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RECOVERY AT SOMERSET MINE

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Somerset Mine is located in Gunnison County, Colorado, on the North Fork of the Gunnison River. This mine was opened in 1902 and was operated by various companies prior to 1961, when United States Steel Corporation assumed operating responsibility.

Somerset production is shipped via railroad to our Wellington Coal Preparation Plant in Utah where it is blended with Geneva mine coal and washed and dried. Plant product is shipped to U. S. Steel's Geneva Works near Provo, Utah as the high volatile component of the coking coal blend. The mine is not only vital to U. S. Steel's western steel operations but is a major factor in the economy of the North Fork Valley and surrounding area.

"B" Seam, the only one being mined in 1972, is 20 to 22 feet thick and has all the properties and physical conditions conducive to spontaneous combustion. "C" Seam has not been known to ignite spontaneously. "B" Seam and overlying "D" and "E" Seams have, through the centuries, been penetrated by a creeping burn, or smolder, to distances of 1000 to 1500 feet from the outcrop. Crevices high up in the mountain emit heat and steam vapors, plainly visible under certain weather conditions. The Indians named it "Fire Mountain."

On April 10, 1972 fire, assumed at that time to be spontaneous, was evidenced by smoke entering the main haulage through a man door opposite the center of three sealed 1st Raise Entries. Direct fire fighting was employed using water from an approach east of the fire, and foam and water through the man door. Backing up of intense smoke and heat defeated these efforts and it was elected to seal. The area feasible for sealing consisted of two parallel entries 4200 feet long, located between two fans, and requiring 14 seals.

Initial sealing was accomplished and seemed to be successful, although analysis showed leveling off of trends before reaching the desired low levels of oxygen and carbon monoxide.

On May 7 fire erupted around one of the seals and, despite conventional direct fire fighting, the fire could not be abated. This necessitated sealing the mine at all portals. Temporary seals were completed on May 8, and 72 hours later were converted to permanent ones.

It was fully appreciated that seals at the portals could not be expected to deny oxygen to the extent desired. In fact, it is safe to state that a decision to wait for the desired levels of mine gases before re-entry would be equivalent to permanent abandonment of the mine.

Intensive study was conducted at once and a plan evolved to re-enter the "B" seam promptly, with air lock control, for a distance of 4500 feet. At this point, four dams could be built and water could be impounded behind them throughout much and perhaps all of the known fire zone. Other advantages will be covered later in this presentation.

Discussions were held in May and early June among officials of the Bureau of Mines, State of Colorado, United Mine Workers of America, and United States Steel Corporation. Tentative plans and prints were supplied to these concerned parties.

On June 22, 1972 representatives of these four interested parties met at Somerset. There was agreement and approval that the proposed re-entry should be effected, but that an effort should first be made to drill a vertical hole into the fire zone for sampling purposes. Sampling through a fire zone break in a six-inch main water line would be acceptable if the vertical drill hole failed to reach the fire zone.

Case Histories

This presentation continues with sections devoted to Organization, The Recovery Operations, and Analytical Controls.

Organization

U. S. Steel Corporation fully accepts responsibility in the operation of its coal mines. Even during the 72-hour waiting period between the temporary and permanent sealing, intensive recovery studies took place. People were delegated to develop elements of a mine recovery plan and upon approval of the plan to get their parts accomplished.

Elements of planning included:

1. Engineering the recovery plan and establishing the mechanics of providing engineering support throughout the operation.
2. Determining requirements for additional mine rescue people and effecting their training.
3. Projecting logistical and maintenance support needs to assure that facilities, apparatus, equipment, and supplies would be ready as needed and maintained in good operating condition.
4. Developing recovery guidelines with some flexibility to meet contingencies, including control of entrance to recovery work areas, sampling mine gases, monitoring at portals, etc.
5. Setting up a laboratory analytical control program.
6. Incorporating all accepted elements into a general recovery plan, with appropriate prints, profiles, and exhibits.

Needless to say, many recovery ideas were advanced and reviewed. Alternate main haulage routing had to be considered to reach the active workings beyond the fire zone.

One of the routes considered led to early recovery of the "C" Seam. While never deemed a desirable option, timely action could reduce "B" Seam downtime by months. In the interim, obvious advantages would accrue from early opening of a mining section for Somerset employment and production.

"C" Seam recovery was valuable, as well, in sharpening our trained nucleus of 25 mine rescue men, seven of whom were supervisors. Moreover, all planners benefited in firming up their planning assignments.

High energy refreshments were found to be good for mine rescue teams. Salt tablets and high-potassium drinks were provided because of high temperature exposure.

After a lot of study and discussion it was agreed that certain physical factors should be considered in developing a plan for the recovery of "B" Seam.

1st Raise, where the fire broke out, is the westerly end of a level area. The fire was estimated to have spread generally westward toward 2nd Raise, which is at an elevation some 38 feet above 1st Raise. Twelve-hundred feet east of 1st Raise the haulage starts rising to the portal.

Dams across the four entries of 5 West at the east end of the level area would impound 27 million gallons of water at a maximum head of 25 feet. This would assure flooding of a major part, if not all, of the fire zone, without flooding any of the haulage or the active workings west of 2nd Raise.

An underground reservoir of enormous capacity lies north of, and below, the optimum location for the dams.

A three-part plan evolved:

Part I projected a prompt re-entry of Elk Creek portal and a controlled advance 4500 feet to the proposed dam sites.

Advantages of this plan were: (1) Oxygen would be denied the fire zone from surface fissures and from the burned coal zones; (2) The main pumping station for an unlimited water supply would be recovered; (3) The fire zone could be cooled and heating overcome with the quenching action of water, a most effective heat exchanger; (4) The area to the proposed dam locations could be easily ventilated by the Elk Creek portal fan; (5) An effective water seal could be maintained throughout the major recovery; (6) The sealed portion of "B" Seam would be moved beyond the recovered "C" Seam workings, assuring there would be no adverse effect if the two seams were to connect as mining resumed in the "C" Seam.

Part II involved recovery of the major portion of the mine from Hubbard Creek portal, including Hubbard and Bear Canyon intakes and fans, and the active workings of 5 West Entries, 3 South, and 3 Dip.

Finally, Part III involved draining and breaching the dams, recovering and ventilating 5 West Entries from the dam sites to 2nd Raise, and determining whether recovery of the main haulage throughout the fire zone would be feasible.

It was decided that 30 additional mine rescue volunteers should receive training to assure availability of six teams even after most of the supervisors would be needed elsewhere as recovery progressed.

Bureau of Mines instructors trained the volunteers in two groups, providing the needed number in timely fashion. It is noteworthy that supervisors and mine workers of the maintenance department were well represented in the initial complement and additional volunteers. This fact assured needed balance to the teams and maintenance support in restricted areas during recovery operations.

As previously noted, Part I was approved by all concerned parties in the June 22 meeting. Detailed planning accelerated. The vertical hole was drilled but failed to hit an open area in the fire zone, in spite of concentrated efforts at hole alignment and offset drilling.

Maintenance people devised a hand-powered vacuum pump to pull samples at Bear Canyon from the six-inch water line and later converted it to an air motor-powered vacuum pump.

The maintenance department made other preparations before Step I of the Elk Creek portal re-entry began:

1. Communication to all key points was established.
2. Prefabricated air lock doors and two fold-up rubber-tired flatcars for the mine rescue teams were constructed.
3. Adjustable uprights for use in air lock construction were provided.
4. Ventilating fans were reconditioned and modified in preparation for use. Removal of wheelbarrow loads of tar-like deposits from the Bear Canyon fan was necessary.
5. A six-inch water line and pumping facilities at the river were installed to provide water for fire fighting as mine rescue teams advanced and to supplement the mine sump pumps during impoundment.

An organization table was developed, naming people and their responsibilities.

Modeled after the makeup of the June 22 meeting, a coordinating group was established. The state, the Bureau, the UMWA, and U. S. Steel each named its own representatives. All had a common purpose: to recover Somerset Mine safely and to restore it to production without avoidable loss of time.

Functions of the coordinating group were:

1. To review, amend as needed, and approve plans and procedures.
2. To act as a forum for communicating activities and ideas for improving techniques, methods, and plans.
3. To resolve problems that might arise.

Two of the regular mine worker representatives of the coordinating group were safety committeemen and mine rescue team captains and the third is president of the local union, a safety committeeman, and was monitor at the mine rescue portal during rescue teamwork.

A draft of basic guidelines for the total recovery was completed. It set the standards for tight control of the sealed mine atmosphere as step-advances were explored, air locked, and ventilated. It outlined procedures to insure that all people underground would react quickly and safely to an unexpected emergency.

Only people trained in mine rescue were allowed underground during the controlled step-advance to the dam sites. Those not recently trained in mine rescue were required to be checked out on the use of Chemox apparatus before entering restricted areas. A sufficient number of Chemox were kept at the fresh air base to insure that all people in a restricted area would have oxygen breathing apparatus available. Because of greater distances from the portal, restricted areas were modified during the recovery through Hubbard.

One guideline required at least three mine rescue teams on duty when mine rescue work was being performed. A reserve team on the surface and a backup team at the fresh air base were to be in place whenever the third mine rescue team was exploring or working beyond the fresh air base. Modifications were made to make the reserve team more readily available as distances from the Hubbard portal increased.

Throughout the recovery, step plans were developed within the framework of the approved guidelines. The draft of each step plan was prepared in writing. A 50-scale map was provided with each copy of the draft. These maps were made from 50-scale tracings that USS Western District Engineering had procured for the recovery. The maps identified each step-advance by numerical/alphabetical and color code. Preferred locations of step air locks and preferred travel routes were either shown on the map or outlined in the written draft.

On July 5, 1972 the coordinating group met for the first time at Somerset Mine. U. S. Steel presented a draft of the basic guidelines as well as a draft and map of the first step in the advance to the projected dam sites. Improvements to basic plans resulted during discussion and the revised plan was approved by the four interested parties. The Bureau of Mines representative suggested that a system be adopted to identify crosscuts on the left and right sides of the track haulage. This was done starting at the portal of Elk Creek and then again starting at Hubbard portal.

This identification made a significant contribution to the recovery. It made it possible to quickly and accurately reference specific locations while voice-communicating between the mine rescue team and the fresh air base, and it provided an improved visual aid during coordinating group meetings, during mine rescue team briefings, and during individual discussions.

Experience with high ambient temperatures in the "C" Seam recovery had led to alerting the Chief Inspector of USS Frick District that liquid oxygen ARO apparatus and expert instructors might be needed.

Somerset Mine maintenance department did a commendable support job on the surface, as well as in the underground areas of the mine. Power was provided. Equipment was overhauled and modified for specific applications, such as for transporting and placing concrete.

Earlier, a hoist and car for mine rescue apparatus and supplies and, later, car dumping facilities were devised and installed at Hubbard Creek. The latter incorporated motorized wheels to assist in closing bottom doors where locomotive power was not available. Mine cars were modified to be hoisted up the steep Hubbard incline.

Two 20,000-gallon tanks were installed at Hubbard to provide water for fire fighting.

Engineering provided many services throughout recovery operations, including: 25 maps prepared for each step-advance; information necessary for evaluation of contingency plans such as water levels, relationship of overlying "C" Seam workings to recovery areas, and alternate haulage routes; designs for reinforced concrete dams, and hoisting and car dumping facilities at Hubbard Creek; procurement of equipment and materials required during the recovery; and general day-to-day engineering support for the mine recovery teams.

The USS accounting department provided invaluable support in its area of responsibility, largely ordering and expediting materials and supplies required in the recovery operations.

The Recovery Operations

This story of the recovery operations starts with limited re-entry from the main mine portal to the proposed dam sites, then moves to Hubbard portal from which the major recovery took place, and finishes with coupling the two parts after draining impounded water and breaching the dams.

A recovery shift consisted of a foreman in charge, an assistant foreman, an official in charge of communications and team direction, and three mine rescue teams of six men each. Representatives of the regulatory agencies were present during rescue team activities and ventilation advances.

At the outset, Somerset was equipped with 22 McCaa self-contained oxygen breathing apparatus.

The foreman in charge, using written step procedures and maps depicting each step, briefed the teams each day. Each team captain was given copies.

Voice and signal communications between the fresh air base and the mine rescue team were maintained. The procedure required returning to base if the voice system became inoperable. Voice communication was the primary method.

Permissible pocket-sized amplifiers, connected by a carrier line, and two small speakers were the elements of a highly effective yet somewhat delicate system.

One of the miners on each team was assigned to communications. His carrier line was coiled on a bracket in a figure eight. He fed it off as the team advanced and wrapped it as the team returned to base.

This communications man reported conditions, work in progress, oxygen supply, instrument readings, and other pertinent information. All members of the team could hear both sides of conversations.

One official attended the communication system at fresh air base throughout the recovery. The amplified system permitted everyone at base to hear the messages and even hear the communications man breathing.

This official kept a record of teams entering the air lock and of conditions as they were reported. He recorded the oxygen supply of the low man at scheduled intervals. He noted that the team carried out specific procedures involved in the written plan. A 50-scale map was used by the team and at the fresh air base to reference specific locations and conditions. Another complete log of events was kept by the Bureau inspector.

A nylon rope lifeline on a reel was used as a backup for the voice system. Emergency signals were standardized. The line was advanced or retreated as required during exploration and was kept readily available at work locations.

Bureau research experts requested a field test of walkie-talkie radios designed for underground use. Signals became weak at about 300 feet and one entry off line. It was most effective in a straight-line application as far as 1000 feet. These radios have promise and merit further development.

Teams entered into irrespirable atmosphere through air locks. This minimized the amount of oxygen that could enter the sealed area.

Air locks were built, using 4"x4" uprights similar to a measuring stick. These were used whenever timbers of proper length were not available at or near the sites. After uprights or timbers were in place, a framework of 1"x6" lumber was attached and covered with reinforced nylon plastic curtain. This curtain was cleated, after which the perimeter and joints were foamed with Rigi-Paks.

Materials for air-lock construction were hauled on a rubber-tired collapsible flatcar. This car could be folded and passed through a 4'x5' air-lock door. Material to build two air locks was hauled in one load, saving time and reducing physical exertion by apparatus teams.

A six-inch water line was extended after each ventilation advance. First-aid equipment and materials were moved forward. Power lock-out gaps were established 200 feet out by the fresh air base.

The first two steps were ventilated with a blower fan and tubing until an overcast of corrugated pipes could be installed to permit starting the Elk Creek fan.

Before electricity could be restored to the mine, a battery-powered Uni-Trac was used to transport materials from the surface.

During Step III on July 10 at 2:00 P.M., teams were withdrawn because of a high oxygen sample that had been taken at Bear Creek return. This sample proved erroneous, but did test the withdrawal procedure. During Step V high temperatures were encountered, rising to 120°F as the proposed dam sites were approached. Humidity was 100 per cent and vision limited. Temperatures within the McCaa apparatus became unbearable.

Temporarily installed curtains on pogo sticks seemed to improve visibility, but the prevailing hostile conditions reduced mine rescue team excursions beyond fresh air to less than 25 minutes. Physically fit, well-conditioned men were "wrung out" in this atmosphere. Sponges soaked in ice water were placed in their caps to alleviate the heat. But by Step VII the teams seemed to be stymied.

At 4:30 P.M. on July 20 a call was placed to the general manager of U. S. Steel Coal Operations in Pittsburgh who coordinated a U. S. Steel air transport of 20 ARO liquid oxygen apparatus and three Frick District experts to instruct and consult. They arrived at Grand Junction during the night and were at Somerset, charging the apparatus, as teams arrived on July 21 at 8:00 A.M.

Mine rescue teams were instructed in use and care of this type of apparatus. After thorough orientation, the teams were anxious to try the apparatus under actual conditions. Each team made a practice excursion beyond the air locks and performed well. All team members adjusted to the new apparatus quickly.

This apparatus supplies oxygen at 70°F to the wearer, dropping to no lower than 42° when the wearer is breathing heavily.

Step VII was modified to advances of 100 feet, the proposed dam sites were reached, and air locks were installed. This permitted another air split which ventilated the main mine pump station and the east side of the track haulage.

Four block seals were installed and foamed, after which construction of the dams started. A sharp decrease in oxygen and carbon monoxide was recorded from the fire zone sampling points promptly after the objectives were reached and blocked off. In fact, while the dams were under construction, it was agreed by the coordinating group that re-entry from Hubbard could begin.

Apparatus teams then moved to Hubbard portal, from which the major portion of the mine was recovered. Air locks were installed beyond the bottom of Hubbard intake, a 42-degree incline. Teams had to negotiate 215 steps on the stairway, while wearing apparatus, until a blower fan and tubing could be used. Four advances had to be completed before Hubbard fan could be started. The fan was started on August 19 with six explosion doors secured in the open position to bypass air.

Magnehelic gauges were kept at copper sampling tubes in step air locks to monitor pressure differentials. Differentials were controlled within ± 0.15 inches water gauge. Recovery progressed 2700 feet until on August 24 six air locks were doubled. Recovery was recessed while water was impounded in the fire zone.

There were no indications of excessive pressures nor hydrogen generation and ignition. By September 5 the planned water level was reached and pumping stopped, except as needed to maintain a constant head.

Ventilation advances were made up to Step "N" air locks, near the bottom of 3 South Raise. Exploration verified that it would be safe to open Bear Canyon intake seal and ventilate all of 3 South Raise in one step. Apparatus men followed the air through Bear intake, checked for leaks and applied Rigi-Pak sealant as needed. The two operating sections in 3 South Raise were ventilated, inspected, and found to be in reasonably good condition. Equipment seemed ready to operate. This completed the first of four major ventilation steps without mishap.

The second large ventilation step followed. Seven air locks across 5 West Entries and 3 South Aircourses isolated the 3 Dip area.

Hubbard Creek fan volume was increased by closing three explosion doors and partly closing another three. All of 3 Dip was ventilated in this step. Several million cubic feet of methane were cleared, after which a mine rescue team wearing apparatus made an inspection.

A continuous miner, roof bolter, and coal drill were behind caves in the 4 West Section. Three pieces of equipment in 4 East Section were waterlogged, but equipment in 5 West Section was in good condition.

Next, two air locks were installed east of 2nd Raise in line with seals across the two upper entries of 5 West, enclosing the flooded fire zone to the dams, and all was ready for the third large ventilation step. Bear fan seal was removed and the fan started September 28, 85 days after the first seal was opened. This fan initially was set at 0.8 inches water gauge, so that 2nd Raise seals would be on low pressure. Inspection of 2nd Raise to the Bear fan revealed that the return air course had literally acted as a chimney for the fire. Heavy tar deposits coated the ribs from 5 West to Bear fan. Old sealant on 2nd Raise 2 East seals was scorched from the heat and top coal had spalled.

Draining of impounded water behind the dams was started October 3. Progress to 1st Raise was made possible by advancing air to a crosscut as fast as mine rescue men crawled and timbered over caves and explored for hot spots. On October 19 dams and air locks were opened to ventilate 5 West Entries to 2nd Raise, the fourth major ventilation step.

Inspection of the original haulage entry disclosed that roof caving and damage from the fire were extensive. Nearly all timber had burned and sloughage had widened the entry excessively. Before the fire, track and trolley had been on line and grade. Timber and lagging had been installed on line and clearances were adequate.

It was decided that a parallel entry above the original haulage should become the main haulage for a distance of 2500 feet.

Inspection of the 1st Raise seals established that the April 10 fire had not been spontaneous but had occurred when roof over the middle entry seal breached as a result of heat from the outcrop "burning" zone. Abatement was assigned first priority. Fly ash dams were decided upon to impound a 25-foot head of water, flooding to a point above 1 East off 1st Raise. Bureau research experts from Bruceton came to Somerset and gave on-site equipment modification and construction advice. A bentonite/cement slurry was pumped into a 12-inch space between a squeeze seal and a thick concrete block seal, which became the back form of the dam.

Cleanup and rehabilitation of 5 West entries resumed December 18 after 1st Raise was protected by water seals.

On January 18, 1973 spontaneous combustion developed in a crosscut between the original track haulage and the lower parallel entry. Heating developed along the crosscut rib line, beneath a top coal and roof rock cave. Water was applied, hot material loaded out, and rehabilitation of the new haulage continued.

Track was connected to the original haulage beyond the fire-ravaged area on March 21. Two sections of 3 South were in production by April 1, while rehabilitation continued in other recovered areas.

Although not mentioned previously, there were many times between the dams and 2nd Raise that water in great quantities was sprayed over hot piles of fallen coal and rock, seeping through and draining to the lower entry.

This practice bought time for rehabilitation and reinforces the views expressed by Mr. John A. Rockett, official in the U. S. Office of Fire Research, who said: "In fact, about the only thing that won't change in the future is the use of water. Exotic foams will be used in special situations, but water has too many advantages to be ignored. It's an amazing chemical. It's always available, absorbs heat nicely, is cheap, nontoxic, relatively non-corrosive, and has nice handling characteristics. If water weren't around, we'd have to invent it."

Analytical Controls

Somerset Mine fire precipitated an intensive program of monitoring mine gases. Certified people designated as monitors used instruments and, on a scheduled basis, took samples for on-site laboratory analysis. This monitoring program, which was followed throughout recovery operations, furnished valuable information for planning and scheduling purposes. As recovery progressed, all involved parties knew the current state of mine gases and could evaluate the effectiveness of control measures.

When it became necessary to seal the mine, copper tubes were installed at the main openings to facilitate sampling and make instrument readings of the mine gases. A management trainee for U. S. Steel had been trained in the use of the Orsat during previous operations. Continuous daily sampling started immediately and Orsat analysis was made in the makeshift laboratory set up in the basement of the mine office. USBM samples were taken twice a week to supplement Orsat results. The return seals at both Bear Creek and Hubbard Creek were the most reliable sampling points because of their tendency to exhaust.

Other seals were quite often found to be inhaling and resulted in air dilution. Orsat results at Bear Creek return showed that oxygen dropped to 6.0 per cent three days after the mine was sealed and reached 1.0 per cent 37 days later. Methane was 3.2 per cent and 14.0 per cent, with carbon monoxide being 1.0 and 0.6 per cent on the same days.

At the meeting of June 22, re-entry to flood was scheduled to begin on July 6. The existing seals had become ineffective insofar as creating a more desirable atmosphere. On July 5 USBM supplied a computerized Perkin-Elmer model 900 chromatograph that was set up in the mine laboratory. It was decided that chromatograph results would be official during recovery operations and Orsat results were used for backup analysis. The seal on the main portal was opened on July 6, nearly two months after the mine had been sealed.

On July 8 samples were drawn through the six-inch water line that surfaced at Bear Creek fan. An air motor-driven Roots blower was constructed in the shop to evacuate the pipe, the speed of which could be regulated to deliver a desired volume. Since this pipe had broken in the fire area during fire fighting on May 8, the length of the pipe was known. The amount of time needed to run the blower to obtain a sample directly from the fire area was calculated and verified by using nitrogen to clear the line. The gases were detected with detector tubes as they came through the blower. Water bottle samples taken for Orsat results were also run on the chromatograph in comparison to the vacuum bottle samples. They proved reliable for analytical purposes and allowed for continued analysis when vacuum bottles were not available. This was the first time it was possible to sample directly from a fire area. Samples taken by the mine rescue teams were analyzed promptly to help protect the teams.

The laboratory soon became a popular place inasmuch as all responsible parties were interested in the sample results. As soon as results became available, they were made known to U. S. Steel officials, USBM, state, and UMWA representatives on the coordinating group. They were phoned to the communications base at the portal to be relayed to the fresh air base so that recovery officials and team members could be currently informed. A log of results was kept in the laboratory and in the mine office for reference.

Samples taken by the mine rescue teams during initial steps of re-entry confirmed that oxygen was present behind the seals. During the first 2000 feet of re-entry, oxygen was high and no carbon monoxide had been detected by either detector tubes or sample analysis. As re-entry progressed, oxygen content decreased and carbon monoxide increased to near the same levels as were obtained through the six-inch pipe.

Samples taken at the control points, however, showed that control was effective in limiting the amount of fresh oxygen to the fire area. Trends in the state of mine gases were gratifyingly modest. Only once, on July 10, was concern aroused. A sample taken at Bear return showed an oxygen increase to 15.51 per cent with 4.41 per cent methane. This information was called down and the rescue teams were withdrawn from the mine. Another sample was run and it was determined that the previous sample had been air diluted due to bad sampling technique.

On July 24 the four entries in the area of the fire were checked off with Step 7 air locks and immediately oxygen and carbon monoxide trended downward and methane upward, indicating that sources of oxygen had been reduced. By July 27 cinder block seals were completed and work on the dams was begun.

Around noon on July 27 the cooling motors on the chromatograph burned up and it was shut down for repairs. Orsat results became official until the chromatograph was back on line. Continued use of the Orsat along with the chromatograph had developed a reliable relationship between results. This obviated any need for delay in recovery operations.

Recovery began from the Hubbard Creek portal on August 7, weeks sooner than originally anticipated, because the favorable trends noted above had justified such decision. On August 10 the Hubbard Creek return seal was opened and one sampling point thereby eliminated. Control was continued with samples taken by rescue teams at Bear Creek return and through the six-inch pipeline.

On August 24 impoundment of water behind the dams was started. Special attention was given to whether hydrogen was being generated in detectable volumes. After ten days of observation, no indication of hydrogen being produced in explosive amounts had been found and it was agreed that recovery work should be resumed.

By August 30 carbon monoxide content in the samples had dropped below the detectable range of the chromatograph so lengths of stain tubes were used to keep track of carbon monoxide in the fire area.

On September 17 our pipeline was converted to a water line and could no longer be used as a sampling point. Bear Creek return and underground air locks became the main control points.

As recovery continued, sample results remained stable. Samples were taken and analyzed before each major ventilation step to assure that mine gas conditions permitted the action.

On September 22 samples showed air dilution due to consistent inhaling of Bear Creek return. This seal was opened and Bear fan was started on the 29th, completing the third major ventilation step.

One area remaining to be recovered was that part of 5 West Entries between the dams and 2nd Raise. Controlling samples were taken at air locks and seals along 2nd Raise until this area could be recovered. Monitoring was continued throughout the cleanup operations with special attention to analyses of samples taken from 1st Raise seals after they were reached and repaired.

Between April 11 and May 7, 96 bottle samples were taken through seals along 5 West Entries. Forty-seven were taken for Orsat analyses on the mine property, 45 USBM samples were analyzed either in Denver or Mount Hope, West Virginia, and four were sent to Provo, Utah for chromatograph analyses at U. S. Steel's Geneva Works. Seven hundred thirty-eight samples were run on the Orsat after May 8 until the major part of the mine was recovered. Two thousand one hundred twenty-seven samples were analyzed on the chromatograph from July 5, 1972 to May 4, 1973, when 1 West off 3 Dip was ventilated. Eighteen USBM samples were sent to Mount Hope for analyses between May 8 and July 15, 1972. This comes to a grand total of 2,951 samples analyzed in connection with Somerset Mine fires and recovery.

Whether by Orsat or chromatograph, the fact of having on-site analysis for immediate results is deemed essential. Its contribution to timely planning, scheduling, and reflection of control effectiveness proved to be an important element in assuring the highest degree of safety attainable for mine rescue teams and their supporting casts.

Conclusion

In conclusion, these points should be emphasized:

1. Liquid oxygen type apparatus was a "must" when mine teams worked in high temperatures and high humidity conditions. It is hoped that Bureau of Mines Research will support development of a ventilated suit that will permit mine rescue teams to operate comfortably in such adverse conditions.

2. Voice communications audible to all team members and people at fresh air base were effective. The equipment, especially cable and unreeling devices, needs further improvement. Hopefully, walkie-talkies will be developed to be fully effective.

3. Impounded water is the most effective seal.

4. Fly ash cement dams proved more effective and were quicker to construct than those of reinforced concrete; they have an added advantage of resisting squeeze.

5. Reinforced nylon curtain and Rigi-Pak foam in conjunction with adjustable uprights and boards provide quick and effective materials for erecting air locks. A total of 174 were built, 110 of them by rescue teams under apparatus.

6. Planning, coordination, communications, and daily briefings are essential elements.

7. At all times adequate sources of water should come from behind firefighters. By a like token, the sources should be extended with each step of a recovery operation.

8. Attention to analysis of mine gases is an essential part of control.

9. An infrared scanning device for early detection of spontaneous combustion should be further developed.

The Coal Mine Inspection Department of the State of Colorado, and other state agencies; The United States Bureau of Mines; members and officials of the United Mine Workers of America; U. S. Steel management at all levels in the corporation; Somerset's neighbors and suppliers; and Somerset Mine rescue teams and other miners in supporting roles, including all their families—brave and dedicated people, second to none in the entire mining industry—all of these people worked together to accomplish a difficult job of fire fighting, mine sealing, and subsequent mine recovery, without major mishap and without the loss of any life.

IMPROVED METHODS OF CABLE SPLICING

By WILL B. JAMISON
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The Federal Coal Mine Health and Safety Act of 1969 severely limited the use of temporary splices in trailing cables powering underground machines. In part, the Act stated: "One temporary splice may be made in any trailing cable. Such trailing cable may only be used for the next 24 hour period. . . ." The Act further required that permanent splices in trailing cables shall be mechanically strong, effectively insulated, sealed to exclude moisture, flame resistant, and well bonded to the outer jacket.

Prior to the passage of this Act, one state (Pennsylvania) required the replacement of a trailing cable when it contained five temporary splices. The Pennsylvania law had no specific requirements regarding the making of a temporary splice or the materials to be used, except for the obvious right of an inspector to condemn a defective or unsafe splice. Pennsylvania at that time required permanent splices to be brazed, welded, or fused, and the insulation to be vulcanized. I do not believe that any other state or federal law had specific requirements for splices made underground.

When these portions of the Act regarding splices became effective, the industry had little experience and few good choices. Of course, a damaged cable could be removed from the mine and be repaired by brazing and vulcanizing at a shop specializing in cable repairs. In the mine, cables could be joined with "beat rings," compression sleeves, or by welding techniques. Portable vulcanizers were available, and many mines made substantial purchases of such units. Shrink tubing had not yet been approved, and the commonly used tapes did not pass the flame resistance tests or did not possess the required flexibility.

Our experience showed that field-made permanent splices, even when vulcanized, were not generally satisfactory, especially on shuttle car cables. Replacement of a damaged cable for shop repair involves a lot of work and causes excessive down time of the machine. Initially, we did not have a very good idea of the number of splices made on a section, but later we found that one splice per shift per section was about normal. Further study revealed that splicing is more frequent on shuttle cars and that a high percentage of splices were made as the result of failures of previously made splices.

We concluded that the first priority was to find or develop a way to join the conductors, a way that would be mechanically and electrically acceptable for the severe duty of a shuttle car cable. We felt that if the conductors could be joined satisfactorily on the section, then we would study the problems of restoring insulation.

Laboratory Testing Procedure

The only real test of a cable splice is its performance in actual underground service. But in-mine testing is too slow, inconvenient, and testing results can be affected by random accidents. Therefore, we built a simple testing machine. While we realized that this machine was not as realistic as the reverse bending type machine used by Anaconda Wire and Cable Company, we believed, and experience has proved, that the simple machine can show relative performance of various splices. Later results of in-mine testing confirmed the results obtained with the machine, especially as to flex life. We do not feel that ıy m^chine can accurately simulate the al^^sion or scuffing which occurs undergro..nd.

The initial tests of methods of joining conductors were not very successful. Standard butt splice compression sleeves gave reasonably consistent but very short life. Beat rings gave longer life, as measured by the number of flexes before failure, but performance varied widely from test to test. Band or strap clamps (such as the Bandit and Punch Lock) gave variable results and were little better than beat rings. We tried other connection methods, including Cadweld, a wire braid sleeve, but these were not encouraging.

At this point, I must give credit for the success of our program to Frank May, who is a senior mechanical design engineer at Lee Engineering. The progress which we have made is mainly the result of the imagination, skill, and persistance which he brought to the project.

The Flared Short Sleeve Lap Connector

Frank was quick to recognize the basic merits of the compression sleeve: convenience, simplicity, and uniformity of performance. Failure of conventional sleeves occurred from severe localized flexing at the ends of the relatively long sleeve. It was decided that the flexing could be reduced if the sleeve were shorter. But the only way to shorten it appreciably was to lap the conductors inside the sleeve. The work eventually led to the flaring of each end of a very short sleeve and to improved compression dies which gave controlled compression with four balls set in the same plane radially about the compression sleeve. The compressive action of the balls on the sleeve is made uniform by rotating the work between balls as the dies are gradually hammered to their closed position. In the plane of the balls, the strands of the conductors and the sleeve are fully compressed so that the cross section appears to be solid copper. The curvature of the balls gradually and uniformly lessens the compression in each direction at right angles to this plane and then the flaring of the sleeve gradually spreads the flexing of the strands away from the plane of the balls. The short sleeve greatly reduces the degree of flexing at a pulley. This has resulted in consistent and predictable flex life, appreciably greater than the best splices made using other connectors.

The development of flared sleeves and compression dies for the various sizes of cables used by Consolidation Coal Company and proving them under operating conditions took considerable time. Then we found that dies designed for some of the short flared sleeves needed for lap connections of shuttle car cables could also be used on butt sleeve connectors specially designed for larger sizes of cables not subject to the flexing of shuttle car cables. For example, the 1/0 die used to make a lap connection with 1/0 conductors can also be used with a special 4/0 butt sleeve to butt join 4/0 conductors. It was also found that a long heavy wall butt conductor could be used to fill a void up to three inches long in a power conductor of a non-reeled cable. Finally, the flaring of all connectors has recently been improved by chamfering or tapering the outer wall at the flares. This chamfering has reduced the tendency for the flares to cut into the surrounding insulation.

The system of connectors and dies has gained good acceptance in the CONSOL mines. As with anything that is new, it has been misused, yet only reasonably intelligent workmanship is needed. Stupid mistakes are made, such as using the wrong sleeve size for the conductor, using the wrong die set for the sleeve, using die halves of different sizes, or not rotating the work as the dies are hammered together. To try to provide instruction for mine personnel on the use of the sleeves and dies, we have printed Lee Engineering Bulletin "Trailing Cable."

Performance of the Short Flared Sleeve

A satisfactory connector for conductors of a reeled trailing cable must have good life under flexing, must have consistent and controlled pull-apart, and must have good electrical conductivity.

We have compared flex life of beat rings, conventional butt compression sleeves, strap connectors (Bandit, Punch Lock, and Fastlok) and the double flared sleeve by extensive tests on our laboratory machine. The following chart shows

MECHANICAL SPLICE METHOD	*POOREST SAMPLE*	*BEST SAMPLE*	*LIFE EXPECTANCY*
Lee Double Flared Sleeve	400,000	800,000	500,000
Compression Butt Sleeve	350	1,100	500
Beat Ring	1,150	150,000	Unpredictable
Strap-Bandit, Punchlock, Fastlok	5,000	175,000	Unpredictable

the results of these tests, and compares the poorest and best samples of the life expectancy, if predictable.

We found that the compression dimensions of the Lee dies could be adjusted to control the compression given to the double flared sleeve. We decided that we should seek to obtain pull-apart of the splice at approximately 85 per cent of the safe cable tension. The objective is to have a splice fail before damage can occur from stretching other good portions of a cable. Generally, pull-apart occurred at a value within ±25 pounds of the desired value.

We subjected sections of cables containing splices to increasing overcurrents to find if the splices could carry high currents. In every case, with a properly made splice, the conductor burned apart at a spot away from the connector. The lapped conductors, surrounded by the short copper sleeve, were always cooler than the conductor away from the splice.

The Problems of Restoring Insulation

Up to this time, the criteria of the Bureau of Mines (now MESA) related to permanent splices on trailing cables have been limited to the flammability of the materials used to re-insulate the cable. Mechanical strength and the effective sealing of the splice against moisture are factors which may show up in defective splices. Enforcement of good splicing techniques is the prerogative of the inspector.

During the period that we were working on joining conductors, two new methods for restoring insulation were approved by the Bureau; namely, the heat shrink tubing such as Raychem or American Pamcor; and the cold slip-on sleeve such as Fairview Bit or Gooding Rubber. Probably, the heat shrink tubing has been the more popular. Also, the 3M cold splice was developed later, but its high cost has held back acceptance.

We tested most of these splices, made on a variety of cables from single conductor to various sizes of type G, on our test machine. Also, we were able to examine in detail a large number of splices which had been made underground and which had been in service. The following comments seem to cover our findings:

1. Too many of the splices made underground showed poor workmanship and inadequate attention to the need for cleanliness. Heat shrink tubing, cold slip-on sleeves, vulcanized tapes, or any other material just will not bond to dirty, greasy, or wet insulation or jackets.
2. Heat shrink splices tend to have limited flex life but stand abrasion well. Usually, the ends of the shrink tubes fail to bond properly to the cable jacket.
3. Cold slip-on sleeves have good flexibility and abrasion resistance, but frequent contact with pulleys or the spooling device can cause a sleeve to slide along the cable.
4. A number of inspectors bend the cable severely at the end of the splice. Often, shrink splices or cold sleeves will show an opening between the sleeve and the jacket of the cable. While I do not agree that such a severe localized bending is a valid test, quite often a violation is cited.
5. Well made vulcanized splices are probably the best splice; but the time needed to make a good vulcanized splice makes this method inconvenient as a fast method of cable repair and, consequently, getting a machine back in operation.
6. The need for flame or heat in making shrink or vulcanized splices introduces problems and risks when the splice must be made in the face area of a gassy mine.
7. Shrink or cold sleeve splices require that the cable be parted so that the sleeve can be slid over one end of the severed cable before making the splice. These methods of restoring the insulation could not be used to repair a cable where the jacket or insulation required repair. Since initial development of the shrink splice, variations have been worked out that allow putting the sleeve over the cable and then shrinking the tubing.
8. One additional problem with shrink splices is that a given size of shrink tubing can be shrunk on a limited range of cable sizes. Therefore, many sizes of shrink tubes must be kept on hand to repair any of the several sizes of cable in use on a section. The problem is even more severe with the cold sleeve, which must be molded to fit the exact shape of the cable on which it will be used. The logistics of keeping the needed inventory of these splice materials on the working section is difficult.

We decided that the manufacturers of special re-insulating systems such as Raychem, American Pamcor, and Fairview Bilt were doing a good job in improving their products. While it made sense for us to continue to evaluate improvements, we did not feel that we could contribute much to their systems. Instead, we thought that we should seek tapes that would pass the flammability tests of the Bureau of Mines and ways to use them to make an effective permanent splice.

When we started to study tapes, we found as a general rule that combustible tapes are superior to tapes which have sufficient flame resistance to pass the Bureau's flame test. The combustible tapes provide better abrasion resistance, flexibility, and self vulcanizing capabilities.

Initially, we contacted a number of manufacturers of insulating tapes. The response and cooperation which we received from the Okonite Company has been outstanding.

I will not attempt to cover in detail the many tests made on an almost infinite variety, number, and arrangement of tapes. It was found that flex life of the insulation of a splice and abrasion resistance were essentially opposing qualities; in other words, in order to choose qualities in a tape for good flex life, the tape has to be soft and pliable, and therefore it has poor wear qualities. On the other hand, harder and more abrasion resistant material is less flexible. One of the major problems has been to select the best compromise of qualities, and this selection process ultimately must be the result of actual use in the mine. Needless to say, actual in-mine testing of special tapes is difficult, since the tape must be flame tested as part of the proposed splicing system and must be approved and marked as satisfying the requirements for flame resistance before it can be used underground.

We found that normal flame resistant jacketing tape will stand more flexing if it is laid length wise in strips on the cable. The ends of the strips were secured by wrapping them with narrow jacketing tape. Continued study of this phenomenon disclosed that tape develops a grain structure as the result of being rolled in one direction. During manufacture, the tape material is rolled into a long strip, three feet wide and of the desired thickness. Then the material is put into a slitting machine and cut into strips of the desired width and rolled up into the familiar rolls. The rolling of the raw stock stretches the material in the direction of the rolling. This stretching approaches the elastic limit of the material. Strips cut crossways from the three-foot-wide rolled material are able to stretch much further without breaking than would tapes cut in the normal longitudinal way from the rolled material. Now we use small strips of tape, three feet long, cut crossways, and can tape a splice in the familiar helical wrap, retaining the best flexibility of the tape. By using the best flexibility of the tape, we are able to increase the hardness of the tape; improving its wear life without losing the degree of flexibility which we think is needed.

In-mine testing showed the need for better ways to clean the jacket and insulation of cables before any method of restoring the insulation is used. Accepted practice was to use a wire brush or file to clean and roughen the jacket. We observed continually that the mechanic's wire brush, file, and hands had enough grease and dirt to defeat the effort to clean the jacket. We studied solvents, and after submitting several to the Bureau, we received their acceptance for using a non-flammable solvent. This solvent is allowed underground if packaged in metal containers of one quart or less in size. We find that the solvent cleans the jacket and insulation easily and effectively; and while cleaning the cable to be spliced, it does a pretty good job of removing the grease and dirt from the mechanic's hands.

Even with a clean splice area, we found that the bonding of tape to the original material of the cable was marginal. We investigated cements and found a non-flammable, fast drying cement. The tape could be applied to the cemented jacket immediately. Dissatisfied with the brush applicator on the cap of the can, because cleanliness was not possible in practice in a mine, we found a reusable screw-on applicator, similar to the squeeze pump of an oil can, which readily adapted to a new can of cement. The trick was a replaceable tip on the squirt end, and the tip was made of a plastic to which the cement does not stick. Now the cement is in a squirt can which has a tip that can be used to distribute and spread the cement over the area to be taped, including the sleeve and conductors. The cement gives effective and quick bonding of the tape to the old jacket.

We use glass tape to bind ends of the wires and to prevent these ends from penetrating the insulation during flexing of the splice. We fill the gap between insulation with a filler tape which can be worked like putty. We usually tape over the filler tape with glass tape and then use the three foot long outer jacketing tape, pulled and stretched, as a final jacket covering.

We are continuing to search for better materials, and for tougher but still flexible jacketing tape. We have had the tape manufacturer make the tape harder as a result of in-mine testing and use. We would like to have an even harder tape, but we know that if the tape is too hard, then failures from cracking will increase greatly. We know that wear takes place yet it is easy to apply another layer of tape to cover this wear. Cracking may expose a conductor, with a consequent risk to people handling the cable.

Advantages of Taped Splices

I have indicated that we would like to have tougher tapes which retained the flexibility of the tape which we are using now. We are really not satisfied with the abrasion resistance of the tapes which we now have.

However, some of our mines think that the other advantages of taped splices outweigh this disadvantage. These advantages are:

1. No size problem. The same material is used on all splices.
2. Damaged spots can be repaired easily. If one conductor is damaged, a complete repair can be made without having to cut the other conductors.
3. When good workmanship is observed, the splicing materials bond to the old jacket.
4. The tapes can be used effectively on other electrical repairs involving repair of insulation.
5. No flame.
6. Low cost.

Again, training is important. We have printed Lee Engineering Bulletin (LEB-2), titled "How to Insulate a Cable," to show our electricians and mechanics how to make a good splice.

Future Improvements

We hope that some tape manufacturer can make a major breakthrough in material and will develop a flame resistant tape with even better physical properties than we can get in existing non-flame resistant tapes. But we understand that the nature of the materials and solvents needed to make a tape flame resistant makes this unlikely. We wish that the inspection agencies would keep the matter of flame resistance in reasonable perspective. We are not sure how important flame resistance of splices, which constitute less than two per cent of the cable, should be, especially if a non-flame retardant splice might be physically superior. But, we have not tested and do not know how much better a non-flame retardant splice might be.

We are encouraged by the work going on now by at least one manufacturer to develop and furnish permissible connectors for cables. Anything that can be done to help quick replacement of damaged cables or damaged portions of cables will be important, since then the damage can be repaired without the pressure to get a machine back in service quickly.

Finally, I would point out that the European mines use some interesting cable constructions and some unique methods for electrical safety which we have not tried. I think that we should try some of their ideas and equipment, and perhaps from such trials we might evolve better and safer systems.

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