NEW DEVELOPMENTS FOR MINE RESCUE

Richard L. Stein, Harry Dobroski, Jr., and John N. Murphy

Pittsburgh Mining and Safety Research Center
Bureau of Mines
U.S. Department of the Interior
Pittsburgh, Pennsylvania, USA

INTRODUCTION

Since 1969 the Bureau of Mines has been actively engaged in research to enhance the detection and rescue of miners trapped underground following a disaster. In many cases, miners who were fortunate enough to escape the primary disaster (fire, explosion, roof fall, etc.) often fell victim to secondary effects such as toxic gases or lack of oxygen. For this reason, it is imperative that they be located and rescued as quickly as possible.

The Federal Coal Mine Health and Safety Act of 1969 included provisions for such postdisaster detection and rescue, and since then the Bureau of Mines has pursued research in this direction. This research concerns methods of detecting and locating trapped miners by seismic and electromagnetic means, the development of self-contained breathing apparatus for miners, and specialized breathing apparatus and cooling garments for rescue teams.

THE DETECTION OF TRAPPED MINERS

The Seismic System

The seismic system uses an array of sensitive geophones that are placed over an area where trapped miners are thought to be. The miners have been trained to strike the roof or wall of the mine in a certain manner to generate seismic signals. Because of the pattern of the geophone arrays, the seismic signals arrive at individual geophones at different times. These signals are stored on magnetic tape in an instrumentation truck brought to the mine site. The truck also contains other sophisticated equipment for processing the signals. By analyzing these signals, either by small local computers or by connection to more powerful computers over the telephone lines, the location of the source of the seismic signals is determined. Figure 1 illustrates the concept.

Tests to date have shown the system to be quite effective. Under conditions of low natural seismic activity, detections up to 800 m are possible if the geophones are directly over the signal source. At mines up to 300 m depth, detection is possible if the geophones are offset by 300 m. Additional testing has shown that geophones placed in the mine, rather than on the surface, may be even more effective. This is important because often it is possible for rescue teams to safely enter the mine for great distances soon after the disaster that trapped the miners. To exploit this advantage, it will be necessary to develop a portable seismic system that the rescue teams can use in the mine itself. This will be investigated in the future.

The seismic system described here is kept in readiness by the Mine Safety and Health Administration (MSHA), U.S. Department of Labor, and is being constantly improved.

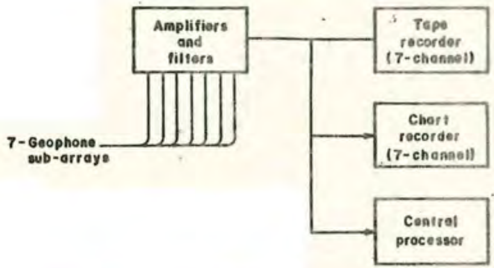

Figure 1.--The seismic system

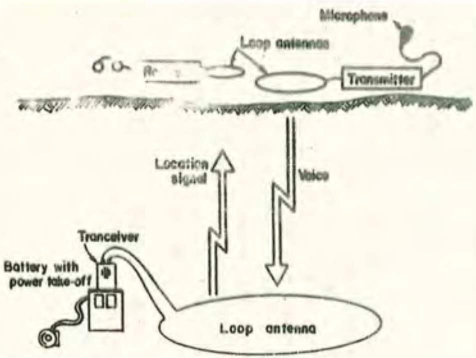

Figure 2.--The electromagnetic system

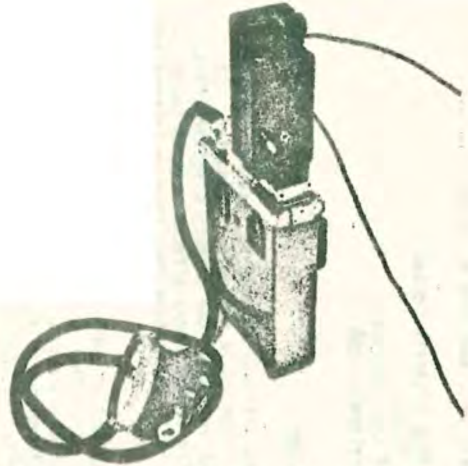

Figure 3.--The electromagnetic transmitter
deployed for operation

The Electromagnetic System

The electromagnetic system for trapped miner detection is based on the fact that low-frequency radio signals can penetrate conducting mediums such as the earth, with relatively small attenuation, if the conditions are favorable. For a given conductivity of earth above a mine (the overburden), signal penetration improves with decreasing transmission frequency. However, other factors come into play that make it impossible to lower the frequency beyond a certain lower limit. These factors are primarily atmospheric and man-made electromagnetic interferences. For these reasons, it appears that an electromagnetic detection system of practical size and power consumption is limited to the frequency range of 600 to 3,000 Hz. Lower frequencies encounter the atmospheric/man-made noise regions, and higher frequencies become attenuated by the overburden very quickly. With these limitations in mind, the Bureau of Mines has developed a practical signaling device (the transmitter) that is small enough to carry on a miner's belt. It is completely self-contained such that transmitter and antenna are in one integrated package. Sensitive search equipment was developed so that surface search teams could locate the underground transmitters. Once located, two-way communications with the trapped miners can be established. Figure 2 illustrates this system.

The transmitter consists of circuitry that produces discrete frequencies in the 600 Hz to 3 kHz range. The transmitter is used with an antenna consisting of 100 m of wire deployed in the largest area possible. Each transmitter produces only one frequency and can, therefore, be identified by its frequency alone. The coding technique is that of pulsed continuous wave (CW) with a duty cycle of 10 percent (100 ms on/900 ms off). This pulsed CW makes it easier to detect under poor signal to noise (S/N) conditions.

The transmitter receives power from a special power connection on top of the cap lamp battery. Figure 3 shows the actual configuration of the transmitter, antenna, and battery in operation. A fully charged cap lamp battery can operate the transmitter for about 40 hours. A battery partially discharged after an 8-hour work shift can operate the transmitter for about 16 hours.

In addition to the transmitter, the device also contains a baseband voice receiver, a button, and a switch. This receiver permits the trapped miner to receive voice messages from the surface. These voice messages are produced by amplifiers that are connected to large loop antennas laid on the surface of the earth. The reception of voice messages by the trapped miner is extremely important. Because it gives confidence and hope of rescue, it is a sure indication that a location has been made. It also permits the rescue team to communicate with the miner, to extract information concerning his or her condition. As an example, if the surface team instructed the trapped miner to signal "yes" to certain questions by a certain number of signals from the transmitter, or "no" by another number of signals, this could be done with the button provided.

Special receivers have been developed to detect the signals from the trapped miner's transmitter. These receivers are of two types: One is designed to be carried by helicopter and can scan up to six frequencies simultaneously. The other is designed to be carried by a person on foot. The helicopter unit is used for rapid searches over vast areas when it is unknown whether or not any transmitters have been activated. Its primary function is to make a fast search and a rough estimation of signal location. If signals are detected, the helicopter personnel inform the ground search teams where these signals are and on what frequencies. Thus informed, the ground search teams go to the area.

Using the portable search receivers, the ground search teams perform a precision location. Once they are within range of the signals, they can locate the source of the signals by seeking out characteristics in the field pattern. By holding the search antennas vertically, it is possible to locate a null in the signal due to the fact that there is no coupling of the magnetic field into the receiver antenna with this orientation. By moving about and performing this procedure several times in the vicinity of the signal, intersecting lines can be drawn that locate the position of the underground antenna.

The ultimate success of this system depends on what percentage of coal mines can use it. This, in turn, depends on mine depth, overburden conductivity, and noise. Except for knowing the range of probable depths at a given mine, these parameters are unknown. During 1977-78, this problem was addressed experimentally.

The transmitters were taken to 93 coal mines in various areas of the United States. They were deployed in the mines and signal strength was measured on the surface. From calculations based on actual signal strength, the apparent earth conductivity (σ_A) was obtained at each mine site; this value of σ_A could not be obtained by any other method. It represents the apparent conductivity of the overburden as seen by the system when deployed under actual operating conditions. This apparent conductivity ranges from about 0.01 MHOS/m to 0.1 MHOS/m.

The general results from the 93 mines were favorable. The system worked very well to depths up to 500 m (about 90 percent of U.S. coal mines are presently under 350 m). In almost all cases, the underground transmitters succeeded in sending signals to the surface, and receiving voice signals from the surface. In 1979 a new generation of these devices will be built, and in 1980, more long-term testing will begin. This testing will be to determine both the operational and mechanical integrity of the transmitters.

SELF-CONTAINED BREATHING APPARATUS

The 10/60 Oxygen Self Rescuer

The self-rescuer currently worn by miners provides protection against carbon monoxide but does not provide protection in atmospheres deficient in oxygen or containing other gases and vapors. Because of this limitation, there is a need for a self-contained escape device capable of providing respiratory protection in any atmosphere. Two such devices were recently developed under Bureau of Mines contracts (1). One device was lightweight and small enough to be worn by a miner continuously, but it was capable of providing only 10 minutes of protection. The second device provided respiratory protection for 60 minutes. Although both devices provide the desired type of protection, the necessity of discarding the 10-minute unit in order to don the 60-minute unit while in a contaminated environment was considered to be a severe drawback.

The 10/60 device combines the concept of a small and lightweight short-duration (10-minute) belt-worn device with a larger and heavier long-duration (60-minute) device than can be safely "plugged into" the 10-minute device while in a contaminated environment. The 10-minute device will be carried by the miner at all times and the 60-minute device will be stored near the miner. In the event of a disaster, the 10-minute device would be donned immediately. The miner would then proceed to the stored 60-minute units and plug the 60-minute device into the 10-minute unit. This system was developed by Mine Safety Appliances Company, Pittsburgh, Pennsylvania, under contract to the U.S. Bureau of Mines. The final system weight, volume, and size are given in Table 1.

Table 1. [illegible] 10/[illegible] oxygen and self-rescuer system

Device	Size (cm)	Volume (cc)	Weight (kg)	Service life (min)		
				Light work	Medium work	Heavy work
10 min	18.1x18.1x7.	2343	1.77 packaged 1.20 used	14-15	10-14	7-10
60 min	26.7x22.2x10	3900	[illegible].26 used	75-90	65-75	55-65
10/60 system			[illegible].46 used	89-100	75-89	62-75

For the 10-minute unit, the system chosen to meet the requirements for underground use is a breathing circuit where air is passed through a chemical bed twice per respiration. The chemical bed contains about 250 gm of potassium superoxide (KO_2). The 60-minute canister differs from the 10-minute unit in that air is drawn only once through the chemical bed per respiration. Approximately 1 kg of KO_2 is used. Although the double-pass system allows more efficient bed utilization, its use in a long-duration device results in excessive heat buildup, in which case a complex and cumbersome heat exchanger would be necessary. Since the 60-minute canister will be in storage until needed, the miner does not have to carry this larger, heavier device during a normal work day. Both canisters are equipped with a chlorate candle to supply 100 percent oxygen during initial use since the KO_2 chemical reaction requires about 1 minute to generate enough O_2 to meet escape needs.

The inhalation gas temperature must be reduced to a comfortable level and the user must be protected from physical contact with any hot areas on the apparatus. Both devices employ separate heat-management techniques. A 6 cm finned aluminum tube located in the breathing tube acts as a heat exchanger in the 10-minute device. Location of the heat exchanger in the breathing tube also prevents the breathing tube from closing.

The breathing bag and a manifold in the 60-minute unit are used as the primary heat exchanger. The aluminum heat exchanger located in the breathing tube of the 10-minute unit remains part of the 60-minute system. Inhalation temperature is reduced to about 43° C, a temperature that is easily tolerated by a wearer. Canister wall temperatures reach approximately 120° C. To protect the user from burns, both canisters have a felt protective cover.

Operation of the system involves connecting the 10-minute canister and the 60-minute canister in a hazardous environment while minimizing trapped gases. Since the package size of the 10-minute unit is limited, the additional hardware required to couple the two canisters is housed in the larger 60-minute unit. After connecting the 60-minute device, the breathing circuit is switched from a pendulum system to a loop system. Two check valves are required, one at the inlet and one at the outlet of the 60-minute canister. A third (shutoff) valve is required in order to disassociate the 10-minute canister from the system. If this were not done, a bypass of the 60-minute device would occur. To eliminate pressure buildup in the 10-minute canister after the coupling has been made, one side of the canister is left open to the breathing bag. Thus, any further oxygen generation from the 10-minute bed will be utilized.

The 10-minute container has a belt clip that allows the wearer to remove that unit from the belt quickly. The 10-minute unit is donned over the head, and the breathing bag acts as the neck sling to support the complete apparatus. Insertion of the mouth bit and firing of the candle activates the unit. When the nose clip is securely in place, the wearer is protected for escape. Placing the goggles

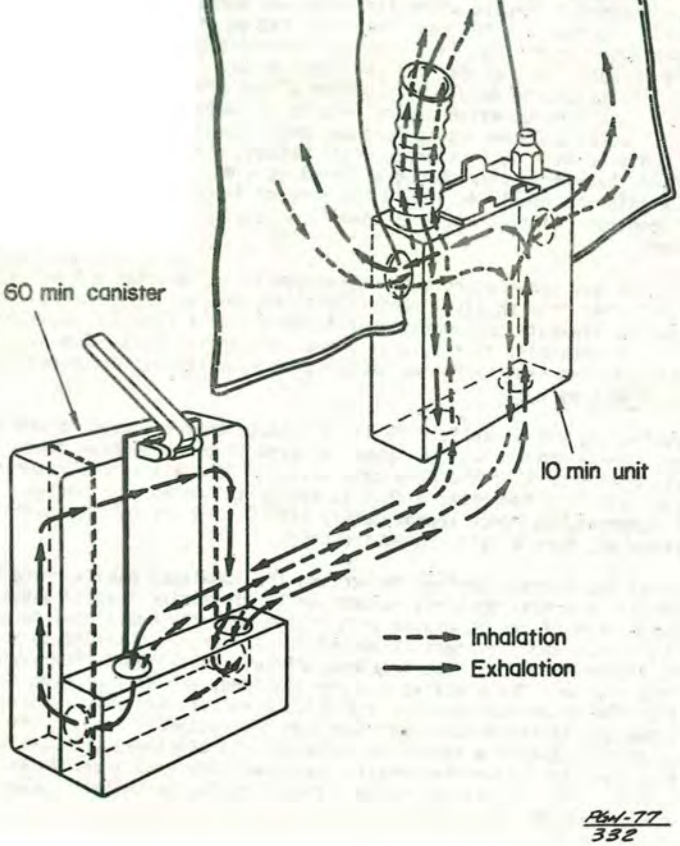

Figure 4.--Detailed schematic of flow path in 10/60 system

over the eyes and attaching a simple string around the wearer to anchor the unit firmly to the chest completes the operation. Attaching and starting either the 10-minute or the 60-minute device requires less than 30 seconds. (See Figure 4)

Furthermore, additional tests showed that an escaping miner could travel over 7 km (4.3 miles including inclines) while using the 10/60 system. Since KO_2 produces O_2 directly in response to a wearer's need, this travel distance is nearly independent of work rate.

A NEW RESCUE BREATHING APPARATUS (RBA)

Following a mine disaster, rescue teams frequently have to enter sections of a mine that are filled with irrespirable or toxic gases in order to locate and rescue trapped miners, to control fires, and to reestablish ventilation. Presently, there are two 4-hour compressed-oxygen breathing apparatus that can be used. Both of these devices have been certified for a rated service life of 4 hours under Phase 11, Subchapter B, Chapter 1, Title 30, U.S. Code of Federal Regulations (30 CFR 11h).

After surveying the existing technology, the Bureau of Mines concluded that a 4-hour positive pressured compressed O_2 mine RBA could be designed which weighs less than the devices currently available. In addition to an overall reduction in weight, a simple cooling system could be integrated with the RBA to provide for cooler inspired air temperatures and a means to remove heat from the rescued miner. This would represent a major improvement over existing systems and significantly increase the effectiveness of the mine rescue team. Mine Safety Appliances has been developing this new RBA under Bureau contract.

The apparatus is a positive-pressure, closed-circuit, compressed oxygen system. The weight of the apparatus, including a cooler, is about 13.5 kg.

The two major areas for weight reduction are the compressed O_2 cylinder and the CO_2 scrubber. The availability of a composite oxygen cylinder consisting of an aluminum liner shell wrapped with glass fiber resulted in a weight reduction of 2 kg. The use of lithium hydroxide (LiOH) in an aluminum canister resulted in a weight savings of 1 kg over the more commonly used alkali or soda-lime used for CO_2 scrubbing. Thus, 3 kg was reduced in these areas alone. An additional weight reduction of about 1 kg was accomplished by simplifying the oxygen flow circuit and using a lightweight, yet highly impermeable, breathing bag.

Positive pressure is maintained in the breathing circuit at all times. The positive pressure is created by providing a constant, external force to the breathing bag so that a higher pressure exists in the face mask relative to ambient pressure. This means that all leaks due to poor face-piece fit are out of the mask, and not into the mask as is possible with demand-type apparatus such as the McCaa and Drager units. Positive-pressure apparatus have protection factors of 10,000 and are recommended for use when the wearer is entering air that contains toxic gases of unknown concentration. Such situations occur underground, and this is the major reason for use of such equipment.

A simple ice cooler was developed to reduce inhaled-air temperatures. The ice cooler is placed adjacent to heat exchangers built into the apparatus. Breathing air is cooled mostly by conduction. The cooler is easily removed from the apparatus, so that its use is optional for the wearer. It weighs about 2.3 kg and provides about 100 kcal of cooling.

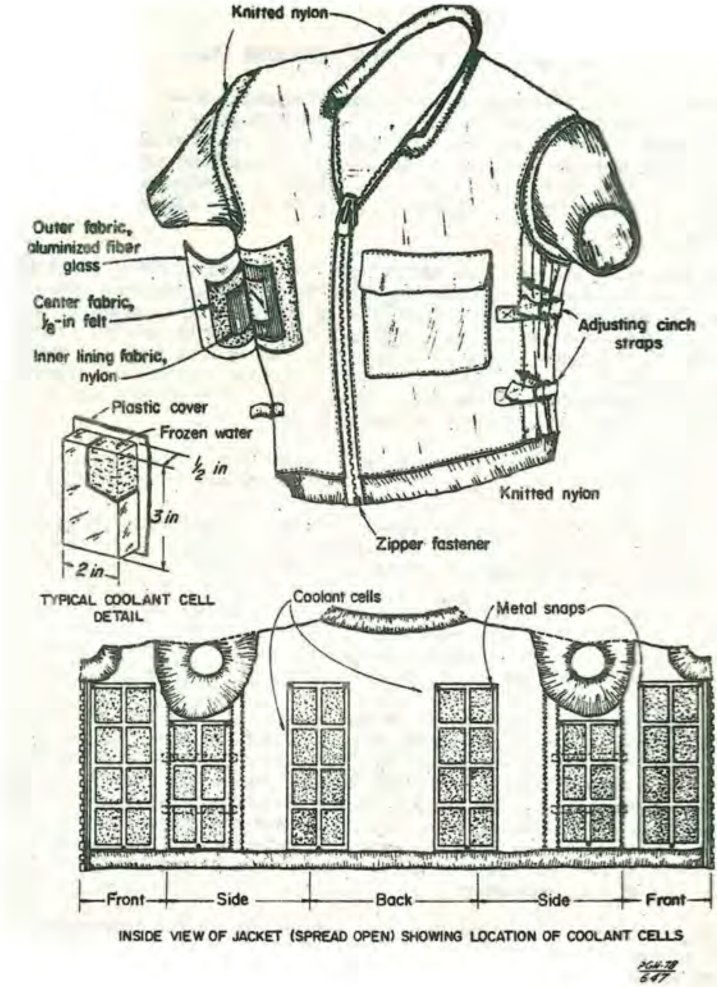

Figure 5.--Inside view of jacket (spread open) showing location of coolant cells

Some machine and human tests of the apparatus have been completed. Performance characteristics featured that have been demonstrated in these tests are (1) high protection factor due to positive pressure, (2) safe use of the apparatus at temperatures down to -32° C (-25° F) because of the excellent CO_2 absorbing characteristics of the LiOH canister, (3) use of the apparatus at high temperatures by attaching a replaceable cooler which provides both low temperature breathing gas and body cooling, (4) 12- to 14-hour service life when breathing at a sedentary rate, and (5) improved wearing comfort based on repositioning the weight of the apparatus on the hips. Commercially available units are expected within a year.

Cooling Garments

To protect rescue personnel from heat during rescue operations, new cooling garments have been developed. One is a liquid cooled vest, the other is an ice jacket.

The liquid cooling system consists of liquid circulation garments and a belt-worn heat sink unit. A special mixture of alcohol and water flows through the heat sink unit where it is cooled by contact with a frozen ice canister. It then flows through tubes to the head and chest garments where the wearer is cooled. The water and alcohol mixtures that have picked up heat from the wearer flows back to the ice canister where it is recooled.

The heat sink unit consists of a frozen canister, a pump, and a rechargeable battery. It weighs about 4.3 kg and provides about 2 hours of cooling. The freezable cooling cartridge and rechargeable battery are replaceable in a few seconds. The unit is belt mounted so there is no umbilical to hinder the miner.

The head liner cooling garment is designed to wear with a face mask. Thus, there is no face seal leakage when the unit is worn by rescuers. The cooling garments are modular so that a head garment could be worn in moderately hot conditions, but the complete head and vest garment could be worn during severe heat. Total system weight is about 4.8 kg using the head garment and 5.2 kg using the head and vest garment.

Testing in controlled hot environments indicates the effectiveness of this system. Thermal strain on the wearer is cut in half, heart rate is lowered 30 to 50 beats per minute, and body temperature is lower than the uncooled subject. This means increased safety for miners who must work in a hot environment, especially for those miners unacclimated to heat.

Successful field tests on the liquid cooling system have also been carried out in steel mills, by race car drivers, in sugar refineries, and in aircraft carriers.

The second cooling system is an ice cooling jacket. The jacket holds a total of 44 individualized ice packets, which are held firmly near the wearer's skin. These packets remove heat from the wearer, reducing heat stress and keeping rescuers comfortable during work.

The jacket is constructed in three layers. The outer layer is an aluminized fiberglass cloth. The aluminized surface reflects any radiated heat during firefighting; the fiberglass cloth provides fire resistance and strength to the jacket. The middle layer is a 3 mm thick polyester felt for insulation from the hot mine air. The inner layer is a tightly knit nylon. The nylon surface makes the jacket easy to slide on and off, and it also protects the felt from moisture and abrasion. The sleeves, neck, and waistband are made of a stretch knit material to provide an air seal about the upper torso. Ice pockets are attached to the inside of the jacket by conventional snaps located in the chest and back area. Straps on the sides of the jacket provide adjustment for various size workers and to keep the ice packets close to the worker's body.

The ice packets are a ganged group of water cells about 5 x 8 x 2 cm each. There are four 8-cell packets and two 6-cell packets providing a total of 44 cells to the jacket. Total weight of the ice packets is about 3.5 kg which will provide about 400 kcal of cooling capacity. Total weight of the jacket with ice packets is about 5 kg.

The individual ice packets can be frozen in a freezer overnight. When cooling is required the packet can be easily snapped into place on the jacket and used for about 1-2 hours, depending on the heat and work levels involved. Since each cell is small, a broken cell will not materially effect cooling capacity. This system allows the wearer to replace individual packets rather than the whole jacket, keeping the overall cost of using the system low. The jacket is shown in Figure 5.

Both of these cooling systems are now commercially available.

CONCLUSIONS

Over the past several years, the Bureau of Mines developed several systems to assist in the post disaster detection and rescue of trapped miners. These consist of seismic and electromagnetic location and communication systems, self-contained oxygen generating breathing apparatus, and special breathing apparatus and cooling garments for rescue teams. The location and communication systems have been thoroughly tested, and the results are very favorable. The breathing apparatus and cooling garments have also been tested with good results.

REFERENCE

1. Stein, R. L. Development of Two New Oxygen Self-Rescuers, Bureau of Mines Report of Investigations 8102, 1976, 25 pp.

JUGOSLOVENSKI KOMITET
ZA SIGURNOST I ZAŠTITU NA RADU U
RUDARSTVU, GEOLOGIJI I METALURGIJI

Savez inženjera i tehničara rudarske,
geološke i metalurške struke Jugoslavije

XVIII
MEĐUNARODNA KONFERENCIJA O NAUČNIM ISTRAŽIVANJIMA U OBLASTI SIGURNOSTI RADA U RUDARSKOJ INDUSTRIJI

XVIII
МЕЖДУНАРОДНАЯ КОНФЕРЕНЦИЯ ПО НАУЧНЫМ ИССЛЕДОВАНИЯМ В ОБЛАСТИ БЕЗОПАСНОСТИ ТРУДА В ГОРНОЙ ПРОМЫШЛЕННОСТИ

XVIII
INTERNATIONAL CONFERENCE ON SCIENTIFIC RESEARCH IN THE FIELD OF SAFETY AT WORK IN MINING INDUSTRY

XVIII
CONFERENCE INTERNATIONALE SUR LES RECHERCHES SCIENTIFIQUES DANS LE DOMAINE DE LA SECURITE DE TRAVAIL DANS L'INDUSTRIE MINIERE

XVIII
INTERNATIONALE KONFERENZ ÜBER WISSENSCHAFTLICHE FORSCHUNG AUF DEM GEBIET DER ARBEITSSICHERHEIT IN DER BERGBAUINDUSTRIE

REFERATI,ДОКЛАДИ, PROCEEDINGS,

REFERATS, BERICHTE

C, D, E, F, G

SFR JUGOSLAVIJA
Cavtat (Dubrovnik)
7—14. oktobra 1979.