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Mine Safety and Health Administration
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Mine Waste and Geotechnical Engineering Division

January 14, 2008

MEMORANDUM FOR IRVING McCRAE
Contracting Officer, Acquisitions Management Division
MSHA - Headquarters, Arlington

THROUGH: STANLEY J. MICHALEK
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SUBJECT: Summary of Look-Ahead-Radar (LAR) Mine Void Detection Demonstration Project, Stolar Research Corporation, Mine Void Detection Project Account Number B2532534, MSHA RFP No. J53R1011

Stolar Research Corporation (Stolar) has recently fulfilled their contract to demonstrate the use of their Look-Ahead-Radar (LAR) device to detect underground mine voids in advance of mining. As the Contracting Officer's Technical Representatives (COTRs) for this project, we were responsible for overseeing the demonstration of the LAR on behalf of the Contracting Officer. This work was performed under account number B2532534 in connection with MSHA RFP No. J53R1011. This memorandum provides a general summary of the LAR project and a discussion of the final results.

PROJECT SUMMARY

The objective of the Look-Ahead-Radar (LAR) project was the demonstration of a radar device with a graphical user interface that could detect the presence of air-filled or water-filled mine voids immediately ahead of underground mining activities.

Knowledge regarding the presence of mine voids in close proximity to underground mining activity is critical in preventing water or gas inundations resulting from penetration into unmapped or poorly-mapped mine workings.

The fundamental technical concept employed by the LAR is that mine voids can be identified by the reflections and phase changes that occur when electromagnetic waves encounter changes in their transmission media such as those produced at a coal-void interface. As such, the LAR is an in-seam geophysical method that detects underground mine voids by transmitting electromagnetic waves through a coal seam and measuring the reflected signal. At this time, the method involves deploying a portable radar antenna against a coal seam, transmitting electromagnetic waves through the coal, and recording wave reflections indicative of a void. The distance to the void is determined by the velocity of the wave and the time between transmission and reflection. The ultimate goal of this technology is the development of a device that can be mounted on the cutting drum of a continuous mining machine to monitor for mine voids in real-time with no post-processing of data. The advance of the mining machine could then be automatically suspended if a dangerous condition was being approached. This concept is depicted in Photo 1. Photo 2 shows conceptually how the device was to be mounted to the cutting drum of a continuous miner in the same manner as the company's Horizon Sensor which is used for selectively cutting coal. However, the technology is not yet sufficiently developed for this application. By funding this project, it was expected that the technology could be further advanced toward this ultimate goal.

Activities performed under the contract included: theory validation and literature searches; equipment assembly, laboratory and field testing; design modifications; demonstration; and report preparation. The initial project kickoff meeting took place on January 13, 2005, at Consolidation Coal Company's office in Washington, PA. The meeting was attended by representatives of Consolidation Coal Company, Stolar Research Corporation, West Virginia University, Coal Mine Safety and Health Districts 2 and 3, MSHA Technical Support and MSHA Headquarters staff. At the time of the meeting, the specific test sites were not yet identified, but it was anticipated that the testing would be performed at Consolidation Coal Company Mines in Western Pennsylvania, Northern West Virginia, and Utah. During the meeting, project roles and responsibilities were defined, and Stolar was informed of the relevant safety regulations and the Districts' responsibility for ensuring a safe work environment during testing. Follow-up discussions were held with representatives of Coal Mine Safety and Health District 9, due to anticipated testing within their jurisdiction.

PRELIMINARY LABORATORY TESTING

Initial laboratory testing was performed using a Stolar-developed Resonant Microstrip Patch Antenna (RMPA) in their laboratory in Raton, New Mexico. This initial testing utilized salt blocks to simulate the coal seam and a reflective steel plate to simulate a mine void. Stolar considered this a reasonable test condition, since the dielectric characteristics of salt are similar to those of coal. The handheld RMPA antenna worked well in the laboratory. The antenna test set-up and associated handheld graphical interface are shown in Photo 3. Photo 4 shows that the reflector plate is identified by an abrupt phase change in the data record at a distance of 23 feet.

INITIAL FIELD TESTING, MAY 23, 2006, CONSOLIDATION COAL COMPANY, EMERY, UTAH

The initial field testing took place at the Consolidation Coal Company Emery Mine on May 23, 2006. The testing involved measuring reflected electromagnetic wave energy as the continuous miner (and the associated mine void) approached the test set-up location. This testing was performed during the development of two crosscuts in the 1st North Section of the mine. The company mines the lower portion of a 23-foot-thick coal seam. They leave approximately 2 feet of coal in the floor and a significant thickness of coal in the mine roof, bolting the roof with 5-foot resin bolts on 5-foot centers. They make a 60-foot extended cut using a remote control continuous miner, and do not bolt until the entire cut is complete. Due to the roof conditions, they were able to access the area under development for measuring, permitting accurate measurements to be made. The 20-foot mine entries were on 75-foot centers, resulting in a total crosscut length of 55 feet. The mining height ranged from about 8.5-9 feet in the areas tested.

The purpose of the preliminary testing was for Stolar to evaluate the performance of a number of candidate antenna systems, so that they could select the best one prior to the scheduled final demonstration in June 2006. To do this, Stolar installed a variety of transceiver antennas in an entry and location where the continuous miner was expected to cut through the coal barrier (photo 5). Frequent measurements were taken as the crosscut approached the antennas. Constant communication was maintained. Measurements were taken from the start of the crosscut, and continued until the miner was approximately 10 feet away.

In addition to the Resonant Micropatch Patch Antenna (RMPA) which was originally proposed for the handheld system, the company also tested 33-inch and 58-inch resistor loaded folded dipole antennas. Also, a 1 MHz transceiver with induction tool was set up. This instrumentation was being tested for another project that Stolar is working on. In spite of being successful under highly-idealized laboratory conditions, it was not clear whether it would work in the final handheld LAR device in a coal mine. The other systems were being tested for possible substitution if necessary.

A large quantity of data was collected by measuring the intensity and phase of the electromagnetic signal as the miner approached the antennas. The progress of the miner was accurately measured and timed as the crosscut was made. Stolar collected data as the miner approached them as well as periodically with the miner backed out of the crosscut, so that they could determine whether they were detecting the miner or the void that it created. Data was collected and observed using a laptop computer (photo 6) and commercial signal analysis equipment (photo 7). The data which was immediately apparent in the field did not show an indication of the approaching mine void, but Stolar was optimistic that post-processing would reveal the void location. Data processing software and algorithms would then be integrated into the handheld LAR device prior to the final field demonstration.

Although it appeared to work in the laboratory simulation, the RMPA antenna did not work in the actual mine environment, probably due to the less ideal conditions and the presence of multiple reflection surfaces. Stolar began looking into other possible antenna systems to solve this problem. This necessitated that they use separate transmission and receiver antennas, increase the size of the antennas, and separate them by a sufficient distance to suppress the effect from the initial reflection boundary. While this improved the effectiveness, it complicated their ability to make the device compact enough to install in the cutting drum of a continuous mining machine.

FIELD TESTING OF SEPTEMBER 19-20, 2006, CONSOLIDATION COAL COMPANY, MINE 84

From September 19-21, 2006, Stolar was at Consol Energy, Incorporated (Consol), Eighty Four Mining Company, Mine 84, to perform additional testing. This was originally to be the final field demonstration, but the status of the equipment was not considered adequate for the demonstration to be considered acceptable. The specific work plan for this testing was outlined in a report submitted by Stolar on September 11, 2006. In addition to a dynamic test similar to that which was previously performed at Emery Mine, a static test was proposed which involved testing the system across a tapered pillar (of varying thickness) toward both air-filled and a simulated water-filled void.

The general test conditions are depicted in Photo 8. The dynamic testing could not be performed at this time due to: (1) issues related to coordination with Consol's production schedule, (2) resolving safety concerns, and (3) obtaining approval from Coal Mine Safety and Health, District 2. Stolar determined that the dynamic testing would best be performed at a later time with improved hardware, smaller antennas, optimized LAR, and the final software and PDA display.

A series of static reflection tests was performed across a tapered pillar using tripod-mounted, 150-250 MHz broadband spiral transmitter and receiver antennas. The antennas were approximately 15-18 inches in diameter. They were driven by Stolar's LAR electronics module and controlled by a software-definable transceiver (SDT), running on a laptop computer. For this series of tests, the transmitter and receiver antennas were placed side-by-side on the same side of the pillar (photo 9). Data was collected using the laptop computer (photo 10), commercial test equipment (Signal Generator and Spectrum Analyzer – photo 11), and a Stolar-designed LAR electronics module (photo 12).

The test was initially performed by directing the electromagnetic wave energy toward an air-filled void. Various antenna orientations were attempted. A similar series of tests was then performed to demonstrate the system's capability to detect a water-filled void. In order to facilitate this test a chamber was constructed to impound water against the coal rib (photo 13). The chamber was formed by a concrete block wall on three sides, and the coal rib as the fourth. Since the wall initially leaked at a rate faster than it could be filled with the mine water supply, the chamber was lined with a plastic membrane (photo 14) and filled with water and the tests were repeated.

A meeting was subsequently held on November 1, 2006, at Stolar's office in Raton, New Mexico, to discuss their plans for fulfilling this contract. During this meeting Stolar explained the reasons that the testing at Mine 84 was not successful. We discussed the additional development work which was necessary to their system before they could complete final assembly and perform a final field demonstration test. The meeting was followed by additional theory validation, equipment assembly, algorithm development and laboratory testing. Modifications were made to the LAR design and the final demonstration took place in February 2007.

FINAL DEMONSTRATION AT BOWIE MINE #2, BOWIE RESOURCES

The final LAR demonstration was conducted at the Bowie Resources' Bowie Mine #2, in Paonia, Colorado, on February 21 and 22, 2007. Bowie Mine #2 is a drift mine with a coal seam height of 8 to 10 feet. The demonstration consisted of two types of tests, a static test and a dynamic test. The static test involved using the LAR to detect a mine entry through a tapered coal pillar at various pillar widths while the dynamic test involved making measurements through a coal pillar that was being actively reduced in width from the opposite side by a continuous mining machine.

The static test was conducted on February 21, 2007, at the intersection of Cross-Cut #52 and Entry #5 in the 1st North Mains. The tapered shape of the coal pillar at this location allowed the simulation of mine voids at various distances from the LAR (photo 15). During the test, the LAR transmitting and receiving antennas had to be placed directly against the rib to minimize interference from radar reflections in the entry. Photo 16 shows the position of the LAR against the rib during the static test. Measurements for this test were made at three locations along the rib corresponding to pillar widths (i.e., simulated void distances) of approximately 10, 20, and 30 feet. Additional measurements were made at the 30-foot distance after water-filled containers were placed against the opposing rib to simulate a water-filled void (photo 17).

The results of the static test were mixed. The LAR detected the simulated void at a distance of 20 feet; however, the condition of the opposing rib at a distance of 10 feet was reportedly too deteriorated for good measurements and the simulated air- and water-filled voids at a distance of 30 feet were not detected. Despite the results, Stolar considered the static tests to be useful in obtaining site specific information that was used to calibrate the LAR for the subsequent dynamic test.

The dynamic test was conducted the following day, February 22, 2007. Measurements for this test were made through a coal pillar where a cross-cut was being developed. The LAR was again set up against the rib of the opposing entry and measurements were made through a 45-foot-wide coal pillar that was being mined from a parallel entry by a continuous mining machine. Photo 18 shows a diagram of the dynamic test set-up. The intent of this test was to simulate the LAR being mounted on the drum of the continuous mining machine for the detection of an air-filled void ahead of the machine. However, because the LAR technology is not sufficiently developed for this application, the LAR remained stationary on the rib of the entry as the continuous mining machine proceeded toward it through the pillar.

One dynamic test was completed before vibrations from the continuous mining machine caused a rib fall which damaged the LAR support stand and ended the test. During the test, the LAR technician made numerous radar transmissions and recorded 50 reflection data sets. After the test, the data record was correlated with the locations of the opposing cross-cut face and the continuous mining machine at the time of the reading. The results showed that the LAR detected the opposing coal-air interface at a distance of approximately 30 feet from the LAR. Photo 19 shows an image of the LAR data record at one point in the dynamic test. The data peak indicated by the blue line shows the air-coal reflection at a distance of 30 feet from the LAR. The data peak indicated by the yellow line shows a reflection representing the location of the continuous mining machine, which had been withdrawn approximately 8 feet from the coal face at the time of the reading.

FINAL REPORT

A draft final report was submitted for peer review in March 2007. Review comments were received and the final report was submitted in June 2007. A prototype LAR consisting of the following components was received in September 2007:

- Set of radar antennas (TX and RX antennas)
- SDT (software definable electronics) component (green box)

- Battery pack (black bag)
- Battery charging cord
- Fixed-position tripod
- PDA (personal digital assistant) with charging stand and power adaptor, and
- Extension cord

CONCLUSION

One successful LAR test was completed and a prototype LAR device was provided to MSHA. During demonstration testing, the LAR detected an air filled mine void at a distance of approximately 30 feet. The LAR data required post-processing insofar as the existing algorithms were not able to detect the void distance in real time. At this time, the LAR has not been made small enough for it to be mounted on cutting head of continuous mining machine due to the large sizes and separation of transmitting and receiving radar antennas. The LAR is currently an experimental geophysical method and not commercially available.

Please contact us at 412-386-6929 or 412-386-4470 you have any questions regarding this memorandum.

cc: M. Hoch – Chief, PS&HTC

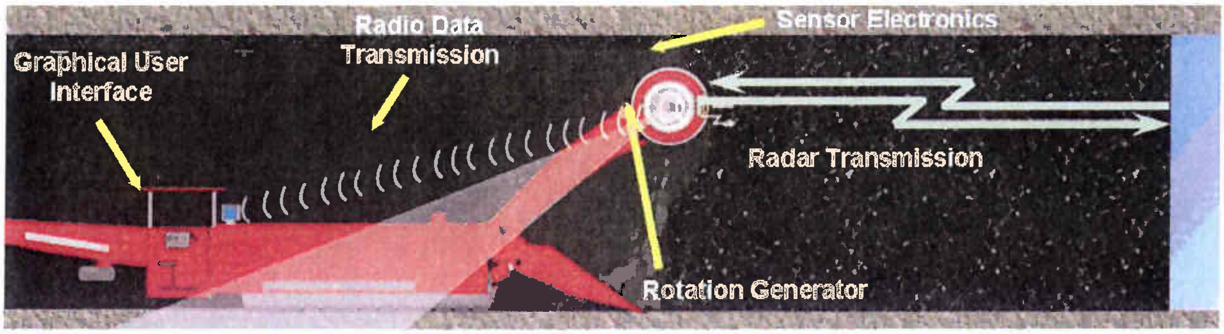

Photo 1: Conceptual machine-mounted Look-Ahead Radar (LAR) device in operation.

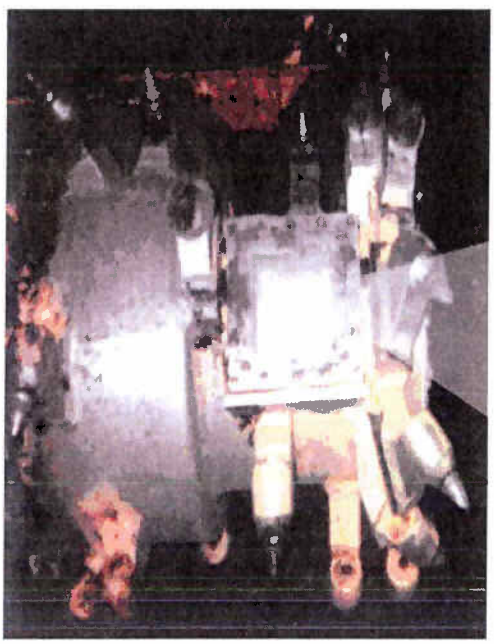

Photo 2: Housing for Horizon Sensor™ on cutting drum of continuous miner as conceptual housing for LAR.

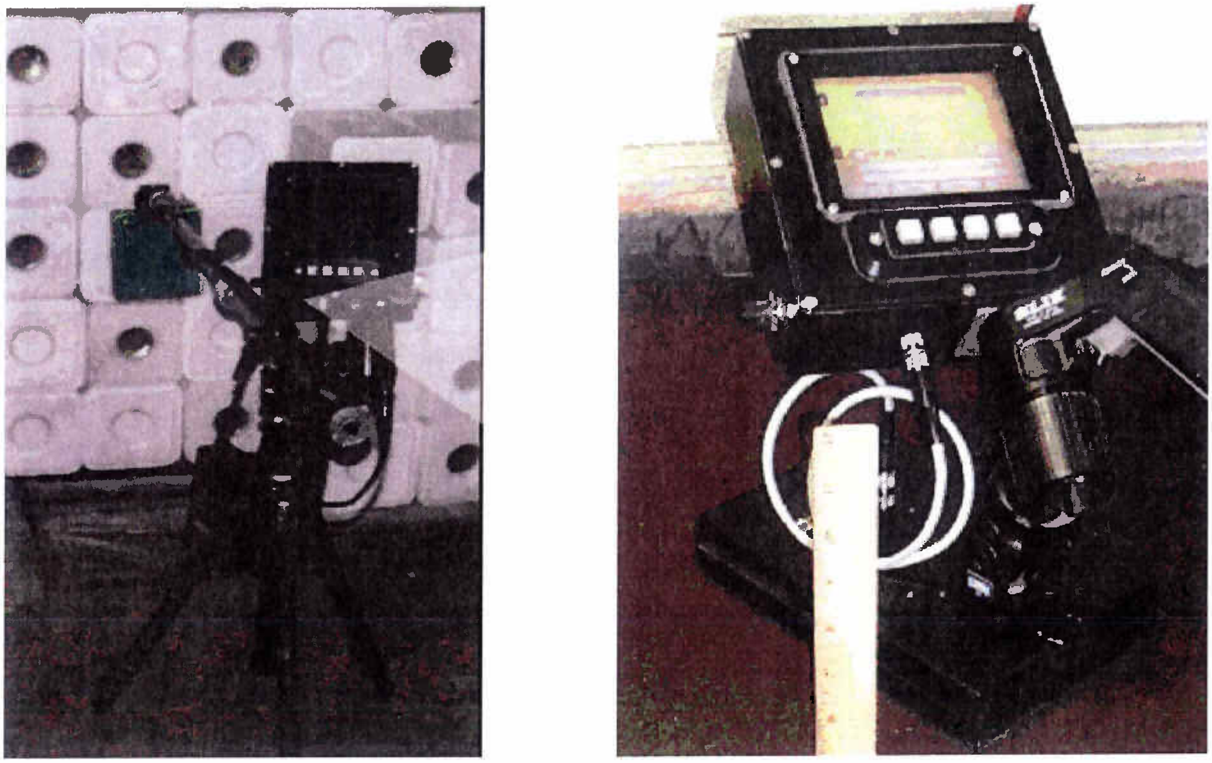

Photo 3: Hand-held RMPA Antenna and graphical interface used in laboratory simulation.

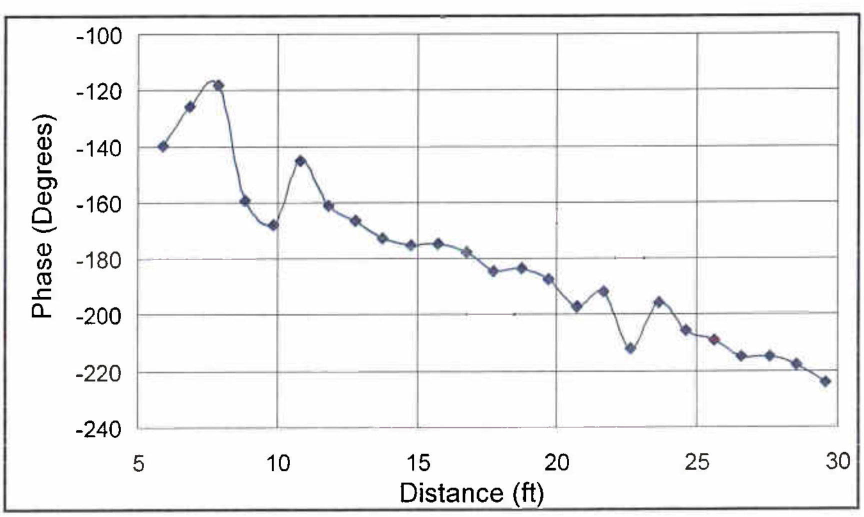

Photo 4: Results of laboratory simulation showing reflection at 23-feet.

Photo 5: Various antennas set up in test location where crosscut is expected to cut through the coal barrier during preliminary testing at Emery Mine.

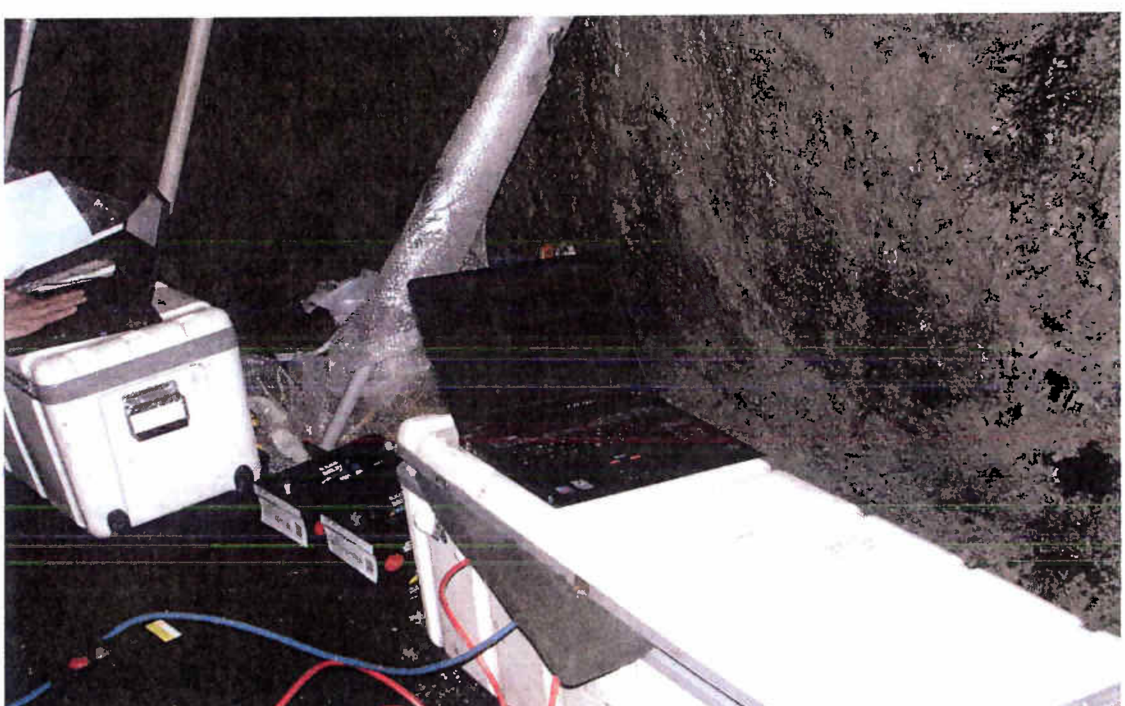

Photo 6: One of the laptop computers being used to acquire and view data during testing at Emery Mine.

Photo 7: Commercial signal analysis equipment used during preliminary testing at Emery Mine.

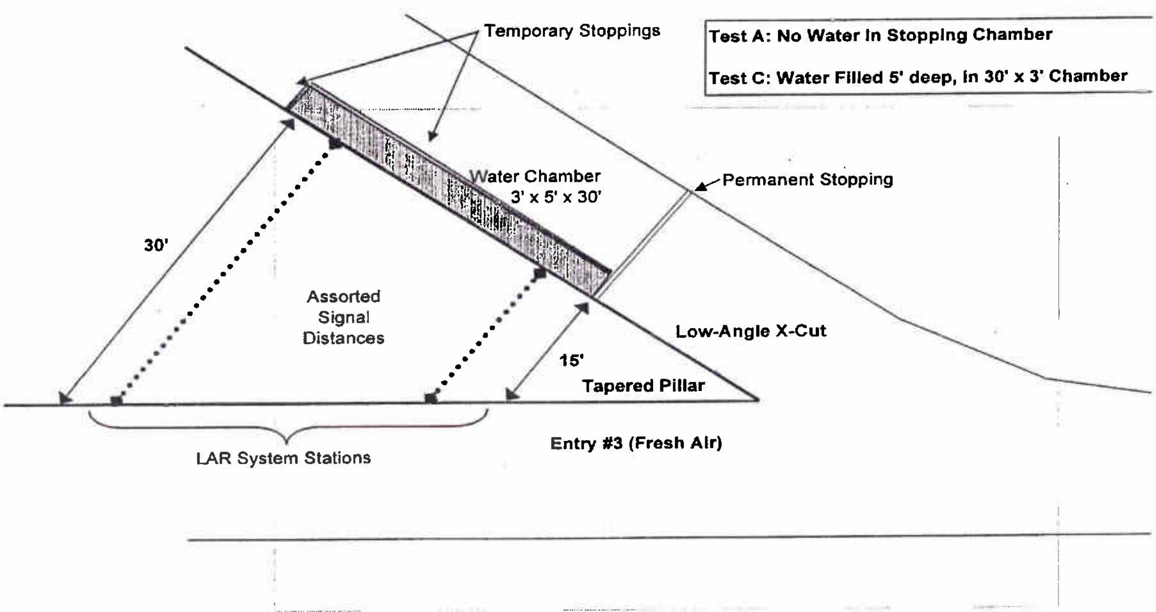

Photo 8: Test Plan for testing at Consolidation Coal Company, Mine 84 through a tapered pillar directed toward both Air-Filled and Water-filled voids.

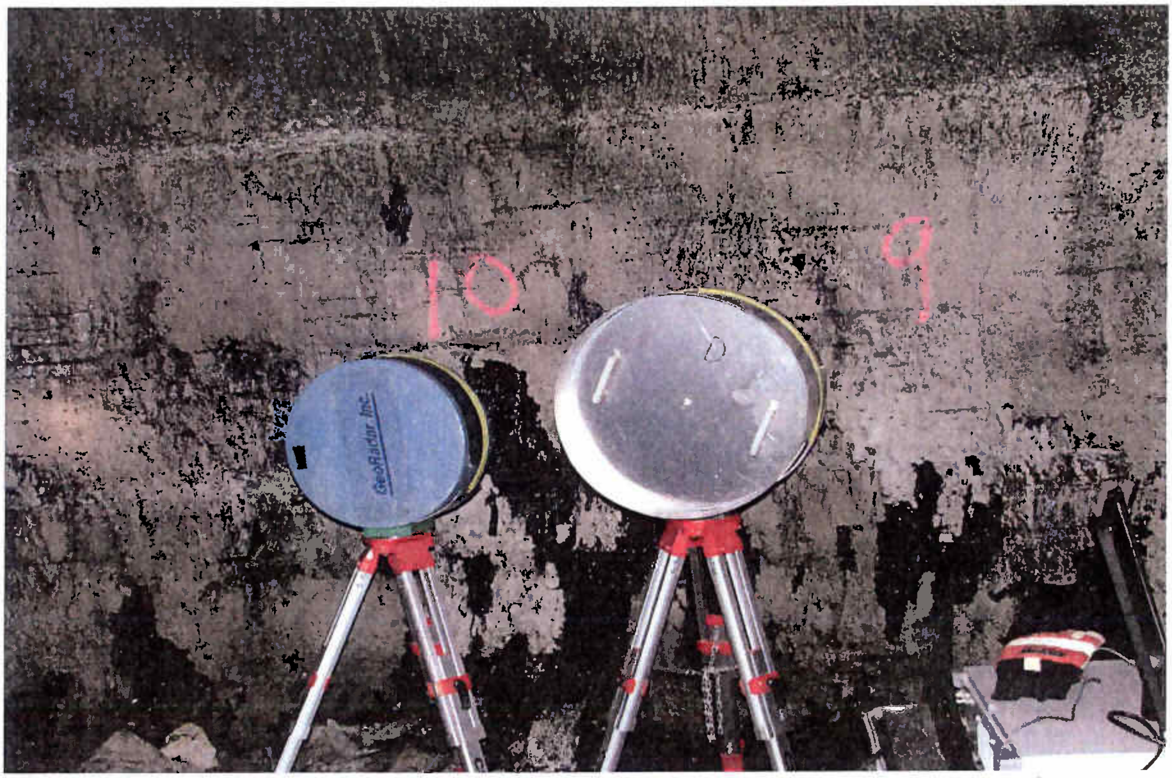

Photo 9: Transmitting and Receiving Antennas for reflection test at Mine 84.

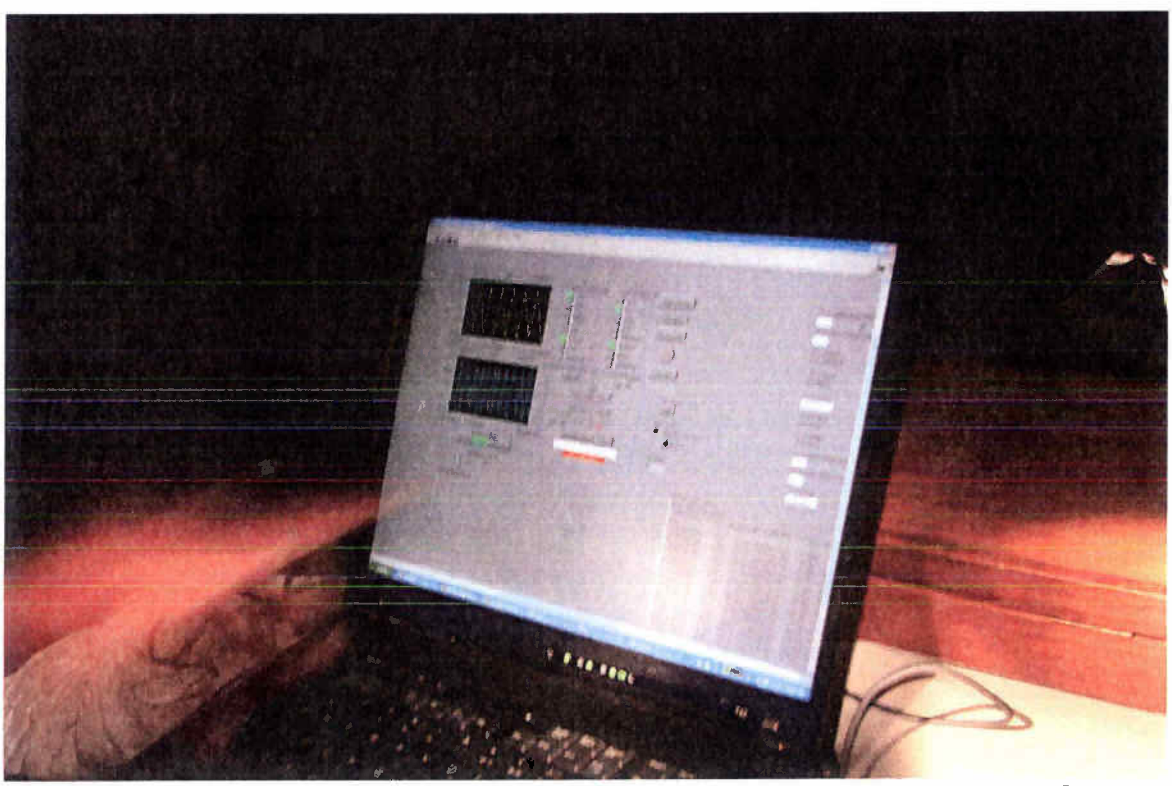
Photo 10: Data collection and monitoring using a laptop computer at Mine 84.

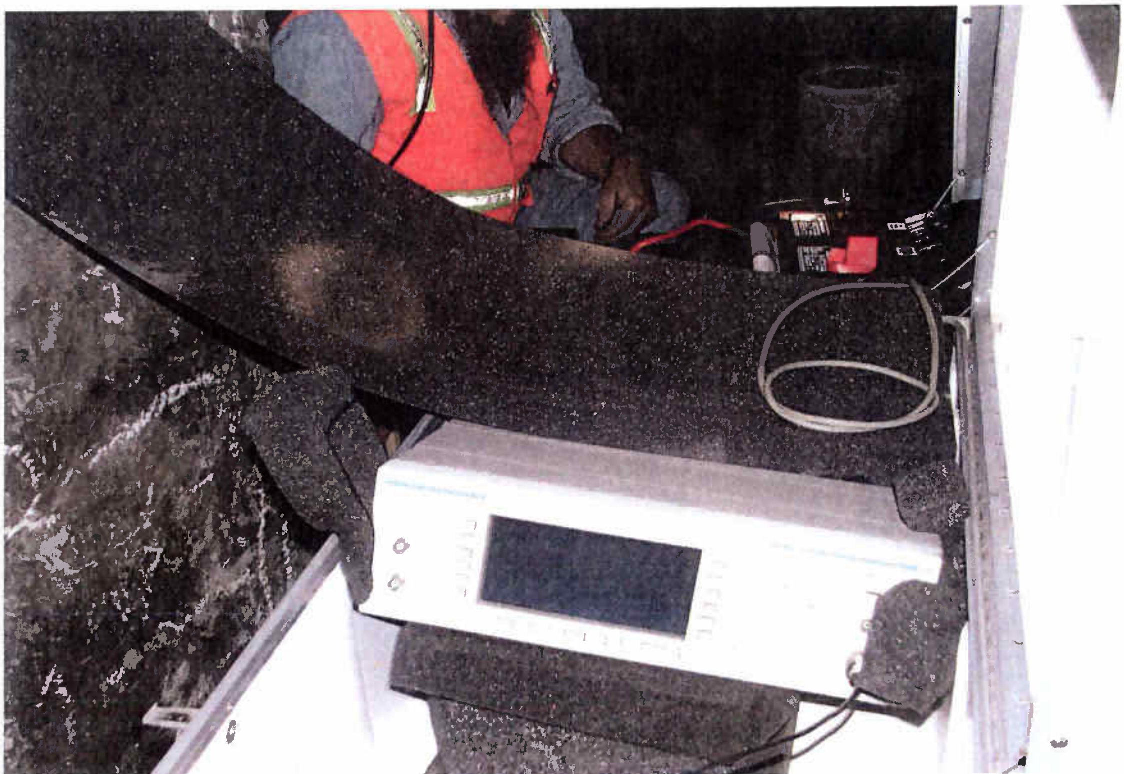

Photo 11: Data collection using commercial signal generator/spectrum analyzer during preliminary testing at Mine 84.

Photo 12: Stolar-designed Look Ahead Radar electronics module in use at Mine 84.

Photo 13: Chamber constructed to impound water against mine rib during preliminary testing at Mine 84.

Photo 14: Chamber constructed to impound water against mine rib during preliminary testing at Mine 84 lined to prevent excessive leakage.

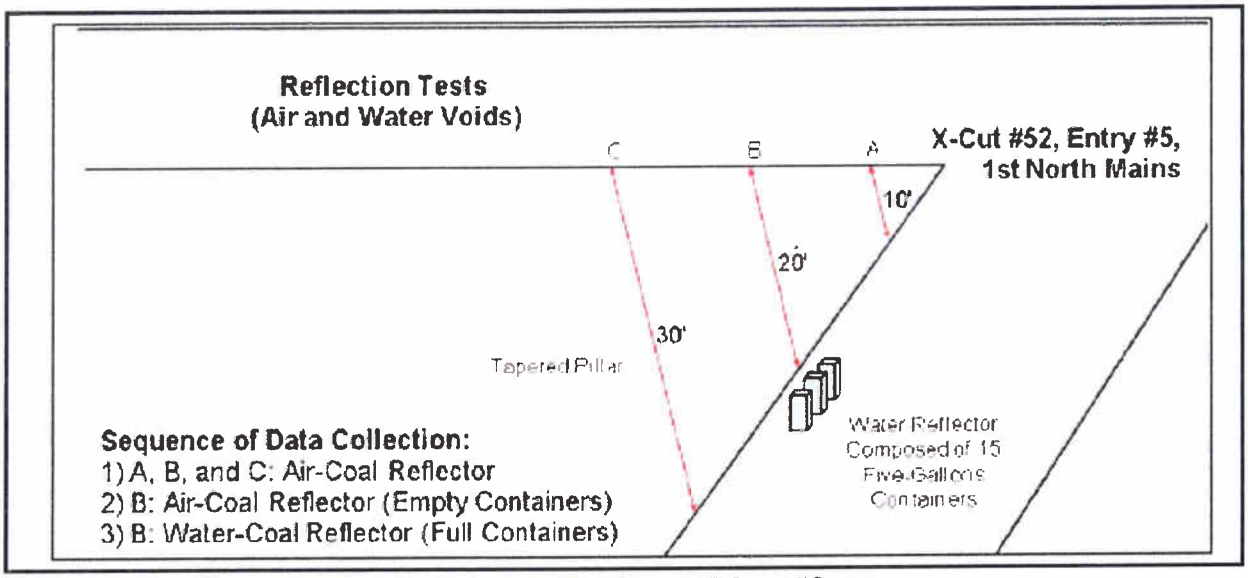

Photo 15: Diagram of LAR static test site at Bowie Mine #2.

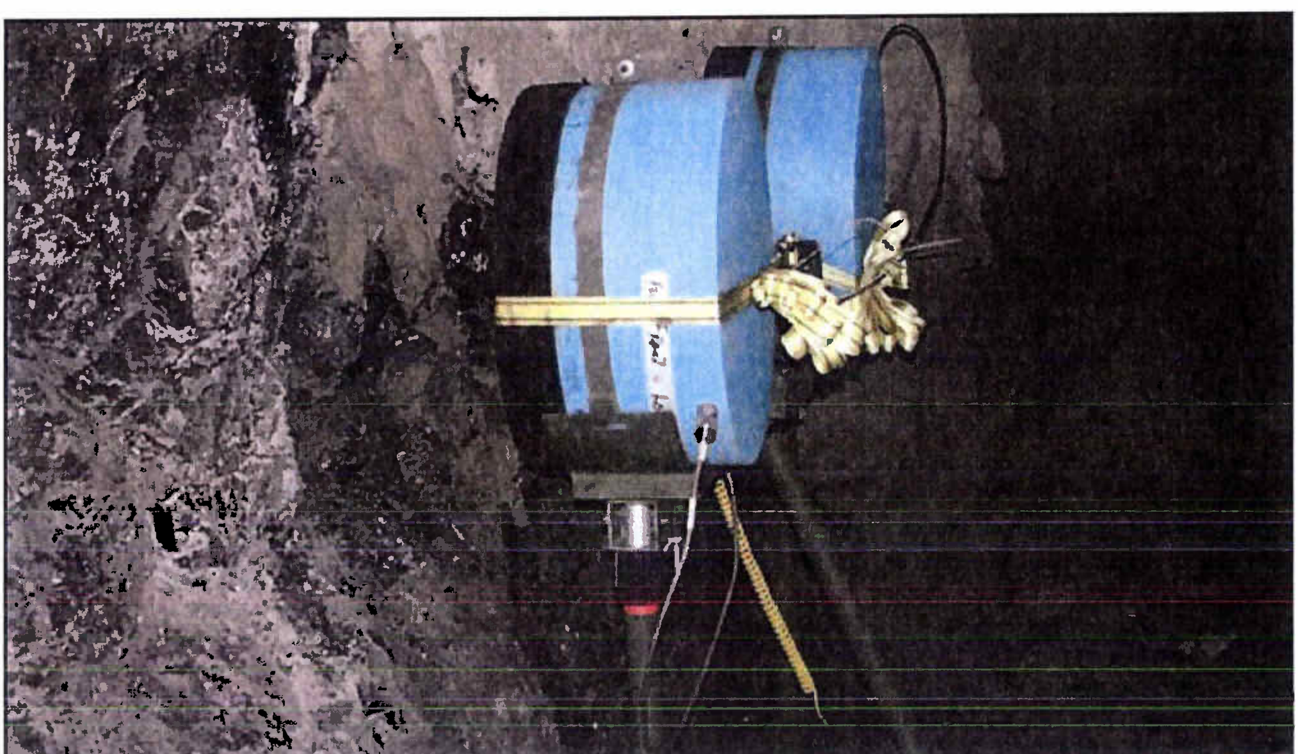

Photo 16: LAR making static test measurements through tapered coal pillar at Bowie Mine #2.

Photo 17: Water-filled containers placed against tapered coal rib for water-filled void static test.

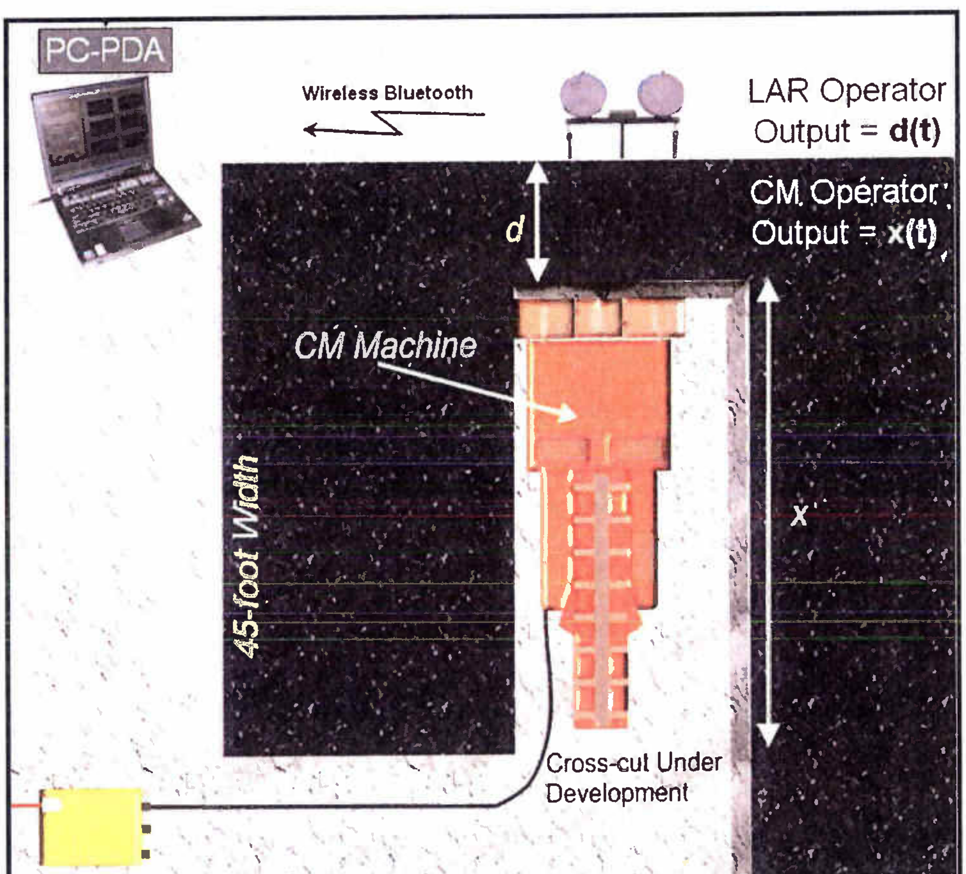

Photo 18: Diagram of LAR dynamic test site at Bowie Mine #2.

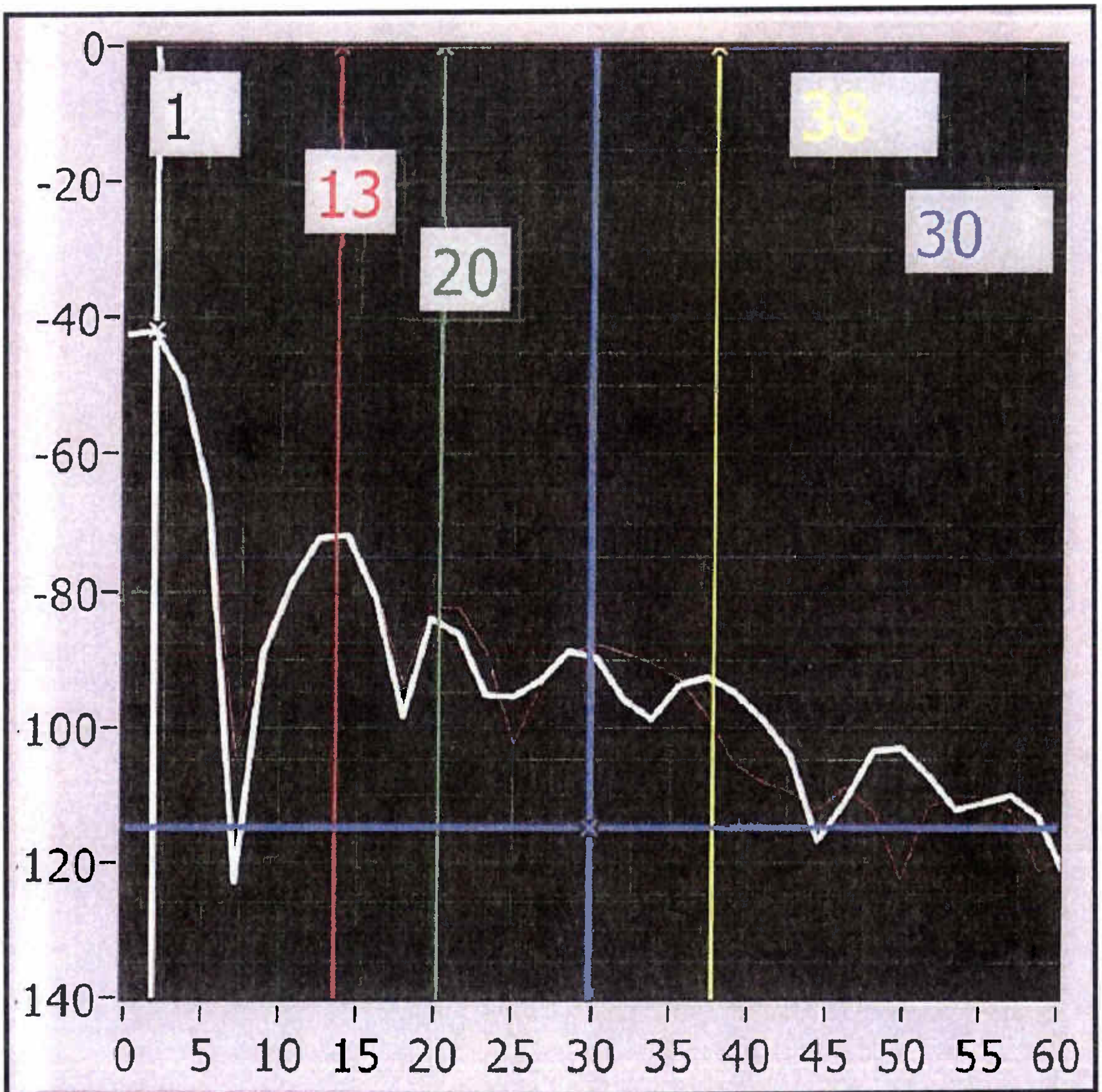

Photo 19: LAR display of air-coal reflection in crosscut at a distance of 30 feet (peak at blue line) and a continuous mining machine reflection at a distance of 38 feet (peak at yellow line).