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**Results of Phase I Postburn Drilling
and Coring, Rocky Mountain 1
Underground Coal Gasification Site,
Hanna Basin, Wyoming**

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Topical Report

**S.R. Lindblom
J.R. Covell
R.L. Oliver**

September 1990

Work Performed Under Cooperative Agreement No.: DE-FC21-86MC11076

For
U.S. Department of Energy
Office of Fossil Energy
Morgantown Energy Technology Center
Morgantown, West Virginia

By
Western Research Institute
Laramie, Wyoming

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SUMMARY

The Rocky Mountain 1 (RM1) Underground Coal Gasification (UCG) test consisted of two different module configurations: the controlled retracting injection point (CRIP) and elongated linked well (ELW) configurations. The postburn coring of the RM1 UCG site was designed in two phases to fulfill seven objectives outlined in the Western Research Institute's (WRI) annual project plan for 1988-1989. The seven objectives were to (1) delineate the areal extent of the cavities, (2) identify the extent of roof collapse, (3) obtain samples of all major cavity rock types, (4) characterize outflow channels and cavity stratigraphy, (5) characterize the area near CRIP points and ignition points, (6) further define the structural geology of the site, and (7) identify the vertical positioning of the horizontal process wells within the coal seam. Phase I of the coring was completed in the summer of 1989 and served to partially accomplish all seven objectives.

In relation to the seven objectives, WRI determined that (1) the ELW cavity extends farther to the west and the CRIP cavity was located 5-10 feet farther to the south than anticipated; (2) roof collapse was contained within unit A in both modules; (3) samples of all major rock types were recovered; (4) insufficient data were obtained to characterize the outflow channels, but cavity stratigraphy was well defined; (5) bore holes near the CRIP points and ignition points did not exhibit characteristics significantly different from other bore holes in the cavities; (6) a fault zone was detected between VIW-1 and VIW-2 that stepped down to the east; and (7) PW-1 was only 7-12 feet below the top of the coal seam in the eastern part of the ELW module area; and CIW-1 was located 18-20 feet below the top of the coal seam in the CRIP module area.

Phase II of the RM1 coring should be designed to complete the seven objectives. Bore holes should be drilled to further define the areal extent and location of cavities, evaluate outflow channels for both modules, and to further characterize the structural geology of the site.

INTRODUCTION

The Rocky Mountain 1 Underground Coal Gasification (UCG) test was conducted from November 16, 1987, through February 26, 1988, approximately one mile south of Hanna, Wyoming (Figure 1). The test consisted of dual-module operation to evaluate the Controlled Retracting Injection Point (CRIP) technology, the Extended Linked Well (ELW) technology, and the interaction of closely spaced modules operated simultaneously. As a result, two cavities were formed in the Hanna No. 1 coal seam. Both cavities were characterized and evaluated in the postburn coring program. Evaluating the different UCG configurations facilitates economic determinations and process development. Inspection and evaluation of affected materials may show any potential environmental problems and associated solutions. The geohydrologic structure of the coal and boundary strata served as the reactor vessel for the UCG process and was the major influence on the overall efficiency of the process. The postburn coring program provides critical data in determining the extent of cavity growth away from the process wells and aided in determining the efficiency and success of the coal gasification project.

The Hanna #1 coal seam was approximately 30 feet thick across the site and averaged a high volatile C bituminous ranking. At the test site, the depth to the top of the coal ranged from 340 to 370 feet, and the coal seam dipped 6-7° to the northeast. The coal seam is overlain by shales, siltstones, and sandstones. The coal seam was considered an aquifer; however, approximately 100 feet separated an overlying aquifer. The coal seam contained several shaley carbonaceous zones. The upper extent of the lower carbonaceous zone was approximately five feet above the bottom of the coal seam. This lower zone served to define the lower extent of the coal seam for the RM1 test.

The ELW module consisted of two vertical injection wells (VIW-1 and VIW-2) intersecting horizontal production well PW-1 (Figure 2). It operated for fifty-seven days and consumed 4430 tons (4,027,272 kg) of coal. The module produced 170 million scf (4.8 Mm³) of dry gas with an average heating value of 261 Btu/scf (9,730 kJ/m³).

Although the gas heating value was satisfactory, several problems were encountered with the module operation. Thermocouple data showed that gasification occurred in only the upper one-half of the coal seam. This reduced gasification efficiency and resource use. The water content in the ELW product gas was also excessive, twice the average content of the CRIP product gas. This resulted in lower gasification efficiency because heat was being used to turn the water to steam instead of being used for endothermic gasification reactions. The operation was terminated early because excessive oxygen was detected in the product gas.

The CRIP module consisted of a vertical production well (CPW-2), a horizontal production well (CPW-1), and a horizontal injection well (CIW-1). Well CPW-2 was used to ignite the coal and for initial production. Once CIW-1 and CPW-1 became pneumatically linked, production was shifted from CPW-2 to CPW-1. Figure 3 shows the CRIP configuration. A horizontal injection well was drilled to intersect a horizontal production well at some angle (13° in the RM1 test). Casing was set just

Figure 1. Location of RM1 Site

Figure 2. Location of Postburn Bore Holes, Thermocouple Wells, Process Wells, and Approximate Cavity Boundaries for the RM1 CRIP Module

Figure 3. Location of Postburn Bore Holes, Thermocouple Wells, Process Wells, and Approximate Cavity Boundaries for the RM1 CRIP Module

into the coal seam. A liner was inserted inside the casing and open borehole in the coal seam with an ignitor and burner inserted inside the liner.

Initially, the coal was ignited at the end of the liner, and the ignitor and burner was retracted back some distance from the end of the liner. Gasification continued with injection through the end of the liner until the gasification efficiency declined to the preset value. The gas heating value was used as a criteria in this case. At this point, the ignitor and burner were moved a specified distance from the active gasification zone. The burner was ignited, which burned off the liner and exposed unaltered coal to the UCG process. The ignitor and burner were then retracted back into the liner until the next CRIP maneuver.

The CRIP module operated very well. It burned for ninety-three days and consumed approximately 11,300 tons (10,300,000 kg) of coal. The module produced 447 million scf (12.7 Mm³) of dry gas with an average value of 287 Btu/scf (10,700 kJ/m³). Three successful CRIP maneuvers were performed at 60-ft intervals from the end of the CRIP liner. Shortly after the second CRIP maneuver, an unexplained 30-ft shortening of the CRIP liner occurred. This occurrence was termed auto-CRIP.

Seven objectives for the postburn evaluation were outlined in the Western Research Institute (WRI)-U.S. Department of Energy (DOE) Cooperative Agreement Annual Project Plan: (1) delineate the areal extent of the cavities, (2) identify the extent of roof collapse, (3) obtain samples of all major cavity rock types, (4) characterize the outflow channel and cavity stratigraphy, (5) characterize the area near CRIP points and injection points, (6) further define the structural geology of the site, and (7) identify the vertical positioning of the horizontal process wells within the coal seam.

The main goal of the project was to provide critical data for final evaluation of the test including process efficiency and environmental impacts. Postburn characterization of earlier tests provided valuable data on the relationships between process parameters, geohydrologic regime, and environmental impacts. The Rocky Mountain 1 test provides the first opportunity to perform such an evaluation using an excellent preburn data base. The postburn evaluation project was designed in two phases to meet the seven objectives outlined in the annual project plan. Phase I was completed during the summer of 1989, and the results are presented in this report.

TECHNICAL DISCUSSION

During phase I of the RM1 postburn coring program, nineteen bore holes were drilled in and around the gasification cavities. Another bore hole was drilled between process modules, adjacent to EMW-1. Nine bore holes (CPBC-1 through CPBC-9) were drilled in and around the CRIP cavity, and ten bore holes (EPBC-3 through EPBC-12) were drilled into the ELW cavity. The phase I ELW boreholes complemented two bore holes (EPBC-1 and EPBC-2) that were drilled and cored in June 1988. Of the twenty boreholes drilled in this program, thirteen were cored. Figures 2 and 3 show the locations of bore holes during phase I of this research. Hole

locations were initially chosen and later modified as described in subsequent parts of this report.

Seven bore holes were drilled to provide inexpensive information on cavity heights and locations so that appropriate core points and locations could be established for the remaining bore holes. The drilled holes included EPBC-7, EPBC-9, EPBC-11, and EPBC-12; and CPBC-1, CPBC-4, and CPBC-7. CPBC-4 and CPBC-7 showed no sign of heat alteration. This led to the adjustment of the locations for CPBC-5, CPBC-6, and CPBC-8. A total of 489 feet of core was cut from the remaining bore holes, allowing the recovery of 267.9 ft of material for testing and analysis. Through this approach, large amounts of useful information and samples of all cavity rock types were obtained at a substantial saving of cost and time. Information for each bore hole (i.e., core footage, roof and floor depths, and total depth) is summarized in Table 1.

Drilling was conducted with air using mist/foam injection. The foam additive was a biodegradable surfactant. Some coring was conducted using water alone to reduce groundwater production at the surface, and the remainder of the coring was conducted using air. Cores were collected with conventional coring techniques using a split core barrel and diamond core bits. The recovered core was measured, marked, described, packaged in plastic sleeving, and boxed to protect the core material. Unaltered material was not packaged in sleeving. Some of the cores were sent to the University of North Dakota for mineral evaluation and the remainder were stored by WRI. A description of the geologic log has been included in the Appendix.

Evaluation of the postburn drilling and coring was based on the drilling report submitted by the site geologist (Oliver 1989), information from the June 1988 cores, and pertinent process information. The site geologist based his interpretation on visual inspection of the cores and drill cuttings and on drill rig performance. Thermocouple data during UCG operations, injection point locations, and material consumption data were used in conjunction with the drilling and coring data in this evaluation. After completion of the drilling and coring operations, all holes were plugged with hole plug and Enviroseal (bentonite) slurry to the surface. All pits were then backfilled and the drilling sites reclaimed.

RESULTS

Phase 1 of the postburn evaluation project provided data and information sufficient to address, at least in part, all of the seven objectives outlined for the project. Of the nine bore holes near the CRIP module area, seven penetrated the gasification cavity. In the ELW module area, all the drill and core holes intersected the gasification cavity.

The first objective, to delineate the areal extent of the cavities, was partially accomplished. The ELW cavity was at least 170 ft in length, extending from EPBC-1 to EPBC-12 (Figure 4). The ELW cavity extended farther to the west than anticipated. Based on results from EPBC-10 and EPBC-11, EPBC-12 was drilled 20 feet farther west in an

Table 1. Summary of Postburn Bore Holes

Hole	Core Footage	Roof	Floor	Total Depth, ft	Comments
IMPBC-1	351-370	--	--	370	Unaltered
EPBC-1	360-392	367	370	392	
EPBC-2	340-393	356.7	375	393	
EPBC-3	260-380	?	374.6	380	Good roof
EPBC-4	349-380	363.1	373.1	380	
EPBC-5	330-340 350-370 390-400	332.0	374	400	Coal base
EPBC-6	340-385	341.0	379.0	385	Good roof
EPBC-7	Drilled	--	--	340	Not cored ^a
EPBC-8	350-376	?	374.0	376	Good core
EPBC-9	Drilled	--	--	340	Not cored ^a
EPBC-10	340-376	?	373.6	376	Good floor
EPBC-11	Drilled	345	375	380	
EPBC-12	Drilled	340	374	380	Blowing air out of VIW while drilling; voids
CPBC-1	Drilled	337	370	375	
CPBC-2	320-380	350	377?	380	Good roof
CPBC-3	326-371	?	369	371	Water from cavity wells
CPBC-4	Drilled	--	--	380	Unaltered
CPBC-5	320-349	?	--	349	Bit twisted off, no more core
CPBC-6	320-374	?	364.6	374	May have intersected wall
CPBC-7	Drilled	--	--	395	Unaltered
CPBC-8	320-378	?	370	378	Huge upper void
CPBC-9	340-376	?	370.3	376	

^a Not cored because excellant core was obtained from EPBC-8

Figure 4. Structural Cross Section, ELW Module

attempt to encounter the outflow channel. It too intersected the cavity. The width of the module was at least 30 feet, extending from EPBC-3 to EPBC-4 (Figure 5). The only area of the cavity that could be accurately defined was the back-burn area between VIW-1 and EPBC-1 because of the location and number of thermocouple wells and bore holes in that area.

The CRIP cavity was at least 160 ft in length, extending from CPBC-2 to CPBC-9 (Figure 6) and 40 ft in width, extending from CPBC-1 to CPBC-2 (Figure 7). The CRIP cavity appeared to have developed laterally around horizontal injection well, CIW-1. The northern extent of the cavity was well defined by the postburn wells and the thermocouple wells. The eastern extent was defined only by the last CRIP injection point. The extent of the cavity to the east and south was not well defined by thermocouple data or postburn wells. This should be defined in a later phase of the postburn investigation.

An approximate areal extent of the gasification cavities was calculated for each of the modules using material balance data, postburn drilling and coring data, and thermocouple data. In the ELW module, thermocouple wells were located near VIW-1. Data from these thermocouple wells and from the University of North Dakota core holes (EPBC-1 and EPBC-2) easily defines the eastern extent of the cavity. By assuming an average coal seam consumption (e.g., 12 ft for the coal seam east of VIW-2) and examining thermocouple responses from VIW-2, an average sweep width can be calculated. This was done for the width of the gasification cavity both east (50 ft) and west (43 ft) of VIW-2. Cavity extent to the east was defined by core hole EPBC-1. Cavity extent was partially defined by core hole EPBC-12 to the west. Based on drill rig performance and the presence of altered rocks, we interpreted that core hole EPBC-1 was inside the cavity but very near the cavity wall and that core hole EPBC-12 intersected the cavity. This limited the eastern wall of the cavity to within 1-2 ft of EPBC-1 and placed the western boundary of the cavity west of the EPBC-12 core hole. Because the cavity extended west of EPBC-12, it is likely that the sweep width was narrower west of VIW-2.

The CRIP cavity was more difficult to delineate because of the uncertainty of the CRIP injection locations and the limited number of thermocouple wells and postburn boreholes. The documented location of the end of the CRIP liner (Stearns-Roger 1989) did not account for any deviation in the drilling path. Without consideration for well deviation, the end of the CRIP liner (initial injection point) was approximately 15 ft west of CPW-2. Thermocouple responses in TC-7 suggested that the end of the liner was located more than 35 ft west of CPW-2. This discrepancy probably resulted from deviations in the well drilling.

In general, the locations of the postburn drill and core holes were based on the premise that RM1 CRIP cavity geometry was similar to the CRIP cavity produced in the Partial Seam CRIP (PSC) test conducted near Centralia, Washington. The Centralia cavity was excavated and extensively evaluated in 1986 (Oliver 1987; Cena et al. 1987). The RM1 CRIP cavity development appeared to have deviated from that observed in the PSC cavity. In the PSC cavity, coal was completely consumed between

Figure 5. Structural Profile Across ELW Module

Figure 6. Structural Cross Section, CRIP Module

Figure 7. Structural Profile Across CRIP Module

the horizontal injection and production wells beyond and some distance back from the injection point. If this had been the case with the RM1 CRIP cavity, borehole CPBC-7 should have detected part of the gasification cavity. However, we should note that the RM1 CRIP module operated much longer (93 days versus 16 days) and consumed more coal (11,000 tons versus 1,327 tons) than the PSC test.

Material balance data show that the total areal extent of the CRIP cavity is 14,452 ft² (1,343 m²), assuming 18 ft (5.5 m) average vertical coal consumption and 11,277 ton (10,251,818 kg) consumed. The areal extents for the individual injection points were 6509 ft² (605 m²) for the first injection point, 3565 ft² (331 m²) for the second injection point, 3205 ft² (298 m²) for the third injection point, and 1097 ft² (102 m²) for the fourth injection point. The calculation for the third injection point included the coal consumed after the auto-CRIP.

Both cavities were probably larger than the specified dimensions (Figures 2 and 3). In addition, the CRIP cavity was probably located 5-10 ft farther to the south than we previously anticipated. This was because CPBC-4 and CPBC-7 showed no indication of heat alteration, and CPBC-6 shows only minimal heat alteration (Figure 7). These facts also imply that the horizontal injection well (CIW-1) was located 5-10 ft farther to the south than originally estimated. The exact dimensions and spatial location of the modules must be addressed further in phase 2 investigations.

The second objective, identify the extent of roof collapse, can be adequately met from phase 1 results. Roof collapse associated with the ELW module was minimal. The maximum amount was 25 ft in the area of EPBC-5 and EPBC-6. The amount of roof collapse was greater in this area than in the rest of the module, probably due to the presence of small faults (Figure 4). Areas of increased roof collapse along faults were present in the Hanna IV cavities (Oliver et al. 1986). Roof collapse in the ELW module was contained within the lower overburden unit (unit A) claystones and siltstones, thereby, preventing any interconnection of the main water-bearing units at the site, the Hanna No. 1 coal seam and Unit C (Mason et al. 1987).

A somewhat greater amount of roof collapse occurred in the CRIP module. The greatest amount of roof collapse was 35 ft in the area of CPBC-8 and CPBC-9 (Figure 6). The large amount of slightly altered overburden present suggested that a large percentage of the collapse occurred after test shutdown. Although it was somewhat greater than what occurred in the ELW module, roof collapse in the CRIP module was also contained within unit A.

The third objective, obtain samples of all major cavity rock types, was satisfied. Excellent roof transition zones, from unaltered to highly altered, were recovered in cores from EPBC-3, EPBC-6, EPBC-8, and CPBC-2. Floor transitions from slag to char to unaltered coal were recovered in cores from EPBC-8 to EPBC-10. The wall zone was most likely recovered in core from CPBC-6 (Table 1). These cores provided excellent material for detailed analysis and evaluation to determine temperature regimes, metamorphic sequences, and environmental contaminant processes.

The fourth objective, to characterize the outflow channel and cavity stratigraphy, was only partly met by phase 1 activities. Because the ELW cavity extended much farther to the west than anticipated, no bore holes penetrated the outflow channel. EPBC-12 was moved 20 ft farther to the west than originally planned in an effort to encounter the outflow channel. However, cavity is still present at that location, approximately 60 ft west of VIW-2. The evaluation of outflow channels should be included as part of phase 2 investigations.

Cavity stratigraphy was identified by phase 1 coring. In general, from top to bottom, the sequence included void, a thin zone of slightly altered overburden, a thin slag layer, a thin char layer, and unaltered coal. The altered overburden contains intermittent voids and widely varying colors and oxidation conditions. The void beneath the slag layer is generally 3-4 ft thick, and the char zone was generally less than 6 inches thick.

The fifth objective, characterize the area near ignition points, was met by phase 1 drilling and coring. Core holes CPBC-5, CPBC-8, and CPBC-9 were located near CRIP points, as indicated on a map provided by Lawrence Livermore National Laboratory. All of these bore holes exhibited characteristics not significantly different than other bore holes that penetrated into the cavities.

The sixth objective, further define the structural geology, was partially met by phase 1 results. Because of various hole problems (i.e., bentonitic zones, caving cavity material, and char fines plugging bits), it was very difficult to advance the bore hole to the bottom of the coal. This was only accomplished in EPBC-5. This hole, however, provided a critical data point to further define the structural geometry in the area of the ELW module (Figure 4).

A structural deformation (fault zone or fold) is present between VIW-2 and VIW-1 that downsteps to the east. Total displacement across the zone is approximately 7 to 8 ft. This structural deformation was shown as two faults on the cross section in Figure 4; however, more displacement may be present. This structural deformation was probably related to the structural anomaly that was detected in the preburn characterization; it trends north-northwest between CH-6 and CH-7. This trend will place faults or folds east of the CRIP module, and they are, in fact, not indicated by structural analysis of the CRIP module area (Figure 5).

The effect of the structural deformation was that the horizontal production well (PW-1) was higher in the coal seam in the eastern one-half of the module. This resulted in a limited use of the coal seam during gasification. The structural deformity was the most likely cause for reduced gasification efficiency. Less coal was consumed before roof materials were exposed to the gasification environment. This resulted in more heat loss to the overburden and a reduction of gasification efficiency. In addition, fractures associated with the fold or faults can promote overburden collapse for a further reduction in gasification efficiency. These fractures can also act as conduits for water flow into the gasification environment. Vaporization and heating the water and steam can reduce the energy available for the preferred endothermic

gasification reactions. This may have been the reason that the water content of the product gas from the ELW module was significantly higher than the water content of the product gas from the CRIP module.

The seventh and final objective, identify the vertical positioning of the horizontal process wells within the coal seam, was met by phase 1 results. Excavation results from the UCG project in Centralia, Washington, showed that a UCG cavity will develop upward from the level of the horizontal process wells and will not extend significantly below that level (Oliver 1987; Cena et al. 1987). Based on this, the vertical positioning of the horizontal process wells at the RM1 site was determined by identifying the lowest extent of the cavities.

For the ELW module (Figure 4), PW-1 was located 7-8 ft below the top of the coal seam in the area of EPBC-2, 10-12 ft below the top of the seam in the area of EPBC-5, and nearly 20 ft below the top of the seam in the area of EPBC-12. For the CRIP module (Figure 5), CIW-1 was located 18-20 ft below the top of the coal seam, allowing for more effective recovery of the coal seam.

Additionally, the interaction of modules was evaluated by placing a bore hole between EMW-1 and EMW-2. This bore hole (IMPBC-1) showed no heat alteration of material, even though EMW-1 was leaking product gases during the test. Tracer tests showed that the modules were hydraulically connected (Boysen et al. 1988). However, temperatures between modules were not high enough to cause visual alteration of the coal. This generally requires temperatures greater than 200°C (328°F).

CONCLUSIONS

This investigation showed that the ELW module consumed little coal to the east of the injection well, VIW-1. The cavity did extend farther to the west than expected. A structural deformation was detected between VIW-1 and VIW-2 that may have been responsible for a lower operating efficiency than expected. This structural deformation produced a down-dropping of the coal seam to the east and caused the production well to be situated higher in the seam. The lower vertical extent of the ELW cavity ranged from 7 to 20 ft below the top of the coal seam. Roof rock was exposed to the gasification environment more rapidly in the area to the east of the deformation causing early heat losses and reduced gasification efficiency. The deformation may be the major reason for more water production in the ELW module than in the CRIP module.

Phase I results suggest that the CRIP gasification cavity 5-10 ft farther south than previously anticipated and formed around the injection well. The vertical location of the injection well (18-20 ft below the top of the coal seam) caused good resource recovery during gasification. No structural abnormalities were detected.

Phase I of the RM1 postburn evaluation produced excellent results and met most of the objectives as outlined in the annual project plan: (1) the ELW cavity extended farther to the west and the CRIP cavity was located 5-10 ft farther to the south than anticipated; (2) roof collapse

was contained within unit A in both modules; (3) samples of all major rock types were recovered; (4) insufficient data was obtained to characterize the outflow channels, but cavity stratigraphy was well defined; (5) bore holes near the CRIP points and ignition points did not exhibit characteristics significantly different from other bore holes in the cavities; (6) a fault zone was detected between VIW-1 and VIW-2 that stepped down to the east; and (7) PW-1 was only 7-12 ft below the top of the coal seam in the eastern part of the ELW module, and CIW-1 was located 18-20 feet below the top of the coal seam in the CRIP module. Phase II should concentrate on defining the lateral and western extent of the ELW cavity and the southern and eastern extent of the CRIP cavity.

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DISCLAIMER

Mention of specific brand names or models of equipment is for information only and does not imply endorsement of any particular brand.

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APPENDIX A

Description of Geologic Log

Bore number EPBC-1 was located 12 ft east of VIW-1 and was taken on June 4, 1988. The hole had a total depth of 392 ft with a 2 inch core started at 360 ft. From 360-361 ft the core showed slightly altered overburden with variable coloring and relict bedding. This was followed by 3 ft of black, vesicular, glassy, altered overburden from 361-363 ft. From 363-365.2 ft, the core consisted of black altered overburden rubble, vesicular toward the base. The core was lost from 365.2-367 ft before encountering a void from 367-370 ft. The remainder of the hole consisted of unaltered coal from 370-392 ft, with core loss from 375-384 ft and from 388.8 to 392 ft.

Bore number EPBC-2 was located three ft southwest of VIW-1 and was taken on June 7, 1988. The hole had a total depth of 393 ft with a 2-inch core begun at 340 ft. The interval from 340-354.5 ft consisted of unaltered overburden followed by altered, in place overburden from 354.5-356.7 ft. Voids and core losses stretch from 356.7-375 ft. Other indicators showed altered overburden from 363-368 ft and slag from 371-373 ft. Core collected from lower strata showed altered orange and black overburden that was locally vesicular from 375-376 ft. This interval may have contained some slag. From 376-376.3 the core showed char, followed by unaltered coal from 376.3-391.2 ft. Core was lost from 391.2-393 ft, but the lithologic profile shows unaltered coal in this interval.

Bore number EPBC-3 was located 15 ft north, 7 ft west of VIW-1 and was taken on August 2, 1989. The hole had a total depth of 380 ft with a 2.5-inch core begun at 360 ft. The core indicated red and black altered overburden rubble from 360-361.1 ft. This was followed by orange and black banded altered overburden with some vesicles and was more orange toward the base from 361.1-364.8 ft. Core was lost from the 364.8-365 ft interval but indicated brown, orange and grey altered overburden from 365-366.2 ft. A void encountered from 366.2-367.4 ft was underlain by blue-grey, vesicular, altered overburden from 367.4-370 ft. Beneath this interval was two ft of red and black, vesicular, altered overburden from 370-372 ft and then yellow, brown and green slag from 372-372.9 ft. A second void from 372.9-374.6 ft was followed by black, slightly altered coal from 374.6-379 ft. The core showed black clay from 379-379.5 ft, and the last 0.5 ft of core (379.5-380 ft) was lost.

Bore number EPBC-4 was located 15 ft south, 7 ft west of VIW-1 and was taken on August 3, 1989. The hole had total a depth of 380 ft with a 2.5-inch core begun at 349 ft. The interval from 349-356.7 ft consisted of unaltered, grey, hard siltstone and was followed by a layer of dark grey claystone, slightly heat altered, containing some red and pink bands. This layer extended from 356.7-362.5 ft. From 362.5-363.1 ft, the core showed grey and lavender, altered overburden rubble. This was interpreted as the roof transition. A void was encountered between 363.1 and 364.3 ft followed by a layer of brown, orange, and yellow slag from 364.3-365 ft. Beneath this were several thin (<1 ft) layers of slag and altered strata. The interval from 365-366 ft consisted of a highly vesicular, brown and grey, altered rock rubble. This was underlain by tan and lavender, vesicular slag from 366-366.3 ft, a yellow-brown vesicular slag from 366.3-366.8 ft, and a dark grey, altered rock from 366.8-366.9 ft. No core was recovered from 366.9-370 ft, but the existence of slag was inferred from the overlying and underlying strata. From 370-370.6 ft, the core showed brown, orange, and black vesicular

slag followed by a void from 370.6-373.1 ft. The interval from 373.1-379.8 ft consisted of black, silty, unaltered coal, with the upper 2 ft being rubble. The final section of core from 379.8-380 ft was not recovered.

Bore number EPBC-5 was located 40 ft west of VIW-1 and was drilled on August 11, 1989. It had a total depth of 400 ft with a 2.5-inch core started at 330 ft. The initial section of core, from 330-330.6 ft, was lost. The first section recovered showed gray, unaltered siltstone with contorted bedding from 330.6-332 ft followed by a void from 332-333.6 ft. The core indicated slightly altered gray, grading to dark gray, siltstone from 333.6-336.3 ft followed by black, dark gray, and purple, altered overburden without vesicles from 336.3-337 ft. The interval from 337-338.1 ft consisted of gray with red altered overburden. This was underlain by several thin (<1 ft) layers of altered overburden of varying color. It was gray-green from 338.1-338.8 ft, red and gray from 338.8-339.2 ft, olive-green from 339.2-339.7 ft, and green and purple from 339.7-340 ft. The hole was drilled from 340-360 ft. The existence of altered overburden was inferred in this interval from the overlying and underlying strata. The next coring interval indicates void space from 360-363.2 ft followed by four layers of altered overburden. Green, altered overburden from 363.2-363.6 ft, orange-red from 363.6-365 ft, green and black from 365-365.3 ft, and red from 365.3-366 ft. This altered overburden was above two ft of buff and black slag that became darker toward the base and contained vugs (366-368 ft). A void was encountered from 368-374 ft. The hole was drilled from 370-390 ft. A coal layer was inferred from 374-390 ft from the behavior of the drilling operation. Coring from 390-400 ft showed unaltered coal from 390-392.3 ft underlain by medium gray, fine-grained sandstone with contorted bedding near the base from 392.3 to 400 ft.

Bore number EPBC-6 was located 40 ft west and 10 ft north of VIW-1 and was started on August 5, 1989. The hole had a total depth of 385 ft with a 2.5-inch core started at 340 ft. From 340-341 ft, the core showed slightly altered overburden followed by brown and green-gray, altered overburden from 341-341.8 ft. Void space was encountered from 341.8-345 ft followed by gray and red, baked, nonvesicular altered overburden (345-347.4 ft) and then another void from 347.4-350 ft. A layer of red and black, altered overburden rubble from 350-351 ft was followed by brown and gray banded, altered overburden with some vesicles from 351-352.7 ft and then 0.3 ft of core loss from 352.7-353 ft. From 353-354.5 ft, the core showed red and black, altered overburden rubble, becoming brown at the bottom. The interval from 354.5-354.7 ft was lost. A layer of gray and red, altered overburden extended from 354.7-355.4 ft, followed by mostly intact, brown, altered overburden with gray bands and some small vesicles from 355.4-358.4 ft. The interval from 358.4-370.5 ft was made of several layers of altered overburden of varying characteristics. Brown, red, and orange banded, altered overburden extended from 358.4-361 ft, followed by mostly red, altered overburden from 361-362.1 ft; brown-orange and red, vesicular, altered overburden from 362.1-363 ft; purple, black, green, and red altered overburden with small vesicles from 363-364.5 ft; red and black, altered overburden with small vesicles from 364.5-369 ft; and tan and orange, altered overburden with large vugs from 369-370.5 ft. Core was lost from 370.5-372 ft. Two small voids (372-373 ft and 373.5-375 ft) were separated by a thin layer of orange, altered

overburden rubble from 373-373.5 ft. The core showed gray, white, and green, altered overburden with large vugs from 375-375.5 ft; brown and red, altered overburden rubble between 375.5-376 ft; and brown-green slag with large vugs and pieces of unaltered coal from 376-377 ft. A void was encountered between 377 ft and 379 ft. This void was underlain by black, unaltered coal from 379-385 ft with core loss between 380-381 ft and 382.5-385 ft.

Well number EPBC-7 was located 10 ft south and 40 ft west of VIW-1 and was started on July 23, 1989. The hole had a total depth of 360 ft and showed dark gray, hard, unaltered siltstone and claystone from 345-355 ft. No core was taken because excellent cores were retrieved from EPBC-5 and EPBC-6.

Bore number EPBC-8 was located 5 ft north and 80 ft west of VIW-1 and was started on August 9, 1989. The hole had a total depth of 376 ft with a 2.5-inch core begun at 350 ft. The first twelve ft of core showed eleven relatively thin layers of altered overburden of varying colors and textures. Olive, vesicular, altered overburden extended from 351-351.8 ft. This was underlain by black, red, and green, altered overburden rubble (351.8-352.2 ft); gray-purple, vesicular, altered overburden (352.2-353.4 ft); dark gray-green, vesicular, altered overburden (353.4-354.5 ft); gray-green with orange, altered overburden with larger vesicles (354.5-355.2 ft); and gray, nonvesicular, altered overburden (355.2-355 ft). Core loss from 355.5-356 ft separated the above layer from a layer of mostly black, vesicular, altered overburden (356-357.8 ft). This was underlain by altered overburden with red and black bands and small vesicles (357.8-359.5 ft); vesicular, altered overburden with red and black bands (359.5-361 ft); brown with gray, altered overburden with vugs and vesicles (361-362.2 ft); and gray-brown, vesicular, altered overburden (362.2-363.3 ft). Void space extended from 363.3 ft to 368 ft. The core showed pink, purple, and black, altered overburden rubble from 368-368.6 ft followed by green and buff slag with vugs and coal chunks (368.6-370 ft). Four ft of void from 370-374 ft was underlain by char (374-374.2 ft) and slightly heat-altered coal rubble from 374.2-374.6 ft.

Hole number EPBC-9 was located 5 ft south and 80 ft west of VIW-1 and was started on July 23, 1989. The hole had a total depth of 340 ft and showed dark gray, hard, unaltered siltstone and claystone from 330-340 ft. No core was taken because excellent cores were retrieved from EPBC-8.

Bore number EPBC-10 was located 40 ft west of VIW-2 and was started on August 10, 1989. The hole had a total depth of 376 ft with a 2.5-inch core beginning at 340 ft. The initial 4.2 ft of core (340-344.2 ft) was lost. The first recovered core showed gray and black, slightly altered overburden from 344.2-346 ft. This was followed by another 2.3 ft of core loss from 346-348.3 ft. Following this, the core indicated purple-gray, altered overburden (348.3-350 ft), followed by green, vesicular, altered overburden with relict bedding, and black and red, altered overburden becoming green toward the base. Another interval of core loss (354.5-356 ft) preceded 4.5 ft of green with black, altered overburden (356-360.5 ft). This layer contained vugs and vesicles, with larger vugs and darker material toward the base. The 0.5 ft of core from 360.5-

361 ft was lost. From 361-364 ft, the core showed green and gray, banded, altered overburden with vugs and vesicles overlying a layer of purple-green, altered overburden with vugs and vesicles (364-367 ft) and a layer of glassy, purple and brown, altered overburden with vugs and relict bedding at the top (367-369.2 ft). Core loss from 369.2-373.6 ft was followed by char and altered coal from 373.6-375 ft. The final 1.0-ft section of core from 375-376 ft was lost.

Hole number EPBC-11 was located 5 ft north and 40 ft west of VIW-2 and was drilled on July 25, 1989. The hole had a total depth of 380 ft and showed black, red, and some dark brown, altered overburden from 345-360 ft, followed by heat-altered coal from 360-365 ft. A void extended from 365-375 ft and then unaltered coal from 375-380 ft. This hole was not cored because excellent cores were retrieved from EPBC-8.

Hole number EPBC-12 was located 60 ft west of VIW-2 and was started on August 11, 1989. It had a total depth of 380 ft. The drilling showed gray, hard, unaltered siltstone from 330-339 ft followed by void space from 339-345 ft. Below this void was altered overburden from 345-368 ft, a second void from 368-374 ft, and unaltered coal from 374-380 ft.

Hole number CPBC-1 was located 20 ft north of CPW-2 and is dated August 10, 1989. It had a total depth of 375 ft with no core taken. The drilling showed gray, unaltered claystone from 315-337 ft followed by void space from 337-340 ft and then altered overburden from 340-342 ft. A second void from 342-350 ft was underlain by altered overburden from 350-362 ft, void space from 362-365 ft, altered overburden from 365-370 ft, and unaltered coal from 370-375 ft.

Bore number CPBC-2 was located 20 ft south of VIW-2 and is dated August 9, 1989. The hole had a total depth of 380 ft with a 3-inch core started at 320 ft. The core showed gray, unaltered claystone from 315-350 ft. Some of this material appeared slightly altered. From 350-350.4 ft, the core indicated brown-green, altered overburden followed by dark gray to black, altered overburden with relict bedding (350.4-352.4 ft); then purple, vesicular, altered overburden with green and black bands (352.4-352.7 ft); dark gray to black, altered overburden from 352.7-353.1 ft; and glassy, purple, green, and white, altered overburden with some dark material and relict bedding from 353.1-355.7 ft. A second void (355.7-361 ft) was followed by purple, green, and black, vesicular, altered overburden (361-366 ft) and buff slag with some vesicles from 366-369 ft. Another void from 369-372 ft was underlain by what may be coal from 372-380 ft.

Bore number CPBC-3 was located 55 ft west of CPW-2 and is dated August 2, 1989. The hole had a total depth of 371 ft with a 3-inch core started at 326 ft. Drilling showed void space from 320-321 ft, slightly altered overburden from 321-324 ft, and another void from 324-326 ft. The core started at 326 ft and indicated a layer of black, sandy to silty, baked overburden with a temperature of about 90°F (32°C) from 326-327.1 ft, followed by a zone of crumbly material from 327.1-332.5 ft. Core loss was interpreted not as a void but as a crumbled zone not recovered by coring. From 332.5-335.3 ft, the core showed black, very crumbly siltstone with some heat alteration overlying black, hard claystone not visibly heat-altered from 335.5-336 ft. Core loss from

336-340 ft interrupted the sequence. The next recovered core indicated black, brown, and lavender-gray, altered overburden rubble (340-341 ft), followed by solid, lavender-gray, altered overburden with relict bedding (341-342 ft); green-gray, somewhat rubblized, altered overburden with relict bedding (342-343 ft); and dark green-gray, vesicular, altered overburden with relict bedding (343-344.6 ft). The sequence of altered overburden continued with altered overburden from 344.6-345.2 ft, green-gray with black, altered overburden with relict bedding and some vesicles (345.2-345.8 ft); black with red, altered overburden rubble with some vesicles (345.8-346.6 ft); green-gray, altered overburden with some vesicles and relict bedding (346.6-347.6 ft); and vesicular, lavender and gray, altered overburden from 347.6-348.3 ft. Another interval of core loss extended from 348.3-352.5 ft. From 352.5-356.5 ft, the core showed dark gray and lavender-gray, altered overburden that has some vesicles and is mostly rubble. Core loss from 356.5-359 ft separated the above strata from gray, vesicular, altered overburden (359-360.8 ft). A void from 360.8-364.9 ft was underlain by yellow, black, and orange, vesicular slag (364.9-366 ft); another void (366-369 ft); and black, unaltered coal, probably the floor, from 369-369.5 ft. The last 0.5 ft of core was lost (369.5-370 ft).

Hole number CPBC-4 was located 27 ft north and 55 ft west of CPW-2 and is dated July 27, 1989. The hole had a total depth of 380 ft with no core taken. Drilling showed dark gray, hard, unaltered siltstone and claystone from 345-355 ft. This was followed by black, unaltered coal from 355-380 ft.

Bore number CPBC-5 was located 55 ft west and 12 ft south of CPW-2 and is dated August 3, 1989. The hole had a total depth of 349 ft with a 3-inch core started at 320 ft. The core showed gray to dark gray, slightly heat-altered siltstone from 320-322.6 ft, followed by a void from 322.6-323.6 ft, and another siltstone layer. This one was dark gray, heat-altered and rubble from 323.6-325 ft. Core loss from 325-330 ft preceded several layers of siltstone and altered overburden. From 335-336.5 ft, the core showed dark gray, slightly heat-altered siltstone. The layer from 336.5-337 ft consisted of lavender-gray, altered overburden rubble with small vesicles. This was underlain by red and black, altered overburden rubble with small vesicles (337-337.8 ft) and gray with lavender, altered overburden (337.8-338.5 ft). Voids and core loss extended from 338.5-349 ft.

Bore number CPBC-6 was located 55 ft west and 15 ft north of CPW-2 and is dated August 5, 1989. The hole had a total depth of 374 ft with a 3-inch core begun at 320 ft. The core showed gray to dark gray, possibly slightly heat-altered siltstone from 320-321.7 ft. Core loss extended from 321.7-330 ft. The layer from 330-334.2 ft consisted of dark gray to black, possibly heat-altered claystone and siltstone rubble with some black, mucky material. Dark gray, unaltered siltstone extended from 334.2-341.9 ft. This was underlain by dark brown-gray, unaltered claystone (341.9-345 ft). Core loss from 345-352 ft was followed by void space from 352-364 ft. A layer of baked, altered overburden with some vesicles from 364-364.6 was the only obviously heat-altered material in this core. Below this was unaltered, silty coal from 364.6-374 ft. This became very silty from 369.5-374 ft.

Hole number CPBC-7 was located 15 ft north and 120 ft west of CPW-2 and is dated August 5, 1989. The hole had a total depth of 395 ft with no core taken. The drilling showed dark gray, hard, unaltered siltstone and claystone from 345-358 ft. Beneath this layer was black, unaltered coal from 358-385 ft. From 385-395 ft, the core indicated gray, unaltered siltstone.

Bore number CPBC-8 was located 120 ft south and 5 ft west of CPW-2 and was completed on August 8, 1989. The hole had a total depth of 378 ft with a 3-inch core started at 320 ft. Drilling showed slightly altered overburden from 315-319 ft. Coring began at 320 ft and showed void space extending from 319-340 ft. From 340-351 ft, the core showed additional voids and rubble. The interval from 351-355 ft consisted of a layer of gray and black, slightly heat-altered overburden rubble, perhaps consisting of late roof fall. This was followed by purple-gray and black, slightly altered overburden rubble with some vesicles (355-355.4 ft); gray and black, possibly heat-altered, overburden rubble (355.4-356 ft); black and dark gray, nonvesicular, altered, overburden rubble (356-357 ft); and purple-gray, altered overburden with some black pieces (357-359 ft). The purple-gray material had some small vesicles. Dark gray-black, nonvesicular, altered overburden from 359-360.5 ft preceded core loss from 360.5-362 ft. Purple, gray, and black, altered overburden with vugs and vesicles (362-365.9 ft) was followed by glassy, buff, and tan slag with blocks of unaltered coal (365.9-366.5 ft); void space (366.5-370 ft); and very silty, unaltered coal from 370-377.7 ft. The final 0.3 ft of core (377.7-378 ft) was lost.

Bore number CPBC-9 was located 150 ft west of CPW-2 and was completed on August 9, 1989. The hole had a total depth of 376 ft with a 3-inch core started at 340 ft. The core showed intermittent rubble and voids from 340-351.1 ft. This was followed by several layers of altered overburden. Dark gray, nonvesicular, altered overburden (351.5-352.4 ft) was underlain by dark gray, nonvesicular altered overburden with relict bedding (352.4-353.8 ft); purple-gray, altered overburden with some small vesicles (353.8-355.7 ft); green and gray, vesicular, altered overburden (355.7-358.1 ft); purple and gray, altered overburden with small vesicles (358.1-360.5 ft); and black and gray, vesicular, altered overburden with relict bedding from 360.5-361.3 ft. Void space from 361.3-363.8 ft was followed by green and buff slag with vugs from 363.8-364 ft. Core loss from 364-366.3 ft separated the above strata from buff and brown slag with vugs (366.3-370 ft); black, altered rock with small vesicles (370.1-370.3 ft); and black, unaltered coal from 370.3-376 ft. The coal became very silty from 374-376 ft.

Bore number IMPBC-1 was located between EMW-1 and EMW-2 and was completed on July 25, 1989. The hole had a total depth of 370 ft with a 2.5-inch core started at 351.5 ft. The core showed unaltered strata from 351.5-357.5 ft followed by black, broken coal from 357.5-358.3 ft. Core loss from 358.3-361.1 ft preceded a layer of black, unaltered coal from 361.1-369.2 ft. The final 0.8 ft of core (369.2-370 ft) was lost.

APPENDIX B

Thermocouple, TDR, and Material Consumption Data

Table 1B. Operations Summary, Rocky Mountain 1 UCG Project

	Total Time, days	Operation Days	Coal Consumed, ton	Corrected Coal Consumed ^a , ton	Heat Loss In Situ, %	Water Influx, gal/min	Average Gas Heating Value, Btu/scf
ELW Total	57.3	4.4-61.8	4,007	4,430	14.2	4.9	261
VIW-1	47.0	4.4-51.4	3,735	4,090	13.5	5.03	265 ^b
VIW-2	10.2	51.6-61.8	260	325	23.5	4.03	203
CRIP Total	93.0	9.7-102.7	9,877	11,277	9.6	3.16	287
1st Cavity	43.7	9.7-53.4	4,098	5,079	6.9	2.90	298
2nd Cavity	19.9	53.5-73.4	2,377	2,782	12.2	4.52	275
3rd Cavity	20.0	73.4-93.4	2,514	2,501	8.2	2.39	295 ^c
4th Cavity	9.3	93.4-102.7	880	856	18.8	3.03	247

^a Corrected for gas loss

^b Average includes initial air injection period, average for oxygen injection is 275 Btu/scf

^c Includes auto-CRIP

Table 2B. Summary of Thermocouple Responses

Well	Location	Initial Response	Failure	Notes
<u>ELW</u>				
VIW-2	tube tip	14.5	50.5	
	-10 ft	14.5	41.7	
	- 5 ft	14.5	51.9	
TC-11	-10 ft	27.0	27.0	Thermocouples burnt off at same time
	- 5 ft	21.0	27.0	
TC-12	-10 ft	42	NF	
	- 5 ft	60	NF	
	0	36	NF	
TC-13	-10 ft	10	10.5	Thermocouples burnt off at same time
	- 5 ft	6.8	11.1	
	0	5.5	11.5	
<u>CRIP</u>				
CIW-1	- 3 ft liner	8.6	11.0	
	- 25 ft liner	8.5	17.7	
	- 55 ft liner	8.6	17.7	
	- 85 ft liner	8.7	70.0	
	-115 ft liner	8.7	73.4	
	-145 ft liner	12.2	82	
	-175 ft liner	12.2	93.4	
	-205 ft liner	12.2	NF	
	igniter tip	52.3	73.3	
	igniter tube-13 ft	--	31.7	
CPW-2	dip tube	6.4	43.7	
	dip tube-26 ft	6.4	6.4	
TC-1	-20	69.8	69.9	
	-15	30.0	73.2	
	-10	30.0	76.7	
	- 5	35.0	58.2	
	0	35.0	77.8	
TC-2	-20	80.0	NF	Very minor responses
	-15	65.0	NF	
	- 0	50.0	NF	
TC-3	-15	38.3	38.4	
	-10	37.6	38.4	
	- 5	38.6	43.8	
	- 0	39.3	39.3	

Table 2B. Summary of Thermocouple Responses (Continued)

Well	Location	Initial Response	Failure	Notes
TC-4	-20	45.0	59.0	
	-15	30.0	59.0	
	-10	25.0	65.4	
	- 5	30.0	66.0	
	- 0	30.0	69.7	
TC-7	-15	10.5	20.5	
	-10	16.5	20.6	
	- 5	20.3	59.2	
	- 0	20.8	59.2	
TC-9	-20	76.0	76.1	
	-15	22.0	76.1	
	-10	22.0	76.5	
	- 5	22.0	85.5	
	0	22.0	89.2	

Table 3B. Time Domain Reflectrometry Data for the RM1 Project

Time, days	Length, ft	Rate, ft/day	Time, days	Length, ft	Rate, ft/day
CRIP			VIW-1		
0.0	837.00		0.0	421.00	
24.000	833.00		24.000	423.00	
26.448	829.00		24.354	383.00	
28.125	823.00		28.604	379.00	
30.417	821.00		30.583	375.00	
32.563	265.00		32.542	248.00	
32.688	823.00		32.708	250.00	
33.417	826.00		33.458	244.00	
35.417	826.00		35.438	250.00	
52.313	816.00	0.4	52.323	239.00	
53.490	795.00		53.493	233.00	
57.333	795.00		57.354	228.00	
72.417	770.00	1.3	72.438	234.00	
73.438	735.00		78.438	234.00	
78.417	706.00		79.438	234.00	
79.417	704.00		93.587	231.00	
80.587	704.00		98.369	231.00	
81.438	704.00		99.500	231.00	
82.583	698.00		100.50	231.00	3.5
83.625	698.00				
84.719	702.00				
85.465	704.00				
86.354	698.00				
87.479	698.00				
91.375	694.00				
93.375	686.00	2.45			
93.396	660.00				
93.479	657.00				
94.354	659.00				
94.719	659.00				
95.719	661.00				
96.719	663.00				
98.368	655.00				
99.500	655.00				
100.50	655.00	0.7			

END

**DATE
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12/13/191