140	14		8,113
601 – 700	115	11	} 10%	10,791
701 – 800	84	8		7,055
801 – 900	78	8		10,631
901 – 1000	57	6		6,746
1001 – 1200	58	8		8,163
1201 – 1400	34	5		5,865
1401 – 1600	15	2	} 15%	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:

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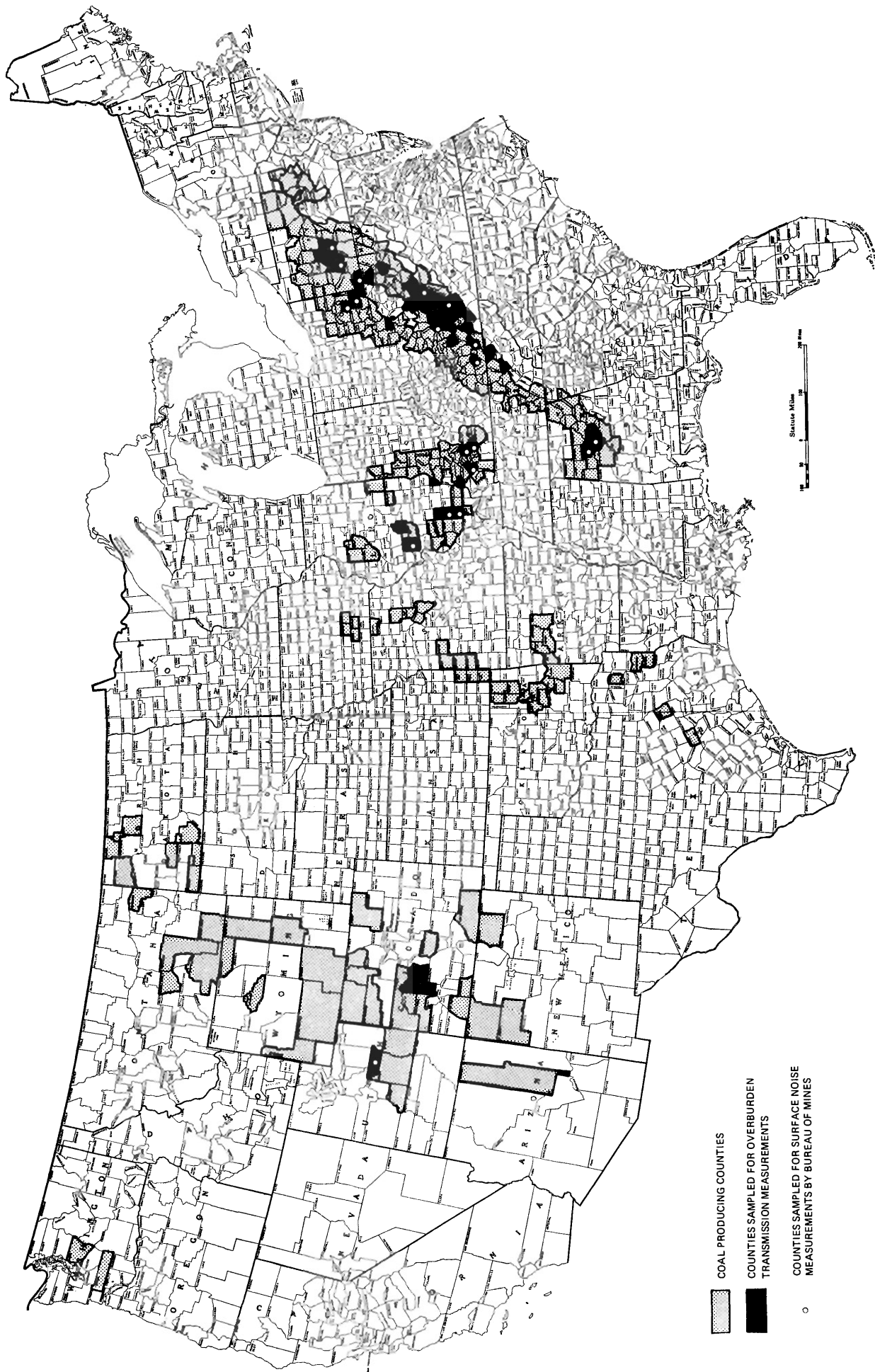
FIGURE III-1 GEOGRAPHICAL DISTRIBUTION OF MINES SAMPLED BY COUNTY IN U.S. COAL FIELDS

COAL PRODUCING COUNTIES

COUNTIES SAMPLED FOR OVERBURDEN TRANSMISSION MEASUREMENTS

COUNTIES SAMPLED FOR SURFACE NOISE MEASUREMENTS BY BUREAU OF MINES

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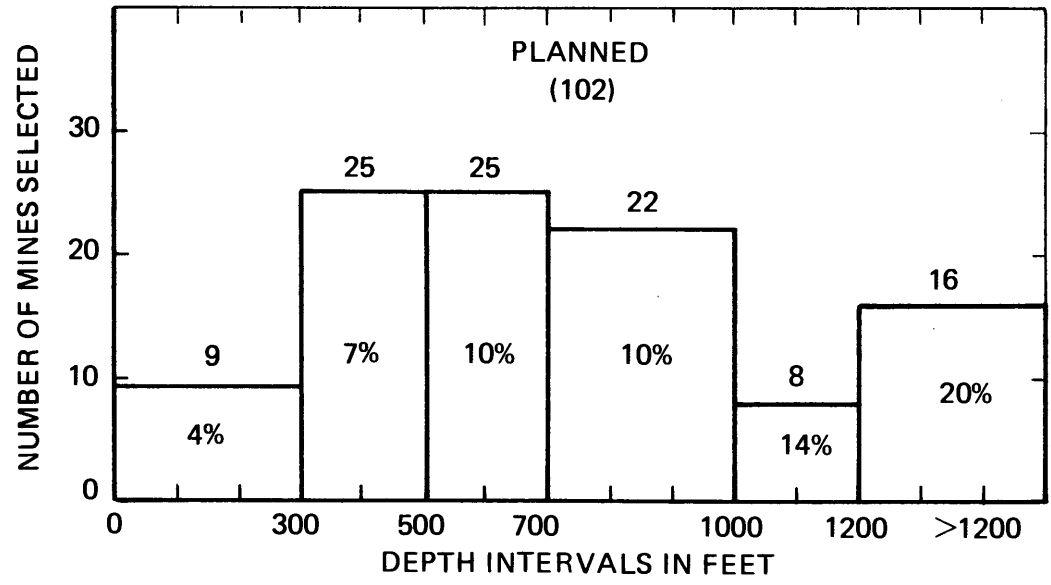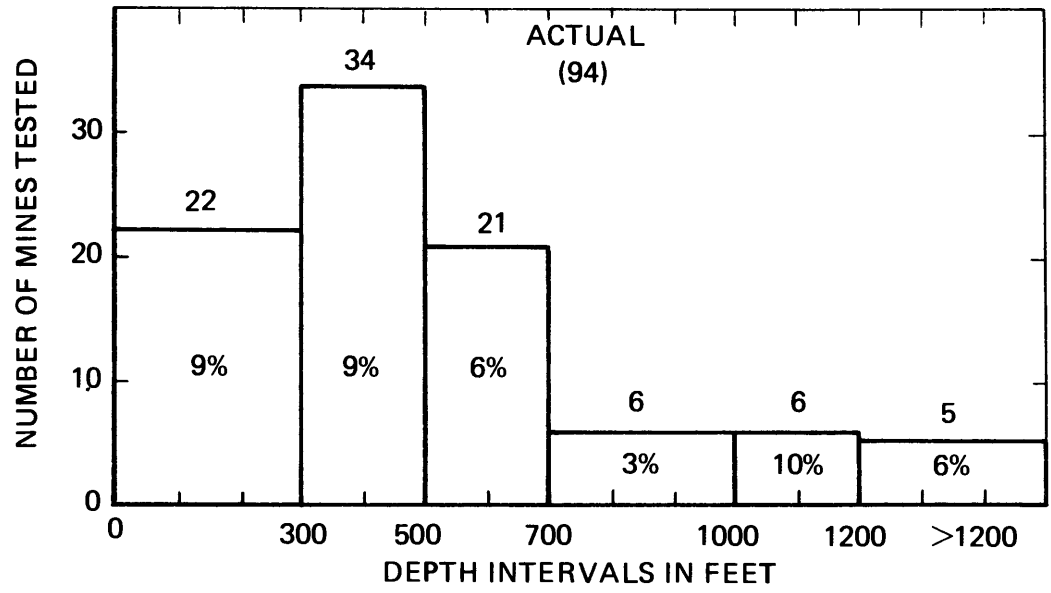
FIGURE III-2   DISTRIBUTION OF MINES SELECTED BY
MAXIMUM OVERBURDEN DEPTH

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 cf some over-burden 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.

SUBSURFACE EQUIPMENT

(Transmit)

SURFACE EQUIPMENT
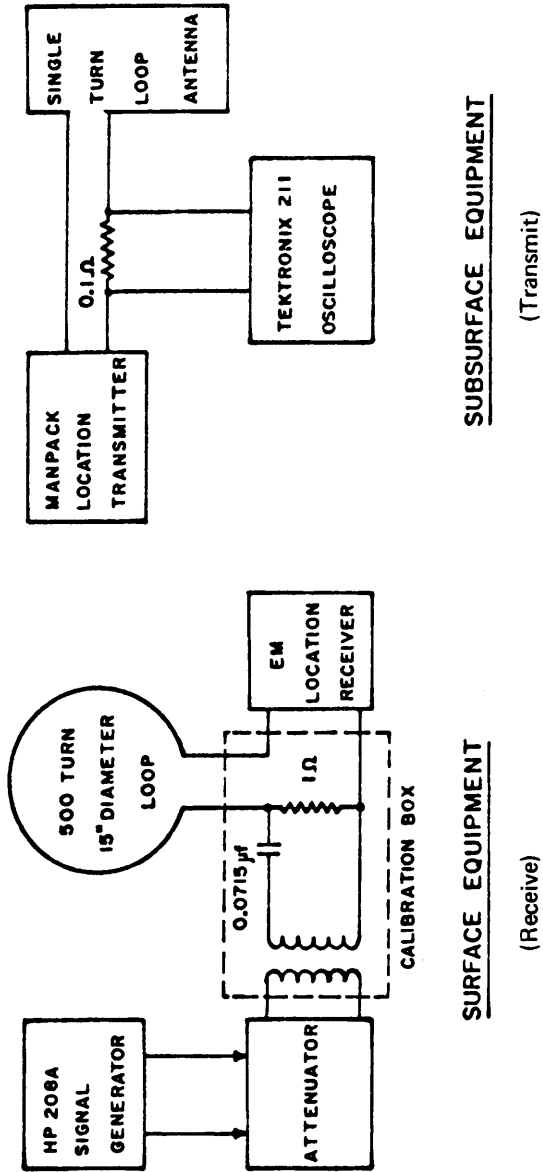
(Receive)

Source: Westinghouse, Ref. 1

FIGURE III-3 UPLINK TRANSMIT/RECEIVE MEASUREMENT EQUIPMENT

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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

FIGURE III-4   SURFACE SEARCHER USING RESCUE RECEIVER HARDWARE
(Loop antenna oriented for miner localization — rotate 90° for miner detection)

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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.

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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 cf 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 environ-
mental 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.

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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

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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, Δ TL, 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:

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

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

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

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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:

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- 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 $\left|-4\right|$ dB; negative transmission losses less than $\left|-4\right|$ 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.

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- 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

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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.)	630	1050	1950	3030
					Frequency (Hz)	
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.

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Table IV-1(Continued)

			Frequency (Hz)			
Mine No.	State	Depth (ft.)	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

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Table **IV-1** (Continued)

Mine No.	State	Depth (ft.)	630	Frequency (Hz) 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

Mine No.	State	Depth (ft.)	Frequency (Hz) 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]

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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]

Arthur D Little, Inc.

Table IV-3(continued)

Mine No.	State	Depth (ft.)	Frequency (Hz)			
			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

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Arthur D. Little, Inc.

Table IV-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

[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, $TLU \geq -4$ dB; i.e.: SEMF $\geq$ 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]

Arthur D Little, Inc.

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)

Mine No.	State	Depth (ft.)	Frequency (Hz)			
			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

[1] Defective surface receiver

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

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

[4] Transmission loss, $TLU| \geq -4 |dB$; i.e.: $SEMF \geq$ 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 over-head 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

Table IV-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

Mine No.	State	Depth (ft.)	Frequency (Hz)			
			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]

Arthur D. Little, Inc.

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

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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 Δ TL,
- 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

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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 agree-
ment. Furthermore, the frequency behavior of the Bureau cf 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

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

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

Mine No.	State	Depth (ft.)	Frequency (Hz)			
			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]

Arthur D. Little, Inc.
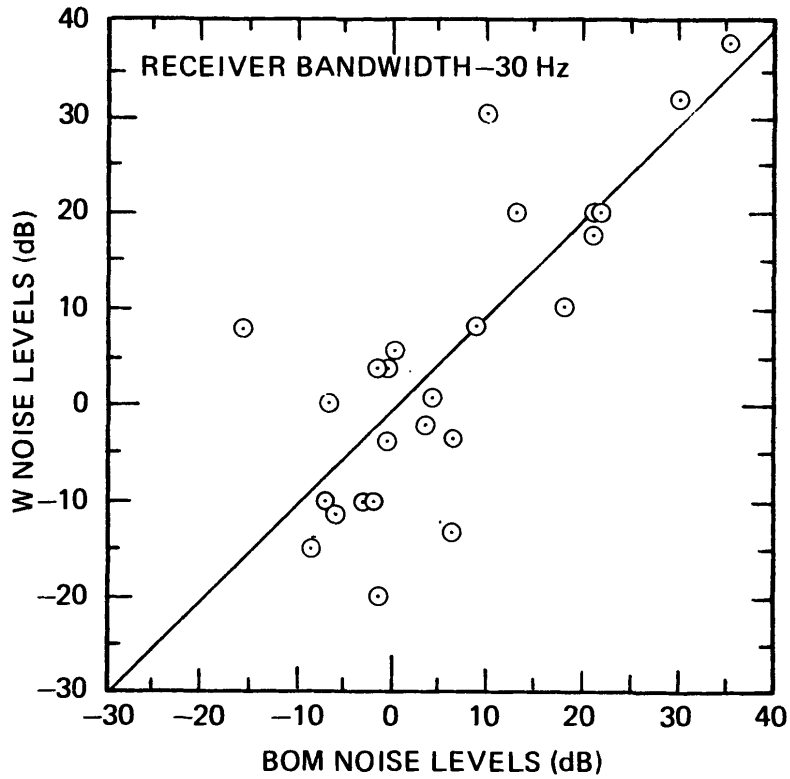
FIGURE IV-1 COMPARISON OF WESTINGHOUSE
AND BUREAU OF MINES MEASURED
NOISE LEVELS (dBre 1μA/m/$\sqrt{30}$ Hz)
FOR 27 MINES AT 630 Hz
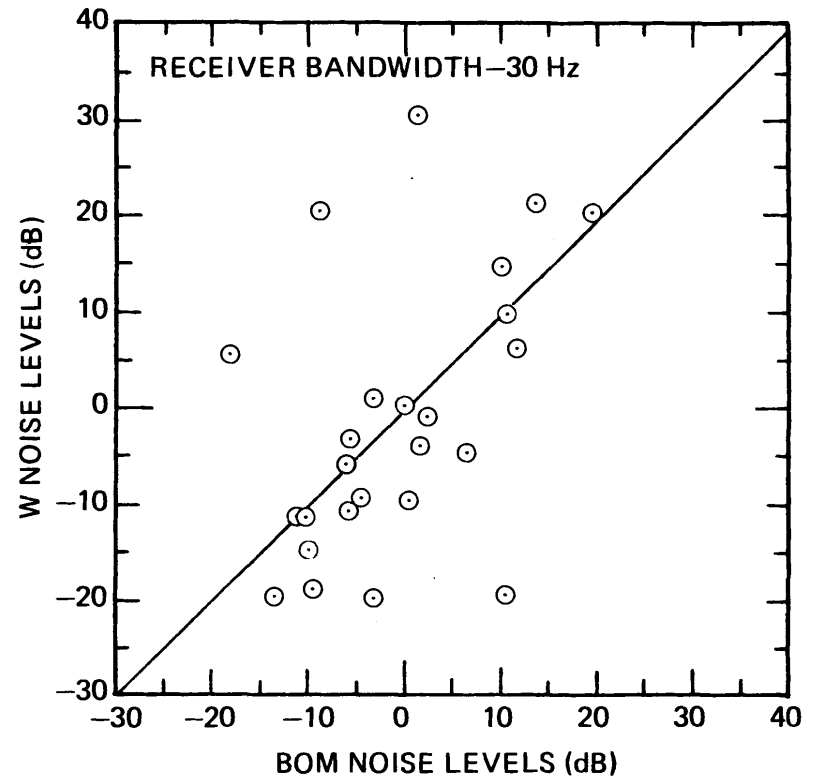
FIGURE IV-2 COMPARISON OF WESTINGHOUSE
AND BUREAU OF MINES MEASURED
NOISE LEVELS (dBre 1μA/m$\sqrt{30}$ Hz)
FOR 27 MINES AT 1050 Hz
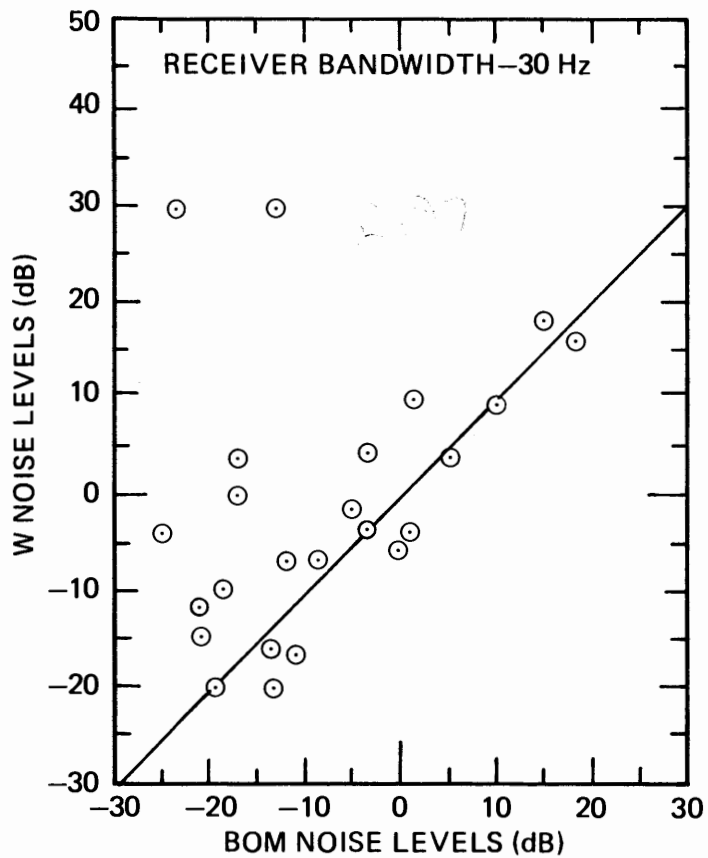
FIGURE IV-3   COMPARISON OF WESTINGHOUSE AND BUREAU OF MINES MEASURED NOISE LEVELS (dBre 1µA/m/√30 Hz) FOR 27 MINES AT 1950 Hz
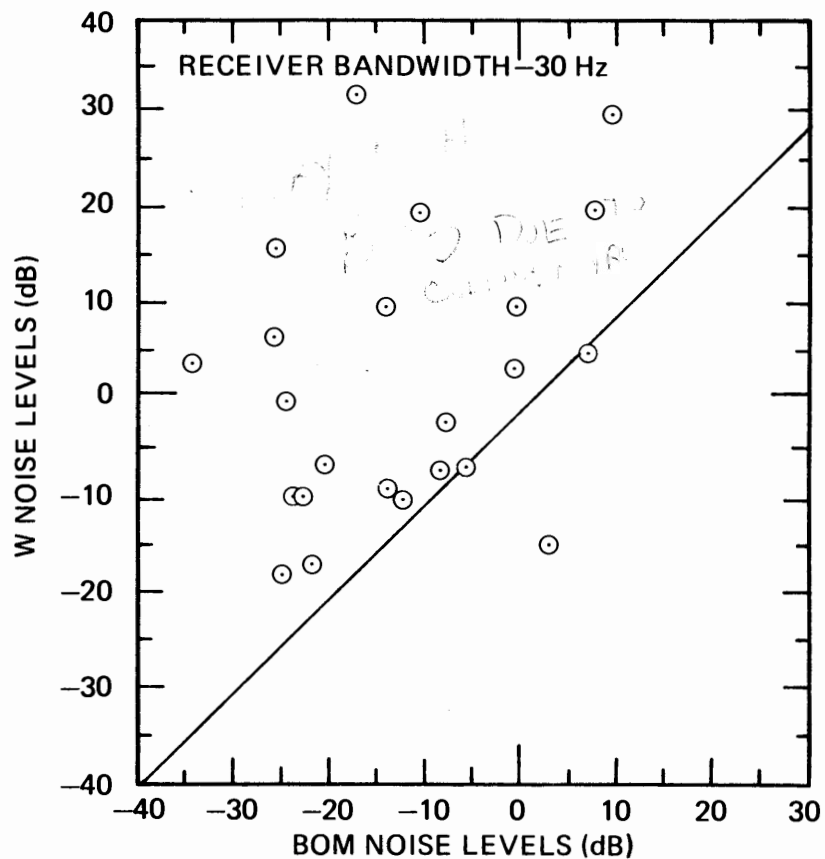
FIGURE IV-4   COMPARISON OF WESTINGHOUSE AND BUREAU OF MINES MEASURED NOISE LEVELS (dBre 1µA/m/√30 Hz) FOR 27 MINES AT 3030 Hz

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:

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- 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/$\sqrt{30}$ 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:

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- Between approximately 500 and 5,000 Hz, the earth iono- sphere waveguide exhibits a maximum in attenuation rate which significantly attenuates atmospheric noise contri- butions 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 thunder- storm 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.

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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 assump-
tion that the vertical magnetic field levels are at least propor-
tional 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 wide-
spread 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

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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 over-burdens, 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

$$\frac{\overline{H}_z}{M} = F(D, f)$$

M (arrow)

(Mine)

NETWORK OF COAL MINE OVERBURDENS

+

H_z (Surface)

−
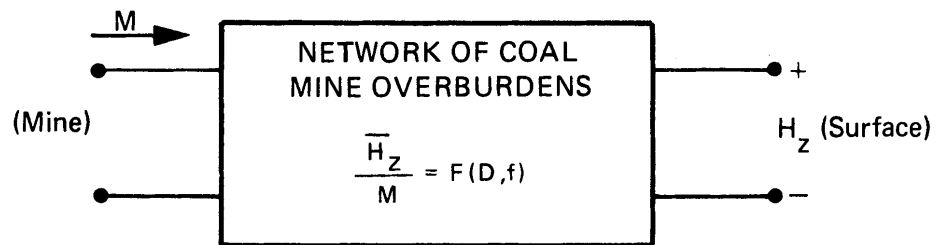
FIGURE V–1   TWO TERMINAL PAIR NETWORK ANALOGY FOR CHARACTERIZATION OF OVERBURDEN SIGNAL TRANSMISSION RESPONSE

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 trans- mitted signal which is capable of being detected by the narrow- band 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.

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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).

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

where:

S_{ij} is the normalized vertical magnetic field signal strength (expressed in dB re 1 μA/m) for the ith 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 (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?

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- Does the inverse cubic relationship suggested by simple dc magnetostatic theory apply; that is, does β_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):

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

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

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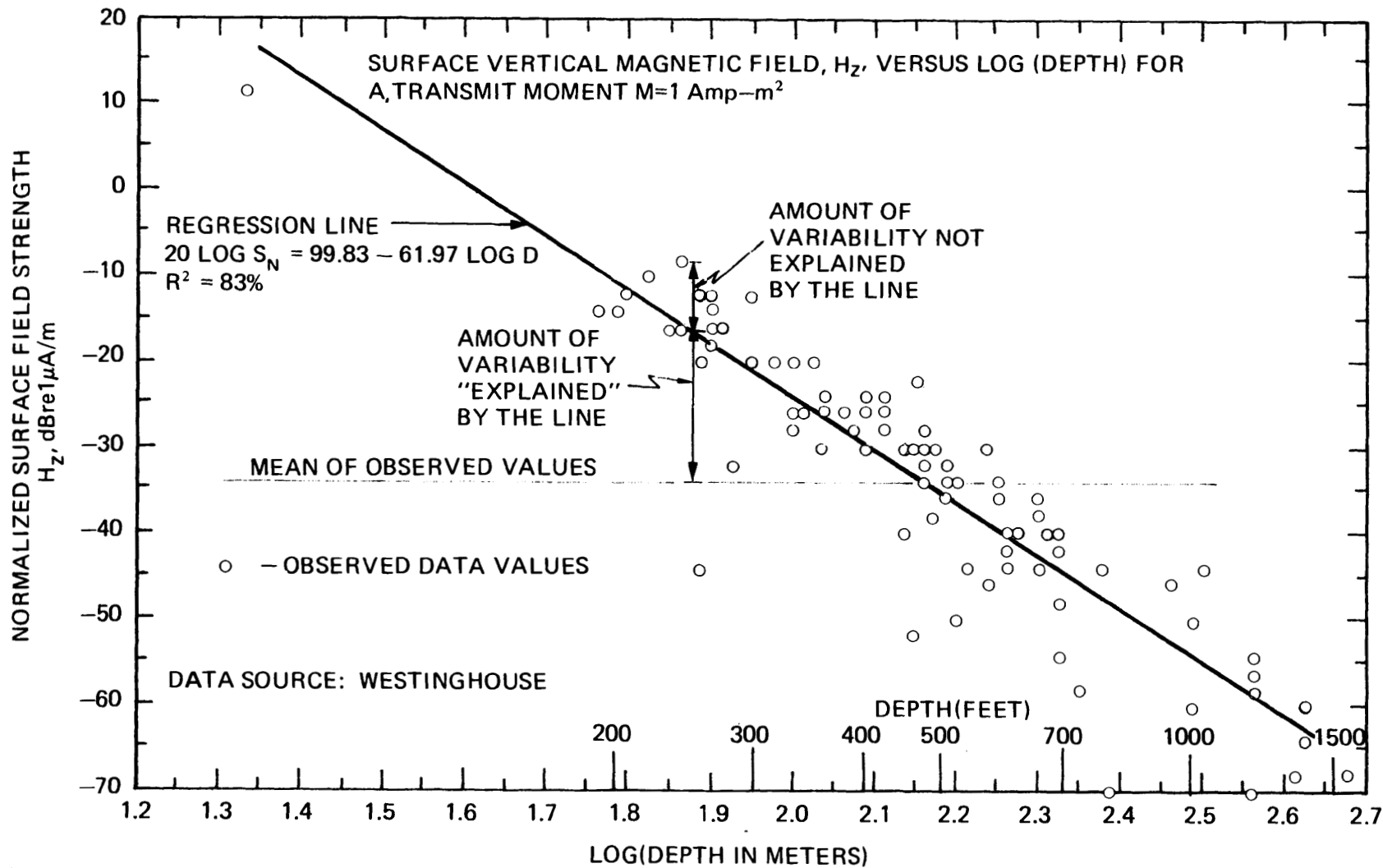
FIGURE V-2   UPLINK NORMALIZED OVERBURDEN SIGNAL RESPONSE DATA AND
LINEAR REGRESSION LOG(DEPTH) MODEL AT 630 Hz

NORMALIZED SURFACE FIELD STRENGTH
H_z, dBre1μA/m

SURFACE VERTICAL MAGNETIC FIELD, H_z, VERSUS LOG (DEPTH) FOR
A TRANSMIT MOMENT M=1 Amp–m^2

REGRESSION LINE
20 LOG S_N = 110.27 – 67.11 LOG D
R^2 = 85%

○ — OBSERVED DATA VALUES

LOG (DEPTH IN METERS)

DEPTH(FEET)
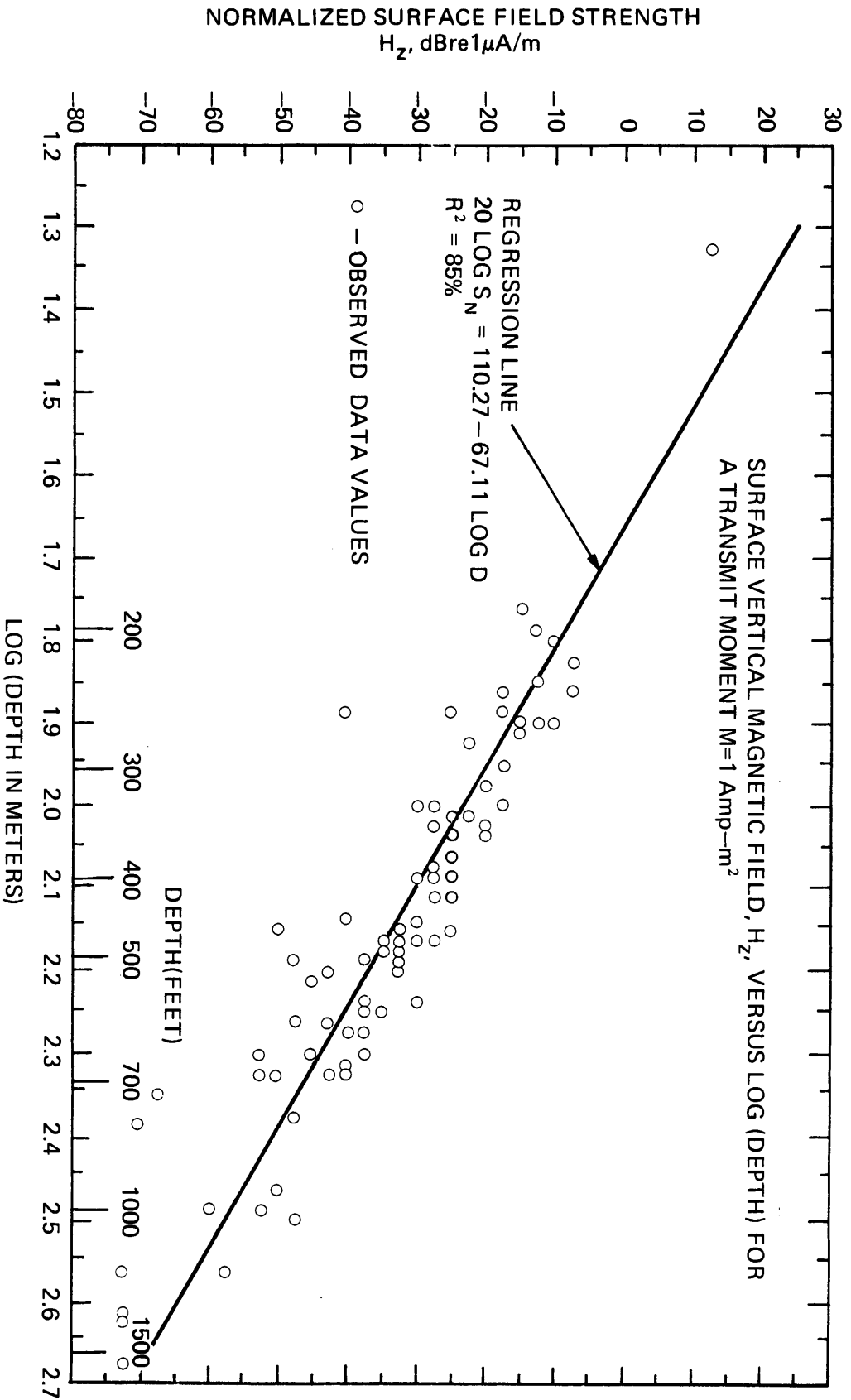
**FIGURE V-3   UPLINK NORMALIZED OVERBURDEN SIGNAL RESPONSE DATA AND
LINEAR REGRESSION LOG(DEPTH) MODEL AT 1050 Hz**
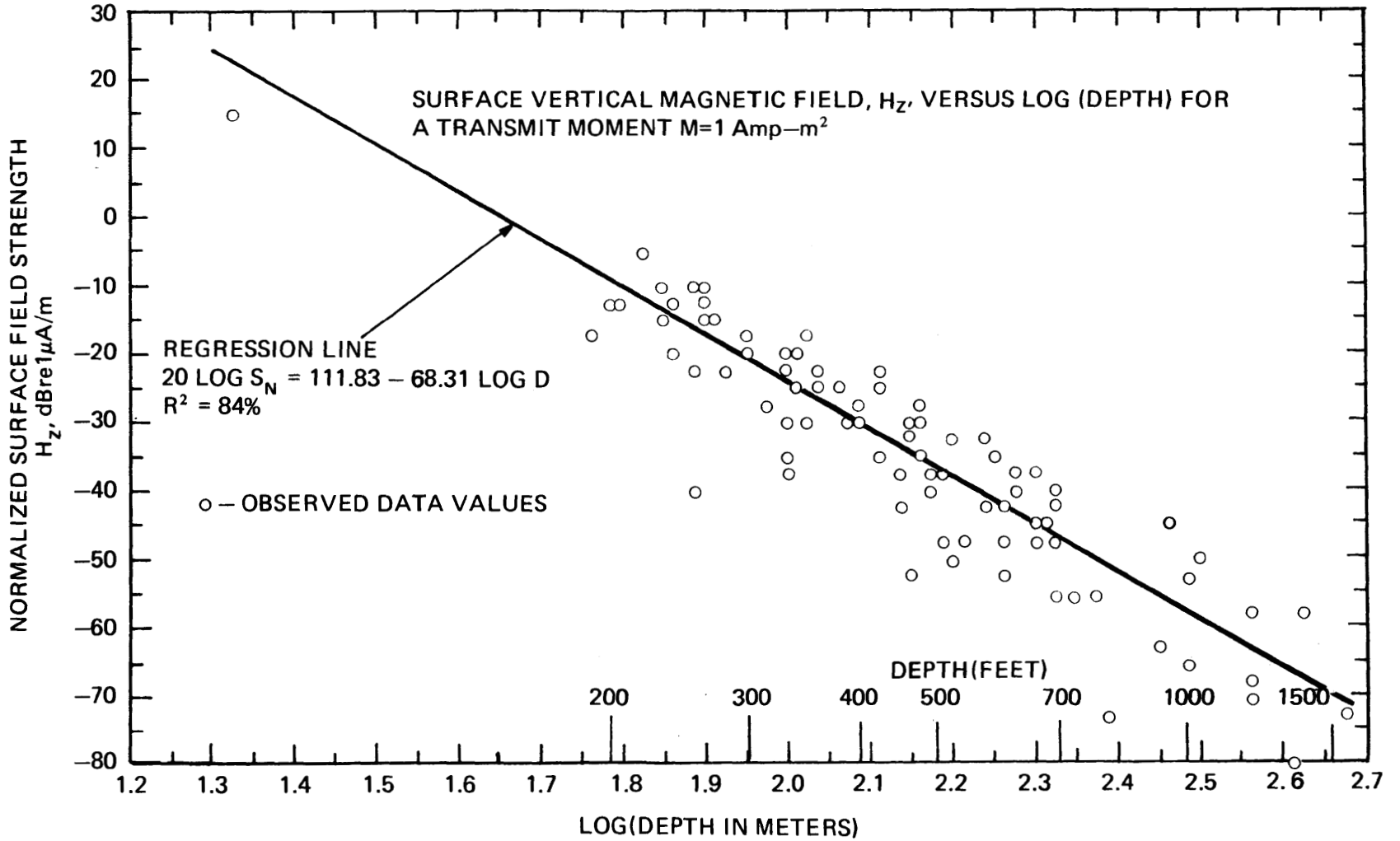
FIGURE V-4   UPLINK NORMALIZED OVERBURDEN SIGNAL RESPONSE DATA AND
LINEAR REGRESSION LOG(DEPTH) MODEL AT 1950 Hz
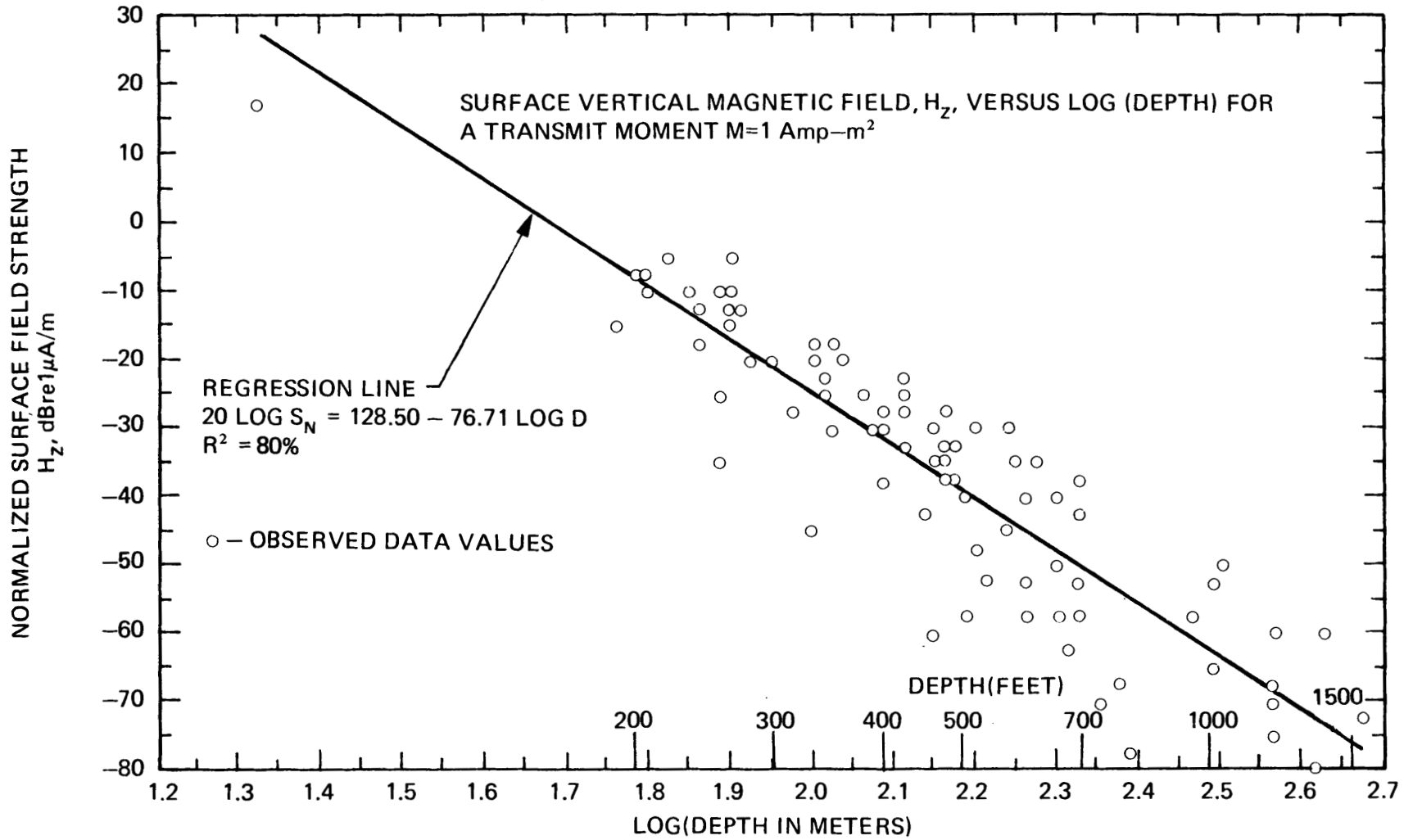
FIGURE V-5   UPLINK NORMALIZED OVERBURDEN SIGNAL RESPONSE DATA AND
LINEAR REGRESSION LOG(DEPTH) MODEL AT 3030 Hz

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:

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

where S_{EST} is the linear (regression) estimate, S_{OBS} is the observed signal value, and $\bar{S}$ 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

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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:

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

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 <u>average</u> 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

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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:

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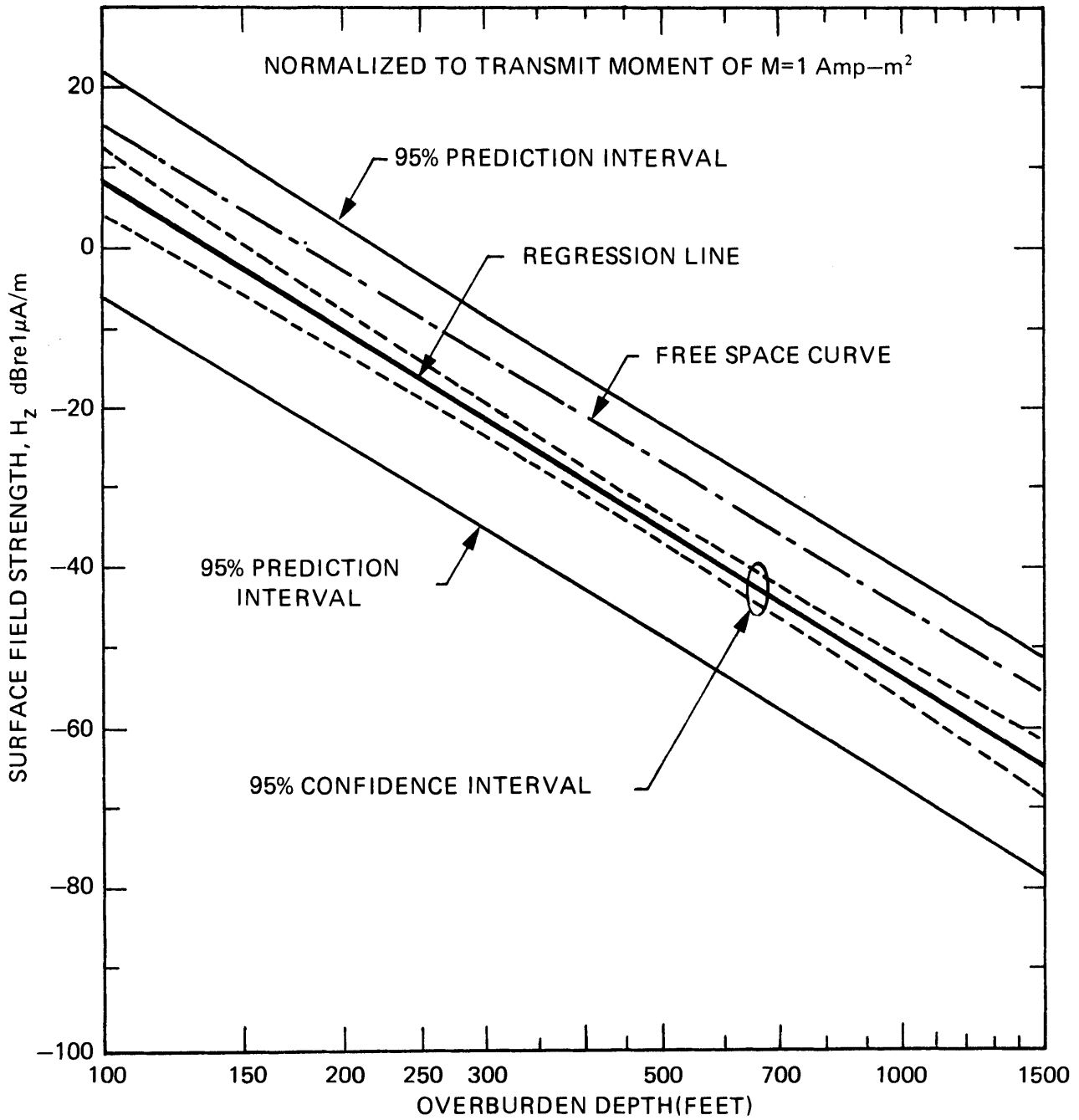
FIGURE V-6   UPLINK REGRESSION RESULTS FOR 630 Hz—NORMALIZED
VERTICAL SIGNAL STRENGTH, H_z, VERSUS DEPTH

The figure shows a plot of SURFACE FIELD STRENGTH, H_z dBre1μA/m (y-axis, from −100 to 20) versus OVERBURDEN DEPTH(FEET) (x-axis, from 100 to 1500). Labels include: NORMALIZED TO TRANSMIT MOMENT OF M=1 Amp–m², 95% PREDICTION INTERVAL, REGRESSION LINE, FREE SPACE CURVE, 95% PREDICTION INTERVAL, 95% CONFIDENCE INTERVAL.

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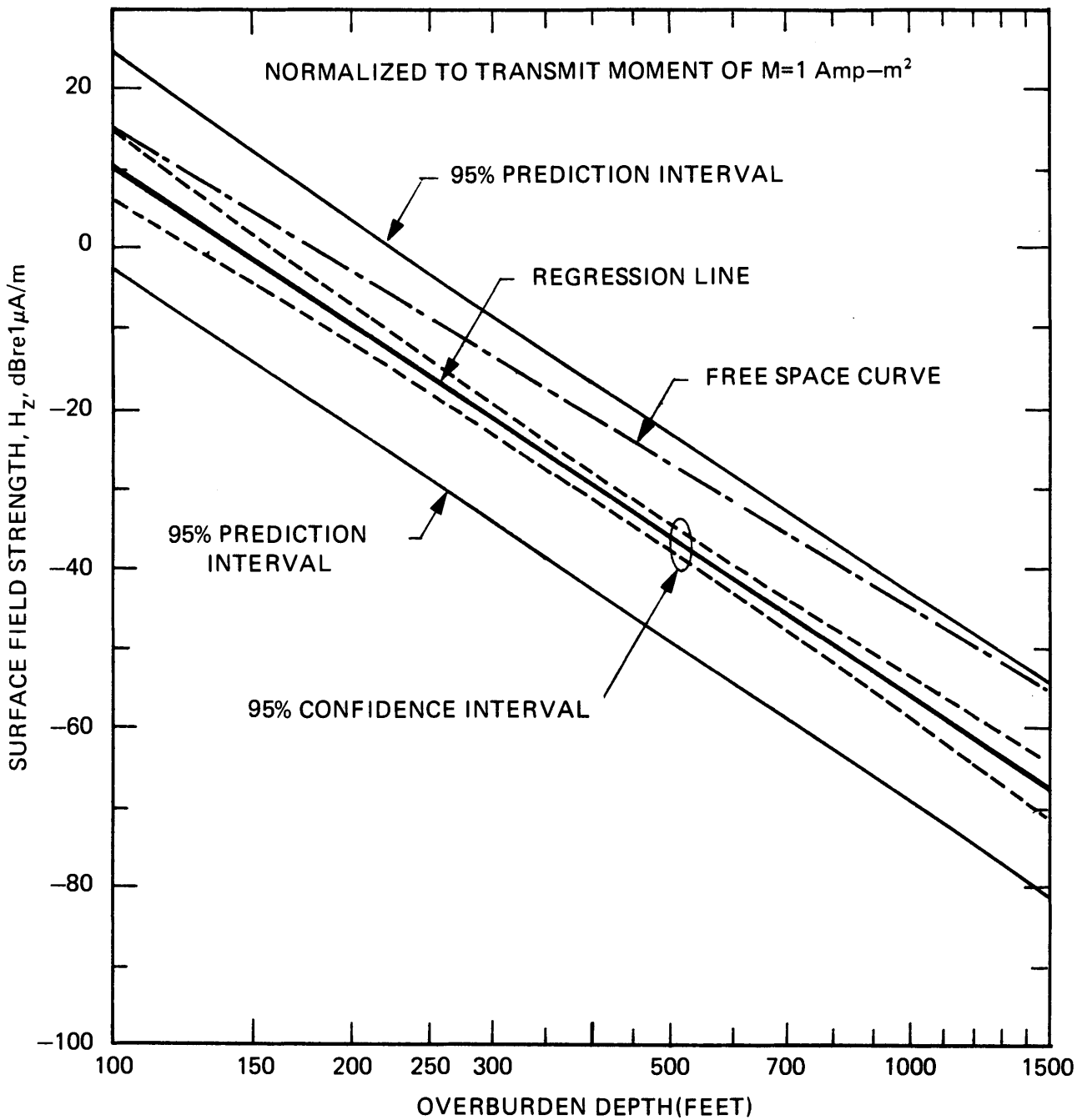
FIGURE V-7 **UPLINK REGRESSION RESULTS FOR 1050 Hz—NORMALIZED VERTICAL SIGNAL STRENGTH, H_z, VERSUS DEPTH**

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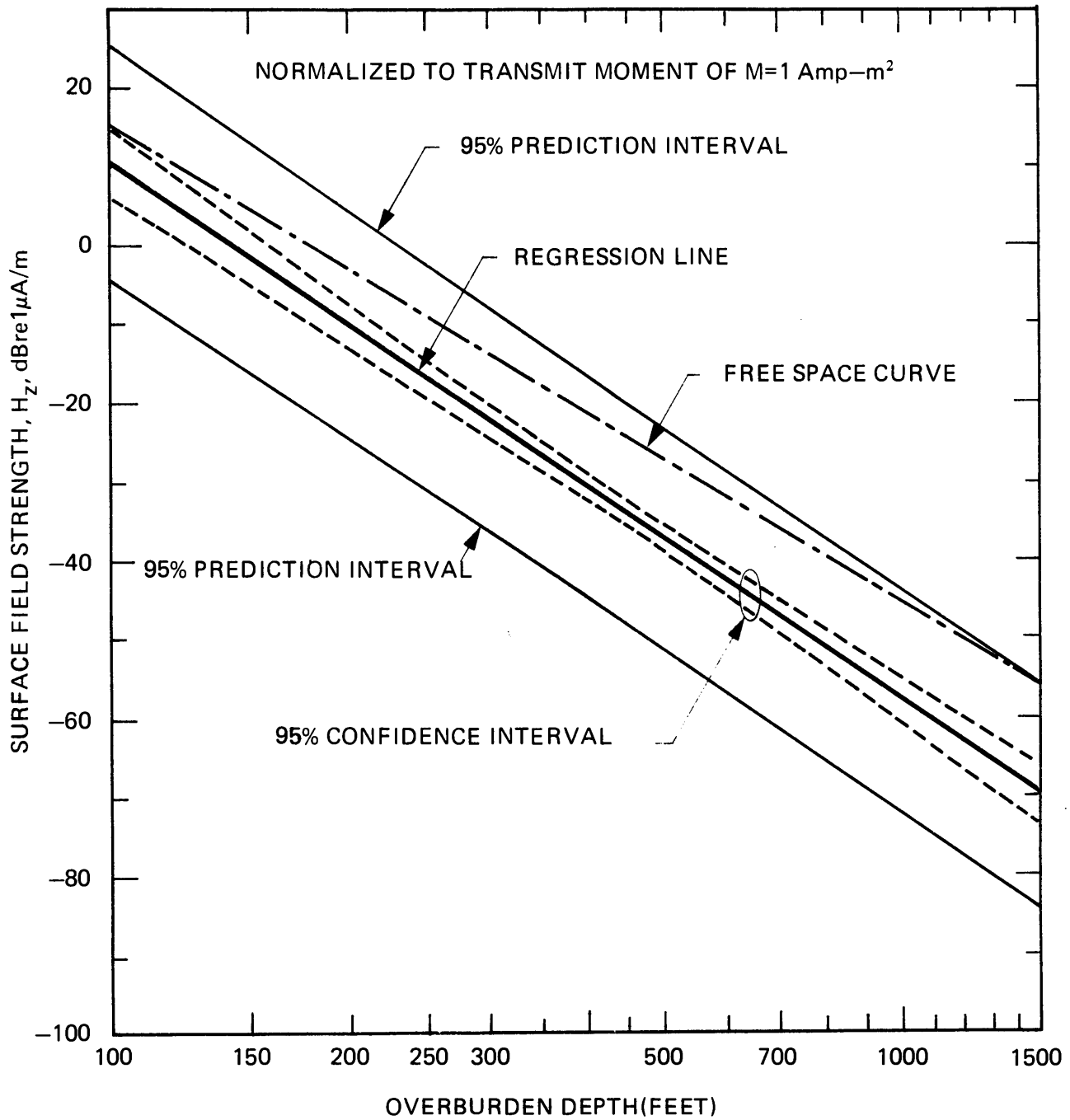
FIGURE V-8   UPLINK REGRESSION RESULTS FOR 1950 Hz—NORMALIZED
VERTICAL SIGNAL STRENGTH, H_z, VERSUS DEPTH

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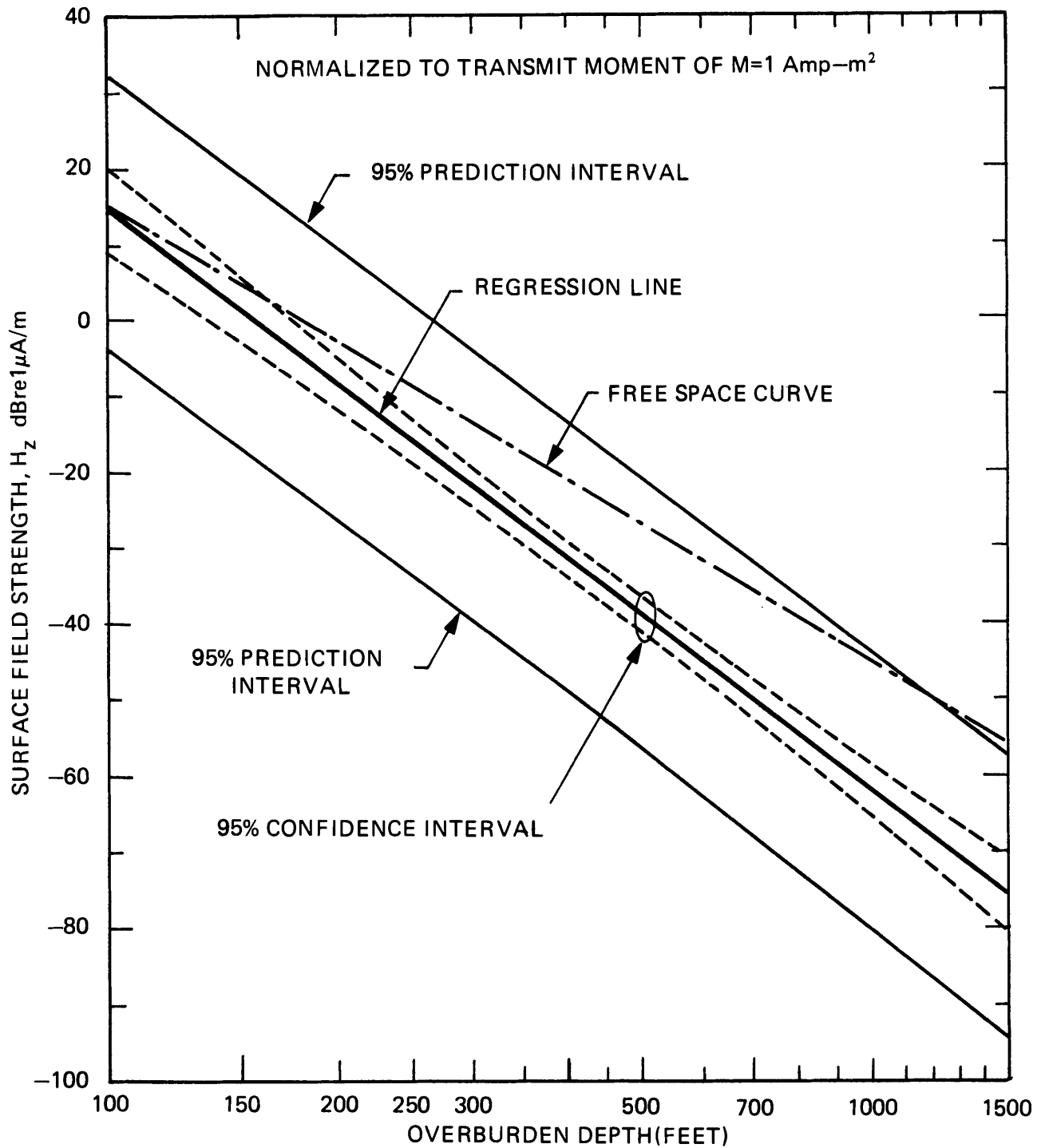
FIGURE V-9 UPLINK REGRESSION RESULTS FOR 3030 Hz—NORMALIZED VERTICAL SIGNAL STRENGTH, H_z, VERSUS DEPTH

The plot is titled "NORMALIZED TO TRANSMIT MOMENT OF M=1 Amp—m^2". The y-axis is labeled "SURFACE FIELD STRENGTH, H_z dBre1μA/m" ranging from −100 to 40. The x-axis is labeled "OVERBURDEN DEPTH(FEET)" ranging from 100 to 1500. Curves labeled: 95% PREDICTION INTERVAL, REGRESSION LINE, FREE SPACE CURVE, 95% PREDICTION INTERVAL, 95% CONFIDENCE INTERVAL.

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

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 trans- mission 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

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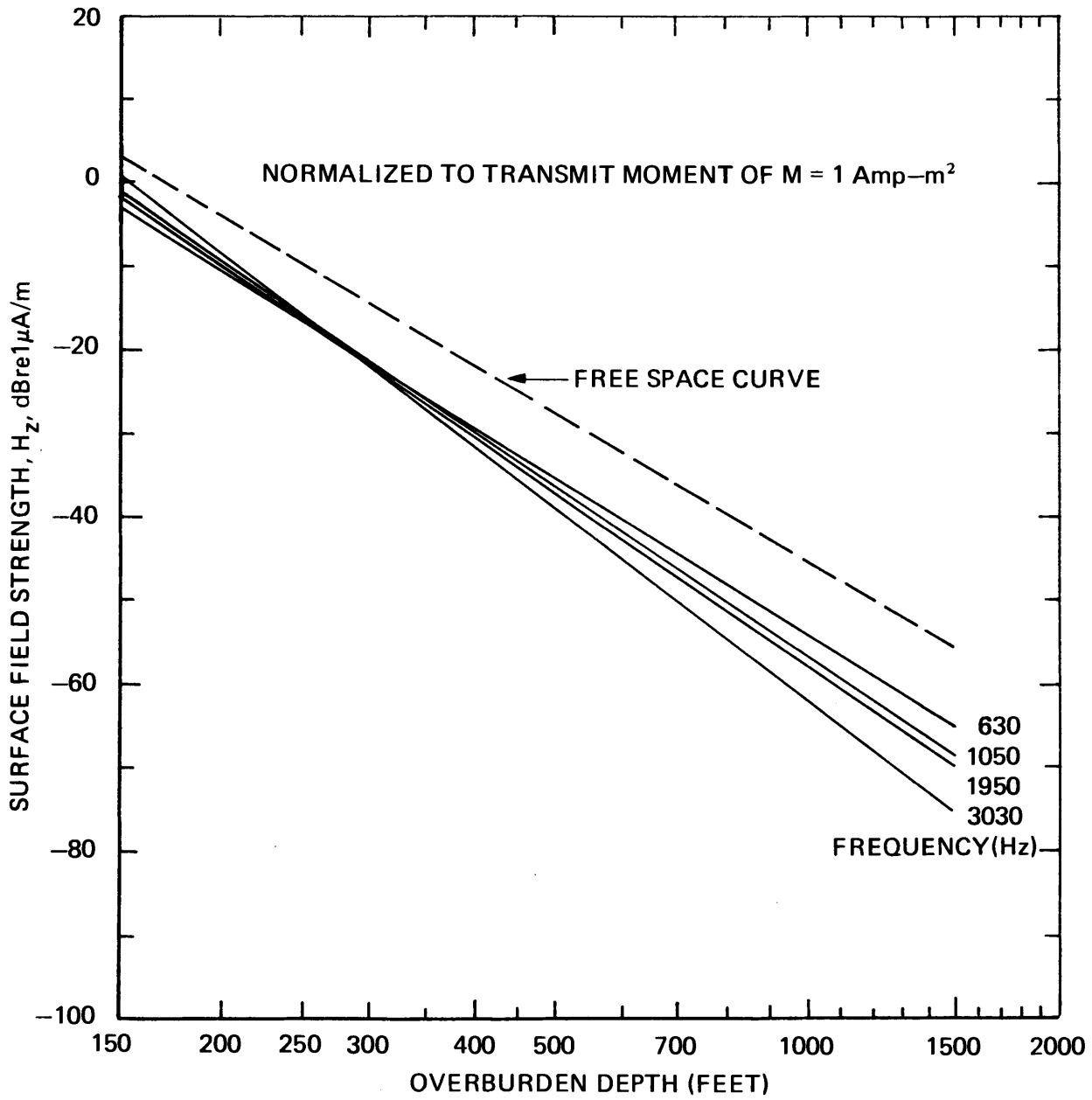
FIGURE V-10   NORMALIZED OVERBURDEN RESPONSE CURVES—UPLINK
REGRESSION RESULTS, AVERAGE SURFACE VERTICAL
SIGNAL STRENGTH, H_z, VERSUS OVERBURDEN DEPTH BY
FREQUENCY

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 question-able signal measurements, without replacements according to the
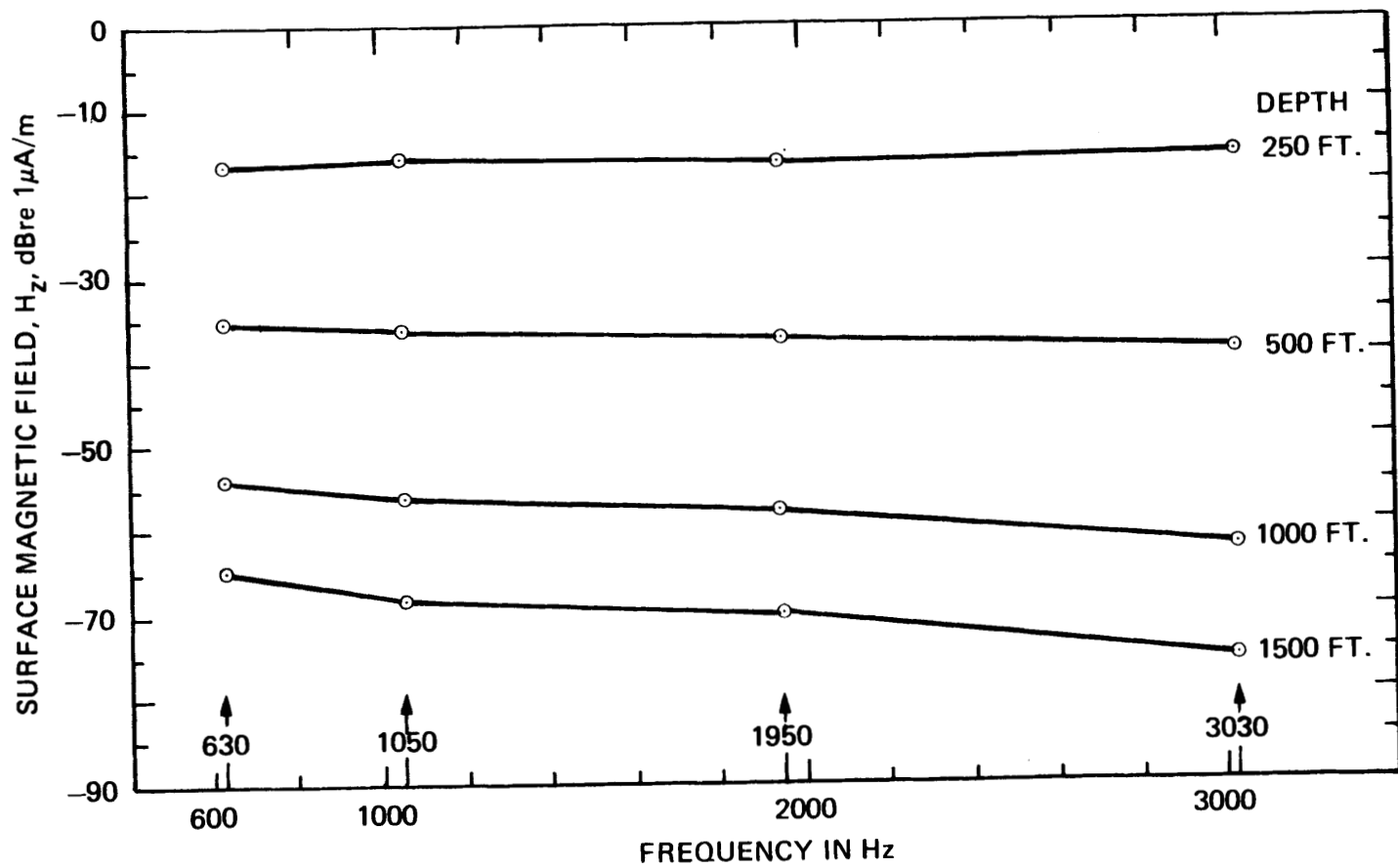
FIGURE V-11   NORMALIZED SURFACE VERTICAL MAGNETIC FIELD, H_z, VS FREQUENCY WITH DEPTH AS A PARAMETER

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:

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

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.

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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.

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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.

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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

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case, since the model explicitly takes into account <u>random</u>
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–m²)	(dB/1A–m²)
630	665	56.5
1050	617	55.8
1950	498	54.0
3030	383	51.7

FREQUENCY (Hz)
630
1050
1950
3030
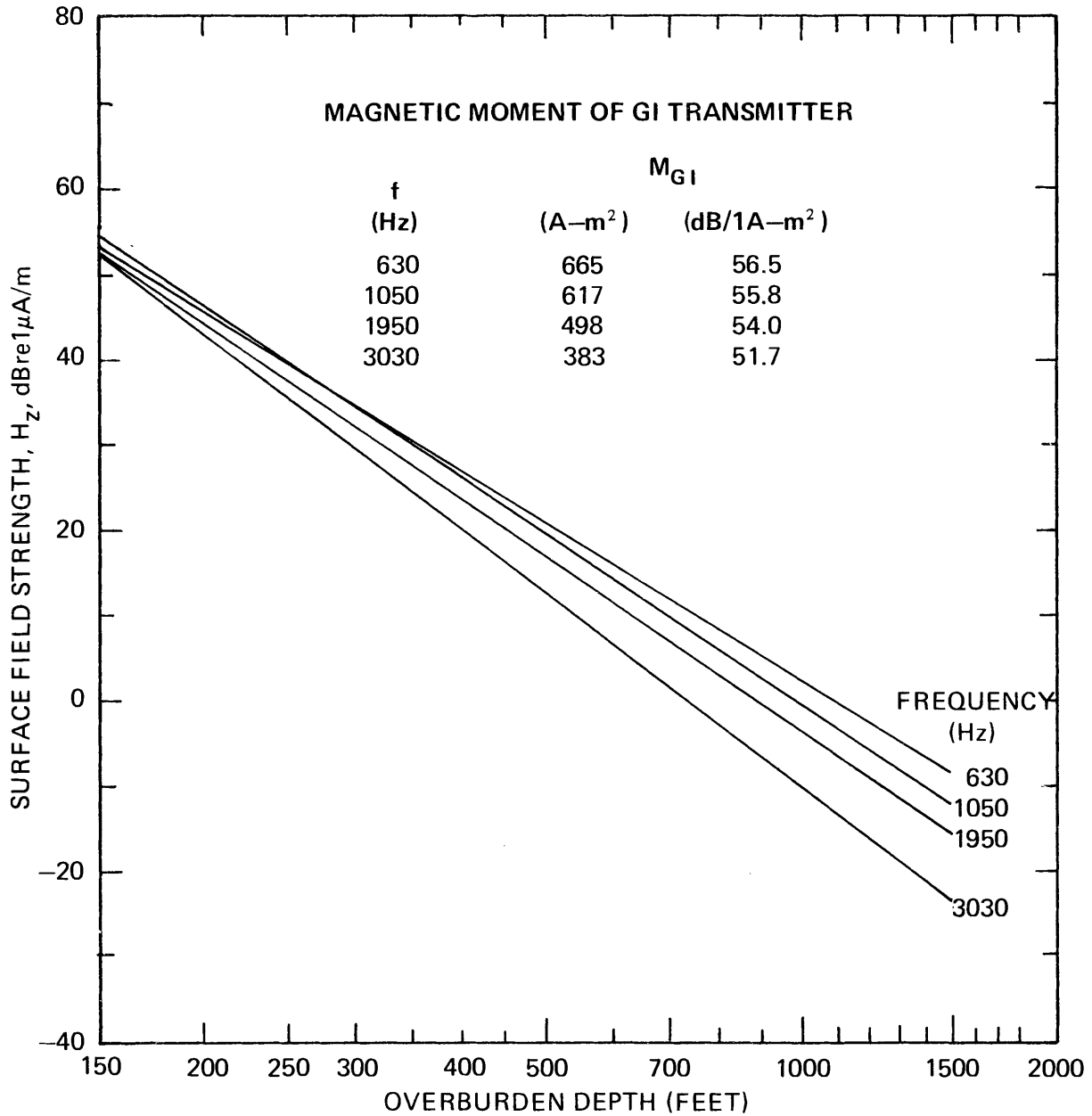
FIGURE VI-1   PREDICTED UPLINK RESPONSE CURVES FOR GENERAL
INSTRUMENTS TRANSMITTER—AVERAGE SURFACE
VERTICAL MAGNETIC FIELD SIGNAL STRENGTH, H_z,
VS DEPTH BY FREQUENCY

loop antenna area with the available wire. Table VI-1 presents
the loop impedance, current, and magnetic moment values calcu-
lated 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

Frequency (Hz)	Loop Impedance		Transmitter Current/Moment		
	R_L (Ohms) for 300 ft. #18 wire	X_L (Ohms) fcr L_I = 136 μH	$\|I\|$ Fund RMS (Amps)	$\|M\|$ Fund RMS (Amp-m^2)	$\|M\|$ 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

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

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

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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

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lowest value the rank n (where n is the total number of obser-
vations), 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 _any_ 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.

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Table VII-1

Illustrative Example for Calculating
Plot Points for Analysis of Noise Data

Noise (dB) (re 1 μA/m/ 30Hz)	Rank (inverse order)	Cumulative conditional probability function	Cumulative distribution function
x	K(x)	H(x)	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.

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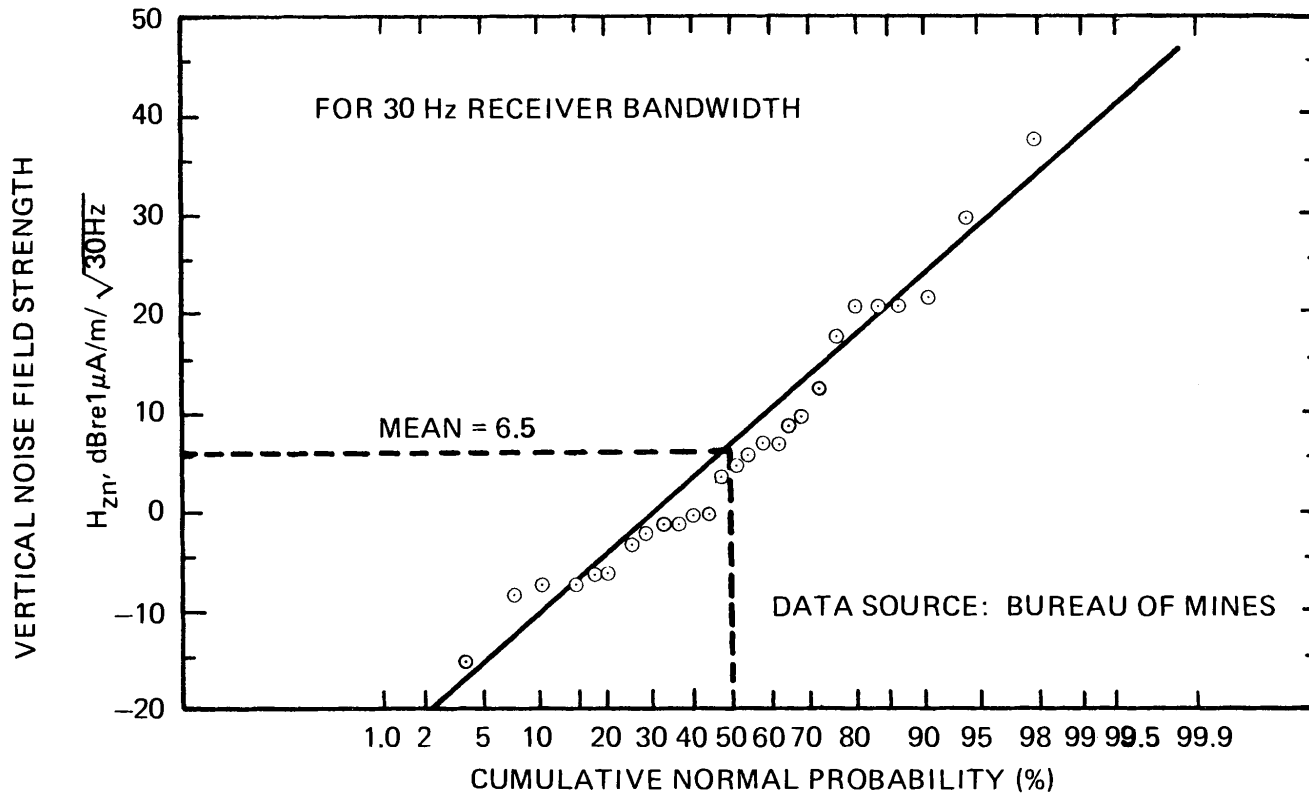
FIGURE VII-1   STATISTICAL DISTRIBUTION OF RMS SURFACE NOISE AT 630 Hz
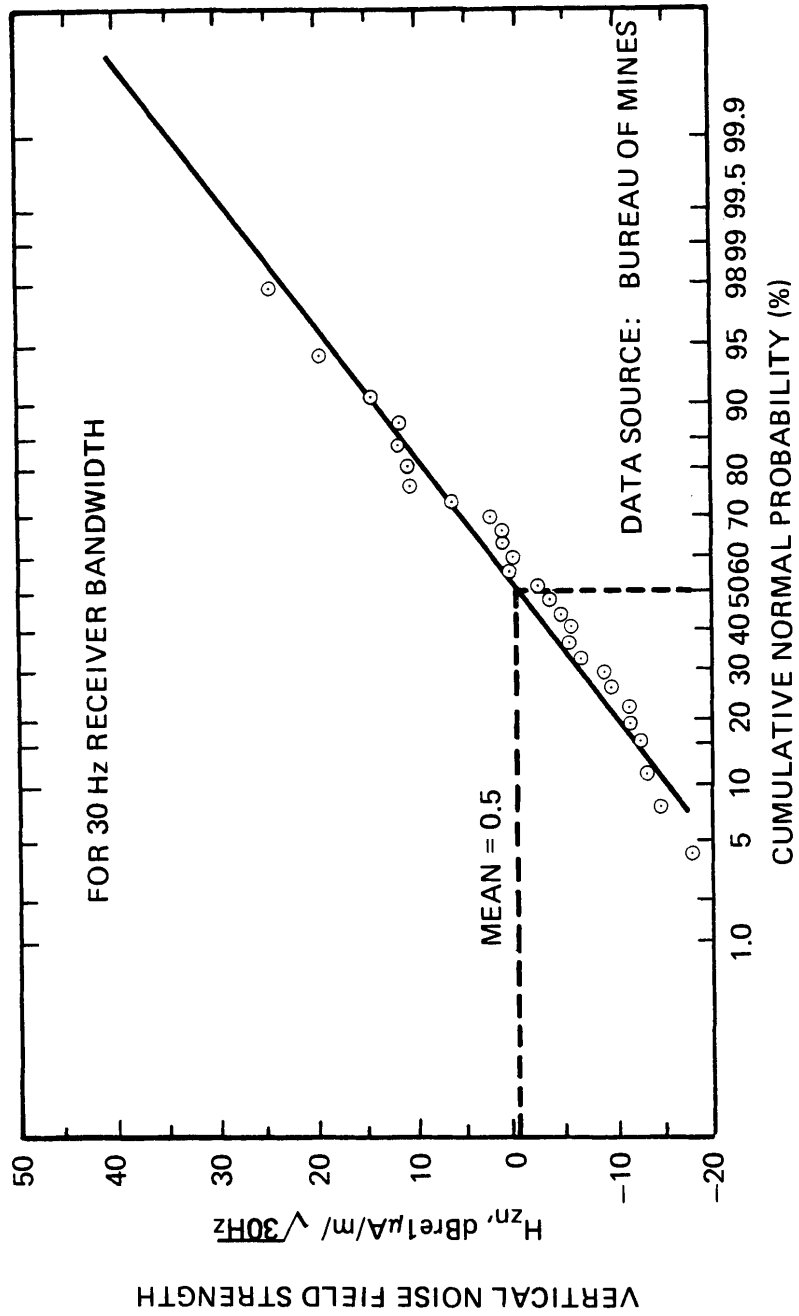
FIGURE VII-2   STATISTICAL DISTRIBUTION OF RMS SURFACE NOISE AT 1090 Hz

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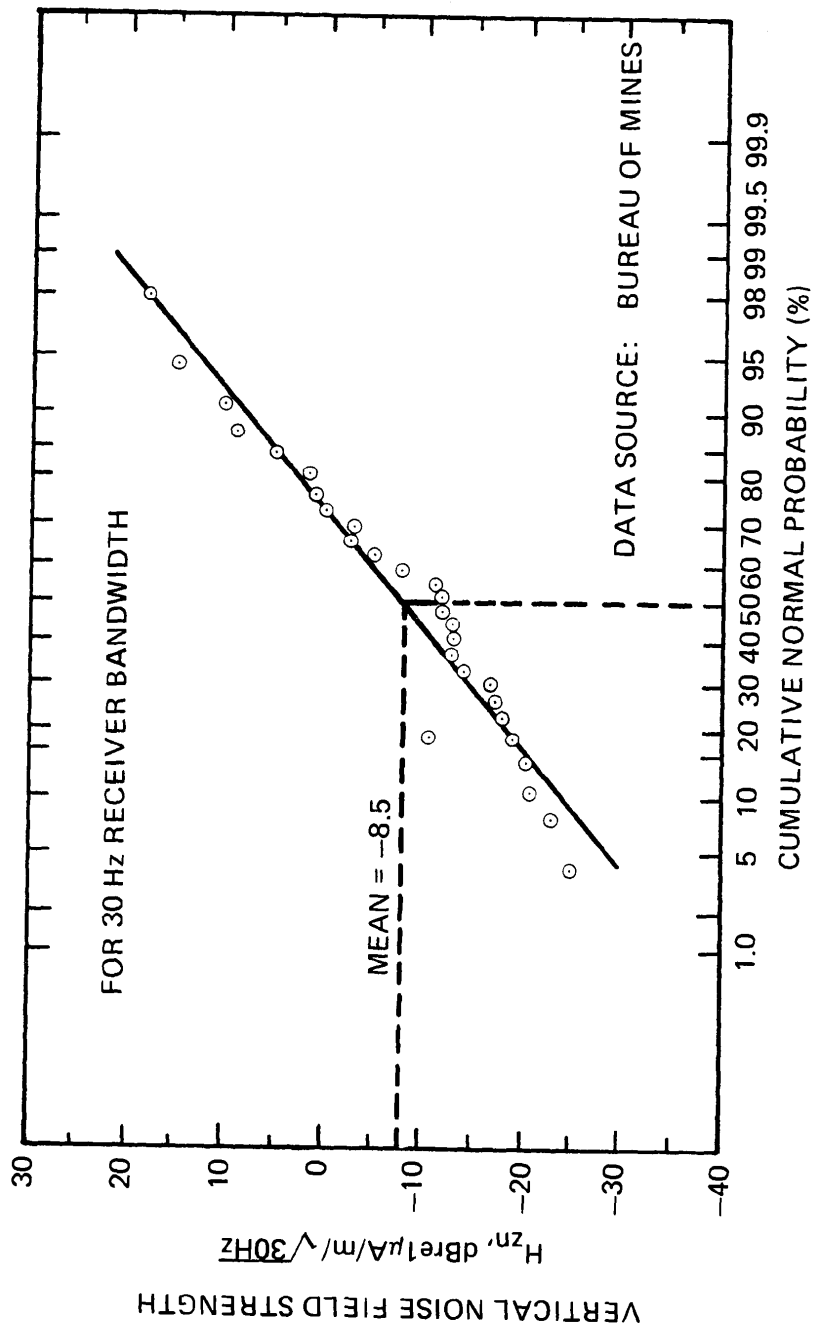
FIGURE VII-3   STATISTICAL DISTRIBUTION OF RMS SURFACE NOISE AT 1950 Hz

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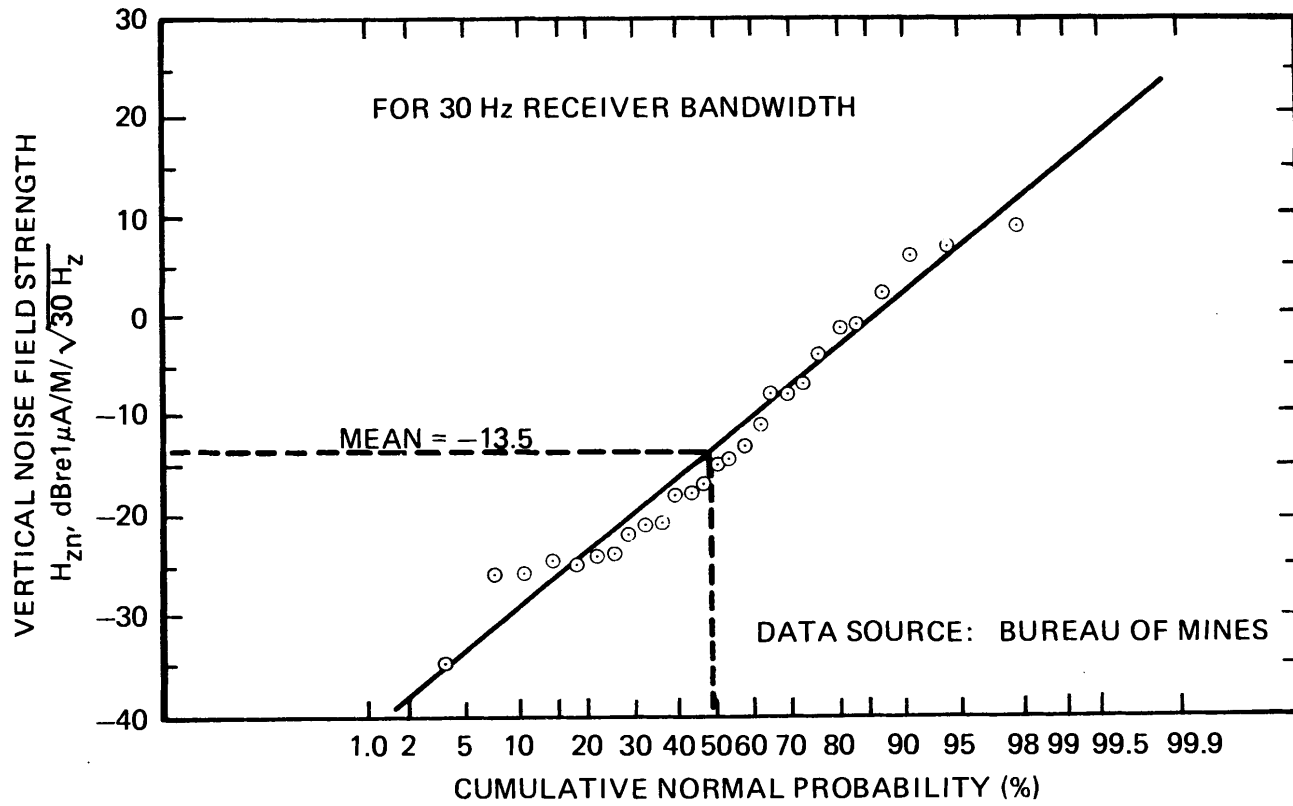
FIGURE VII-4   STATISTICAL DISTRIBUTION OF RMS SURFACE NOISE AT 3030 Hz

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.

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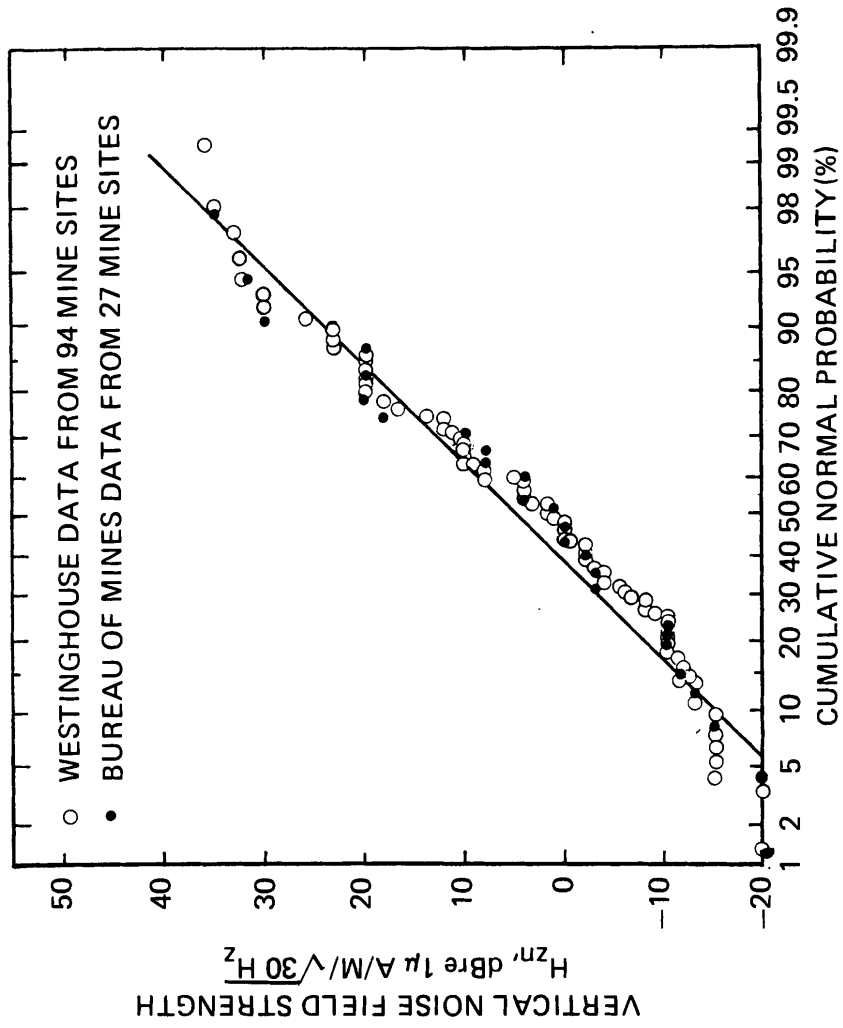
FIGURE VII-5 COMPARISON OF DISTRIBUTIONS OF WESTINGHOUSE AND BUREAU OF MINES NOISE DATA AT 630 Hz

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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.

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Table VIII-1

Estimated Parameters Characterizing Signal
and Noise Distributions Above Coal Mines

Estimated Mean Signal in dB re 1 μA/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 μA/m/$\sqrt{30\ \text{Hz}}$

	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 $\pm$ 15.5 = -12.4 and +18.6 are found at the 16% and 84% points, respectively.

$$f(x) = \frac{1}{\sqrt{2\pi}\,\sigma}\; e^{-\frac{(x-\mu)^2}{2\sigma^2}}$$

$\overline{x}$ = MEAN = −10.36

σ = STD. DEV. = 9.20

$\overline{x}$
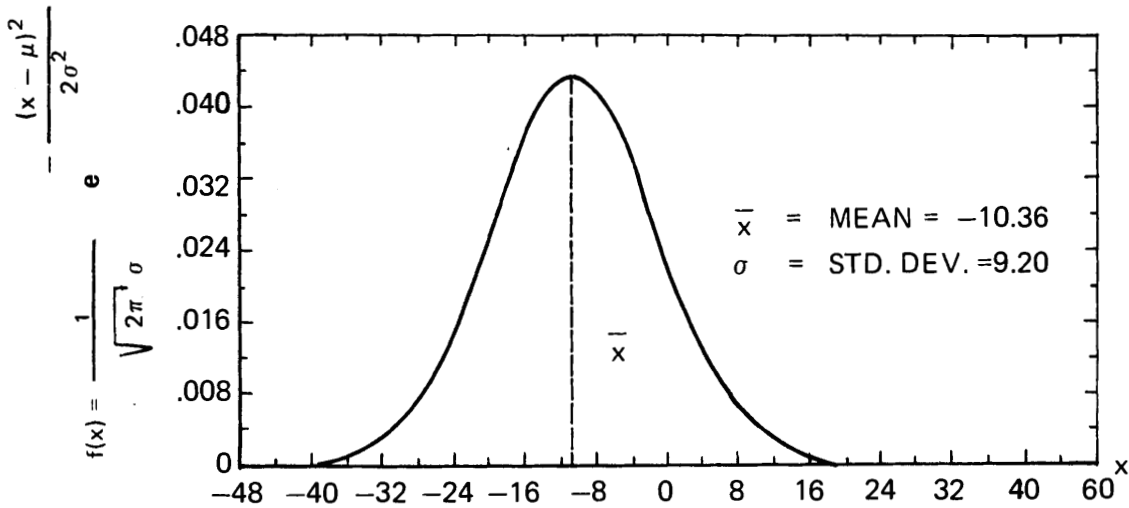
a) NORMAL DISTRIBUTION CURVE, x = LOG SIGNAL (dB)

$\overline{x}$ = MEAN = −13.5

σ = STD. DEV. = 12.5

$\overline{x}$
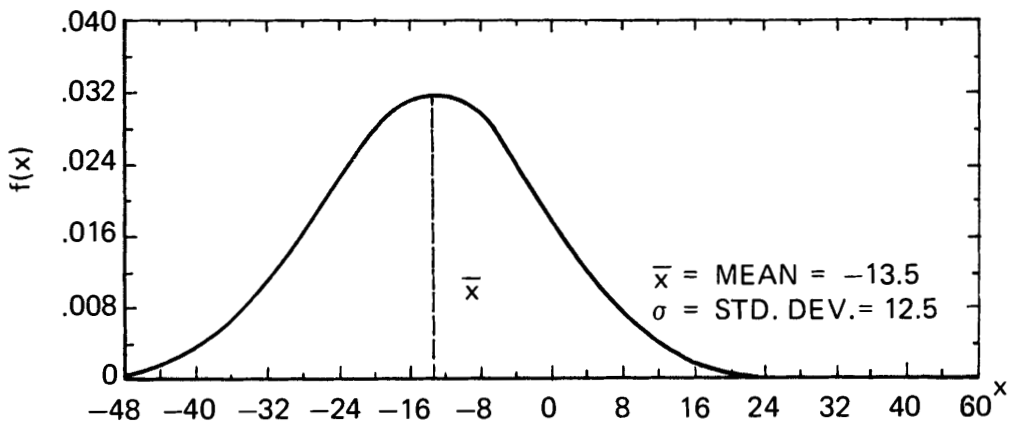
b) NORMAL DISTRIBUTION CURVE, x = LOG NOISE (dB)

$\overline{x}$ = MEAN = 3.14

σ = STD. DEV. = 15.52

$\overline{x}$
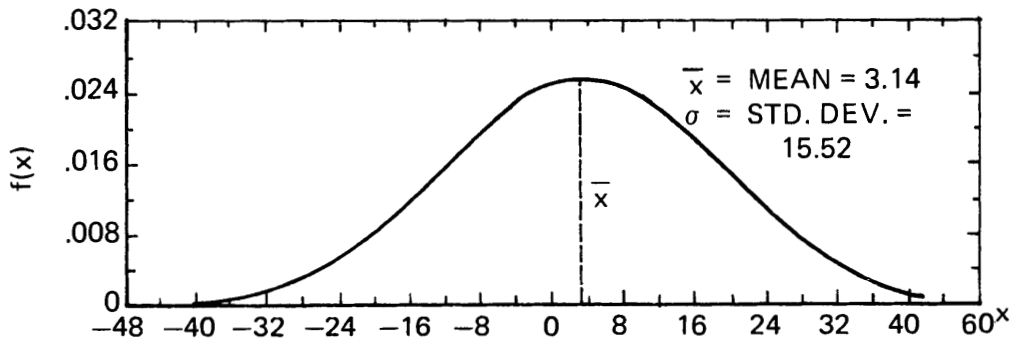
c) NORMAL DISTRIBUTION CURVE, x = LOG(SIGNAL/
NOISE)(dB)

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

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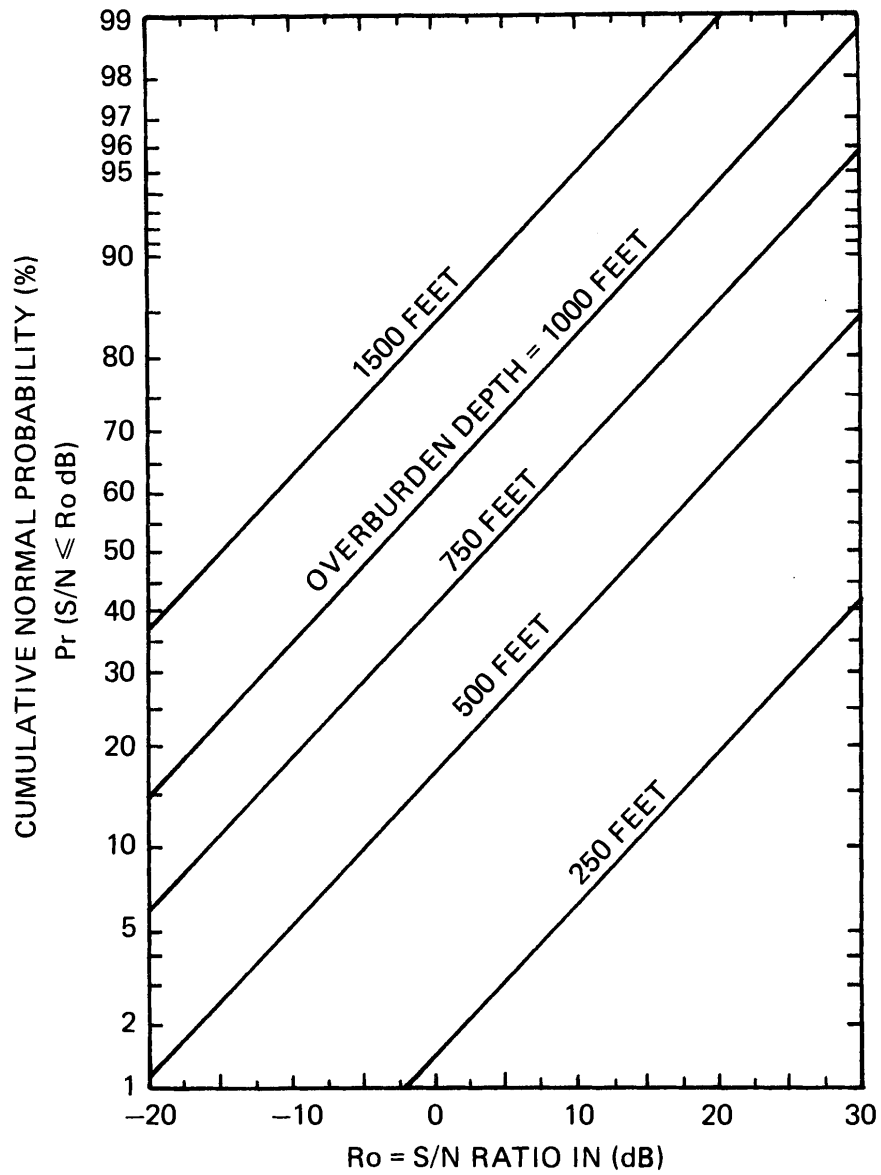
FIGURE VIII-2 CUMULATIVE PROBABILITY DISTRIBUTION OF S/N RATIOS EXPECTED ABOVE U.S. UNDERGROUND COAL MINES AT 630 Hz

135
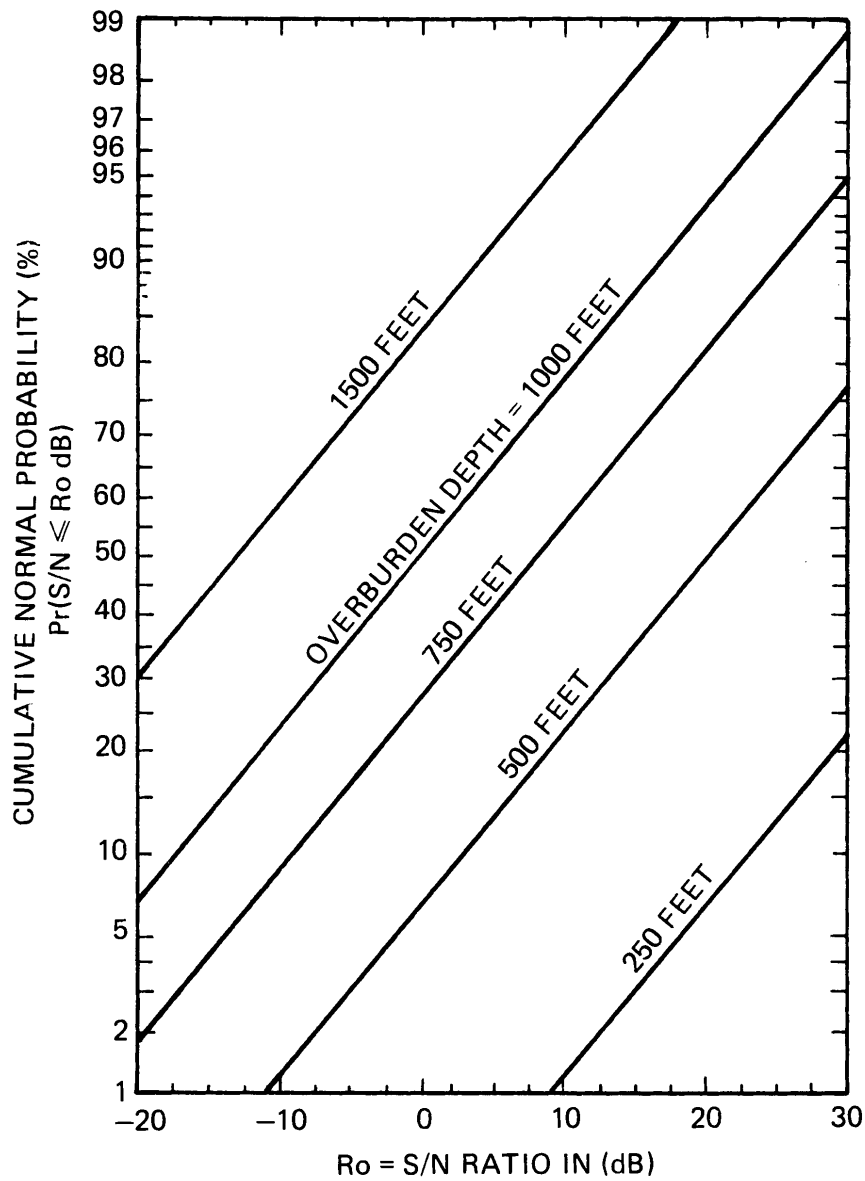
FIGURE VIII-3 CUMULATIVE PROBABILITY DISTRIBUTION OF S/N
RATIOS EXPECTED ABOVE U.S. UNDERGROUND COAL
MINES AT 1050 Hz

136
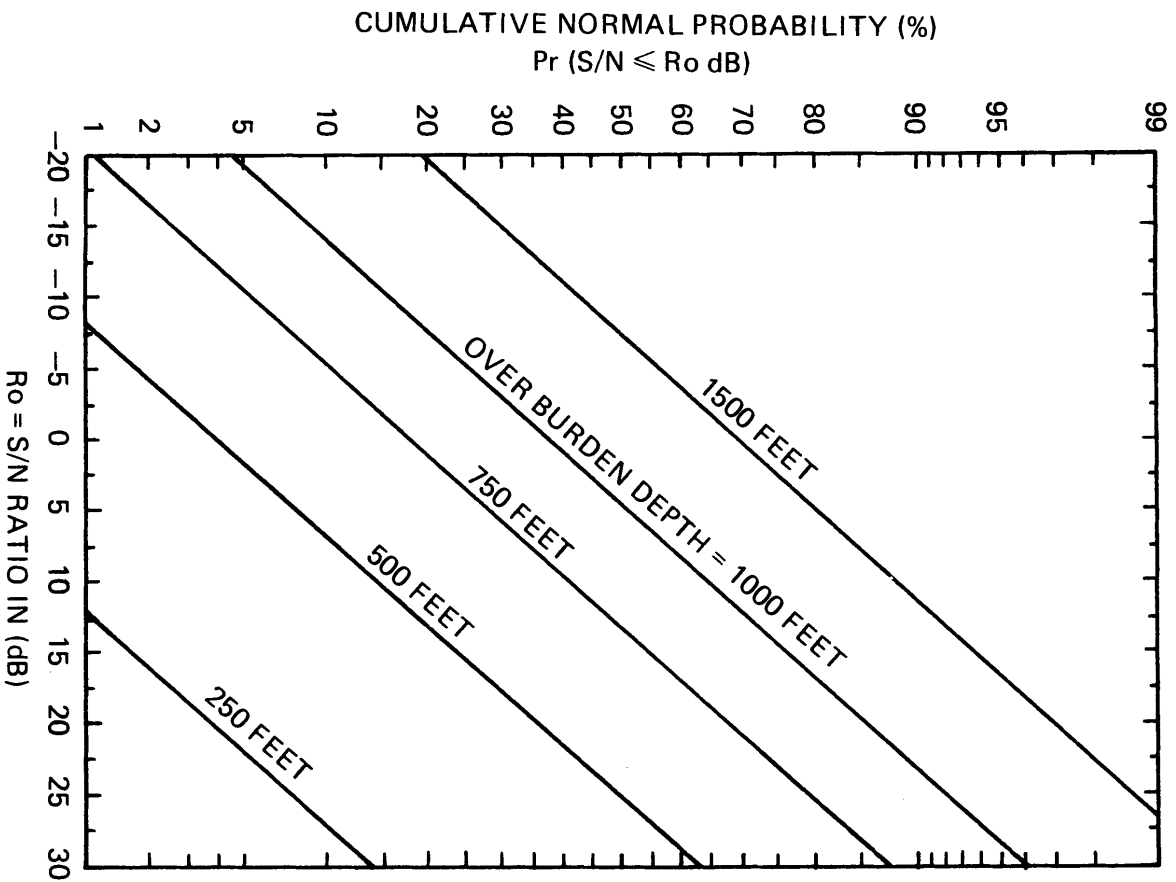
FIGURE VIII-4 CUMULATIVE PROBABILITY DISTRIBUTIONS OF S/N RATIOS EXPECTED ABOVE U.S. UNDERGROUND COAL MINES AT 1950 Hz

137
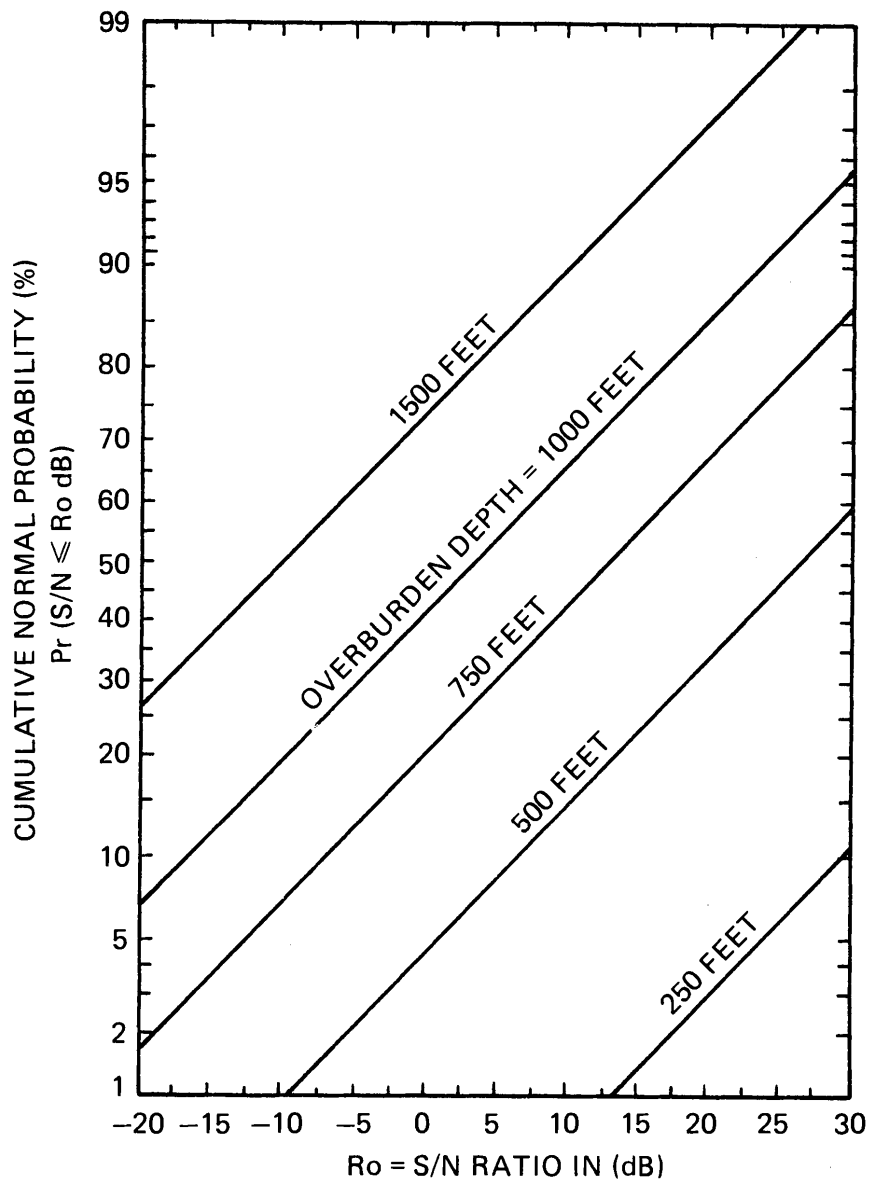
FIGURE VIII-5   CUMULATIVE PROBABILITY DISTRIBUTIONS OF S/N RATIOS EXPECTED ABOVE U.S. UNDERGROUND COAL MINES AT 3030 Hz

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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 over-burden 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	
0 to 3	0.009	0.053	0.075	0.046	
3 to 6	0.013	0.055	0.067	0.034	630 Hz
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		0.065	0.500	0.834	
0 to 3		0.035	0.090	0.051	
3 to 6	0.01	0.044	0.087	0.037	1050 Hz
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		0.039	0.374	0.692	
0 to 3		0.021	0.081	0.058	
3 to 6	0.01	0.030	0.088	0.060	1950 Hz
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		0.045	0.420	0.745	
0 to 3		0.023	0.075	0.056	
3 to 6	0.01	0.030	0.075	0.049	3030 Hz
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.
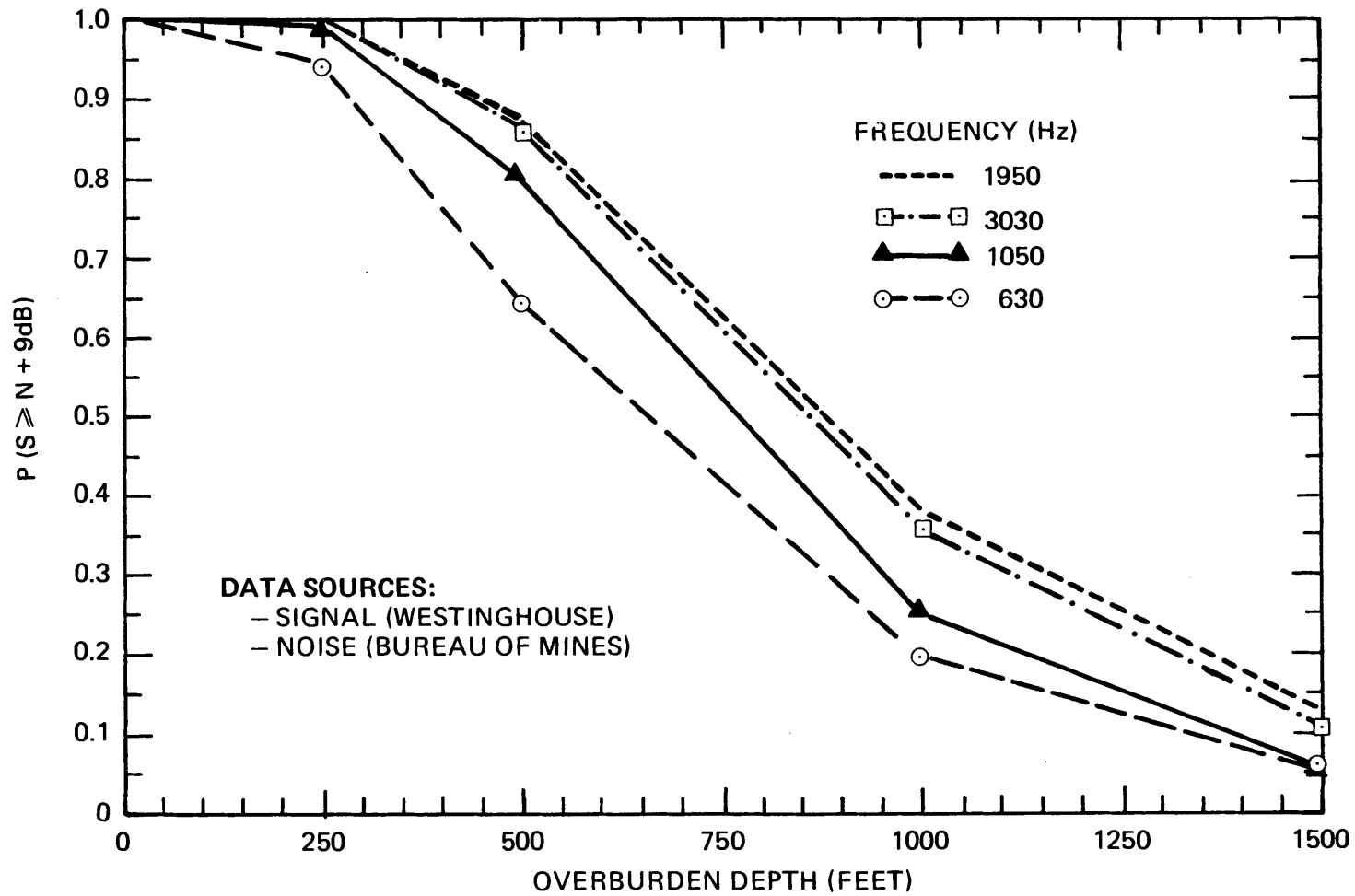
FIGURE VIII-6   PROBABILITY THAT MEAN RMS SIGNAL IS GREATER THAN OR EQUAL TO
RMS NOISE + 9dB FOR THE GENERAL INSTRUMENTS TRANSMITTER
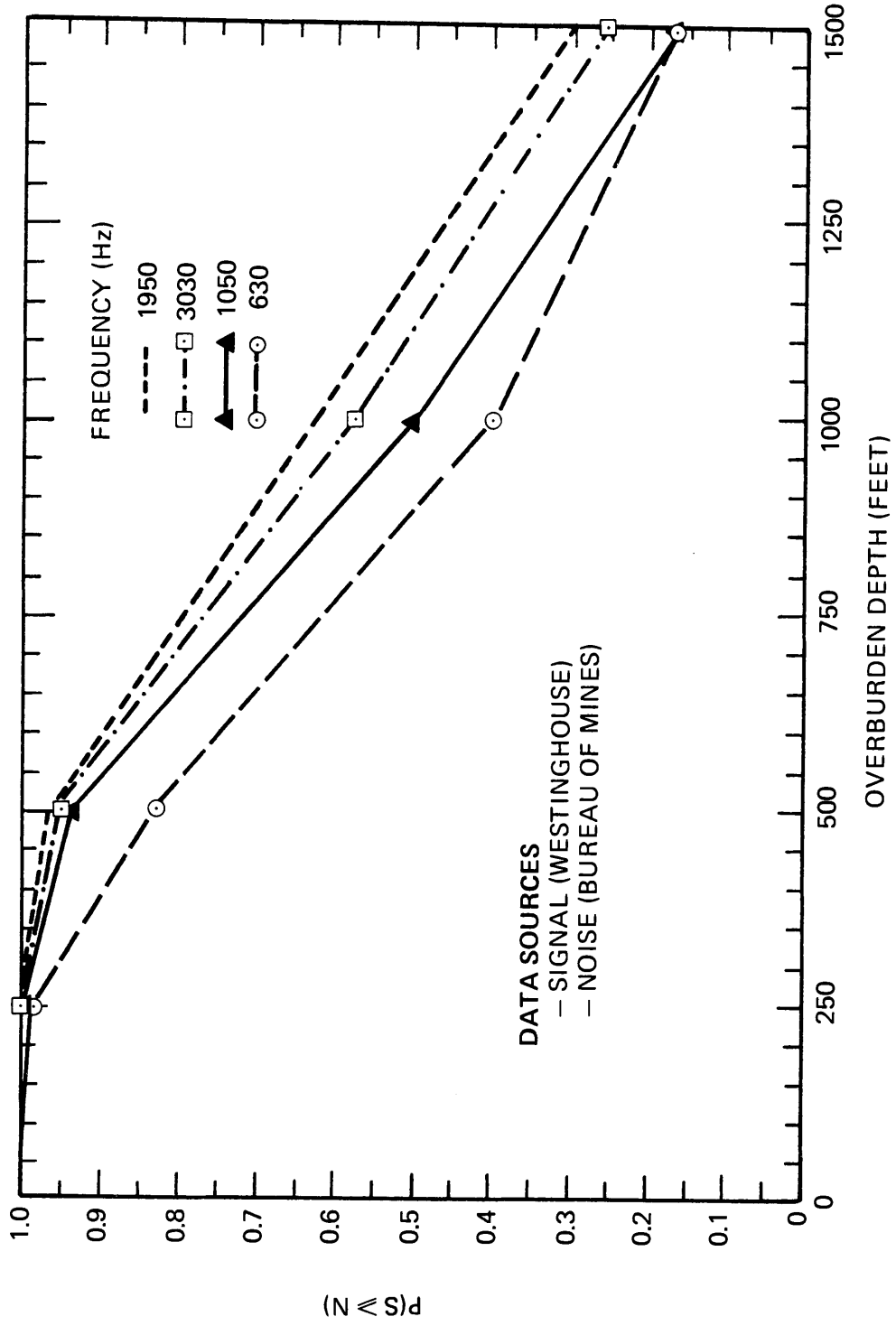
FIGURE VIII-7 PROBABILITY THAT MEAN RMS SIGNAL IS GREATER THAN OR EQUAL TO RMS NOISE FOR THE GENERAL INSTRUMENTS TRANSMITTER

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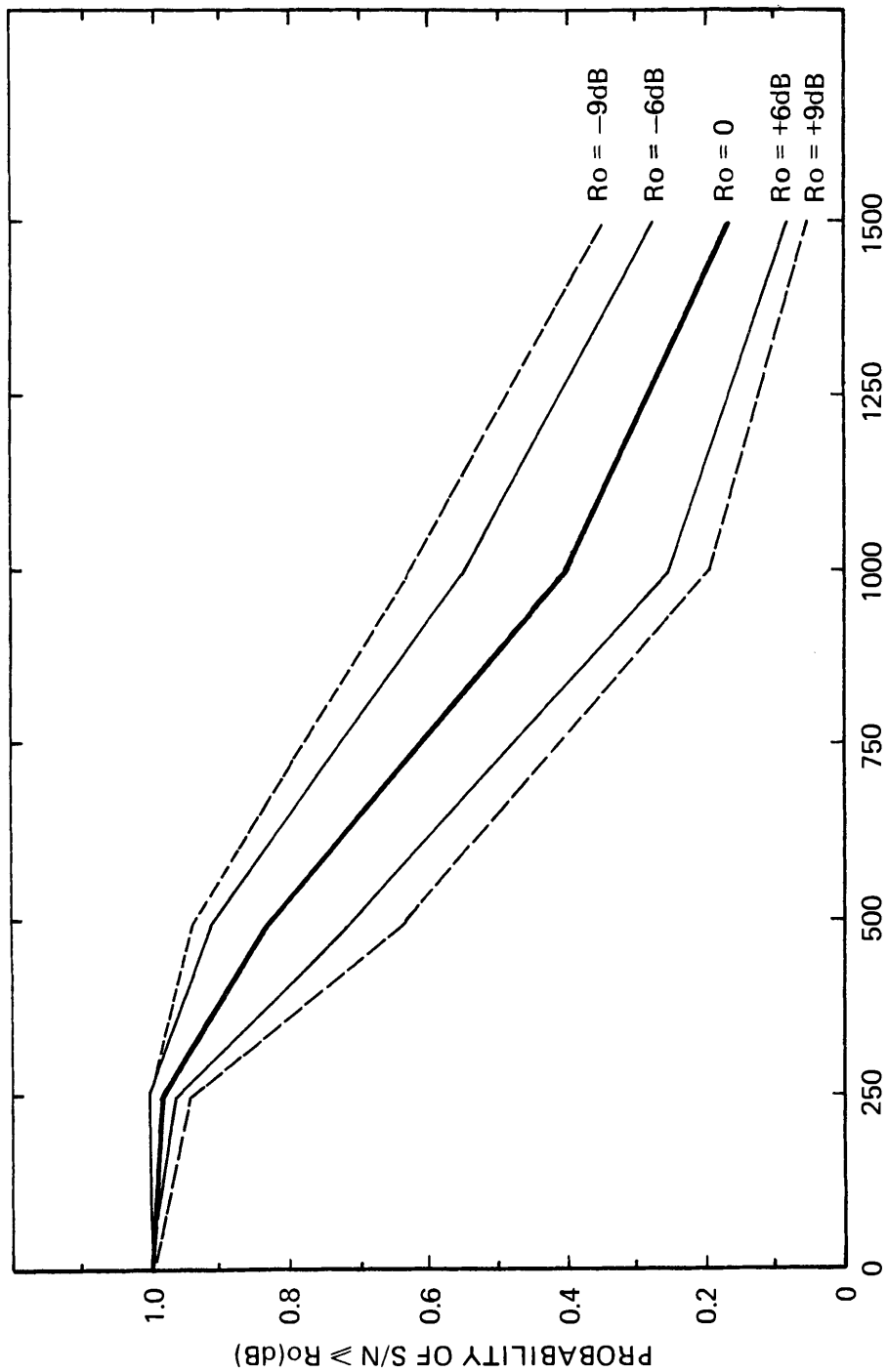
FIGURE VIII-8   RELATIONSHIP OF SIGNAL/NOISE RATIO PROBABILITIES VERSUS DEPTH FOR FREQUENCY = 630 Hz FOR THE GENERAL INSTRUMENTS TRANSMITTER

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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.

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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

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FIGURE IX-1 MEASURED VALUES OF THE CRITICAL BANDWIDTH OF THE EAR
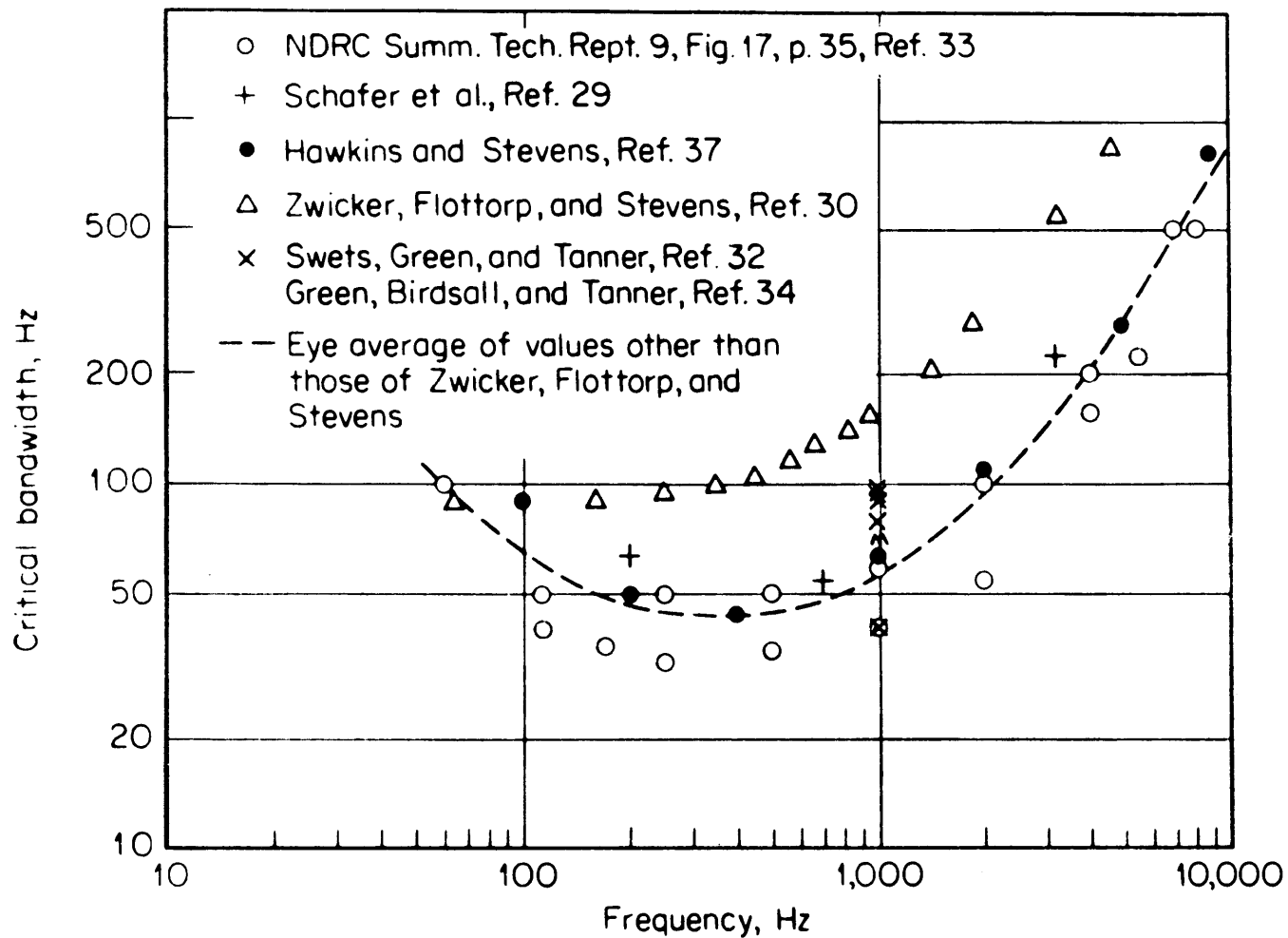
SOURCE: R.J. URICK, "PRINCIPLES OF UNDERWATER SOUND FOR ENGINEERS," McGRAW HILL — 1967, FIG. 12.10, REF. 13.
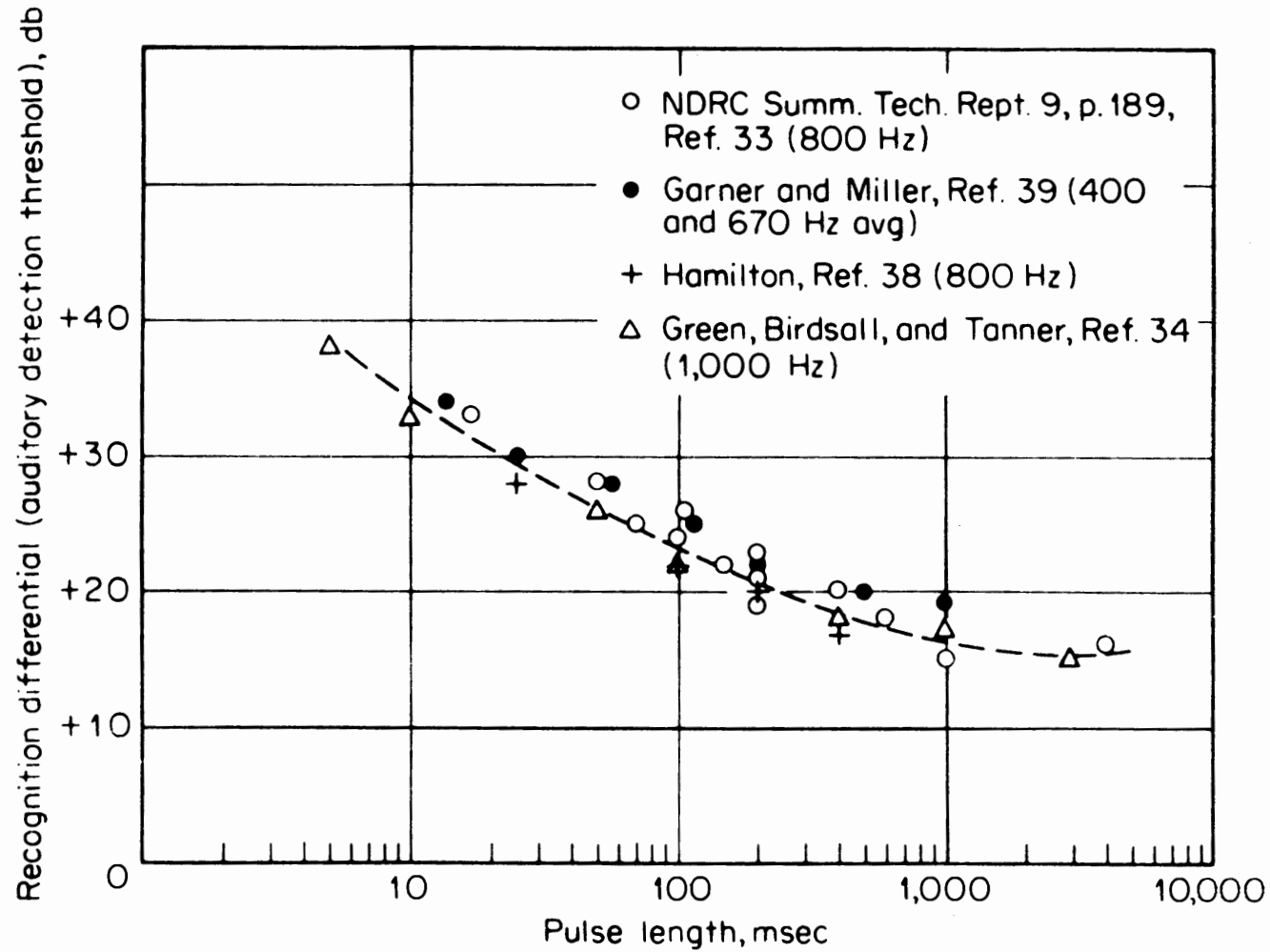
SOURCE: R.J. URICK, "PRINCIPLES OF UNDERWATER SOUND FOR ENGINEERS"
McGRAW HILL–1967, FIG. 12.11, REF. 13.

FIGURE IX-2   RECOGNITION DIFFERENTIAL (AUDITORY DETECTION
THRESHOLD, DT) FOR SINUSOIDAL PULSES IN BROAD-
BAND 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,
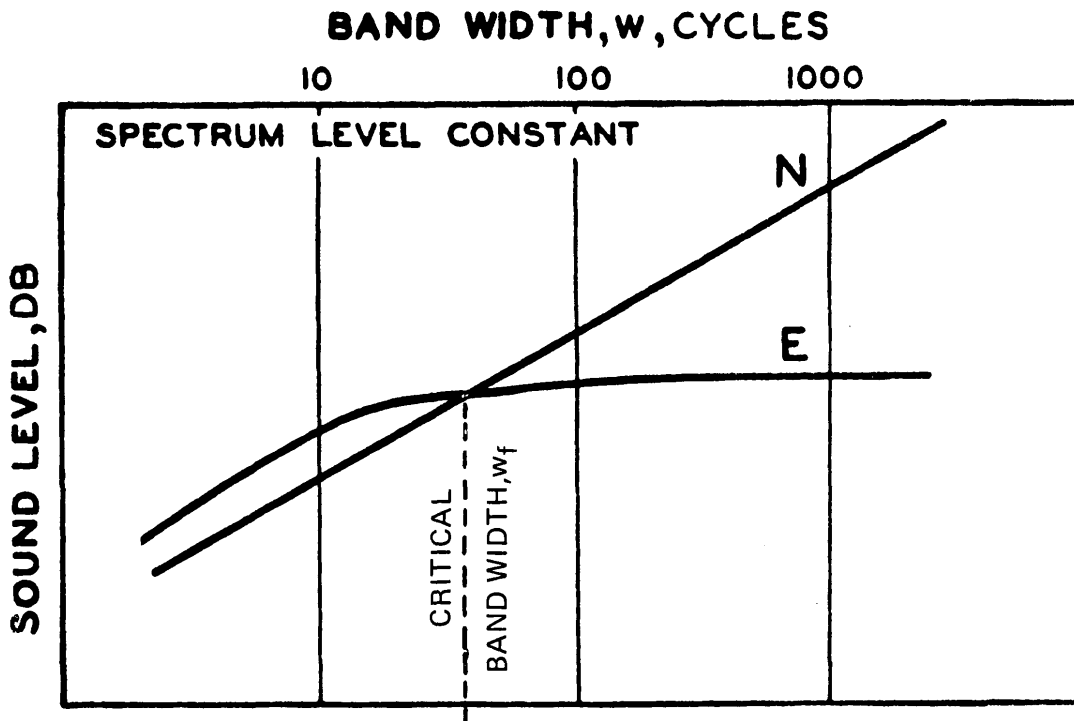
BAND WIDTH, w, CYCLES

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

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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."

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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 contin-
uously 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 illus-
trates 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 obser-
vation 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
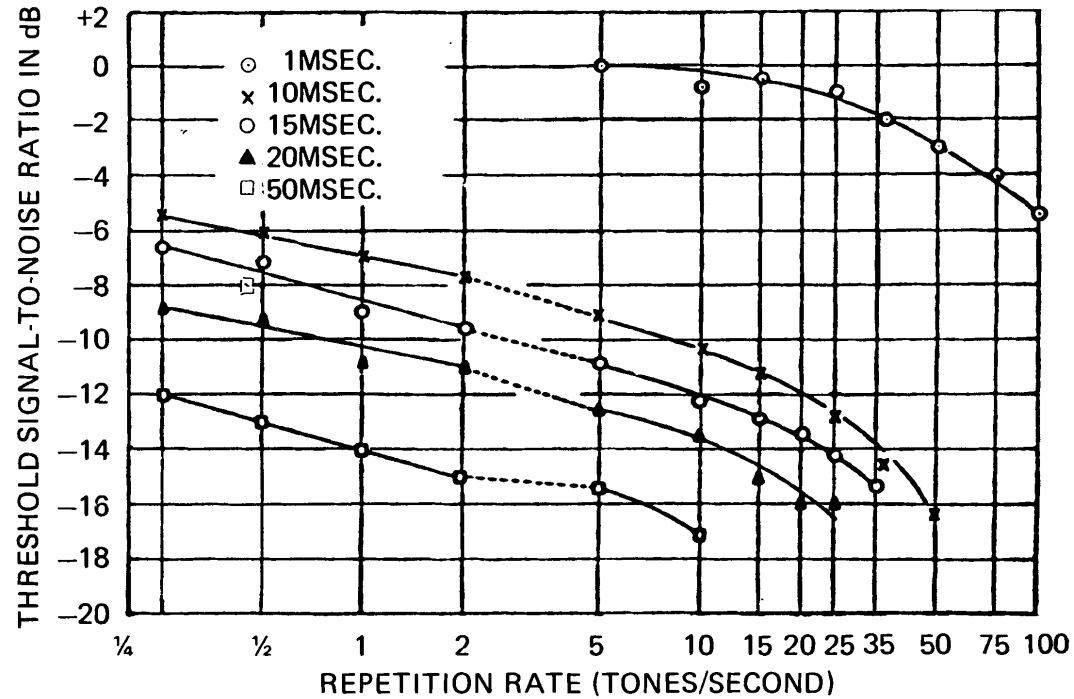
NOTE: EACH CURVE IS FOR A DIFFERENT TONAL DURATION.
THE MASKING NOISE WAS FILTERED WITH A 5000 Hz
LOW PASS FILTER, AND SIGNAL-TO-NOISE RATIOS ARE
WITH RESPECT TO THE TOTAL NOISE ENERGY. THE
INTENSITY OF THE MASKING NOISE WAS APPROXIMATELY
90 dB re 0.0002 dyne/cm². FREQUENCY IS 1000 Hz.

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
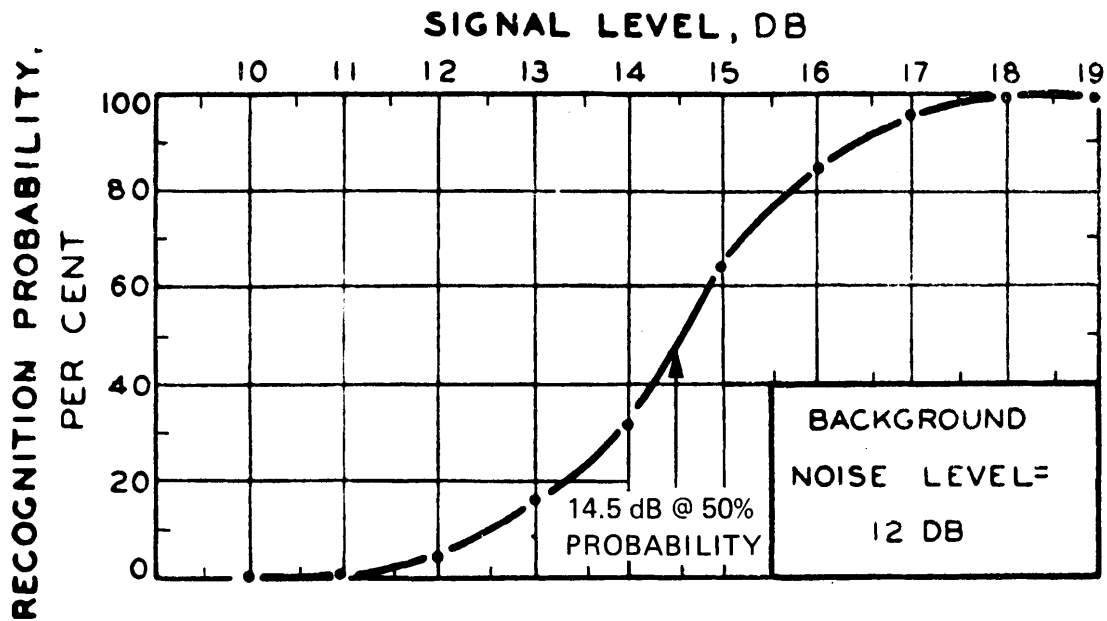
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SIGNAL LEVEL, DB

14.5 dB @ 50% PROBABILITY

BACKGROUND NOISE LEVEL= 12 DB

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

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FIGURE IX-6   AURAL PROBABILITY OF DETECTION VERSUS RMS
SIGNAL-TO-NOISE RATIO FOR TRAPPED MINER
PULSED CW SIGNALS IN BACKGROUND GAUSSIAN
NOISE
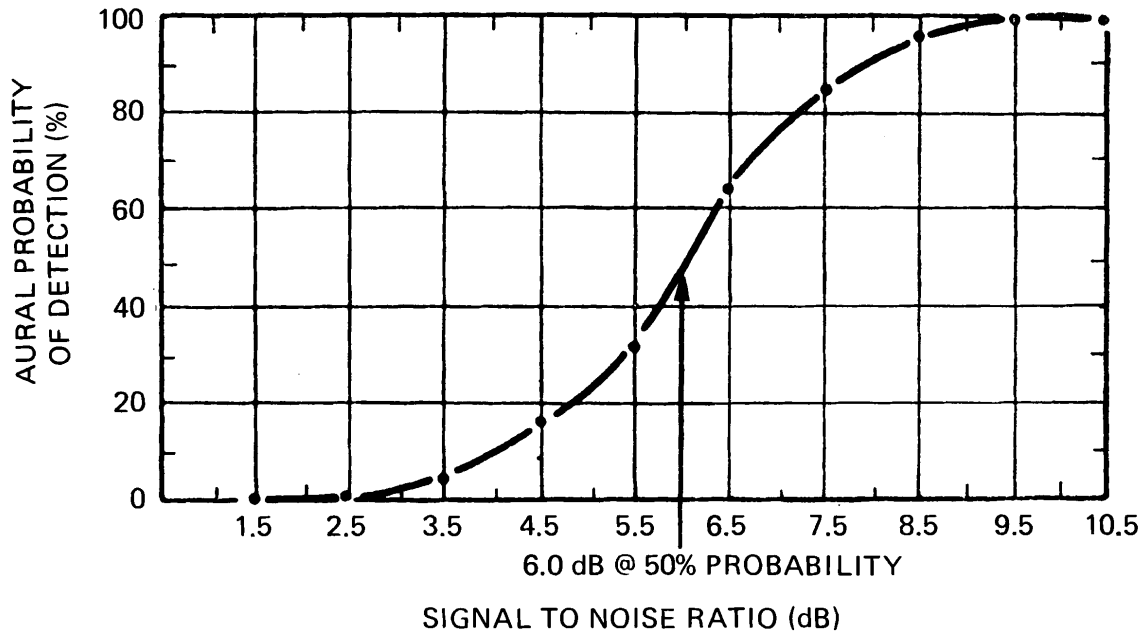
NOTE: FOR 100 MILLISECOND PULSES, 1 PER SECOND REPETITION RATE,
957 Hz LISTENING FREQUENCY, AND 30 Hz RECEIVER BANDWIDTH.

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

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 sur-
face. 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 func-
tion 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 repre-
sented 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 determinis-
tically; 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 increas-
ing signal-to-noise ratio. Various studies have been conducted on

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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:

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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)

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

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 $P_{i,j} \left\{ D \right\}$, 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,

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

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

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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:

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

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

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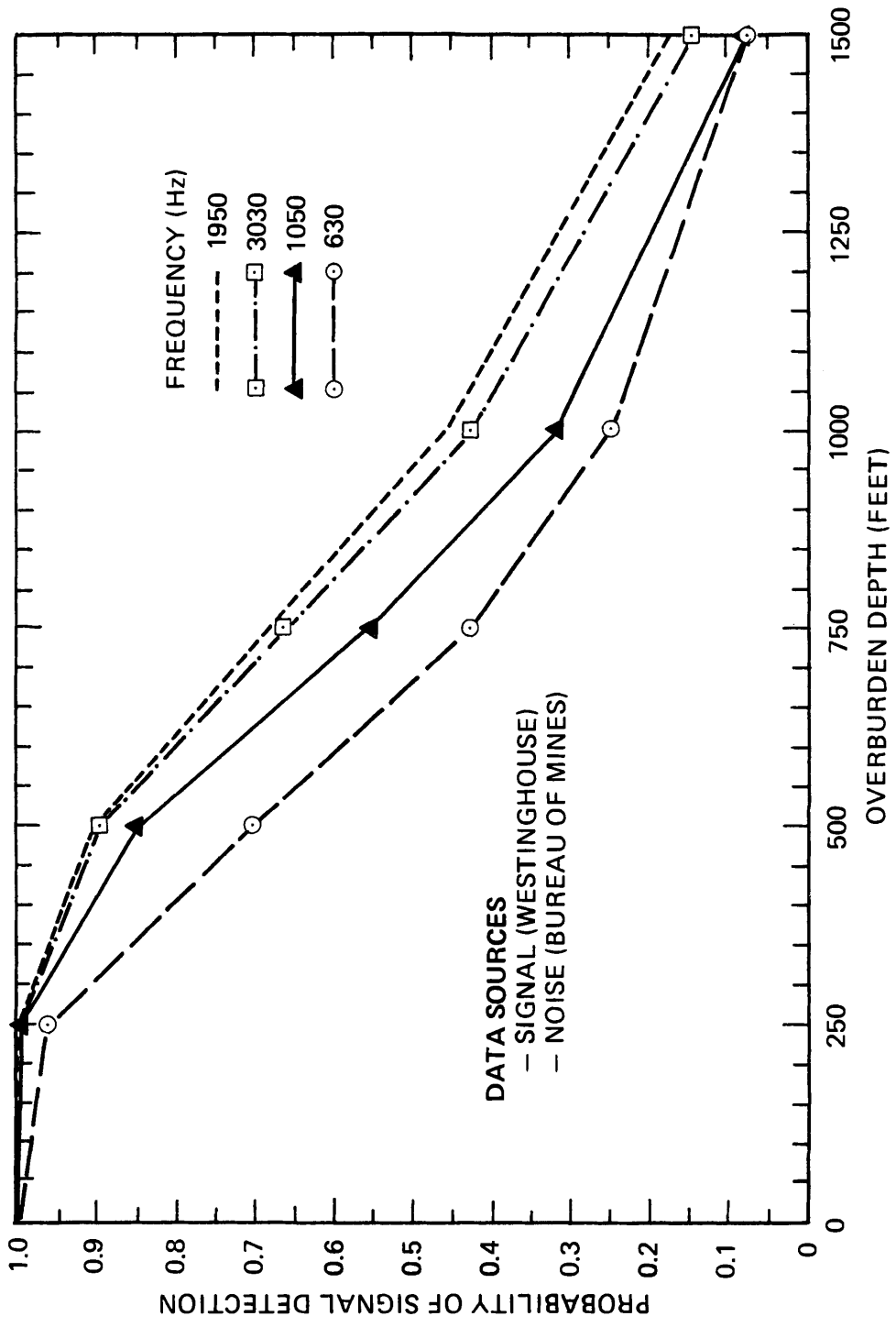
FIGURE X-1   PREDICTED PROBABILITY OF SIGNAL DETECTION VERSUS
OVERBURDEN DEPTH BY FREQUENCY FOR THE GENERAL
INSTRUMENTS TRANSMITTER

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 over-head 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

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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

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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 operator 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

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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

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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

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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 other 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.

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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 cf 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

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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

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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

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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

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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

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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

Arthur D. Little, Inc.

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]

Arthur D Little, Inc.

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

TABLE B1 (Continued)

NORTHERN APPALACHIAN

OHIO

NORTHERN WEST VIRGINIA

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

Mine Test No.	Field Report No.	Mining Co., Mine Name, Town, County, State, *Seam Name*	Seam Thickness Feet	Seam Thickness Meters	Number of Miners	Overburden Depth Feet	Overburden Depth Meters	Offset Uplink Feet	Offset Uplink Meters	Offset Downlink Feet	Offset Downlink Meters	Month/Year of Test	Surface Noise Tape Recordings (BoM)
12	3	Central Appalachian Coal — Five Block 1, Marmet, Kanawha County, WV, *Lower Kittanning*	3.9	1.2	11	250	76.2	0	0	7.2	2.2	3/77	
11	59	Sewell Coal Company — Meadow No. 1, Lookout, Fayette County, WV, *Sewell*	4.9	1.5	285	388	118	0	0	0	0	5/78	
13	67	Allied Chemical Corp. — Harewood, Boomer, Fayette County, WV, *Eagle*	4.6	1.4	500	420	128	91.8	28	131.2	40	6/78	✓
11	56	Armco Coal Co. — Robinhood No. 8, Twilight, Boone County, WV, *Dorothy*	7.9	2.4	200	421	129	0	0	0	0	5/78	
12	63	Bethlehem Steel — Mine 131, Van, Boone County, WV, *Powellton*	5.9	1.8	400	485	148	42.6	13	0	0	6/78	
12	64	Omar Mining Company — Omar No. 4, Madison, Boone County, WV, *Stockton*	4.3	1.3	20	347	108	0	0	0	0	6/78	
12	61	Bethlehem Steel (downlink) — Mine 116, Eunice, Boone & Raleigh County, WV, *Eagle*	3.9	1.2	100	845	258	200	61	400.2	122	6/78	
12	62	Bethlehem Steel (uplink) — Mine 116, Eunice, Boone & Raleigh County, WV, *Eagle*	3.9	1.2	100	645	209	200	61	400.2	122	6/78	
12	66	Eagle Coal & Dock — Hope No. 10, Stickney, Boone & Raleigh County, WV, *Stockton Lewiston*	7.2	2.2	25	250	78	108.2	33	108.2	33	6/78	
11	57	Slab Fork Coal Co. — Mine 10, Slab Fork, Raleigh County, WV, *Pocahontas No. 3*	3.6	1.1	275	1050	320	0	0	0	0	5/78	
11	60	Ranger Fuel — Mine F, Bolt, Raleigh County, WV, *Eagle*	3.9	1.2	39	350	107	0	0	0	0	5/78	
12	65	Amherst Mining Co. — MacGregor No. 8, Lundale, Logan County, WV, *Coalburg*	10.2	3.1	77	227	71	0	0	0	0	6/78	
5	22	Eastern Associated Coal — Keystone, Herndon, Wyoming County, WV, *Pocahontas No. 3*	4.3	1.3	648	569	173.5	41.3	12.6	41.3	12.6	7/77	
6	32	Jumacris Mining Inc. — Mine No. 4, Gilbert, Mingo County, WV, *Lower Cedar Grove*	5.9	1.8	22	330	101	109.6	33.4	109.6	33.4	9/77	
6	33	Hawley Mining Corp. — Bottom Creek No. 1, Keystone, McDowell County, WV, *Pocahontas No. 12*	3.3	1	90	230	70	44.6	13.6	54.8	16.7	9/77	
13	68	Petter White Coal Co. — Brushy No. 2, Isaban, McDowell County, WV, *Lower War Eagle*	3.3	1.0	70	450	137	121.4	37	0	0	6/78	
13	69	U.S. Steel — Gary No. 9, Filbert, McDowell County, WV, *Pocahontas No. 3*	3.9	1.2	350	430	131	49.2	15	49.2	15	6/78	✓
13	70	U.S. Steel — Gary No. 2, Wilcoe, McDowell County, WV, *Pocahontas No. 4*	7.6	2.3	300	915	279	0	0	0	0	6/78	✓

TABLE B1 (Continued)

SOUTHERN APPALACHIAN

VIRGINIA / **TENNESSEE**

Mine Co., Mine Name, Town, County, State, Seam Name	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	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)										

Arthur D Little Inc

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

TABLE B1 (Continued)

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

Region groupings (right-side labels): WESTERN KENTUCKY; CENTRAL; ILLINOIS

TABLE B1 (Continued)

SOUTH ALABAMA

Mine Test No.	42	43	89	90	44	41	40
Field Report No.	8	8	18	18	8	8	8
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*
Seam Thickness Feet	4.6	3.9	3.3	13.5	5.9	5.6	4.9
Seam Thickness Meters	1.4	1.2	1.0	4.1	1.8	1.7	1.5
Number of Miners	200	400	450	500	200	432	218
Overburden Depth Feet	385	296	650	1550	262	485	469
Overburden Depth Meters	109	90	198	473	80	148	143
Offset Uplink Feet	0	0	65.6	0	0	77.7	22.3
Offset Uplink Meters	0	0	20	0	0	23.7	6.8
Offset Downlink Feet	41.3	20	0	0	0	59.7	59.7
Offset Downlink Meters	12.6	6.1	0	0	0	18.2	18.2
Month/Year of Test	2/78	2/78	9/78	9/78	2/78	2/78	2/78
Surface Noise Tape Recordings (BoM)			✓	✓			

WEST UTAH COLORADO

Mine Test No.	76	77	78	79
Field Report No.	15	15	15	15
Mining Co., Mine Name / Town, County, State, / *Seam Name*	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*
Seam Thickness Feet	5.9	4.6	7.9	5.9
Seam Thickness Meters	1.8	1.4	2.4	1.8
Number of Miners	38	380	30	130
Overburden Depth Feet	1200	1000	1200	1400
Overburden Depth Meters	365	305	366	427
Offset Uplink Feet	0	0	0	0
Offset Uplink Meters	0	0	0	0
Offset Downlink Feet	0	0	0	1499
Offset Downlink Meters	0	0	0	457
Month/Year of Test	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 (± 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:

$$R_L = N \ p \ \rho \ \text{ohms}, \tag{1}$$

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

$$L_L = 0.12192 \ N^2 [a \ \ln(2a/r) + b \ \ln(2b/r) + 2\sqrt{a^2 + b^2}$$

$$- a \ \ln(a/b + \sqrt{1 + (a/b)^2}) - b \ \ln(b/a + \sqrt{1 + (b/a)^2})$$

$$-2(a+b) + 1/4(a+b)] \qquad \text{(microhenries)} \tag{2}$$

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[*] Grover, F.W. Inductance Calculations – Working Formulas and Tables, Dover Publications, Inc., New York., p. 60, 1962.
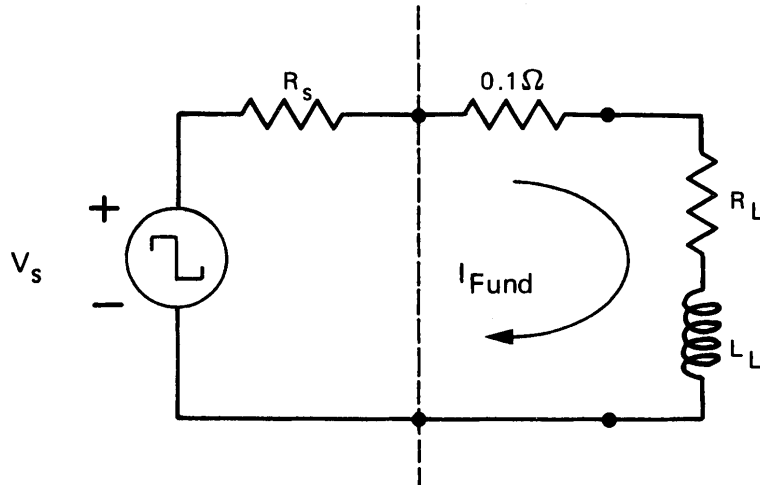
V_s = 6.9 Volt p-p Square Wave* (±3.45 v)

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}

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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:

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

$$M_{FUND \atop RMS} = NA I_{FUND \atop RMS} \tag{4}$$

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

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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.

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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.)

<u>LEGEND</u>

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)

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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	2.044E-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	1.764E-04	5
14	65.0	70.0	270.0	1.0	423.0	0.420	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	0.252	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

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24	2	1.224E-04	79.219	0.235	127.0	1.0	148.0	37.0	37.0
25	2	1.886E-04	164.589	0.461	418.0	1.0	290.0	45.0	100.0
26	2	1.755E-04	148.100	0.413	392.0	1.0	260.0	65.0	65.0
27	2*	8.963E-05	325.583	3.220	1262.0	1.0	460.0	80.0	170.0
28	2	2.126E-04	205.708	0.656	711.0	1.0	350.0	87.5	87.5
29	2	2.422E-04	292.055	0.794	929.0	1.0	500.0	50.0	200.0
30	5	1.794E-04	148.014	0.413	390.0	1.0	260.0	60.0	70.0
31	2	2.056E-04	195.677	0.540	557.0	1.0	340.0	50.0	120.0
32	2	1.730E-04	138.889	0.391	341.0	1.0	246.0	61.0	72.0
33	5*	4.589E-05	55.856	0.805	56.0	1.0	100.0	20.0	30.0
34	2	2.276E-04	238.350	0.635	928.0	1.0	400.0	100.0	100.0
35	2	1.877E-04	160.757	0.445	455.0	1.0	280.0	70.0	70.0
36	2	1.876E-04	160.677	0.445	450.0	1.0	280.0	65.0	75.0
37	2	1.953E-04	173.502	0.476	522.0	1.0	300.0	75.0	75.0
38	2	2.357E-04	258.005	0.683	1068.0	1.0	430.0	100.0	115.0
39	2	1.794E-04	148.014	0.413	390.0	1.0	240.0	60.0	70.0
40	5,6	1.794E-04	148.014	0.417	358.0	1.0	260.0	60.0	70.0
41	2	1.518E-04	110.724	0.318	232.0	1.0	200.0	50.0	50.0
42	2	1.511E-04	110.268	0.318	223.0	1.0	200.0	40.0	60.0
43	5	1.297E-04	86.403	0.254	149.0	1.0	160.0	40.0	40.0
44	2	1.568E-04	116.885	0.333	256.0	1.0	210.0	52.5	52.5
45	2	1.513E-04	168.486	0.460	450.0	1.0	295.2	49.2	98.4
46	2	1.735E-04	139.295	0.391	352.0	1.0	246.0	61.5	61.5
47	2	1.321E-04	88.810	0.260	156.0	1.0	164.0	41.0	41.0
48	5	1.967E-04	178.379	0.495	488.0	1.0	311.6	49.2	106.6

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	264.0	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	1.5a4E-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	0.462	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

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

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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.

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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

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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 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=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	478.880	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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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	495.44	1102.34	3.1586	2.9522	0.5348	-0.0172	-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	36.00	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	2.1053		
28	711	2.26	14.00	F	518.24	1746.09	2.4558	2.4030	0.7217	0.1430	0.5329	5.1847	3.079	
7	639	2.00	48.70	48.70	519.88	1612.80	2.5239	2.4543	0.2208	0.4543	1.7780	22.9627		
63	223	2.69	15.00	39.00	541.20	814.70	3.6534	3.3088	2.6589	0.6188	1.7984	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	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	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	-0.0280	4.685
58	335	2.45	27.00	48.00	560.56	1027.81	3.0681	2.8791	1.9541	0.4291	1.4018	2.4006	1.2248	4.685
1	690	1.77	26.70	48.75	599.91	1598.82	2.3171	2.2802	2.3394	0.5102	2.2000	11.6840	1.1832	1.217
15	267	2.40	17.00	47.00	600.24	931.46	3.4886	3.1941	1.9099	0.3941	1.1438	10.6770	-6.6825	18.367
81	130	2.33	15.00	41.00	600.24	557.83	4.2910	3.7398	3.0154	0.9098	2.4212	8.2237	0.6025	10.075
31	557	2.26	23.00	42.00	619.92	1409.75	2.5310	2.4571	0.9437	0.1971	0.7263	7.4359	4.6219	3.602
73	929	1.20	F	F	626.48	2047.17	2.2036	1.9913	5.2790	0.9913	5.2304		3.9902	3.446
53	564	1.97	20.00	39.00	649.44	1516.04	2.6680	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	656.30	1470.69	2.6886	2.5904	0.9663	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	935.80	3.4397	3.1580	2.1031	0.4580	1.3610	18.2539	7.143	
10	232	2.80	41.00	41.00	688.80	846.66	3.6494	3.3080	3.2013	0.5080	1.4481	13.2618	6.1191	7.143
26	392	2.12	19.00	40.00	688.80	1205.17	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	4.3081	0.1014	4.4221	3.8543		
50	446	1.76	4.00	36.00	744.56	1299.10	2.9128	2.7667	4.3760	0.3760	3.9290	20.9521	10.7617	10.190
38	1068	2.29	22.00	38.00	760.64	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		8.00	18.00	840.24	935.60	3.4397	3.1580					26.3031	
70	543	2.82	F	N	915.12	1466.73	2.7012	2.5006	0.2651	-0.0194	-0.0646			
45	450	2.47	16.00	N	944.64	1265.16	2.815	2.6837	1.1248	0.2137	0.7207	2.5202	22.0883	-19.568
77	418	2.96	N	F	1000.40	1220.27	2.9193	2.7688	-0.1203	-0.1912	-0.5800		15.6667	-19.568
48	488	2.12	13.00	25.00	1010.24	1318.46	2.7026	2.5967	2.1189	0.4767	1.7617	4.1317	4.0000	0.132
57	558	2.38	18.00	38.00	1049.60	1329.24	2.5310	2.4571	0.5343	0.0771	0.2769	-1.2698	21.0560	-22.326
46	352	2.82	6.00	34.50	1150.64	1122.77	3.1897	2.9772	1.0700	0.1572	0.4712	5.4522	21.8797	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	3.573
23	678	1.27	F	15.00	1199.82	1688.25	2.4900	2.4402	5.8479	0.1702	5.6724	21.0802		
78	929	2.33	13.00	29.00	1200.48	2047.17	2.2036	1.9913	0.4445	-0.1387	-0.5331	3.4550	0.2723	3.183
34	929	2.00	-2.00	F	1341.52	2044.97	2.2036	1.9913	0.8421	0.1913	0.7934	15.5511		
5	639	3.26	3.26	F	1397.28	1544.54	2.4171	2.3646	1.6653	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	1.9913	-3.7413	-1.1987	-3.7900	11.7722	32.8308	-21.059

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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	1.83	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	2.2896	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

-- 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	2.69	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

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	36.00	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	6.4412	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

-- 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	-0.3466	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	489	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	.	.

IN ORDER OF INCREASING DEPTH

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

MINE	ANTMIN	IWEST	SEMF	MEMF	DEPTHFT	MMFUND	IFUND	IEST	IDIFF	IUEL	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	-0.2889	-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	1.0288	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	262.104	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	2.010	34.7	60.10	262.400	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	284.640	474.016	0.9081	1.0957	0.6771	0.2557	2.3082	6.888	5.9930	-11.881
43	149	1.700	41.0	58.00	295.200	260.783	1.7502	2.0591	0.2528	0.3591	1.6646	-5.888	10.1127	3.271
54	264	1.060	23.0	40.00	308.320	343.957	1.3029	1.5553	1.7921	0.4953	3.3302	13.383	3.2552	25.483
21	199	1.800	5.0	59.00	324.720	296.318	1.4890	1.7684	-1.6476	-0.0316	-0.1538	28.738	4.7982	-1.186
30	390	1.200	33.0	56.00	324.720	412.573	1.0579	1.2715	-1.0947	0.0715	0.5027	3.613	3.9481	-2.184
35	455	1.340	35.5	60.00	324.720	444.686	0.9773	1.1772	-2.7415	-0.1628	-1.1251	1.764		
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	406.605	1.0790	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	354.960	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	374.305	1.1536	1.3824	-3.0026	-0.2477	-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	446.680	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	352.015	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	478.860	444.686	0.9773	1.1772	-3.1838	-0.2328	-1.5674	12.141		
72	252	1.630	16.0	49.00	486.160	331.332	1.3148	1.5688	-1.8666	-0.0612	-0.3324	8.407	2.2861	6.121

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	485.059	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	322.048	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	560.88	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	3.3175	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	0.8770	1.0531	-0.1056	0.2392	1.4266	.	24.7986	.
89	256	1.340	10.000	38.000	649.44	338.894	1.3238	1.5792	-1.6819	-0.0053	-0.0435	6.842	7.8519	-1.010
75	547	1.060	3.000	N	658.30	477.749	0.8734	1.0547	-2.4043	-0.0821	-0.7441	16.472	.	.
6	639	1.000	-9.890	F	674.04	484.493	0.7582	0.9179	-4.4877	-0.6089	-2.9409	28.868	.	.
62	272	2.120	-6.000	N	685.52	343.965	1.2646	1.5111	-0.0467	0.2577	1.4676	21.562	.	.
16	232	1.400	-3.000	33.000	688.80	323.048	1.3925	1.6577	-2.2504	-0.0991	-0.6522	17.893	14.1191	3.774
26	392	1.370	9.000	52.000	688.80	414.467	1.0573	1.2709	-0.5395	0.0277	0.5079	8.057	-4.0650	12.122
27	1262	0.460	-16.000	N	688.80	545.613	0.4323	0.4877	-0.6887	0.1193	0.9264	3.445	.	.
50	446	1.060	-16.000	18.000	744.56	436.702	0.9792	1.1793	-3.7460	-0.2002	-2.0556	31.483	28.7617	2.721
38	1068	0.950	-11.500	20.500	780.64	659.183	0.6172	0.7498	-1.1217	0.0612	0.5159	29.326	25.0286	4.298
4	581	.	F	-0.781	799.99	455.690	0.7843	0.9488	.	.	.	.	38.8078	.
61	272	1.000	N	16.000	846.24	343.965	1.2646	1.5111	.	.	.	.	28.3031	.
70	543	1.000	F	N	915.12	477.251	0.8788	1.0612	.	.	.	.	.	.
45	450	1.520	-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	0.840	N	20.000	1000.40	411.694	0.9849	1.1859	-3.7690	-0.3341	-2.1559	.	21.0364	.
48	488	1.050	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	1.270	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	1.270	-17.000	23.000	1190.64	394.606	1.1210	1.3451	-3.6169	-0.3549	-2.0039	19.370	13.3797	5.990
76	334	0.780	F	11.000	1197.20	358.351	1.0729	1.2886	-1.4649	0.0186	0.1263	.	25.4958	.
23	678	1.060	F	18.000	1199.82	527.496	0.7780	0.9421	-0.0223	0.1621	1.6400	.	18.0802	.
78	929	0.880	-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	1.000	-24.000	F	1341.52	618.953	0.6670	0.8093	-2.4071	-0.0707	-0.7275	27.171	.	.
5	639	1.100	-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

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 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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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
	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	845.66	3.6494	3.3905	2.5374	10560.0	573.04		11.127	
10	46.25	60.10	253.872	845.66	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	324.770	1197.27	3.0699	1.6458	1.1132	6680.0	990.60	10.8665	4.798	6.068
35	43.00	61.00	324.370	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	2.2130	-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	3.2438	1.2782	0.4251	3930.0	736.80	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	3.7665	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	429.580	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	1099.93	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	1325.86	4.3704	2.825	1.545
49	30.50	50.00	478.880	925.58	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	847.68	3.5226	1.5114	0.7232	7315.0	744.92	6.9669	-1.714	8.681

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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

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	249.436	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	2.6028	-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	778.96	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

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	4.9903	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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Arthur D Little, Inc.

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	232.980	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	278.880	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	-0.7052	1.0290	7250.0	579.70	14.7908	7.9883	6.803
13	36.00	56.00	341.170	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	549.767	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	-0.0903	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	-0.7299	1.1168	655.0	476.80	9.2112	19.6713	-10.460
67	31.00	N	419.840	701.299	1.3487	-0.7206	2.1168	2465.0	644.80	3.5263	·	·
56	29.00	F	423.120	465.796	1.9328	0.2721	0.4572	2032.8	506.10	1.7693	·	·
25	20.00	47.10	426.400	590.898	1.4136	0.0377	1.6321	8700.0	572.66	12.6345	8.8946	3.740
69	32.00	30.00	429.680	606.732	1.4563	-1.5813	1.3862	3250.0	606.10	0.6931	17.2422	-16.549
14	19.00	46.00	446.080	634.685	1.5004	-0.2437	-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	5.5652	8700.0	608.60	·	3.5110	·
82	1.00	N	469.040	513.348	1.8400	-2.8344	-1.6168		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	-1.9750	-0.7882	7315.0	604.80	9.6584	0.2861	9.372

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	495.44	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	0.1240	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	853.24	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	586.56	740.899	1.0738	-1.4576	0.0075	4875.0	876.30	19.853	8.3175	11.536
15	12.00	44.00	599.91	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	600.24	670.698	1.2041	-0.9288	0.4976	8450.0	746.38	6.984	4.9902	1.993
73	21.70	33.00	619.92	930.105	1.0012	-6.5163	-5.0231	3416.0	1969.48		4.8492	
53	10.00	27.00	626.48	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	649.44	710.359	1.2986	-1.1357	0.2670		809.56	10.918		
6	13.00	F	658.30	723.488	1.1328	-0.7854	0.6639	18810.0	792.36	9.466		
62	0.00	N	674.04	501.478	1.8437	-1.2129	0.0004		576.64	18.837		
16	5.00	36.00	685.52	467.420	2.0165	-0.3524	0.7958	13200.0	487.20	13.109	11.1191	1.990
26	14.00	49.00	688.80	610.357	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	-1.3147	0.0853	17700.0	825.36		26.3031	
70	-6.00	D	915.12	709.451	1.3065	-0.1623	1.2091	4008.0	634.50	20.323	28.0883	-25.724
45	-8.61		944.64	622.775	1.3839	-2.6683	-1.3147	17004.0	827.64	2.364	19.2806	
77		21.00	1000.40	608.732	1.4563	0.4949	1.8852	18403.0	605.12			
48	4.00	36.00	1010.24	643.593	1.3127	-2.7101	-1.2837	23106.0	917.91	6.859	6.0000	0.859
57	7.00	0.00	1049.60	671.902	1.2041	-1.6000	-0.3131	8712.0	696.96	3.278	32.5342	-29.256
46	-3.17	27.50	1190.64	579.717	1.6469	-0.6419	0.6614	19800.0	567.80		8.8797	
76	-13.99	17.00	1197.20	527.365	1.5789	0.8062	2.2599	18700.0	718.68		18.7401	
23	-12.90	15.00	1199.82	788.553	1.1631	-3.3948	-1.9016	19575.0	1374.92	7.603	21.0802	
78	2.00	25.00	1200.48	930.105	1.0012	-1.0512	0.4421	9768.0	1048.64	26.699	5.0281	2.575
34	-20.00	3.00	1341.52	929.104	1.0012	-0.7854	0.6639	19600.0	792.36	3.490	30.1825	-3.484
5	-0.02	F	1397.28	723.888	1.1328	-1.4208	-0.0301	15700.0	769.08			
79	F	F	1402.56	653.007	1.3246			24050.0	1579.30	14.920		
90	-12.00	F	1551.44	930.105	1.0012	-4.5986	-3.1053	22200.0				

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------------------------ 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	-0.4861	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	1.3611	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	1.0573	-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	-6.0137	-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	374.905	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	419.840	472.389	0.9084	-0.8345	0.7970	655.0	312.900	16.072	24.1713	-8.099
67	29.00	D	423.120	320.661	1.3305	-0.8660	0.6635	2465.0	520.000	2.094	-8.5555	10.650
56	27.00	N	426.400	399.164	0.9549	-2.4769	-0.8583	2032.8	354.270	0.526		
25	18.53	45.30	429.680	411.634	0.9848	-0.6383	0.9748	8700.0	530.860	-13.773	10.6946	-24.467
69	25.00	32.00	429.680	429.752	1.0160	-2.1410	-0.5339	3250.0	443.080	4.296	15.2422	-10.946
14	9.00	46.00	446.080	323.048	1.3925	8.3904	9.9046	9235.0	549.900	19.693	9.3372	10.356
68	7.86	25.00	449.360	325.062	1.3658	0.9096	2.4307	2325.0	122.960		18.1660	
52	14.00	31.00	459.200	378.721	1.0579	-1.7900	-0.1925	2540.0	292.740	11.512	12.3698	
40	20.78	48.00	469.040	352.010	1.2617	-3.6015	-2.0532	8700.0	465.400		5.5110	-0.857
82	-9.00	N	469.040	474.016	0.9081	-2.7058	-1.0746		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

IN ORDER OF INCREASING DEPTH

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

MINE	SEMF	MEMF	DEPTHFT	MNFUND	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	51.000	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	0.3634	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	-0.1056	1.4266	8470.0			24.7986	
89	10.000	38.000	649.44	338.894	1.3238	-1.6819	-0.0435	9562.0	343.04	6.842	7.8519	-1.010
75	3.000	N	658.30	477.749	0.8734	-2.4043	-0.7441		579.82	16.472		
6	-9.890	F	674.04	484.493	0.7582	-4.4877	-2.9409	18810.0	639.00	28.868		
62	-6.000	N	685.52	343.965	1.2646	-0.0467	1.4676		576.64	21.562		
16	-3.000	33.000	688.80	323.048	1.3925	-2.2504	-0.6522	13200.0	324.80	17.893	14.1191	3.774
26	9.000	D	688.80	414.467	1.0573	-0.5395	0.5079	14500.0	537.04	8.057	-4.0650	12.122
27	16.000	N	688.80	545.613	0.4323	-0.6887	0.9264		580.52	3.445		
50	-16.000	18.000	744.56	436.702	0.9792	-3.7460	-2.0556	16000.0	472.76	31.483	28.7617	2.721
38	-11.500	20.500	780.64	659.183	0.6172			16000.0	1014.60	29.326	25.0286	4.298
4	-24.830	-0.781	799.99	455.690	0.7843	-1.1212	0.5159	7260.0			38.8078	
61	N	N	846.24	343.965	1.2646	-0.5949	1.0285	17700.0			28.3031	
70	F	D	915.12	477.251	0.8789			4008.0	543.00			
45	-6.000	N	944.64	420.200	0.9338	-3.7690	-2.1559	17004.0	450.00	14.946	37.0883	-22.142
77	-13.760	20.000	1000.40	411.694	0.9849	0.0364	1.6704	20076.0	635.36		21.0364	
43	0.000	34.000	1010.60	431.232	0.8837	-2.2777	-0.6286	23100.0	429.44	7.422	8.0000	-0.578
57	3.000	-1.000	1049.60	450.767	0.8078	-3.6160	-2.0339	13068.0	585.90	3.811	37.0560	-33.245
46	-17.000	23.000	1190.64	394.606	1.1210	-1.4649	0.1263	19800.0	598.40	19.370	13.3797	5.990
76	-24.110	11.000	1197.20	358.351	1.0729	-0.0223	-1.6400	20400.0	424.18		25.4958	
23	-13.390	18.000	1199.82	527.496	0.7780	-4.0236	-2.3439	19575.0	528.84		18.0802	
78	-5.000	22.000	1200.48	619.620	0.6670	-2.4071	-0.7275	9768.0	984.74	11.074	8.0281	3.046
34	-24.000	F	1341.52	618.953	0.6670	-2.4043	-0.7441	19600.0	816.64	27.171		
5	-7.000	F	1397.28	484.493	0.7582	-1.8215	-0.1892	15700.0	639.00	6.982		
79	F	F	1400.56	439.699	0.8919			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)

<u>Symbol Legend</u>

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   = $(STD. DEV.)^2$

MINIMUM VAlUE   = Min. Data Value

MAXIMUM VALUE   = Max. Data Value

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STATISTICS FOR SELECTED VARIABLES

FREQ=630

VARIABLE	N	MEAN	STANDARD DEVIATION	VARIANCE	MINIMUM VALUE	MAXIMUM VALUE
IFUND	94	3.10711489	0.59850690	0.3582	0.30590000	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

VARIABLE	N	MEAN	STANDARD DEVIATION	VARIANCE	MINIMUM VALUE	MAXIMUM VALUE
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	45362587.8636	655.00000000	27750.0000000

FREQ=1950

VARIABLE	N	MEAN	STANDARD DEVIATION	VARIANCE	MINIMUM VALUE	MAXIMUM VALUE
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

VARIABLE	N	MEAN	STANDARD DEVIATION	VARIANCE	MINIMUM VALUE	MAXIMUM VALUE
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	-8.41383978	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

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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 $\mu A/m$

MEMF   = In-Mine Vertical Component of Magnetic Field
              Strength in dB re 1 $\mu A/m$

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

TLD   = Transmission Loss Downlink = $20 \, \text{log} \, (2\pi D^3/M_s)$
              $- \text{MEMF} + 120$ 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

FREQ=630   DEPTHINT=1

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE
DEPTHFT	22	240.66254545	46.99638708	58.88000000	295.2000000
MMFUND	22	886.55473182	344.61939392	140.61310000	1443.9045000
MMDN	20	4552.03000000	4130.90398888	852.00000000	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	65.4849462
DELTATL	18	-2.69241128	17.19654822	-6.68939755	29.8172791

FREQ=630   DEPTHINT=2

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE
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	3.73155655	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

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE
DEPTHFT	19	451.94947368	32.17947374	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	19	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

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE
DEPTHFT	10	547.89120000	34.96178449	500.20000000	599.9120000
MMFUND	10	1288.12218000	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	24.2641903
TLD	9	2.49472412	4.44775106	-6.68252280	7.7946578
DELTATL	7	10.09830962	8.63359688	1.21740097	24.2921021

FREQ=630   DEPTHINT=5

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE
DEPTHFT	12	652.50133333	34.05929962	600.24000000	688.8000000
MMFUND	12	1198.85572500	410.37858376	557.82520000	2047.1689000
MMDN	10	10332.77777778	4513.74095894	3416.00000000	18810.0000000
SEMF	11	18.55455455	6.22757796	6.00000000	27.0000000
MEMF	7	41.64285714	2.56115673	39.00000000	47.0000000
TLU	11	8.13173757	2.74408945	2.23835981	18.2538574
TLD	7	4.77441624	2.27553275	0.60247974	7.9350095
DELTATL	7	3.81933577	3.93747238	-0.96518634	10.0745686

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FREQ=630   DEPTHINT=6

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM 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 --------------------------

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE
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 --------------------------

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE
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 --------------------------

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE
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 --------------------------

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE
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

STATISTICS FOR DEPTH INTERVALS
FREQ=1050   DEPTHINT=3

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM 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 -----------

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE
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	7.27775369	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 -----------

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE
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 -----------

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE
DEPTHFT	6	838.5320000	78.55137773	744.56000000	944.6400000
MMFUND	6	1105.2185833	292.15414958	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	11.02683170	-3.79026574	16.0671635

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

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE
DEPTHFT	6	1107.9840000	97.73739575	1000.40000000	1199.8240000
MMFUND	6	1008.6382000	161.07247569	818.83940000	1278.9451000
MMDN	6	21023.0000000	4643.55682640	13068.00000000	25500.0000000
SEMF	6	2.4883333	8.02590909	-9.70000000	14.0000000
MEMF	6	24.1666667	11.03479346	8.00000000	37.0000000
TLU	5	5.5918311	3.55857641	0.44049003	8.4932823
TLD	5	14.4874214	9.36362340	4.37971734	28.0559909
DELTATL	4	-6.8756056	14.49649917	-27.65108906	4.1135689

STATISTICS FOR DEPTH INTERVALS
FREQ=1050   DEPTHINT=8

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM 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	-5.7500000	8.24135582	-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

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE
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	16	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

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE
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

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE
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	7.46621285	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	-16.5491460	10.3352548

FREQ=1950   DEPTHINT=4

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE
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	7.61289539	5.85000000	25.1400000
MEMF	8	36.93125000	10.20234348	20.00000000	50.0000000
TLU	10	9.80656809	11.78904425	-17.68964149	21.8764267
TLD	8	8.65915179	6.44468114	0.97199816	21.1095374
DELTATL	8	-1.56626812	10.26156738	-22.75588924	11.5356866

STATISTICS FOR DEPTH INTERVALS
FREQ=1950   DEPTHINT=5

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE
DEPTHFT	12	652.5013333	34.05929962	600.24000000	688.8000000
MMFUND	12	617.5371667	161.21912725	342.1787000	930.1055000
MMDN	9	1032.7777778	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

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE
DEPTHFT	6	836.5320000	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	7.36388685	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

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE
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	2	17.7524600	9.48397831	6.00000373	32.5341658
DELTATL	2	-14.1984153	21.29497253	-29.25623478	0.8594042

FREQ=1950   DEPTHINT=8

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE
DEPTHFT	5	1378.2560000	126.29916738	1200.48000000	1551.4400000
MMFUND	5	83.2419600	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

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE
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	6.63491034	-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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FREQ=3030   DEPTHINT=2

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE
DEPTHFT	14	342.99428571	22.08603517	308.32000000	387.04000000
MMFUND	14	326.95818571	99.23481308	115.25200000	444.68630000
MMDN	13	6585.77307692	3484.33808017	837.00000000	12360.55000000
SEMF	14	23.96428571	11.69560122	-4.00000000	35.50000000
MEMF	13	51.19230769	7.93079037	33.00000000	60.50000000
TLU	14	8.72309826	9.47827414	-1.37036793	29.27377765
TLD	13	6.18855956	3.37767700	0.96345632	10.32754448
DELTATL	13	0.95371730	7.91284031	-5.99872615	25.4826306

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

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE
DEPTHFT	19	451.94947368	32.12947374	400.16000000	498.56000000
MMFUND	19	371.96291053	64.26287370	260.78300000	474.01590000
MMDN	17	5698.84117647	3941.33116203	655.00000000	15163.50000000
SEMF	19	16.65631579	8.60940907	-9.00000000	29.00000000
MEMF	15	38.26000000	12.16715720	10.80000000	52.00000000
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 -------------------

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE
DEPTHFT	10	547.89120000	34.96178449	500.20000000	599.91200000
MMFUND	10	426.68384000	86.98577983	311.66210000	547.44340000
MMDN	10	7119.70000000	3707.35335516	3112.00000000	12200.00000000
SEMF	10	9.86060000	10.96512407	-7.00000000	23.93000000
MEMF	10	33.96500000	13.62546737	10.00000000	52.20000000
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 -------------------

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE
DEPTHFT	12	652.5013333	34.05929962	600.24000000	688.80000000
MMFURD	12	423.1352650	107.60017640	247.86760000	619.61960000
MMON	9	10332.7777778	4513.74095894	3416.00000000	18810.00000000
SEMF	11	2.7627273	10.18396395	-11.00000000	17.00000000
MEMF	6	33.6666667	9.22315926	20.00000000	44.00000000
TLU	10	14.2711205	9.42881208	3.44534363	28.8678459
TLD	7	10.1313052	9.47403714	-4.06499051	24.7985639
DELTATL	6	4.3738591	5.17241456	-1.47367532	12.1224307

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

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE
DEPTHFT	6	838.5320000	78.55137773	744.56000000	944.64000000
MMFUND	6	465.4985667	105.26127256	343.96530000	659.18330000
MMON	6	12995.3333333	5829.67493662	4004.83000000	17700.00000000
SEMF	4	-14.5825000	7.96202811	-24.83000000	-6.00000000
MEMF	3	12.5730000	11.63226061	-0.78100000	20.50000000
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

STATISTICS FOR DEPTH INTERVALS
FREQ=3030   DEPTHINT=7

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE
DEPTHFT	6	1107.9840000	97.73739575	1000.4000000	1199.8240000
MMFUND	6	429.0241833	57.71293905	358.3506000	527.4956000
MMDN	6	19936.5000000	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
TLO	6	20.5080213	10.12077326	8.0000037	37.0559909
DELTATL	3	-9.2777291	21.01457572	-33.2451441	5.9899787

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

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE
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
TLO	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 μ A/m. SEMFNORM = Surface Vertical Component of Magnetic Field Strength for a Transmit Magnetic Moment of 1 A-m^2.

Arthur D Little, Inc

Table   E-1

Statistical Analysis of Uplink Data

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.

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

PARAMETER	ESTIMATE	T FOR H0: PARAMETER=0	PR > |T|	STD ERROR OF ESTIMATE
INTERCEPT	99.82861848	15.72	0.0001	6.34941600
LOGDEPTH	-61.96740938	-21.04	0.0001	2.94453441

OBSERVATION	OBSERVED VALUE	PREDICTED VALUE	RESIDUAL	LOWER 95% CL INDIVIDUAL	UPPER 95% CL 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	-1.48957385
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

ANALYSIS OF UPLINK DATA
FREQ=630

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: SEMFNORM

OBSERVATION	OBSERVED VALUE	PREDICTED VALUE	RESIDUAL	LOWER 95% CL INDIVIDUAL	UPPER 95% CL 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	-12.87069950
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	-41.85627100	-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	-28.84921949	-34.29072098	5.44150149	-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	-33.56383330	-35.90054254	2.33672923	-49.19441657	-22.60650851
58	-50.84134892	-36.41646531	-14.42448360	-49.71162025	-23.12131038
59	-33.03161730	-36.50149573	3.44987843	-49.79684924	-23.20614221
60	-43.21997672	-37.58311684	-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	-42.85327717	6.50288214	-56.17815133	-29.53040300
73	-39.67599445	-43.49033877	3.81434433	-56.81852233	-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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GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: SEMFNORM

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

                              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.

ANALYSIS OF UPLINK DATA
FREQ=1050

10:30 WEDNESDAY, MAY 14, 1980   11

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

PARAMETER	ESTIMATE	T FOR HO: PARAMETER=0	PR > |T|	STD ERROR OF ESTIMATE
INTERCEPT	110.27017823	17.38	0.0001	6.34489246
LOGDEPTH	-67.11199745	-22.76	0.0001	2.94346922

OBSERVATION	OBSERVED VALUE	PREDICTED VALUE	RESIDUAL	LOWER 95% CL INDIVIDUAL	UPPER 95% CL 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	-9.75577528	-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	-13.52058972	-13.49746735	0.36897763	-27.10087334	-0.44206136
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	-14.79606905	-17.19383908	2.39776912	-30.29005325	-4.09762490
14	-10.40465915	-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	-23.66085846	-7.34287639	-36.70854900	-10.61322273
25	-26.53311699	-23.66088586	-2.87223112	-36.70854900	-10.61322273
26	-18.31255841	-23.66085846	5.34832745	-36.70854900	-10.61322273
27	-29.72406849	-23.95381667	-5.77025182	-36.99985491	-10.90777844
28	-27.78547644	-24.24363270	-3.54164394	-37.28831139	-11.19935401
29	-23.53311699	-25.09695810	1.56384111	-38.13713315	-12.05678305

Arthur D. Little, Inc.

ANALYSIS OF UPLINK DATA
FREQ=1050

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: SEMFNORM

OBSERVATION	OBSERVED VALUE	PREDICTED VALUE	RESIDUAL	LOWER 95% CL INDIVIDUAL	UPPER 95% CL 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	-33.53311592	-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	-45.35101933	-39.34959858	-6.00142075	-51.57814479	-25.52105237
61	-37.86904198	-39.59065104	1.72160906	-52.62271059	-26.55859149
62	-30.28555135	-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	-55.29929344	-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	-46.09501508	-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 VALUE	PREDICTED VALUE	RESIDUAL	LOWER 95% CL INDIVIDUAL	UPPER 95% CL 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

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        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
```

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.

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

PARAMETER	ESTIMATE	T FOR H0: PARAMETER=0	PR > |T|	STD ERROR OF ESTIMATE
INTERCEPT	111.83365893	16.34	0.0001	6.84264449
LOGDEPTH	-68.31077640	-21.51	0.0001	3.17546986

OBSERVATION	OBSERVED VALUE	PREDICTED VALUE	RESIDUAL	LOWER 95% CL INDIVIDUAL	UPPER 95% CL 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	-16.72414611	-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
FREQ=1950

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: SEMFNORM

OBSERVATION	OBSERVED VALUE	PREDICTED VALUE	RESIDUAL	LOWER 95% CL INDIVIDUAL	UPPER 95% CL INDIVIDUAL
30	-25.54886271	-25.95145450	0.40259180	-40.12471125	-11.77819775
31	-29.01709275	-26.51655717	-2.50053557	-40.68700315	-12.34611120
32	-17.65588719	-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	-46.24446891	-17.95851136
41	-24.36391323	-32.36236284	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	-37.67854537	-37.78959995	0.11105408	-51.94413361	-23.63506628
58	-49.75504484	-38.35831372	-11.39673112	-52.51407372	-24.20255371
59	-33.03130734	-38.45204837	5.42074099	-52.60802920	-24.29606754
60	-47.08568375	-39.64439045	-7.44129279	-53.60364247	-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	-59.24256042	-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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Arthur D Little, Inc.

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: SEMFNORM

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

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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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

PARAMETER	ESTIMATE	T FOR H0: PARAMETER=0	PR > ITI	STD ERROR OF ESTIMATE
INTERCEPT	128.50374772	14.78	0.0001	8.69297681
LOGDEPTH	-76.71420882	-18.97	0.0001	4.04314440

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

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: SEMFNORM

OBSERVATION	OBSERVED VALUE	PREDICTED VALUE	RESIDUAL	LOWER 95% CL INDIVIDUAL	UPPER 95% CL 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	-36.03406950	-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	-46.13321886	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	-68.80369755	-52.23691189	-16.56678577	-70.13958591	-34.33423786
79	-67.88012392	-53.81347325	-14.06665067	-71.73309948	-35.89384703

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: SEMFNORM

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

Arthur D Little, Inc.

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

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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[1]	F[1]
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.

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hand, there is no evidence from this experiment that the proba-
bility 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 pro-
portions, 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 represen-
tative, 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

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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.
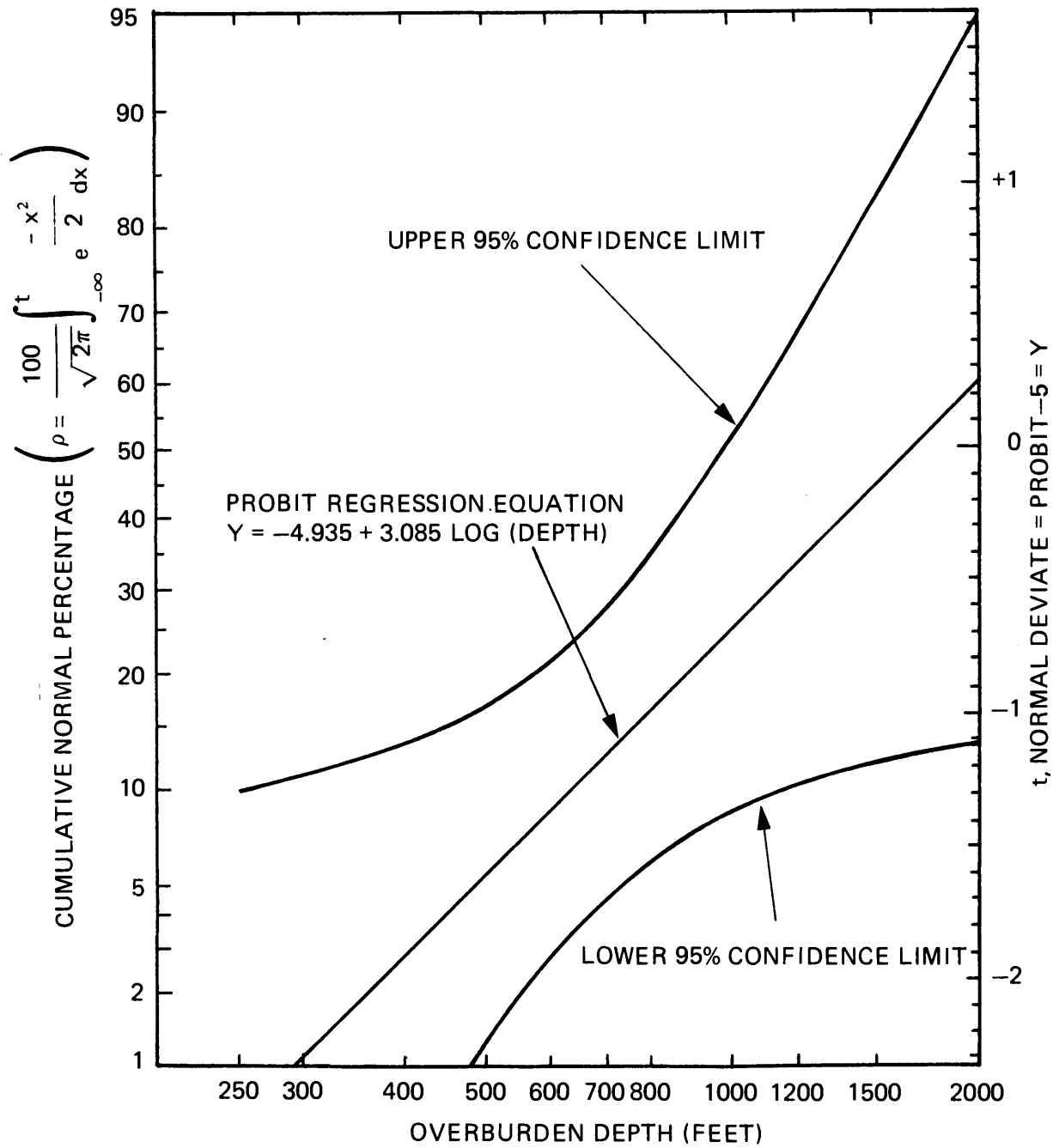
FIGURE F—1   RESULTS OF PROBIT ANALYSIS

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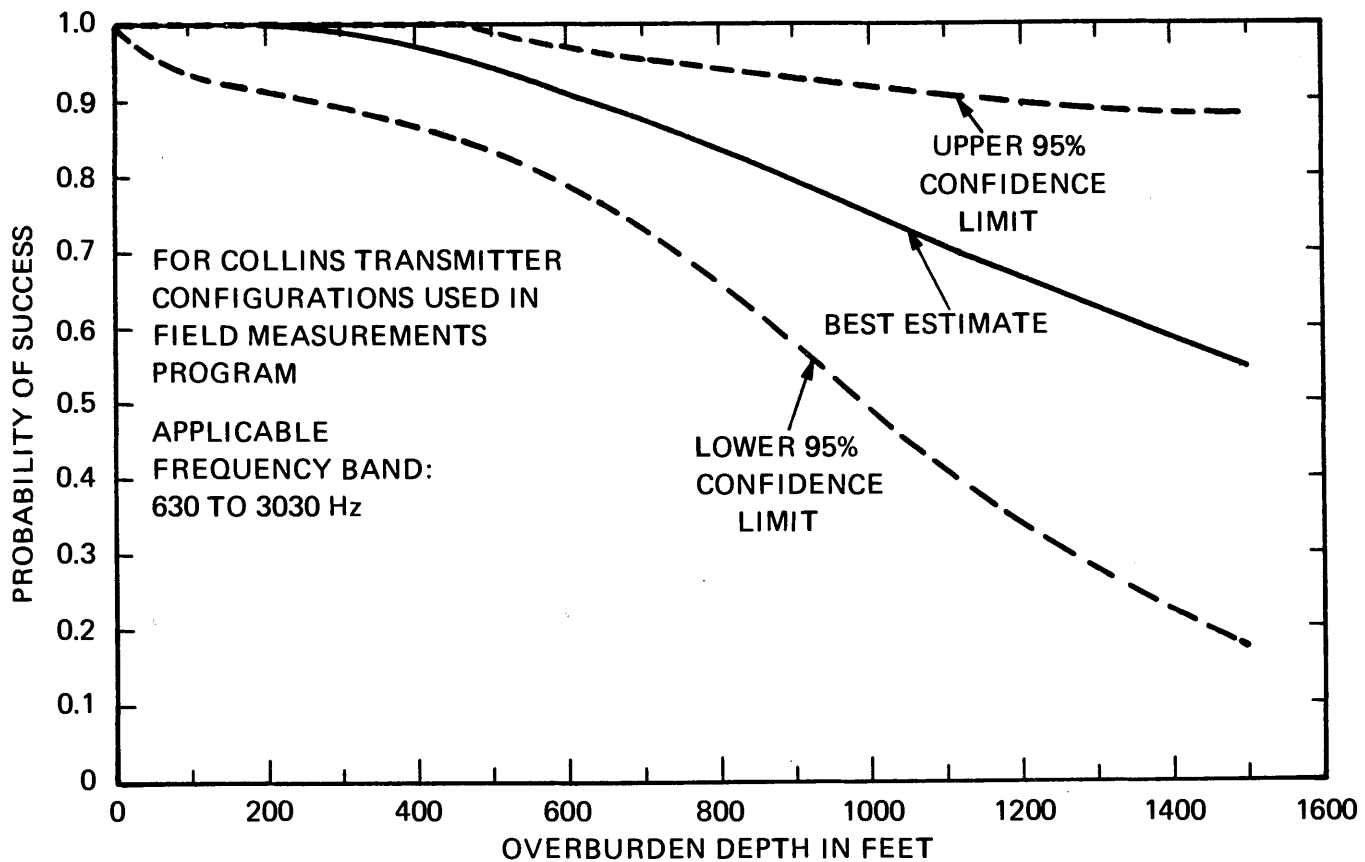
FIGURE F-2   ESTIMATED UPLINK PROBABILITY OF SUCCESSFUL
DETECTION VS OVERBURDEN DEPTH (BASED ON
SUCCESS/FAIL DATA FROM 94 MINE FIELD TESTS)

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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.

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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^{th} region, i = 1, 2, ...,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

$$W_i = 2 \int_0^\infty x \, p_i(x) dx, \tag{1}$$

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.

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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^{th} region;

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

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

To a first approximation, s_i is proportional to the expected number n_i of miners trapped in the i^{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^{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^{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^{th} region at time t:

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

The derivation of (5) is given below.

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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

$$Q_i = 1 - P_i(t). \qquad (7)$$

Then

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

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

$$L_i(t) = \int_0^t \lambda_i(x)dx. \qquad (9)$$

The condition expressed by Equation (4) then becomes

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

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 $P_i(t_1 \mid$ 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

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

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

where

$$b_i = A_i/W_i. \tag{12}$$

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

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

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

$$L_i(t_1) \geq 0, \quad i = 1, 2, \ldots, k. \tag{14}$$

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

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

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where

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

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

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 $j \in \{J\}$ 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 $L_j(t_1) > 0$, $j \in \{J\}$.

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

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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

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

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

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

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

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

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

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

Restoring the index i, we obtain

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

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

$$L(t_1) = ut_1 , \qquad (26)$$

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

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

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where

$$a_i = (1/v_i) + (1/s_i) \, , \qquad (28)$$

and

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

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.

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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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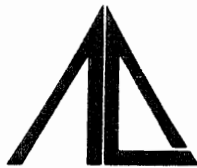
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