The Use of Procedure Trainers, Part Task Trainers and Simulation Devices to Supplement On-The-Job Training of Heavy Equipment Operators

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Mr. Contor's duties include advisement of mining technology students, classroom instruction of industrial technology and mining technology courses and participation in research and development programs. Since 1980, Mr. Contor's research activities have centered about the development and evaluation of workbook and audio visual training material for the evaluation of the dragline simulator. He participated as an instructor and evaluator on the dragline simulation evaluation for DOE in 1981 and is currently developing new dragline simulation programs for surface mine management, supervisor and operator personnel for the Coal Research Center in Carterville, Illinois.

Mr. Contor had eleven years experience at McDonnell Douglas in St. Louis. While assigned to the McDonnell Douglas Electronics Company, from 1974-1980 he was responsible for partial development of the Underground and Surface Mine Coal Miner Certification Program for the state of West Virginia, the design and development of the training program for the continuous miner training simulator and the dragline simulator. Other responsibilities while at McDonnell Douglas included design of the cockpit of the F15 prototype, F18 Fighter aircraft and design of the air combat simulator for research and development and test pilot training. He also prepared proposals and developed CRT and visual display subsystem for aircraft.

During the 1960 decade, Mr. Contor participated in the design and development of space vehicles in the Mercury, Gemini, and Apollo programs, including flight simulation, astronaut training programs and the design of astronaut work stations including ground and flight control consoles.

Other programs included operator control station and cockpit designs for rescue submarines, aircraft, aircushion vehicles, jet flying belts, missile systems and the Apollo space laboratory and telescope mount.

Mr. Contor has over 22 years experience in aerospace, mining, industry, and education in addition to several years of consulting experience.

Abstract

The report provides a brief history of simulators used during World War II; nuclear power facilities and missile launching simulators during the 1950's; manned orbital and lunar flight in the 1960's and 1970's and indicates there is an increased industrial need for trainers in the future. The increasing sophistication and expense of the simulators were the direct result of both the cost and complexity of the systems being simulated and the size and number of computers required for high fidelity simulation. With
the advent of minicomputers and microprocessors it is feasible
to develop realistic simulations at a greatly reduced price. The
U.S. Bureau of Mines and the Department of Energy have been
responsible for the development, test and evaluation of these
simulators for large mining equipment. The prototype continuous
miner and dragline simulators have been completed and the results
appear favorable. A brief description of both these training systems
is provided. Further use and development of these types of training
devices is contingent upon the need and acceptance of simulators
by industry, management and labor.

INTRODUCTION

History

1940's. The first large scale use of training devices in the
United States had its origin during the Second World War. The
training devices developed included mockups of cockpits of aircraft,
gunnery practice using aircraft scale models, and aircraft trainers
to teach instrument flying to pilots. These devices were inexpensive,
developed the requisite trainee skills and most importantly, allowed
large numbers of individuals to get hands-on experience when the
production items were in short supply. In the case of the flight
trainers two additional features became apparent. First, the student
received emergency training which would be difficult to accomplish
on a real aircraft e.g., aircraft ditching or water egress. Second,
if the student made a serious error it did not result in personal
injury or damage to equipment e.g., missed instrument approach and
missed aircraft carrier landings.

As the military and civilian aircraft became more complex the
training devices became as expensive as the aircraft and required
multiple operator and maintenance personnel for operation. The only
training device that remained relatively simple and inexpensive was
the driving simulator to train high school students and adults to
drive automobiles.

1950's. Sophisticated and expensive training devices and
simulators were required with the advent of atomic powered generators
for electricity, ships and submarines. Also, highly trained,
experienced, skilled personnel were required at launch control
centers and mission control centers for experimental, military,
communication, and manned space flights. In most situations, this
training could only be accomplished using simulators. These
simulators required several years to design; cost millions of
dollars to build and required a large cadre of highly skilled
personnel for operation and maintenance. The aircraft, space craft
and nuclear facilities were improving so rapidly that at times
simulator development was lagging behind system development.

1960's. The manned space program developed from the one-man
Mercury flight to the two-man Gemini rendezvous and docking vehicle
to the three-man Apollo orbital, lunar landing and space station
flights in less than 15 years. These successes were achieved at
the same time as deep space-unmanned-voyager probes were being
conducted. Development of large, expensive, sophisticated
simulation devices probably reached its peak during this time frame.

1970's. The space shuttle program reflects the current
state-of-the-art in sophisticated vehicles and simulation equipment.
Both the space craft and simulators costing hundred of millions of
dollars.
Today, industry is also utilizing highly sophisticated simulators for training, evaluation, and promotion of personnel employed in electrical and nuclear power generator plants, the shipping industry, petroleum refineries, commercial air travel, and many other areas.

Computers

The computer makes simulation possible, but it is also responsible for the high development, operating, and maintenance costs of these devices. The mass production of mini-computers and microprocessors has resulted in substantial cost reductions, and greatly increased storage capacity. Consequently, the development of training devices and simulators for operators of large, expensive mining equipment is being investigated by the U.S. Bureau of Mines.

The need for inexpensive, relatively simple trainers to improve operator performance, increase production, and improve safety has been recognized again.

Types of Trainers and Simulators

The basic types of training devices are recognizable by the levels of sophistication and the training that can be achieved on each device.

Procedure Trainer

The procedure trainer is extremely simple and may consist of a partial or full scale, cardboard, wooden or metal mockup of a control panel, work station or vehicle compartment. The controls and displays may be represented by drawings or pictures but seldom do the consoles have the actual controls and displays. These controls and displays are not operative. Procedure trainers are used to train the student the location, configuration and design of the equipment so he may learn hand motion, visual references and sequence of operations for tasks such as pre-operation inspection, checkout, start-up, operation, shutdown and post-inspection.

Skill Trainer

A skill trainer is a full scale, cardboard, wood or metal mockup which has some or all of the controls and displays in operational condition. As the trainee manipulates the controls there is limited feedback either through the displays, indicators, or a CRT. Feedback may result from mechanical, electrical, or computer activation.

Part Task Trainer

A part task trainer is usually a permanent, full scale, structure with many or all of the controls and displays fully operative. Mechanical, electrical, and computer interaction provides feedback with the operator. Total training cannot be accomplished, however, due to limitations usually associated with the visual system. The visual system may consist of slides, movies, television projections, CRT displays and/or computer generated images.

Simulator

The simulator is the most versatile of the training devices and has several levels of sophistication. It is usually a full
scale replica of the operational equipment and work station. The system may be fully interactive with the trainee, the visual system approaches realism or may be real world and the program for training is continuous. Figure 1 shows a comparison of the training devices and the trainer components which would be used in selecting the design sophistication for a large shovel simulator.

Selection of Training Equipment

To be cost effective it is necessary to also compare trainer type with the training objectives to determine the level of sophistication required to achieve the desired results. Figure 2 is an example of a matrix used to specify system complexity by training objective for the large shovel. The greater the sophistication the longer the development time; costs increase rapidly; training is more complex; and operation and maintenance requirements increases as does down time and repair time.
The matrix is completed by determining if the type of training equipment will provide the necessary hardware, electrical components, controls, displays, visuals and interaction required to meet the objectives. The Y's and P's are totaled after the matrix has been completed and then trade offs concerning the different type of training equipment which can be used are initiated.

**Development of Heavy Equipment Training Devices**

When systems approach or exceed a million dollars, usually one or more of the following conditions exist: the number of systems are limited; operators must be trained to prevent damage to equipment or personnel; production cannot be delayed; and operating costs are important. To overcome these problems some formal means of training is usually required. In the past, large equipment operators rarely received any structured form of training prior to operating the equipment. The apprenticeship method and hands-on training provided the skilled work force. However, to provide adequately trained operators for the sophisticated, expensive equipment the traditional hands-on-training and apprenticeship program must be improved. Several different simulation techniques have been funded and evaluated by the U.S. Bureau of Mines and the Department of Energy in the last ten years in an attempt to see if aerospace simulation devices and training techniques are applicable to training of mining equipment operators. These programs have as their prime objective (1) acceleration of skill acquisition by reducing training time, (2) improving safety by training the operator to handle emergencies and (3) reduction of accidents by providing more experienced and skilled operators. Over the years, safety data indicates a high frequency of accidents among new operators. Also, experienced operators learning to operate new equipment with unfamiliar or differently located controls and displays are accident prone.

**Trainers Being Evaluated**

The U.S. Bureau of Mines and the U.S. Department of Energy has funded the evaluation and development of trainers and simulators to assist in the training of operators of underground and surface mine equipment. These programs have resulted in the development of proto type trainers for the shuttle car, continuous miner, and large draglines. In addition, the Bureau of Mines has funded and evaluated a training device which allows an instructor to alter the reading on the gauges and displays on a dump truck so the instruments would be representative of a malfunctioning of the truck. The purpose being to train the operator to recognize and take corrective action when an impending emergency exists. Other devices used to improve operating efficiency, reduce accidents and contribute to improved maintenance of large equipment include electronic devices on crawler tractors, front end loaders, draglines and excavating and loading shovels. The devices monitor electrical, mechanical, and hydraulic systems to determine that the systems are within safe operating parameters and the energy consumption is optimum for the task being performed. A two way radio coupled to the monitoring system transmits the data to the mine office central computer upon request.

Other trainers have been developed by equipment manufacturers.
These include (1) procedure or part task trainers to assist in the development of new continuous miner operators. These devices, along with a student/instructor workbook package, are produced to be sold to large mines, to community colleges having mining programs and to equipment operator training centers associated with academic institutions. (2) Over the road semi-truck operator training centers have used a truck simulation device for driver training. (3) Heavy construction equipment operator schools are provided by private training centers, union training centers, and the U.S. Army at Fort Leonard Wood in Missouri. These schools and training centers use smaller equipment, hands-on supervised training, lectures and classroom instruction to train new operators. The course material contains information on checkout, operation, shutdown, maintenance and safety. (4) Companies with underground coal mines have developed simulated mines built in buildings above ground or used special underground sections for training of their operators. Both of these types of training facilities use actual equipment for operator training. (5) A railroad locomotive simulator to train the engineer has also been developed. All of these techniques have had varying degrees of success i.e. some have failed, some have been developed but have not been adequately evaluated and others are under development and still remain to be evaluated.

Current Status?

Roof Bolters

Of the training devices funded and investigated by the Bureau of Mines, it was determined that the training of operators of roof bolting machines could best be achieved using the actual machine in a real mine or a simulated environment where the roof bolter drills in overhead cement slabs.

Simulators for scoop and man trip vehicles have yet to be developed. Development seems to be dependent upon the success of the shuttle car part task simulator.

Shuttle Car

Several million dollars has been funded for the development of two prototype models of the shuttle car over the last eight years by the Bureau of Mines. The first development model was considered a failure and the second improved model has exceeded the original development schedule by two years. This system is designed to use a 16mm movie for the visual system. Consequently, the trainer is not fully interactive with the trainee. It is to be evaluated at Wabash College in Indiana in 1982-1983.

Continuous Miner

The continuous miner simulator was completed over two years ago by the McDonnell Douglas Electronics Company. Since then it has been used at Rend Lake College to train new and experienced Inland Steel Coal Company operators and although the second evaluation appears successful the final results have not been published.

The continuous miner training system is located at Rend Lake College in Ina, Illinois and is available for instructional purposes. The recommended class size is small (2-3 trainees) and course
duration is 2-4 days due to the amount of time available for hands-on-operation of the simulator by each student.

Figure 3. Continuous Miner Simulator Equipment

The continuous miner trainer is a dynamic, interactive, computer controlled, part task trainer. A picture of the continuous miner system is shown in Figure 3. It has a full scale work station with operational controls. The visual system consists of the CRT with plan and elevation scenes of an underground mine and a line drawing of a continuous miner (see Figure 4).

Figure 4. Continuous Miner CRT Display

The operator controls the CRT image through manipulation of the mockup controls. Two 35mm back projectors present pictures of underground mine scenes that are representative of the conditions that the student would see when tramming or cutting coal underground. Time and error scores are recorded by the computer. The students
intersperse operation of the trainer with student workbooks and classroom instruction.

The total training package is available as a commercial product or the simulator equipment can be purchased without the training material.

Dragline

Evaluation of the dragline simulator was completed in August of 1981 at the Department of Energy (DOE) Facilities at Carterville, Illinois. The dragline simulator was built by McDonnell Douglas Electronics Company for the Department of Energy. The DOE has given management of the facilities and dragline simulator to Southern Illinois University-Carverville. The simulator is being used for operator training, research and academic courses. A mine supervisor training program is being developed for the Peabody Coal Company from the original operator program.

The dragline simulator consists of a full scale dragline cab and operator station, a 15 ft x 18 ft. scale mine, and a 1/50 scale 110 cu. yd. dragline model. The visual system is a television camera and a TV projector which displays the scale model mine scene to the trainee on a back projected screen in front of the cab. See Figure 5.

The simulator is completely interactive, responding to inputs from the controls operated by the trainee. The computer has a keyboard and printer to record performance parameters, record errors, provide malfunction initiation, and allow program changes so it can represent any make or model of dragline.

A second TV camera and recorder is used to provide instant playback or performance review by the student and the instructor.

Figure 5. Dragline Simulator Visual System

In addition to the simulator, the training package includes over 90 minutes of sound slide and video films, student workbooks, a 1/150th scale model mine and a 1/50th scale dragline model for dynamic concepts training. See Figure 6 and Figure 7.

The operator training course is ten days in duration and the class size is limited to six students. The ten-day/six-student programs provides 10-15 hours of simulator hands-on training for each student.
The instructor can have the computer record and provide a printout of the total number of cycles completed, average cycle times, average dig times and dig lengths and average swing angle. Common errors such as bucket shock, tight lining, boom stress, overspool, multipass, bucket fill and excessive drag are also recorded by the computer. The instructor may also select machine malfunctions which are displayed on the caution and warning panel thereby training the student the correct response to these malfunctions.

**On-Board Display - Dragline**

Two companies are marketing a computer controlled device which is installed on a large dragline. The device monitors and records performance data of the dragline, power consumption and provides displays to the operators informing them of their operation and production performance. The device is reported to be designed to function as a training device for experienced operators, thereby, reducing operating costs and increasing productivity. A display system and keyboard device is located in the operator cab to request past or present performance information displays and the operator can also select specific parts of an operational cycle for review and evaluation. With this data, the operator can then change his operation tactics to increase performance. At the end of the shift the computer will sum the stored data and provide a printout of the information to the operator. The data can be stored for long periods of time and used by mine management personnel for production reports.

**On Board Display - Shovel**

A smaller and simpler data recording device is under evaluation at the present time. It is installed on a BE 2958 shovel that is removing overburden at a mine in Wyoming. This device was not intended to be used by the operator. It functions more as a data recording device and built-in test system for maintenance and repair information.

As indicated early there are several other training or data collection devices being installed on trucks, crawler tractors, front end loaders, and other large equipment. As the operational capability of these devices are proven it is expected that the necessary programs will be developed so that both inexperienced and experienced operators will benefit. However, the on-board devices still require that the production equipment provide the time, wear and tear imposed by training while losses are occurring in the production schedule.
CONCLUSION AND SUMMARY

The use of trainers and simulators as a means of supplements, or in place of, on-the-job training has been used very successfully for the past 40 years in the high risk, high cost, high technology systems and programs. Because of the cost and skills involved in the operation and maintenance of these highly specialized systems, it is feasible to expend the time and resources necessary to develop the simulation devices.

It was not until the mass production of minicomputers and microprocessors that simulation devices became sufficiently inexpensive and had the necessary storage capability to be used in the development of simulators for the large equipment used in the mining and construction industry. Through the efforts of the U.S. Bureau of Mines, private industry, and coal companies it has been possible to accumulate the necessary resources to design, construct, and evaluate these devices.

To date, two simulators have been developed and evaluated with an indication that the operator skills necessary for safe and efficient operation of the underground continuous miner and the large dragline can be achieved using these training devices. The shuttle car trainer system has been developed and the second generation system has been constructed but it is still lacking evaluation at this time.

To be effective the trainer must be designed to meet the training objectives, provide the necessary visual system and have the realism necessary to provide transfer of skill and knowledge from the simulator to the production operation. Other training techniques using computers, mini-computers, and microprocessors are also being evaluated. In most cases these devices are being used primarily as on-board-devices for operation data collection, built-in-test functions, and energy/performance data. Operator training and performance enhancement is secondary.

The feasibility of using these devices to supplement on-the-job training of large numbers of the working force must still be proven in two areas.

First it must be proven to be cost effective from the company standpoint and second, it must be accepted by the operator personnel and unions. It appears that both of these areas of concern can be resolved with education of the benefits to be derived by both groups. The use of aircraft simulators to train and upgrade pilots in the military, commercial, and private flying sectors have shown that management, union, and operators can benefit if the design is adequate and production, safety and personnel advancement can be achieved using these devices.
During the decade of the 1960's a new technique to effect more efficient and safer deep sea diving was verified by the U.S. Navy and effectively applied by the commercial diving industry in support of the worldwide search and production of offshore oil and gas resources.

This technique, called "saturation diving", is based on the thesis that the tissues of the human body, while being subjected to increased gas pressures, will take up gas to a point of equilibration with the increased pressure. The body tissue then becomes "saturated" as the pressure is applied. "Total saturation" occurs after a period of approximately twelve hours. Once the body has reached "saturation", the decompression time required to eliminate this gas in a controlled manner to prevent the onset of decompression sickness or "bends" is independent of the time spent at depth. Therefore, for any given depth the decompression time is fixed. This differs from standard short-term diving where both depth and time at depth significantly alters a decompression profile.

The advantage of this technique is that divers can perform eight or more productive hours of work in a twenty-four hour period, remain under pressure, continue such production for weeks and be decompressed at the end of the project in the same time had they remained under pressure for only twelve hours.

Life support for this technique requires a pressure boundary, or chamber, wherein the divers eat and sleep while compressed in a helium-oxygen atmosphere at the working depth pressure, plus a transfer chamber which delivers the divers to and from the work site at this pressure. Maintenance of life support both in the chambers and for the divers in the water is complex and requires surface technicians on a 24 hour basis to support the operations.

Application of this diving technique has significantly increased the capabilities of manned intervention in the ocean. The most technically significant capability that has been made possible by saturation diving is the dry hyperbaric welding of subsea pipelines and structures. In this technique, working in a dry environment at ambient pressure, and supported through saturation diving, divers are able to bevel, align and weld steel structures with weldments that meet codes of classification societies such as Lloyds, Det Norske Veritas and American Bureau of Shipping. Taylor Diving has been the pioneer in developing this technique and has performed 240 such welds since 1968.
Divers, even with saturation diving have limited capabilities due to depth restrictions. Also the economics of saturation diving are such that remote operated vehicles have been developed to perform visual inspection and limited manipulator tasks at deeper depths where they are economically superior in performing these functions.

This presentation describes the application of saturation diving, dry hyperbaric welding and remote operated vehicles to two unique land based mining projects. The intent of this presentation is to inspire the audience (reader) to consider consultation with qualified subsea contractors to assist in solutions to problems involving flooded mines.

Saturation diving and hyperbaric welding techniques developed on behalf of the offshore oil industry were employed recently to repair the steel liner of a new eight-foot diameter mining shaft which flooded while being constructed in the state of Missouri in the USA.

This was the first known time in the history of the underground mining industry that deep sea divers worked in a mine shaft to overcome adversities that can occur with water.

Taylor Diving & Salvage Company of Belle Chasse, La, performed the unusual assignment in a new shaft that was part of a construction project to develop a new ore body. The completed shaft was 112-inches in diameter to a depth of 1,350-feet.

The shaft was designed to be cased with a 96-inch diameter steel liner. Cement was pumped into the 8-inch annulus between the liner and the rock walls of the shaft to sever the liner and seal off the upper water zone from the water zone in the mining horizon. These two water zones are separated by a 150-foot thick shale bed approximately 1,000-feet below the surface.

After the cement hardened, water inside the liner was pumped down following removal of a steel closure used for floating the liner in place.

During the final phase of pumping down, a crack developed in the liner at 803-feet after water level inside the shaft had been lowered to approximately 690-feet.
After unsuccessful attempts were made by other contractors to grout off the flow, Taylor Diving was contacted to devise a plan for putting diver/welders into the shaft to weld a patch over the crack.

A preliminary engineering and logistical survey of the work site indicated that the job could be performed with Taylor's standard saturation diving equipment and a custom-designed underwater welding habitat. Taylor engineers designed a totally new type of circular habitat, embracing it with an inflatable rubber packer to maintain watertight integrity against the sides of the shaft. However, the close confines of the shaft presented problems not encountered in the open sea. (Figure 1)

Oil States Rubber Company in Houston fabricated the inflatable rubber packer similar to that which had been employed during grouting of the giant legs supporting Shell Oil's Cognac platform in the Gulf of Mexico. This packer proved to be sized ideally for application around the habitat.

The completed habitat included a 9-foot long diver access trunk measuring 20-inches in diameter, fitted inside with all necessary welding equipment.

In the meantime, work progressed on qualifying the weld procedure and diver/welders. The surface support crew included tenders, electricians, hydraulic specialists, life support, and diving supervisors.

Since six diver-welders would be needed to keep the job working around the clock, Taylor elected to use a single chamber from one of the company's newest "twin stacked" saturation units, along with the system's regular diving bell.

Together with the life support system, welding and diving station, winches, air compressors, welding machines, air tuggers, umbilicals, and related gear, the saturation system was loaded in Belle Chasse aboard trucks and transported 800 miles to the work site. Breathing gases were delivered directly from the supplier.

While the diving equipment was being readied, the patch was lowered into the shaft, locating it directly over the crack. The precise positioning was accomplished by viewing the crack over a TV monitor focused through a "window" to the left of the patch's center. Over the monitor, the 22-inch crack, protruding 1.5-inches into the shaft, was clearly evident.
A length of drill string was then used to hammer an opposing section of rolled steel patch in the "scissors" tool until four hinged bars securing the opposing section to the patch were fully horizontal. This had the effect of spreading the tool fully and jamming the 54 x 74-inch patch tightly against the shaft.

The next step was to lower the underwater welding habitat into place via two cables that also were used to suspend it from the top of the shaft. The divers' access trunk fitted easily through the four cross bars of the patch.

Under normal circumstances, the base section of a saturation unit is welded to the deck of a work barge or oil platform, but since there was no way to do this on land, it was decided to let gravity accomplish the job. A Wharton traction winch used to raise and lower the bell was welded to the far end of the base, serving as a counter-balance against the weight of the bell.

The divers started in saturation at 2030 hours on Saturday, July 14 and made their first bell run the following morning. The divers were instructed to obtain a sample from the damaged area and bring it to the surface for laboratory examination. Prior to cutting this coupon, the turbulence from the aquifer was minimized by keeping the water level in the shaft at 130-feet from the surface. Since the water table in this area is also 130-feet, the effect was to equalize the pressure differential, thus eliminating in-flow.

After the coupon was cut, the divers shut a hinged door to cover the "window" and bolted it tight. These bolts, their holes, and the perimeter of the "window" would later be welded. The packer of the habitat was now inflated.

Breathing gas was then introduced into the sealed-off area beneath the habitat until the water level was forced beneath a steel grating which served as a floor for the habitat. This enclosure was essentially like a large bubble under pressure at 800-feet and was held down by 17-tons of lead ballast weight. The top of the habitat was approximately 790-feet below the surface.

Hot water suits were needed to effect the transfer of the divers from the bell to the habitat where they removed their helmets and switched to a breathing mask designed for hyperbaric welding.

Two diver/welders made each excursion, with one remaining inside the bell while the other welded for about three hours before changing positions. The work shifts ran seven hours, with approximately one hour needed each way for retrieving the bell, mating it to the decompression chamber, effecting the crew change, un-mating the bell, and lowering it back to the work site.
The areas to be welded were marked for easy reference and identification by diving supervisors and customer representatives on the surface.

After the welding was completed, magnetic particle inspection was performed before the divers started their decompression. Decompression took approximately eight days (one 24-hour day required for every 100-feet of depth) and was completed during the early afternoon of July 30.

Having completed the basic welding on the patch plate, the water was pumped down below 800-feet after the welding habitat was raised to the surface. The remainder of the repair plate collar was welded in place by standard methods using welders in a work cage.

This exercise marked the first time Taylor worked in very deep water other than offshore or under simulated conditions in the company's hyperbaric research and training complex in Belle Chasse.

The project was a significant milestone both for the mining industry and the commercial diving industry.

The offshore oil industry has experienced a dramatic change in underwater support services during the last six years. This change resulted from the introduction of remotely operated vehicles and which have greatly reduced the cost of performing inspection and light work tasks. The vehicles have also permitted access to areas where it would be unsafe or physically impossible to place divers. We feel these tools could be of value to your industry and wish to take this opportunity to show some examples of the equipment and tasks they have performed.

The most successful and widely used ROV is the Hydro Products' RCV-225. Two of the most significant features are its small size, only 26 inches in diameter, and its extreme depth capability of 6,600 feet of seawater. The deepest commercial dive to date by an RCV-225 was in behalf of the mining industry.
In March 1982, Taylor Diving was contacted to inspect a uranium mine in North America. A 3,200 foot vertical shaft was flooded as the result of intrusion of very warm underground water. The flooding which collapsed a 12-feet thick, 16-feet diameter concrete plug occurred at a time when the mine was inactive. The Taylor RCV-225 team was assigned to inspect the lower 1,900 feet of the shaft. This was the flooded portion through which concrete from the collapsed plug had fallen.

Excursions even to limited depths into the mine would have been impossible for divers, because of large amounts of unstable debris at various levels and the 135° F plus water temperatures. This temperature also limited ROV mission duration to 35 minutes. During the dives, the shaft walls were thoroughly inspected for damage. In less than a week spent at the site, sufficient information was recorded on video tape to enable the mine owner to accurately weigh the cost of reactivating the shaft.

While this is the only recorded use of an ROV in a mine, may tasks performed for the offshore oil industry could be adapted to mine operations. One example is the placement and use of explosive devices. During a three year operation in the Straits of Sicily, several hundred shaped charges were placed in depths to 1750 feet to clear a pipeline right-of-way between Sicily and Tunisia. The right-of-way had several areas of volcanic rock outcropping that had to be cleared to provide a flat bed for the pipe lay. Extensive use of explosives was required to accomplish this task. After attempts at other methods of setting the shape charges, it was determined that the fastest and most effective method would be with the ROV. The vehicle was used to:

1) Locate the blast site.

2) Guide and set the shape charges.

3) Actuate a hydraulic valve to release the charges.
4) Inspect to insure that all detonating cord and electrical cables and connectors were intact.

5) Perform a post survey to assess the effectiveness of the blast.

A similar use for the ROV is the cutting of cables or pipelines using shape charges or thermal cutters. During a recent demonstration a vehicle built and operated by Taylor Diving cut a 2 1/2 inch piece of wire rope. This system could be used to remove tangled cable or abandoned pipelines from a flooded shaft without the risk of tearing out surrounding equipment.

There are additional examples of offshore tasks far too numerous to go into at this time. It is our hope that this paper has served to stimulate your imagination and raise pertinent questions concerning other ways ROV's can help the mining industry.
Figure 1

Saturation Chamber

Underwater Welding Habitat

Diving Bell

Steel Liner

Exhaust Boot

800 ft. Crack in Steel Liner

Ballast Weight

Davis Shale

Mining Level

Shaft

130 ft.

Upper Water

130 ft.

Level

135 ft.

Diver Umbilical

Habitat Umbilical

SOX Umbilical

Inflatable Seal

Patch

Folding Floor

Ballast Weight

Detail View of Weld Site

1153
FIRING MODULE

FRAME

CAGE

MARKER SET BY RCV

MARKER SET BY SURVEY

MOON POOL

FIRING MODULE FRAME

STROBE TURNING LOOP

CHARGES

CAGE

MARKER SET BY RCV

MARKER SET BY SURVEY

OBSTRUCTION

BASKET

RCV