SUMMARY REPORT OF ELECTROMAGNETIC LOCATION TECHNIQUES WORKING GROUP

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1.0 INTRODUCTION

The Location Group conversed in the Petroleum Room of the Green Center with the purpose of addressing the following list of topics in light of the Bureau of Mines' requirements for detecting and locating trapped miners by electromagnetic methods. These topics include: Noise, Sources, Antennas (transmit and receive), the Propagation Medium, Signal Processing, Optimum Frequency, Receivers, Pulse vs. CW Techniques, Passive Location Techniques, and Obstacles. Practical constraints such as equipment size, weight and power requirements, cost and intrinsic safety were kept in mind during these discussions. It was emphasized that in-mine equipment must be inexpensive, rugged, simple and lightweight. Otherwise, the mine operators probably would not buy it nor would the miners be able to effectively use it.

Present techniques for experimentally detecting and locating trapped miners were discussed, along with techniques to improve their location accuracy. Analytical, numerical, and scale modelling methods were considered as a means of giving further insight into measurement anomalies caused by terrain variations, conductivity contrasts, and obstacles.

After discussion of these topics, conclusions were drawn and existing problem areas were identified. These problem areas were addressed in developing guidelines for future efforts. Following the discussion period, the Chairman gave a summary of the Location Group report and comments were solicited from the entire group.

2.0 GROUP DISCUSSION HIGHLIGHTS

2.1 Noise

W. Bensema asked the group whether the noise data provided by NBS was adequate. It was determined that for location systems analysis, the most important form of noise data was the frequency spectra of vertical and horizontal magnetic fields on the surface, and the answer to his question was affirmative. Drs. Wait and Frischknecht pointed out the difficulty in accurately measuring the true vertical magnetic field since these measurements are heavily influenced by the loop setting and the local geology. Nevertheless, these measurements are important since the same perturbations would also affect a receiving loop oriented to receive the vertical magnetic field. Dr. Rankin pointed out that the magnetic noise fields pass through a null somewhere between 0.2 Hz and 5 Hz, that this frequency range may have merit in deep mine detection problems.

2.2 Sources

Sources that have been used most extensively and successfully to date in mine location problems are vertical magnetic dipoles (VMD) consisting of single turn and multiple turn loops of wire powered by a source of AC current. The advantages and disadvantages of using a horizontal magnetic dipole (HMD) as an alternate to the vertical dipole were discussed. The main advantage in using the HMD is that the null field is the vertical magnetic field (H_z) and that a greater resolution of the null plane may be realizable due to a lower H_z background noise. However, the main disadvantages in using a horizontal magnetic dipole source is that only one null plane in H_z is produced by a single HMD source and that additional information is needed to resolve the null point location. Furthermore, there are practical constraints on how large an area can be realized in an HMD configuration and how difficult it would be for a miner to implement in an actual emergency.

2.3 Antennas

Transmitting antennas that have been successful in location exercises for the Bureau of Mines have consisted of single turn and multiple turn loops deployed on the mine floor usually in intersections or around coal pillars. These antennas have produced adequate signals for detection and location at mine depths as great as 1650 feet. However, it was pointed out that these antenna configurations are not possible in most metal mines because of the random mine tunnel construction (following the ore veins) and the relatively narrow width of the walls. Consequently, it may become necessary to revert to long wire antennas tied to roof bolts or large area loops if closed paths are available. Since metal mines are normally deeper than coal mines, the increased moments of these large antennas may be required anyway to produce detectable signals on the surface.

The possibility of using ferrite core transmitting antennas was also discussed. In view of Dr. Gabillard's success with these antennas, it was decided that they warrant further investigation for location purposes.

The relative advantages of using air core and ferrite core receiving antennas were also discussed. Ferrite core antennas are more compact but are not as stable as air core loops. Since much of the experimental work for the Bureau of Mines entails the measurement of absolute field strength profiles, it was concluded that for the present time, air core loops are more desirable.

Other forms of receiving antennas that were discussed were a dual coil system for field gradient measurements and a broadband gradiometer for ultra low frequencies. Some preliminary work has been done by Westinghouse on the dual coil system but it is yet too early to evaluate the results.

2.4 Propagation Medium

In discussing the propagation medium, the general consensus among the members of this group was that the half space/plane earth was well understood. Simple extensions of the plane earth theory, such as hill slope corrections, have proven useful in refining the location accuracy of the measured results. Cylindrical and spherical models have also been developed to account for terrain anomalies but have not been fully evaluated with respect to experimental results. The request was made by Drs. Wait and Lewis that careful documentation of actual field environments including anomalies in the propagation media be made and forwarded to those investigators developing analytical models to further guide them in producing realistic models. Dr. Geyer suggested that analysis of dipping bed conductivity contrasts be investigated to determine their effect on location accuracy.

Analysis of the effects of arbitrary terrain variations in the media were also discussed. Dr. Frischknecht proposed a three-dimensional scale modelling approach to the terrain problem while Dr. Greenfield suggested a two-dimensional numerical analysis technique. It was felt that both of these techniques would enhance our understanding of the effects of terrain on location accuracy although Dr. Wait expressed reservations on the two-dimensional analysis.

Techniques for experimentally determining the apparent conductivity of the medium are well understood and measurement results can be used directly in predicting field strengths when one knows the transmitted moment and the overburden depth.

2.5 Signal Processing/Receiving

In existing EM location receivers, signal processing is straightforward and consists merely of narrowband amplification of an AC signal transmitted from an underground dipole. It was pointed out that for mines appreciably deeper than 1500 feet, it will probably be necessary to use some sort of synchronous detection scheme with expanded integration time to obtain signal to noise ratios suitable for detection and location from existing levels of transmitted moment. Dick Myers suggested the possible use of ambient 60 Hz fields as a common synchronizing source for both transmitter and receiver.

2.6 Optimum Frequency

Although it has been demonstrated that frequencies between 900-3000 Hz are ideally suited to uplink detection and location in most coal mines, the optimum frequency will no doubt be shifted downward when considering their use in deeper and more conductive metal mines. When discussing the range of lower frequencies available, it was suggested by Dr. Frischknecht that we look into the use of magnetometers and broadband gradiometers as field sensors. Dr. Rankin suggested that if ultra low frequencies are used, we should take advantage of the low background noise region between 0.2 Hz and 5 Hz.

2.7 Pulse vs. CW

Source location by waveshape analysis of underground transmitted pulses has been proposed by Dr. Wait. Analytically, these techniques contain diagnostic information not found in simple CW transmissions. However, in light of intrinsic safety requirements, the technique was not considered practical for use in coal mines. Consequently, the Bureau of Mines has pursued the CW approach and with a relative measure of success. However, this is not to say that the pulse technique will not be feasible in hardrock mines where the intrinsic safety limitation no longer exists. Pending the outcome of future CW tests in hardrock mines, the question of pulse vs. CW should be temporarily deferred.

2.8 Passive Location

The passive location technique (also proposed by Dr. Wait) is one which enables a miner to modulate a secondary source in the mine by opening and closing a large coil of wire and by doing so, have a recognizable effect on the impedance of the transmitting loop. Initial investigations into the practicality of this scheme have been somewhat pessimistic in light of realistic parameters of noise, conductivity, and overburden depth. However, it has been suggested that the potential use of this scheme be investigated more thoroughly to decide once and for all whether it is practical. The advantages of such a scheme are quite obvious in that no power is required on the part of the trapped miner.

2.9 Obstacles

It has been shown that obstacles appearing in the mine overburden have a distorting effect on uplink field patterns especially if they occur near the observer location. Dr. Wait suggested that obstacles of primary importance are cylinders and longitudinal conductors. These geometric figures can be used to model buried pipelines and cables and analytical results are available to study their effects. Dr. Wait pointed out that someone should conduct a study to identify what information would be most useful in improving overall location accuracy.

3.0 MAJOR CONCLUSIONS

The uplink detection problem has been solved for the vast majority of coal mines in the United States.

Location techniques (uncorrected) are generally accurate to better than 10% of overburden depth.

The half space/plane earth theory is well understood; however, more work is needed on analyzing terrain anomalies and near surface conductivity anomalies to obtain more refined correction factors for the data.

The detection problem has not been solved for extremely deep hardrock mines; however, removal of intrinsic safety limitations will facilitate this problem. Also it may be necessary to lower frequency, use long wire antennas or coherent receivers to get satisfactory results in these mines.

Noise data of primary importance to location problems are the spectral information on the three component magnetic fields at the surface.

4.0 RECOMMENDATIONS FOR FUTURE WORK

Based on the workshop discussions, the following review session and a later informal session of the location group, the following recommendations for future work are given in descending order of priority. The primary emphasis is on signal detection above deep mines and the secondary emphasis is upon refining location accuracy obtained using existing techniques.

The relative level of effort and the time required to achieve the desired goals are roughly estimated and are indicated by the following:

Level of Effort		Time Duration	
High	(H)	Short Term	(ST)
Medium	(M)	Long Term	(LT)
Low	(L)		

1. Optimize frequency for propagation in deep mines and for minimum influence from anomalies. (H, ST)

2. Investigate alternate detection techniques such as magnetometer, gradiometer, multiple coil systems and coherent detection for use in deep mines. (M, LT)

3. Increase understanding of anomalous location results, i.e.,
   arbitrary terrain effects (scale modelling) (L, ST)
   arbitrary terrain effects (numerical techniques) (M, LT)
   effects of long cylinders and longitudinal conductors (rapid analytical methods). (M, ST)
   geometric terrain effects (spherical/cylindrical). (M, ST)

4. Investigate alternate transmitter techniques: (L, LT)
   Ferrite loop source vs. air core loop.
   Pulse type transmitter for metal mines.
   Hand crank power source.

5. Predict performance of passive detection technique. (L, ST)