

SELF-CONTAINED SELF-RESCUERS: NEW DEVELOPMENTS IN TECHNOLOGY AND TRAINING

J. G. Kovac and C. Vaught

Bureau of Mines, Pittsburgh Research Center, USA

ABSTRACT

One purpose of this paper is to discuss new developments in Self-Contained Self-Rescuer (SCSR) technology. It appears to be technically possible to produce an SCSR that is approximately twice the size and weight of a Filter Self-Rescuer (FSR) and that has a rated duration of 60-minutes. Such an apparatus can be worn on a miner's body, making it immediately available in the event of a mine emergency. The other purpose of this paper is to discuss the development of an innovative SCSR donning method that has been shown to cut SCSR donning time in half, and to significantly reduce errors made by trainees. Because the new method consolidates the task of donning an SCSR into 3 critical steps and 3 secondary steps, it is called the "3+3" method. The 3+3 method is expected to play a significant role in training miners to use the new apparatus.

INTRODUCTION

When a mine disaster occurs, the basic survival technique for a miner is to escape from the mine. After a mine fire or explosion, the atmosphere inside the mine may become oxygen deficient or filled with smoke and toxic gasses. Under these circumstances, escape is nearly impossible unless a miner is equipped with a self-rescue device that supplies oxygen without the need for breathing mine air.

Federal regulations (30 CFR 75.1714) require that every person who goes into an underground coal mine in the United States must be supplied with a Self-Contained Self-Rescuer (SCSR). An SCSR is an emergency breathing apparatus designed for the purpose of mine escape. It must be capable of providing at least a 60-minute supply of oxygen, regardless of the condition of the mine atmosphere. Only SCSR's approved by the National Institute for Occupational Safety and Health (NIOSH) and the Mine Safety and Health Administration (MSHA) can meet the provisions of the regulations.

SCSR's have been deployed operationally in U. S. coal mines since 1981. During that time, two

practical problems have emerged. First, because of the large size and weight of the current SCSR's, in most cases miners and mine operators have elected either to store or carry and store SCSR's in daily operational use, rather than wear them as personal protective equipment. In the event of a mine emergency, SCSR's deployed in either of these two ways would not be immediately available to an escaping miner. The other problem deals with training in the use of an SCSR. The ability to put on an SCSR in the event of a mine emergency is one of the most critical and non-routine of all mine health and safety skills. However, donning an SCSR is not an easy task. The purpose of this paper is to discuss new developments in SCSR technology and training that addresses these problems.

PERSON-WEARABLE, SELF-CONTAINED SELF-RESCUER TECHNOLOGY

The Bureau, through contract and in-house research, has refined SCSR technology to the point where it is now possible to provide miners with apparatus small enough to be worn on the body with sufficient oxygen for escaping miners to reach fresh air. These "second generation" SCSR's are called Person-Wearable, Self-

Contained Self-Rescuers (PWSCSR's). (Sometimes these devices are referred to as "belt-wearable.")

The Bureau, in 1986, awarded a research contract to CSE Corporation (U. S. Bureau of Mines Contract HO368013) to develop a prototype unit called the SRX-80 (Self-Rescuer Experimental - 80 Liters of Usable Oxygen). This contract was based on technical recommendations of the joint Bureau of Mines/Mine Safety and Health Administration/National Institute for Occupational Safety and Health PWSCSR task force (Kravitz and Kovac 1985) and had the approval of the mining industry.

The SRX-80 uses a solid chemical bed (a mixture of potassium superoxide and lithium hydroxide, to generate oxygen and to absorb carbon dioxide) and is equipped with a small oxygen bottle that serves as a quick-start mechanism. The SRX-80 is approximately 70 percent smaller by volume and 40 percent lighter than the average SCSR currently in use. In practical terms, the SRX-80 is about twice the size and weight of a filter self-rescuer (FSR). The size and weight limits were determined during discussions with the Bituminous Coal Operators Association and the United Mine Workers of America. Table 1 compares the size and weight of an FSR, PWSCSR, and average SCSR.

Table 1.

	FSR	SCSR	PWSCSR
Wt	2.5 lbs	8.97 lbs	4.86 lbs
Vol	75.4 in ³	469.25 in ³	130.00 in ³

The research is being conducted in two phases. Phase 1 has been successfully completed. The contractor fabricated ten prototype SRX-80's. The Bureau evaluated the life support performance of the prototypes. Test results indicated that the prototypes met or exceeded all life support performance requirements of the contract and marginally passed the performance requirements of 30 CFR 11 regulations as a 60-minute duration SCSR.

Because of the technical promise of the SRX-80, as well as the interest shown by MSHA and the coal mining industry in deploying practical PWSCSR's, the Bureau has initiated Phase 2. The objectives of Phase 2 are: to obtain MSHA/NIOSH certification of the PWSCSR prototype as a 60-minute duration SCSR, and to fabricate 200 production-quality, approved units to be subjected to an in-mine safety hazard evaluation by the Bureau. Research has been conducted successfully to increase the usable oxygen generated by the SRX-80 by 25 percent, from 80 to 100 liters of oxygen. The new unit is designated the SR-100. Figure 1 contains photographs of the SR-100 comparing it to an FSR, and showing it deployed and ready for donning.



Figure 1.

Figure 2 is an engineering drawing of the SR-100. The SR-100 is being certified under current 30 CFR 11 regulations as a 60-minute duration SCSR. The modifications do not affect the size or weight of the PWSCSR.

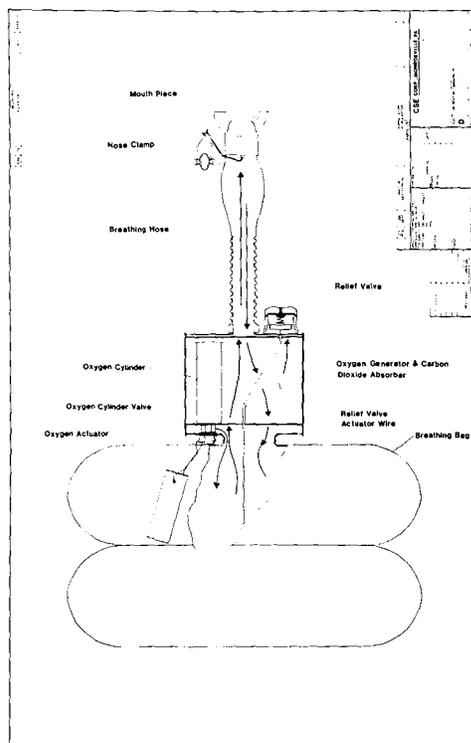


Figure 2.

A joint Bureau/MSHA planning effort is underway to decide how to evaluate the production-quality apparatus. These plans will be presented to the mining industry for discussion and comment. Our current thinking is to subject the PWSCSR's to a series of laboratory environmental treatments designed to simulate various conditions in underground coal mines (Stengel 1982; Kyriazi 1983). The environmental treatments consist of extremes of temperature, shock and vibration. These tests will be used as predictors of the ability of the prototype to survive the in-mine environment with no degradation in protection to the wearer. The PWSCSR's will also be examined and destructively tested to evaluate potential fire and explosive hazards.

Successful mine ruggedness evaluation will set the stage for field trials. There will be limited field

deployment of the SR-100 for in-mine testing. This will involve cooperative ventures with the mining industry. The purpose of this work is: (1) to further establish the credibility of the new technology, (2) to explore practical deployment options, (3) to demonstrate performance under simulated mine escape, and (4) to assess the transferability of recently developed SCSR training methods to the new apparatus. As commercial versions of SR-100 - type apparatus are introduced into the industry, the Bureau's role will change to long-term monitoring of user proficiency and of how well these devices survive in-mine deployment.

THE ISSUE OF SCSR DONNING PROFICIENCY

The introduction of SCSR's into underground coal mines in 1981 made possible a new survival skill: the ability of miners to don the apparatus in order to escape an unbreathable atmosphere. Under MSHA's existing training regulations (in 30 CFR Part 48) was the requirement to provide "...instruction in the use, care, and maintenance of self-rescue and respiratory devices ..." (Code of Federal Regulations 1979). To comply with this regulation as it applied to the newly deployed SCSR's, mine trainers relied primarily upon the use of audiovisual programs or demonstrations by an instructor instead of upon performance trials by the trainees.

The prevailing assumption among most instructors was that workers were generally proficient in donning SCSR's. In the absence of empirical evidence to the contrary, conventional instruction was accepted as being sufficient. Reputed failures of workers to don the devices in situations calling for their use were most often attributed to poor judgment, panic, or both. Evidence mounted, however, that conventional SCSR task training, lacking a hands-on component, was inadequate and that lack of procedural skills might be an important concern. For instance, a

report on the Greenwich Collieries explosion (Fesak and Cavanaugh 1984) alerted Bureau of Mines researchers to the fact that workers might not know how to don SCSR's in spite of the demonstrations they had seen in annual refresher training.

A 1985 experiment conducted by the University of Kentucky and the Bureau of Mines with a group of underground miners who had received hands-on training in 1981, and a demonstration in annual refresher class each year since, resulted in a 39% failure rate. In November, 1986, MSHA completed a nationwide evaluation of the effectiveness of SCSR training. They found that 1,780 of the 8,904 miners tested, or nearly 20%, failed (Federal Register 1987). These findings are hardly surprising when one considers what is known empirically about infrequently used procedural skills in general and procedural skills having a motor component in particular.

First, it has been demonstrated that procedural knowledge is different from declarative knowledge, or knowledge about facts and things (Anderson 1985). Procedural knowledge deals with the process of performing subtasks that will lead to the accomplishment of a desired goal. Further, it is known that increasing the availability of relevant knowledge will help an individual carry out a procedure, while the presence of irrelevant knowledge can inhibit the process and hence impede fast, accurate, and flawless performance. The best way to teach a procedure, then, is to specify clearly the actions that are necessary to accomplish a particular goal (such as how to don an SCSR) and avoid superfluous information, even when that information has value in a declarative context (Mayer 1983).

Mayer's assertion is illustrated in the research reported by Cole, Vaught, Kellner, and Chafin (1987). After reviewing existing SCSR training materials, the authors noted that in addition to mixing declarative (factual) information with procedural information "...the

training materials present no simplified, easy to remember overall procedural rules that can cue miners to recall and properly order the complex array of multiple tasks needed to don an SCSR." In other words, the donning procedure was not presented in such a way that the needed actions were easily understood (Anderson 1985).

A second fact that has been established empirically concerns procedural tasks that have a motor component. Motor learning has been defined as "...a set of processes associated with practice or experience leading to relatively permanent changes in the capability for responding." (Schmidt 1988). The key to learning a motor task such as SCSR donning, therefore, is practice combined with knowledge of results, as the definition suggests. The goal of practice is to reach some criterion of proficiency in which correct actions become more or less automatic. Schmidt has hypothesized the existence of schemas, or general rules governing the performance of a task, which the individual builds up in the course of practice. According to Schmidt, practice movements benefit the learner, because they contribute to building up the schema regarding a particular procedure.

Schemas also guide and direct practice. Without some overall directing framework within which people can assimilate their knowledge and experience, learning of complex procedural skills (motor or otherwise) may focus on small units, and not the whole performance. Learning to be proficient on such tasks usually takes longer without such an initial organizing schema.

There is little doubt that a person learning an infrequently used motor skill should have the opportunity to repeat the procedure and receive feedback on the adequacy of his or her performance once he or she reaches an established criterion. The reason for this "overlearning," especially in the case of seldom-used procedures, is that the level of performance achieved during training

is the best predictor of skill retention. While Johnson (1981) summed up what is known empirically about retention by stating that "...people can't remember what they didn't learn, and they forget over time..." the fact is that they retain more if they have learned more. Repetition combined with knowledge of results does enhance the level of task learning, and that in turn helps sustain an individual's procedural knowledge over periods when there is no practice (Hagman & Rose 1983).

One way to determine the value of training is through systematic assessment. Evaluation of performance itself is a major element in making training effective. This is true in the case of SCSR training for two reasons: First, in the process of developing training techniques, it is necessary to evaluate the performance of trainees in order to determine where in the donning procedure errors and wasted time are likely to occur. Once this has been done, it is fairly easy to devise the most efficient strategy for performing the task. It is then possible to determine the most effective way to teach the procedure. Second, since SCSR donning is largely a motor task and one of the most crucial elements of motor learning is knowledge of results, assessment and feedback to the learner are key to training effectiveness (Schmidt 1988).

INNOVATIVE SCSR DONNING METHOD

The preceding paragraphs suggest clearly that there is an extensive body of literature dealing with issues that are in every way comparable to those that have arisen regarding SCSR training. This research base was used directly in development of the Bureau's new training method.

Cole, Vaught, Kellner, and Chafin (1987) developed evaluation techniques as part of their effort to show what an optimized SCSR training program would include. The researchers first conducted a

detailed task analysis using a controlled experiment in which 36 working miners who had recently gotten refresher training were videotaped in performance trials with the SCSR model in use at their mine. Assessment of the tapes allowed the investigators to target those steps in the procedure where most errors occurred and where most time was lost. It was found that individuals spent a majority of their time adjusting straps and locating goggles that had been dropped on the floor. In addition, many of the subjects became confused and omitted tasks such as putting on the nose clips. Only 22 individuals (61 pct) were able to complete the minimum of steps necessary to isolate their lungs, and approximately half of these required over a minute to do so.

Based on the experimental findings, an instructor's manual and short videotape demonstration were prepared for field testing. This package presents a generic procedure for the four SCSR's in common use (CSE, Draeger, MSA, and Ocenco). It offers the following: (1) a donning position (kneeling) that is easy and efficient; (2) a donning sequence that moves critical steps (those tasks necessary to isolate one's lungs) ahead of the others; and (3) a set of "chunked" procedural rules that facilitate easy retention of the many detailed subtasks in a single overall schema. This "3+3" donning method (see figure 3) has been promoted as an efficient means for providing thorough hands-on SCSR training, and has become the norm for the industry because it is a highly generalizable procedure. It works equally well with each SCSR currently being marketed, and the areas in which miners are prone to have errors are well-known. Individuals who will be expected to don the PWSCSR will have had training in performing the 3+3 for several years.

TASK TRANSFER

Although SCSR's are rugged and well-built, they do not have unlimited service lifetimes. Some units are



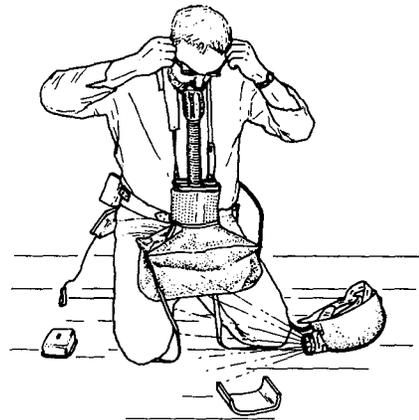
1. Activate Oxygen



2. Insert Mouthpiece



3. Put on Noseclips



+ 1. Put on Goggles



2. Adjust Straps



3. Replace Cap

Figure 3. The "3+3" sequence

lost or expended, others are damaged through misuse, while some simply wear out. To complicate matters, certain SCSR manufacturers have gone out of business or no longer manufacture apparatus for the mining industry. In other words, mine operators face the real problem of replenishing their SCSR's in order to remain in compliance with Federal regulations. Given advantages in both comparative cost and technology, we anticipate that the mining industry over time will purchase and gradually deploy PWSCSR's as replacements for SCSR's. Thus, there may be a need to train miners in the use of two apparatus. To illustrate the potential motor learning problems engendered by this situation, consider the following:

The first one hour person-wearable SCSR to be developed is CSE's SR-100. A worst-case scenario was projected in which a miner would activate the small oxygen bottle that initially fills the bag on the SR-100, and would then inadvertently dump all or part of the bag before getting the mouthpiece in. Dumping the entire bag would result in the loss of eight percent of the total oxygen supply. For this reason, it was suggested that it might be advisable to change the 3+3 sequence to teach users of the SR-100 to insert the mouthpiece before activating the oxygen. This seems a minor modification, and not anything to be concerned about.

Yet, it is known empirically that people are easily confused when they omit steps or get them out of order. For example, out of 624 SCSR donning trials conducted by the Bureau, there were 275 omitted steps. Only 90 of these omissions were subsequently corrected by the subject. The conclusion is that when individuals skip a step, they usually continue with the donning procedure and do not go back and correct themselves. Changing the donning sequence for the SR-100 would, in effect, tell people trained previously in the 3+3 method to skip activating the oxygen until the mouthpiece is in and the noseclips are on, and then to go back and activate the oxygen. This would

actually build in error and would result in many initial failures to activate the oxygen.

The ability to transfer task learning is crucial, especially if PWSCSR's are phased in gradually. While it is easy, given the above illustration, to predict the amount of confusion that would result from mixing the PWSCSR with the SCSR if each had a different recommended donning procedure, it is not known how well the 3+3 extends to the PWSCSR. Schmidt (1988) has hypothesized that there might be low transfer, even among very similar devices. The only data collected by the Bureau concerning this issue deals with 25 subjects' ability to don the Draeger after having been trained and evaluated on the Ocenco. For this group, at least, performance with the Ocenco seems to be a fairly good predictor of performance with the Draeger (see figure 4). It is hoped that future research with the PWSCSR will yield comparable results.

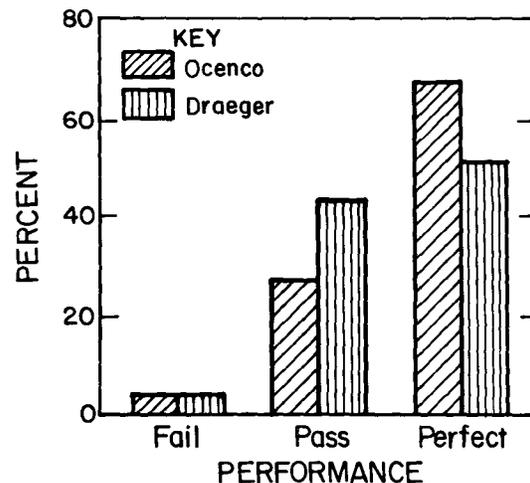


Figure 4.

DISCUSSION

PWSCSR technology based on the SR-100 design is intended as a strict substitute for current SCSR's, without any changes in Federal regulations. Because the SR-100 is belt-wearable, it is also a replacement for the filter self-rescuer. The cost of SCSR's meeting the Federal regulations for mine escape is approximately \$500. A

commercial version of the SR-100 is estimated to cost less than \$350. It is quite likely, therefore, that as existing apparatus are retired they will be replaced with PWSCSR's.

Since 1985 the Bureau of Mines has been engaged in research aimed at evaluating the adequacy of SCSR training, the development of an improved donning strategy, and the assessment of effects of training strategy on SCSR donning performance. With the development of PWSCSR's, attention must be devoted to questions of task transfer. It is becoming increasingly apparent that trainers themselves must be prepared to use appropriate teaching and evaluation techniques in order to insure that miners develop proficiency in donning whatever apparatus they will be expected to use in the future.

REFERENCES

- Anderson, J., Cognitive Psychology and its Implications, New York, W.H. Freeman and Company, 1985, 472 pp.
- Code of Federal Regulations: Title 30 Mineral Resources, Washington, DC, Office of the Federal Register, National Archives and Records Service, 1979, p. 278.
- Cole, H., Vaught, C., Kellner, H., and Chafin, E., Miners' Proficiency in Donning SCSR's, Pres. at the 13th Conference on Training Resources Applied to Mining, Wheeling, WV, August 17-20, 1987.
- Fesak, G., and Cavanaugh, D., Report of Investigation (underground coal mine explosion) Greenwich Collieries No. 1 Mine, Arlington, VA, Mine Safety and Health Administration, 1984.
- Federal Register, Rules and Regulations, V. 52, no. 125 (Tuesday, June 30, 1987), pp. 24374-24380.
- Hagman, J., and Rose, A., Retention of Military Tasks: A Review, Human Factors, V. 25, no. 2, 1983, pp. 199-213.
- Johnson, S., Effect of Training Device on Retention and Transfer of a Procedural Task, Human Factors, V. 23, no. 3, 1981, pp. 257-272.
- Kravitz, J., and Kovac, J., Person Wearable SCSR Task Force Final Report, 1985, 70 pp.
- Kyriazi, N., Kovac, J., Duerr, W., and Shubilla, J., Laboratory Testing of Compressed-Oxygen Self-Rescuers for Ruggedness and Reliability, Bureau of Mines RI 8839, 1983, 17 pp.
- Mayer, R., Thinking, Problem Solving, Cognition, New York, W.H. Freeman and Company, 1983, 425 pp.
- Schmidt, R., Motor Control and Learning: A Behavioral Emphasis, Champaign, Illinois, Human Kinetics Publishers, Inc., 1988, 578 pp.
- Stengel, J., Kyriazi, N., and Benz, S., Laboratory Testing of Chemical Oxygen Self-Rescuers for Ruggedness and Reliability, Bureau of Mines RI 8657, 1982, 21 pp.

APPAREILS AUTONOMES D'AUTO-SAUVETAGE: NOUVEAUX DEVELOPPEMENTS
TECHNOLOGIQUES ET FORMATION

John G. Kovac, Charles Vaught

L'objectif du présent rapport est de résumer deux importantes voies de recherches sur le développement et l'utilisation d'appareils autonomes d'auto-sauvetage (SCSRs). Le Bureau des Mines effectue des recherches pour développer un appareil autonome d'auto-sauvetage à porter sur soi, conçu pour les sauvetages miniers. L'appareil, dont la taille est le double environ de celle de l'appareil d'auto-sauvetage à filtre, fournit une heure d'oxygène. Des recherches supplémentaires ont examiné les résultats de techniques de formation sur l'aptitude des mineurs à mettre ces appareils. Des études empiriques portant sur cette aptitude ont démontré que les méthodes d'entraînement influencent de manière significative et durable la façon dont les personnes accomplissent les gestes nécessaires, alors qu'en l'absence de pratique périodique ces techniques ont tendance à se détériorer assez rapidement.

GRUBEN-SELBSTRETTNER: NEUE ENTWICKLUNGEN IN TECHNOLOGIE UND SCHULUNG.

Hohn G. Kovac, Charles Vaught

Der Vortrag ist eine Zusammenstellung von zwei Richtungen in der Forschung, Entwicklung und des Gebrauchs von unabhängigen Selbstrettern (SCSRs). Das Bureau of Mines führt zur Zeit eine Studie zur Entwicklung eines persönlichen unabhängigen Selbstretters durch, der zur Flucht aus Gruben geeignet ist. Der Selbstretter ist fast doppelt so groß wie der Filterselbstretter und hat einen Sauerstoffvorrat von einer Stunde. Zusätzliche Forschungsarbeiten befassen sich mit der Bestimmung der Wirkung von Schulungsprogrammen auf die Fähigkeit der Grubenarbeiter, die Handhabung der SCSR nicht zu vergessen. Empirische Studien über Anwendungsvermögen ergaben, daß Schulungsmethoden einen bedeutenden Einfluß auf die Art haben, mit welcher der Grubenarbeiter die Filter anlegt, und daß dieser Effekt lange anhält, während er gewöhnlich sehr rasch nachläßt, wenn Nachschulungen unterbleiben.

АВТОНОМНЫЕ САМОСПАСАТЕЛИ: ПОСЛЕДНИЕ УСПЕХИ
В ТЕХНОЛОГИИ И ОБУЧЕНИИ

Джон Г. Ковач и Чарльз Вот

Задача настоящего доклада - обобщение двух главных направлений в исследованиях, относящихся к разработке и использованию автономных самоспасателей (SCSR). Горное Бюро США проводит исследования по разработке переносного шахтного автономного самоспасателя. Этот аппарат по размеру в два раза превосходит фильтровый самоспасатель. Он вмещает часовой запас кислорода. Дополнительные исследования были направлены на определение эффективности обучения шахтеров быстро и правильно приводить самоспасатели в готовность. На основании этого исследования было определено, что большое значение имел конкретный метод обучения людей, и что люди сохраняли способность правильно обращаться с оборудованием в течение длительного времени, хотя эти знания в значительной степени терялись без периодических тренировок.

设备齐全的自救器：技术和培训的新发展

约翰 G. 柯凡克 及 查理 福特

本文扼要地叙述有关设备齐全的自救器 (SCSRs) 两项研究项目。矿业局正在研究发展一种单人穿的设备齐全的自救器用来逃出煤矿。这种自救器约为过滤式的自救器一倍大小，它可以供给一小时的氧气。另外一项研究项目为针对培训矿工保持穿戴自救器的熟练性。根据穿戴熟练的经验，培训方法对矿工熟练的程度和持久性有很大的关系。但是如果经常练习则也很容易生疏。



U.S. BUREAU OF MINES
OPEN FILE REPORT

OFR 27-89

PROCEEDINGS OF THE

**23RD INTERNATIONAL CONFERENCE OF SAFETY IN MINES
RESEARCH INSTITUTES**

**23 МЕЖДУНАРОДНАЯ КОНФЕРЕНЦИЯ
НАУЧНО-ИССЛЕДОВАТЕЛЬСКИХ ИНСТИТУТОВ
ПО ГОРНОЙ БЕЗОПАСНОСТИ**

**23. INTERNATIONALE KONFERENZ GRUBENSICHERHEITLICHER
VERSUCHSANSTALTEN**

**23^{ème} CONFERENCE INTERNATIONALE DES INSTITUTS DE
RECHERCHES SUR LA SECURITE DANS LES MINES**

第23届采矿安全研究学院国际会议

**Washington, DC
September 11-15, 1989**

Organized by the U.S. Department of the Interior, Bureau of Mines