IMPACT ANALYSIS OF OSM REGULATIONS ON HIGHWALL MINING SYSTEMS

Final Report
Contractor—Skelly and Loy

September 1980

Contract No. U.S.D.O.E. AC01-79ET11268

U. S. Department of Energy
Assistant Secretary for Fossil Energy
Office of Coal Mining
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FINAL REPORT

U.S. DOE Contract No. DE-AC01-79ET 11268
Task Order Number 023

Prepared for:
U.S. DEPARTMENT OF ENERGY
Washington, D.C. 20545

September 1980

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EXECUTIVE SUMMARY
EXECUTIVE SUMMARY

The U.S. Department of Energy has initiated this study to assess the potential effects of the federal surface mining regulations on the auger mining industry, and to evaluate techniques that may minimize the impact of these regulations.

A review of the state of the auger-mining industry indicates that auger production has been declining over the past decade for several reasons. The enactment of reclamation laws by many states in the late 1960's and early 1970's caused augering costs to increase and restricted auger use in many situations. The increased preference for maximized recovery by mineral rights owners has also limited the use of augering. Prior to the enactment of the federal surface mining regulations, the average auger mining recovery rate (35%) was well below the recovery achieved by underground (50%) and surface (90%) mining methods. However, the operating costs and production per man-day of augering are favorable compared to the cost and the productivity levels of underground or surface techniques.

The establishment of the federal surface mining performance standards has placed additional restraints on auger mining. The federal regulations impose barrier pillar and hole sealing requirements on augering, stipulate time frames for hole sealing and discharge treatment, and prohibit auger mining under certain conditions. Barrier pillar requirements between groups of auger holes and between auger holes and underground workings.
decrease the augerable reserve base on a site by a minimum of ten (10) percent. Barrier requirements may also reduce productivity levels due to increased delay and scheduling problems. Federal auger hole sealing requirements are more stringent than most state regulations, and consequently have increased the cost of augering in almost all auger mining areas. The availability of impervious materials on the site and the extent of backfilling required to form a "water-tight" seal may have the greatest effect on auger hole reclamation costs.

The federal regulations require auger mining to be prohibited if adverse water quality impacts cannot be prevented; if stability of sealings cannot be achieved; if subsidence resulting from augering may damage powerlines, pipelines, buildings, or other facilities; or if coal reserve recovery is not maximized by augering. As a result, all up dip augering may be restricted on the grounds that seal stability cannot be maintained for long time periods if water pressure builds behind the plug. Also, since traditional augering techniques have a lower recovery rate than surface or underground methods, augering may be prohibited in many situations by the stipulation that maximum resource recovery will not be achieved.

Auger mining in the steep slope regions of Appalachia may potentially suffer the most from the regulations. The common occurrence of underground workings near outcrops in the area will prevent much coal from being augered due to the barrier-pillar requirements. The narrow pit widths and backstacking techniques common to the steep slope regions are
more subject to equipment congestion when additional auger hole sealing equipment is placed in the pit; thus, productivity will decrease and costs will rise.

Several new augering techniques and machines are being developed which may reduce the impact of the federal regulations by increasing the productivity and recovery rate of auger mining. The continuous mining auger has the potential for achieving up to 85 percent recovery rates under favorable conditions. A high angle auger concept is designed to recover reserves from steeply downward pitching seams that in many cases cannot be economically or technically extracted by other methods. Also, the potential for acid drainage is greatly reduced when downward dipping seams are augered. New guidance system approaches for auger machines that allow more controlled operation and innovative square hole and backreaming auger heads may eventually increase standard auger recoveries to almost 60 percent. These new augering techniques and components as well as novel hole sealing techniques and materials must be further developed and tested to make augering compatible with OSM regulations.

If barrier pillars are not left between groups of auger holes, development costs for an underground mine may be too extreme to allow mining to be economically feasible. A methodology is presented at the end of this report that can be used to determine the relative economics of underground mining on sites with and without the utilization of barrier pillars. Evaluation of three test sites indicated that the barrier pillars
will have the greatest impact on maximizing reserve recovery when steep slope conditions exist, the reserve base is limited, and the mine site has already been reclaimed.
INTRODUCTION
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Since their introduction in the mid-1940's, auger mining methods have provided a low-cost means of recovering coal beyond the economic highwall limit of surface mining methods. Coal production from augering techniques steadily increased in the United States until its peak of 20 million tons recovered in 1970. However, the auger mining industry has declined since 1970 in spite of the favorable costs of augering compared to surface and underground methods.

Several factors can be cited for the decrease in auger mining during the period from 1970 to 1977. With the advent of more efficient surface mining methods and equipment, and increases in coal market values, second and third cuts on previously surface mined lands became economically attractive. However, coal owners found previously augered areas sterilized from further development. Because of the low recovery rate of augering (35% average) compared to surface methods (90% average), mineral owners are not realizing their full reserve recovery potential in these cases. Also, in situations where augering was conducted around a mountain ridge, access to potentially recoverable underground reserves was rendered nearly impossible. The possibility of freezing these reserves from further development has forced many mineral rights owners to refuse mine operator's requests to auger.

Many states introduced regulations during the late 1960's and early 1970's which restricted augering under many situations and/or made it more costly. These regulations were a major cause in the decline of
auger mining. During 1975, Minerals Yearbook showed auger production of only 3.5 million tons, with the majority of production coming from eastern Kentucky.

The most recent deterrent to auger mining was imposed on August 3, 1977, when U.S. Public Law 95-87 was signed. The Federal Surface Mining Control and Reclamation Act places restrictions on all surface mining methods including additional restraints on auger mining. Since augering usually requires initial contour mining to create a bench, additional costs incurred in an augering operation due to P.L. 95-87 are twofold: the operational costs of excavating the required bench have increased, along with the actual augering and auger hole reclamation costs.

The objective of this study is to examine techniques that may minimize the impact of the federal mining regulations on the production of coal by auger mining. In order to accomplish this objective, this report has been divided into four basic components. Initially, a review of the current augering methods and economics is conducted. The end result of this task includes an evaluation of auger applications and recovery rates.

Following the state-of-the-art review, an assessment of the effect of the federal regulations and performance standards are delineated for both the Appalachian Region and the Eastern Interior Region, the predominant auger mining areas. Scheduling problems and production losses that may be incurred by current augering methods are the primary impacts investigated.
The third component of this study presents descriptions of innovative auger machines and techniques. The ability of these methods to mitigate the impacts of the federal regulations is discussed along with their feasibility of increasing production and productivity while minimizing environmental impact.

The last section of this report evaluates the feasibility of increased underground mining due to the barrier pillar mandate of the federal regulations. The engineering possibilities for developing underground mine access in situations where barriers were left and in cases where barriers were not left are illustrated. These development possibilities are investigated for active stripping operations, reclaimed sites, and abandoned sites. A methodology for determining the amount of reserves that could potentially be sterilized if barriers would not be left between groups of auger holes is also developed. This methodology is based on the economics associated with accessing underground reserves for the various mining situations and site specific factors.

This study was performed by Skelly and Loy for the U.S. Department of Energy under the provisions of Contract No. DE-AC01-79ET11268. This report contains the data, engineering derivations and assumptions, and conclusions generated to complete the objectives of this study.
REVIEW OF CURRENT AUGER MINING OPERATIONS AND ECONOMICS
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REVIEW OF CURRENT AUGER MINING OPERATIONS AND ECONOMICS

The share of total coal production attributable to auger mining has been steadily decreasing since 1970 when auger mining accounted for 3.3 percent of production. In 1974, the last year for which separate augering statistics are available, augering's share of total production had dropped to 2.6 percent. Although statistics indicate that approximately one hundred (100) horizontal coal augers may be owned by mining companies, not all are in use. Results from a survey of mining companies reporting auger production in the most recent Keystone data file indicate that approximately forty-one (41) percent of these companies are actively using augers; an additional forty-seven (47) percent reported that they were considering augering.

Evidence of the declining auger industry can be seen in several other indicators in addition to its percent share of total production. Auger sales also have decreased in recent years, with only 26 surface augers sold between 1974 and the second quarter of 1978. The breakdown by years is: 1974 sales - 5 units; 1975 sales - 16 units; 1976 sales - 1 unit; 1977 sales - 4 units; and 1978 sales - 0 units. In addition, many of the old augers operating in the early 70's have now been scrapped. The slowdown of auger advertising and the absence of auger equipment at recent mining shows also indicate that the recent attitude of operators towards augering is negative.

It should be noted here that the literature search revealed that data
availability for auger mining is extremely limited. This is due mainly to the size and state-of-the-art of the industry. Auger mining is extremely sensitive to fluctuations in the price of coal. This is caused by the fact that auger mining has been primarily confined to the Eastern coal mining region and is utilized primarily by small operators. A few auger operations are located in the Eastern Interior region, including Indiana, western Kentucky, and Illinois. Minimal augering is practiced in the West due to the thickness of the coal seams and their ease of accessibility by other surface methods.

The topographic, geologic, and surface mining characteristics of the Appalachian and Eastern Interior Regions are presented in the following discussions. This will allow the impacts of the federal auger regulations to be presented more clearly for each region later in this report. This information should also make evident the reasons augering has been most predominant in the steep slopes of the Appalachian region.

AUGER MINING CHARACTERISTICS - APPALACHIAN REGION

Approximately twenty (20) percent of the nation's identified coal reserves are located in the Appalachian region, and the vast majority of the nation's auger production also occurs there. Although much of Appalachia can be classified as hilly or rolling, central Appalachia is generally considered mountainous. Because of the steep terrain, particularly in southern West Virginia, eastern Kentucky, Virginia, and Tennessee, overburden is often too great to allow mountaintop removal.
Contour surface mining is commonly done around the coal outcrop, but strip ratios soon become too high to continue further into the hillside. Auger mining can be utilized at this point to recover more coal, at a low cost, before the land is reclaimed.

About 90 mineable coal seams occur in the Appalachian Region, ranging in thickness from two feet to about six feet, with an average of approximately four feet. Overburden generally consists of sandstone, siltstone, shale, clay and non-marine limestone. Coal thicknesses and presence of partings often vary over short distances, and faults are fairly common. These conditions cannot always be predicted beforehand, and consequently can cause low auger recoveries.

The bituminous coal seams in the Appalachian Region are relatively flat-lying, with only localized dips of any significance. Coal quality ranges from low-grade steam to high-grade metallurgical. Approximately thirty-five (35) percent of all strippable coal is low-sulfur, averaging less than one (1) percent total sulfur content (USBM IC8680, 1975, p. 5).

According to Ford, Bacon, and Davis (1975), augerable reserves to a penetration depth of 200 feet in the Appalachian Region total 2,597 million short tons, assuming a 25% recovery from augering with the following state-by-state breakdown:

<table>
<thead>
<tr>
<th>State</th>
<th>Million Short Tons</th>
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<tbody>
<tr>
<td>Alabama</td>
<td>31</td>
</tr>
<tr>
<td>E. Kentucky</td>
<td>756</td>
</tr>
<tr>
<td>Maryland</td>
<td>13</td>
</tr>
<tr>
<td>Ohio</td>
<td>254</td>
</tr>
<tr>
<td>Pennsylvania</td>
<td>322</td>
</tr>
</tbody>
</table>
State | Million Short Tons
---|---
Tennessee | 37
Virginia | 148
West Virginia | 1,036

Only those seams dipping at less than $10^\circ$ were considered for augering, and it was assumed that surface mining could first be accomplished to an economic strip ratio limit prior to augering.

**AUGER MINING CHARACTERISTICS – EASTERN INTERIOR REGION**

Some augering is conducted in the Eastern Interior Region states of Illinois, Indiana and western Kentucky. This area is characterized by flat to rolling topography with coal seams ranging from flat to dips of 20–30 feet per mile. The combination of relatively flat beds and level terrain provides for fairly constant strip ratios during operations.

Contour mining is not the predominant mining method since a number of parallel cuts can usually be taken before the limiting economic highwall is reached. In many instances, natural and property boundaries limit the extent of a mining operation, and not the strip ratio of the final highwall. If a limiting strip ratio is the factor which limits the extent of mining, stripping can often be re-initiated at the old limiting highwall when market values increase. These conditions are in direct contrast to the rapidly increasing strip ratios encountered in steep slope Appalachia. Because of the possibility of future stripping, augering is not commonly practiced by operators or allowed by reserve owners in the Eastern Interior Region.
Reserves in this region are contained in seams which average 4 to 6 feet in thickness, and are primarily high-sulfur (more than 2%) bituminous steam coal. Bedrock consists primarily of shales, with thin limestone and sandstone intervals.

According to Ford, Bacon, and Davis, augerable coal reserves to a 200 foot penetration depth total 59 million tons. A state-by-state breakdown based on 25% recovery from augering, follows:

<table>
<thead>
<tr>
<th>State</th>
<th>Million Short Tons</th>
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<tbody>
<tr>
<td>Illinois</td>
<td>36</td>
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<td>Indiana</td>
<td>11</td>
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<tr>
<td>W. Kentucky</td>
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CURRENT TECHNOLOGY

Since the introduction of auger machines in the mid-1940's, augering has presented several unique advantages to operators. One of the primary advantages is that auger machines have a very low capital cost compared to the capital expenditures required for other mining techniques. The low capital cost of auger equipment can be attributed to their relatively simple design. Through the years, almost all improvements to auger machines have been based upon modifications to existing machines. The low demand for new auger equipment in the past decade has provided a disincentive to research and development of new auger technology. Research and development of other mining equipment has been growing since demand for this equipment has been high. Consequently, the majority of auger machines in use today are very similar in design to those in use a decade ago.
However, in the 1950's and 1960's land owners and regulations were not as concerned with high recovery factors. Since auger methods of coal recovery were popular, much attention was given to auger research by manufacturers. Improvements, refinements, and advancements continued to be made such that an eighty-four inch diameter auger was built by 1960. Other developments made as technology expanded include: self-contained skids used to move from hole to hole; built-in hydraulic leveling jacks; automatic coupling and uncoupling devices; integral conveyors; multiple head augers; and other features, all intended to increase coal production. At this point, the base components of auger equipment will be delineated. This allows a later discussion of operating procedures and equipment selection criteria to be more easily understood.

Major Design Components

The basic components of current augering machines have remained primarily the same over the past two decades. These are the cutting heads, the auger flights, the working platform frame, the flight handling system, the operator control station, and the power drive unit.

Cutting Heads

The three basic types of augers can be classified as single-, dual-, or tri-head. Each of these has certain advantages depending on seam thickness. In order to achieve optimum recovery, the proper auger head arrangement, hole diameter, and web thickness must be matched to the
thickness of the seam to be mined. The tri-head yields the best potential recovery in coal seams up to 37 inches thick; the dual-head in seams from 37 to 40 inches and the single-head in seams from 46 inches to the present design limit of 7 feet (Ford, Bacon and Davis; 1975). In general, the tri-head auger will recover about 10% more coal than the single-head, while the dual head auger will recover 5% to 10% more coal than the single-head. Dual-head augers tend to wander slightly in the vertical direction, but are much more easily controlled in the horizontal plane than single augers. Ease of storage and handling decreases with the number of auger heads. Because each type of auger head has its own advantages and disadvantages, the best choice for any auger application is based on site specific conditions.

Auger cutting heads are of fixed diameters which are usually a few inches larger than the flight diameter. Drag bit style cutting heads are the standard for current auger machines. Bits are located around the outside periphery of the cutting head and in a smaller diameter ring in the center of the cutting head. The design and placement of the drag bits on the cutting head is essential for proper breaking and feeding of the coal to the flights.

Auger Flights

The standard flight has a screw-conveyor helix design with a pitch approximately equal to its outside diameter. A variety of auger flight lengths are available and are standardized at 6-foot, 12-foot, 15-foot, and
20-foot lengths. Flights are usually constructed of conventional steel; however, some experiments with high strength light-weight steel have been conducted. Eliminating weight from the auger string provides more available horsepower to turn the auger and cut and convey coal. The only drawback to this approach is the added cost of auger flights (approximately 16% above standard steel flights.) However, this cost must be weighed against the increase in cost for a larger engine with greater power requirements that would have to be used with steel flights to deliver the same horsepower.

As was previously mentioned, the diameter of auger flights should always be less than the diameter of the cutting head to minimize binding problems in the hole. The friction problem associated with binding increases with the depth of penetration.

The present auger connection or coupling device is generally a type of push, pull-pin arrangement. There have been many complaints and problems associated with this type of connection. When retrieving flights, pin-pulling is a manual operation. Previous reports have labeled the pin-puller as having the highest total hazard factor of any person in the auger crew. The pin or coupling point frequently sticks, binds or pinches the pins, complicating removal and causing lost production time.

Working Platform Frame

The working platform frame is the structured component of the auger machine which supports the flight handling system, the operator control
station, and the power drive assembly. The present physical shape is a structurally rectangular boxed-in unit. The design is horizontally oriented and supported on hydraulic leveling jacks. Many of the earlier machines were mounted on skids and were moved along the bench by pushes and pulls from outside equipment like dozers or front-end loaders. The more modern machines have a self-contained moving device. This device is referred to as a Captive Hydraulic Walker. The largest movement stroke, on the largest of machines, is approximately 7 ft. - 6 inches. Walkers are used to move from hole to hole and to jockey the machine into various positions.

**Flight Handling Systems**

The most critical time related element in auger mining is flight handling since it is time lost from cutting coal. Existing handling is by a variety of methods, usually depending on the capabilities of the auger machine. The larger machines, which may use the heavier larger diameter augers, will have overhead winch or crane-mounted cable lifts with a semi-automatic hooked pick-up. The pick-up point is usually at the center or balance point of the auger flight. Smaller machines will have manually operated hydraulic cable winches that can roll on an overhead swing arm frame. In each of these handling systems, a worker manually moves, aligns and un-couples the auger flights.
Operator Control Station

Present augers either have the operator station to the rear of the machine, away from the highwall, or the operator will stand and ride with the horizontal drilling movement. Earlier models did not always provide cab protection for the operator as current models do. This is a very important safety feature of auger machines since the nature of auger operations necessitates that they be located at the base of the highwall during operation.

Power Drive Units

The standard power source utilized in present auger machines to provide the required torque to the cutting heads is a diesel engine. The horsepower of the engine depends on the cutting head diameter, and the number of heads, with a common range being from 200 h.p. to 510 h.p.

Model Characteristics

The number of auger manufacturers is relatively small when compared to the number of surface mining or underground mining equipment manufacturers. The current auger manufacturers for highwall mining applications are Advanced Mining Equipment Company, Long-Airdox Company, and Salem Tool Company. In fact, these companies are manufacturing or are merged with other companies which are manufacturing other types of mining equipment.

- 24 -
The approximate capital costs for acquiring some of the most popular auger models can be seen in Table 1. A tabulation of the characteristics of these machines is included in Table 2.

### TABLE 1

**AUGER CAPITAL COSTS**

<table>
<thead>
<tr>
<th>MODEL</th>
<th>COST *</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salem Model 1500B (Single Head 24&quot;, 27&quot;, 30&quot;)</td>
<td>$260,000 - $265,000</td>
</tr>
<tr>
<td>Salem Model 1500B (Dual Head 24&quot;, 30&quot;)</td>
<td>$625,000 - $635,000</td>
</tr>
<tr>
<td>Salem Model 1500B (Triple Head 14&quot;, 22&quot;)</td>
<td>$660,000 - $670,000</td>
</tr>
<tr>
<td>Salem Model 1600 (Single Head 30&quot; to 48&quot;)</td>
<td>$410,000 - $420,000</td>
</tr>
<tr>
<td>Salem MC-MUL-T (Single Head 18&quot; to 51&quot;)</td>
<td>$550,000</td>
</tr>
<tr>
<td>Compton Models 28, 30, 36</td>
<td>$415,000 - $460,000</td>
</tr>
<tr>
<td>Long-Airdox Model 155-H (Single Head 24&quot;, 30&quot;)</td>
<td>$105,000 - $120,000</td>
</tr>
</tbody>
</table>

* Approximate 1979 purchase price

There are a number of important operational factors which should be considered before selecting an auger.

1. Seam thickness is ordinarily the determining factor in auger diameter. A variety of cutting head sizes are available.

2. Selection of dual or triple head augers in extremely thin seams.

3. Tonnages required.

4. Power necessary to penetrate to the expected depth in the seam.

5. Maximum dimensions of auger which will allow other operations in the pit to continue unhindered.
TABLE 2
AUGER MACHINE CHARACTERISTICS¹

Adapted from Eibliography Source No. 30.

<table>
<thead>
<tr>
<th>SPECIFICATIONS</th>
<th>MANUFACTURER AND MODEL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LONG-AIRDOX CO.</td>
</tr>
<tr>
<td></td>
<td>AUGERMINER MODEL 155-H</td>
</tr>
<tr>
<td>Height</td>
<td>12'8&quot;</td>
</tr>
<tr>
<td>Width</td>
<td>8'</td>
</tr>
<tr>
<td>Length</td>
<td>25'6&quot;</td>
</tr>
<tr>
<td>Primary Power (H.P.)</td>
<td>227</td>
</tr>
<tr>
<td>Crowding Thrust (Lbs.)</td>
<td>10,000</td>
</tr>
<tr>
<td>No. of Drive Heads</td>
<td>1</td>
</tr>
<tr>
<td>Auger Flight Length</td>
<td>8'</td>
</tr>
<tr>
<td>Auger Diameter²</td>
<td>18/42&quot;</td>
</tr>
<tr>
<td>Nominal Depth³</td>
<td>100'</td>
</tr>
</tbody>
</table>

¹ This chart is not intended to be comprehensive.
² Minimum and Maximum - See Manufacturers literature for detailed breakdowns.
³ Normal working depth - Will vary with coal seam characteristics and operator expertise.
6. Mobility of the auger in the footing conditions that exist.
7. Adaptability of machine to slight variations in seam dip if they are present.
8. Ease of transport from site to site.
9. Crowding (thrust) capability.
10. Bit design that is best for cutting the type of coal present.
11. Speed of carriage, hoist, jack and skids.
12. Ease and speed in lifting, handling, spotting and coupling auger flights.
13. Crew size required for proper operation (two or three).
14. Reliability and capability of continuous operation.
15. Ability of safety features to protect crew from hazardous highwall conditions on site.

For any given auger, there are a number of variables that will affect the production rate obtained. These variables are:

1. Proficiency of the operating crew.
2. Degree of pit floor maintenance conducted.
3. Uniformity of the coal thickness.
4. Stability of the highwall and overriding strata.
5. Curvature of the highwall.
6. Presence of partings.
7. Uniformity and undulations of coal seam.
8. Weather conditions.
9. Pit congestion and/or delays due to other operations.

10. Maintenance routine for auger machine.

These factors and the operational selection factors mentioned previously can be used to predict the auger machine best suited to a site and its potential production rate. A ranking of the most important selection criteria according to the operators and owners contacted can be seen in Table 3.

**TABLE 3**

**SELECTION CRITERIA FOR AUGERING EQUIPMENT**

<table>
<thead>
<tr>
<th>SELECTION CRITERIA</th>
<th>RANK *</th>
</tr>
</thead>
<tbody>
<tr>
<td>Purchase Cost - Salvage Value</td>
<td>X</td>
</tr>
<tr>
<td>Operating Costs</td>
<td>X</td>
</tr>
<tr>
<td>Operating Characteristics</td>
<td>X</td>
</tr>
<tr>
<td>Machine Dimensions</td>
<td>X</td>
</tr>
<tr>
<td>Safety Devices</td>
<td>X</td>
</tr>
<tr>
<td>Manufacture</td>
<td>X</td>
</tr>
<tr>
<td>Location of Sales Outlets</td>
<td>X</td>
</tr>
<tr>
<td>Site Conditions</td>
<td>X</td>
</tr>
<tr>
<td>Operational and Ancillary Equipment</td>
<td>X</td>
</tr>
<tr>
<td>Maintenance</td>
<td>X</td>
</tr>
</tbody>
</table>

* Rank shows the weighting of importance, owners and operators give to each of the indicated selection criteria.
Operational Techniques

The general operational steps that are carried out by an auger crew for any given hole are basically the same regardless of the general mining method used to excavate overburden and create the auger's working bench. However, the support operations for the auger and the sequencing of auger moves will greatly depend on the mining situation and mining region in which augering is taking place. At this time, a discussion of the general operational steps that are performed for each hole is presented. Following this discussion, the support operations and overall mining sequences which are unique to the various augering situations and regions will be presented. It should be noted that these descriptions concern practices followed prior to implementation of the interim or final federal regulations. The effects of the federal regulations on these practices will be discussed in a later section of this report.

General Operations

After the augering machine is in place at its operating position at the base of highwall, the auger crew will initiate the general sequence of events which is carried out for each auger hole. Depending on the type of auger and its degree of automation, a crew of 2 to 4 men is usually required for operation. If a larger crew is utilized, the tons recovered per hour can be maximized by keeping the flight handling times as low as possible. However, a two man crew at times can achieve the highest
production per man-hour in spite of slightly longer flight handling times.

Initially, the first flight and cutting head are inserted into the retracted drive mechanism of the auger machine. The first flight is leveled to the exact entry position through adjustment of the hydraulic support jacks. The initial flight is usually positioned to enter as close as possible to the upper edge of the coal seam. This compensates for auger sag as the depth increases, and thus allows a greater depth to be augered before the rock underlying the coal seam is intersected.

A thin web, usually 6 to 8 inches thick, is left between the outside diameters of consecutive auger holes. This thin pillar serves as roof support, and its proper thickness is a function of maximum overburden depth and auger diameter. The approximate thickness of this web can be calculated; however, many experienced auger operators will use their own judgement. One field technique used to determine if a thick enough web has been left for roof support involves placement of a 2" by 4" wooden prop vertically in the adjacent completed auger hole. If the prop is observed to bend or creak as the current hole is being augered, the operator knows that an insufficient web thickness was left and retracts the auger flights. Further discussions on web thicknesses will be presented along with recovery percentages.

Along a straight highwall, it is advantageous to maintain a uniform web thickness for the entire length of the auger hole. A uniform web allows for maximum coal recovery because a minimal amount of coal will be left between the holes. This aspect of auger mining is directly related
to the auger operator's skill since rough "eyeballing" is utilized to keep the auger holes parallel. Along sharp outside curves of highwalls, an additional space must be left between the initial contact points on the outcrop due to the decreasing pillar thickness as the hole depth increases. This particular of augering is examined in more detail in the section of the report concerning recovery.

When almost the entire length of the first flight has been driven into the seam, the drive mechanism is disconnected from the first flight and retracted to allow the second flight to be positioned behind the first flight. On earlier model auger machines, the disconnection or "pin pulling" was a manual operation.

Depending on the size and type of auger machine, the flights will be lifted by an overhead winch, crane-mounted cable hoist, or manually operated hydraulic cable winch. In each system, a worker manually moves and aligns each additional auger flight in front of the drive mechanism. The drive mechanism advances and automatically couples the flights together. Flights may be stored on either or both sides of the auger's frame, or above the machine. Earlier simplified augers stored flights on the ground until they were needed.

There are various methods available to detect when the cutting head begins to cut rock instead of coal. After a number of holes have been completed, the operator will have a "rough" idea of the penetration depth at which drifting out of the seam will occur from the previous penetration depths. Experienced auger operators claim they can actually "feel" when
rock is being cut. Hydraulic fluid pressures and cutter head speed can also be used to detect drifting. Finally, if rock is observed in substantial quantities in the coal transported out of the auger holes this obviously indicates that drifting has already begun.

After rock cutting has been detected, the rotational direction of the auger flights is reversed and the drive mechanism will be slowly retracted. As the couplings between flights exit from the hole, they are manually released. Each flight is then hoisted and stored in its proper storage location on the flight rack. The drive mechanism is then reconnected to the end of the flight remaining in the hole, and the flight is removed in the same manner as the previous flight. Once all flights have been removed, the machine will be readied for movement to its next operating position.

Potential Operational Difficulties

A number of difficulties can occur during auger penetration that cause reaching augering depth or retrieving all the flights and cutting heads impossible. Due to the "blind" nature of augering, it is virtually impossible for an operator to predict when a problem might occur. However, the more experienced and the more acquainted the operator is with the "feel" of the machine, the better the chances of retrieving all components intact. The following listing presents some of the events which could result in loss of the cutting head.

- intersection of underground workings
- intersection of precious auger hole
- too thin a web thickness causing hold collapse
- intersection of an aquifer
- intersection of a fault
- highwall failure can bury machine
- pockets of weak roof can trap heads in spite of proper web thickness utilization
- failure of couplings during auger retraction

Special Methods

Contacts with auger mine operators and contract augerers have indicated that some operators utilize special methods or deviations from standard practice that allow them to recover additional coal reserves. These techniques include the following:

- Rotational speed can be utilized to cause cutting head vertical height variations in the seam. Starting high on the seam and rotating slowly causes the head to drop. Faster rotation with increased crowding force causes the head to rise.

- For seams 1.5 times thicker than flight diameter, the top of the seam can be augered initially, and then the bottom portion can be entered secondarily.

- The use of shorter flight lengths (approximately six feet) allows for flexure in rolling seams.

- Greater penetration depths can be achieved by using the proper diameter flights for the first few sections of the hole and a slightly smaller diameter flight for the remainder of the hole. This combination can reduce friction forces in the hole, and thus decreases horsepower requirements.
Mining Sequences In Steep Slope Contour Mines

In the steep slope regions of eastern Kentucky, West Virginia, Virginia, and Tennessee, single cut contour mining along the outcrop of coal seams has been the predominant surface extraction technique. Typified by long winding highwalls and narrow benches, (50' to 130' are common), auger operations can be incorporated into the mining sequence, such that they follow within 1,000' of the primary overburden and coal removal operation.

Prior to the advent of federal and state reclamation laws, many contour stripping operations disposed of overburden on the downslope and, consequently, left an exposed highwall and coal seam for the entire length of the operation. Under these situations, augering could be accomplished without scheduling problems or interference from other operations. The only support required involved creating a level working place in the pit. This task was usually performed by a bulldozer.

By the early 1970's, most states where augering was practiced had passed regulations which restricted downslope disposal practices and required some form of sealing for auger holes. This legislation had a major effect on the sequencing of both overburden removal and auger operations. Haulback mining became a popular method of contour mining because overburden was moved laterally along the bench to a backstack area, thus eliminating downslope disposal. Auger operations can be easily incorporated into the mining sequence of a contour haulback oper-
ation. Usually, up to 1,500 feet of pit exists between overburden stripping and backfilling operations on the bench. An auger operation can be conducted between the stripping and reclamation operations if sufficient bench width is available for equipment to maneuver. Very little support is required for the auger operation in these situations since the operating bench already exists and highwall backfilling is performed as part of the contour haulback sequence (Figure 1). However, some additional dozer work will be required for forcing material into the auger holes to insure a good seal.

**Mining Sequences Modified Area Mining**

Modified area and area mining methods are used to recover coal seams in regions where gently rolling or flat terrains exist. With these methodologies, successive parallel cuts are taken into the ridge until the economic limit is reached. Augering operations are sometimes utilized in the final pit to recover additional coal. However, due to the possibility of future stripping, this is not very common. Prior to the enactment of any state or federal regulations, the final highwall and auger holes were seldom backfilled. Once backfilling and sealing of auger holes became mandatory, some additional dozer work became necessary to insure proper sealing prior to pit backfilling.

**Auger Recovery Rates**

Auger mining is conducted on the basis of an individual mine
FIGURE 1. CONTOUR STRIP/AUGER MINE.
operator's skill and his assessment of the geologic characteristics of the augerable seam. Therefore, variation exists in the techniques utilized to auger individual coal seams. For the same reasons, auger mine recovery rates can vary greatly from one operation to another and are dependent on many site specific factors. Among these factors are: web width required based on overburden thickness and coal compressive strength, coal thickness as it compares to the available auger diameters, the contour of the highwall, operator skill, the effectiveness of auger hole layout plan, the number of cutting heads, seam undulation, seam dip, presence of underground working or aquifers, and auger machine condition. Table 4 shows the theoretical recovery percentages attainable with current augers and Figure 2 the production curves associated with these theoretical recoveries for the three existing head drive combinations (one cutterhead is attached to each head drive unit; i.e., a Triple Head Drive has three parallel cutterheads working in the seam). It should be noted that these are the potential recoveries as reported by manufacturers and are based on good conditions and do not reflect average recoveries.

In actual situations, the auger mining recovery percentage achieved may reach as high as 60 percent for penetration depths up to 200 feet. However, the average recovery for augering is in the range of 25 to 35 percent. Compared with the recovery rates usually achieved by underground mining (50 percent) or surface mining (90 percent), the auger is an inefficient method of coal recovery.
TABLE 4
AUGERING RECOVERY PERCENTAGES

<table>
<thead>
<tr>
<th>Head Type</th>
<th>Auger Diameter (Inches)</th>
<th>Coal Height (Inches)</th>
<th>% Recovery*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single</td>
<td>28</td>
<td>36</td>
<td>47</td>
</tr>
<tr>
<td></td>
<td>32</td>
<td>40</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>36</td>
<td>44</td>
<td>52</td>
</tr>
<tr>
<td></td>
<td>40</td>
<td>48</td>
<td>54</td>
</tr>
<tr>
<td></td>
<td>44</td>
<td>52</td>
<td>58</td>
</tr>
<tr>
<td></td>
<td>48</td>
<td>58</td>
<td>56</td>
</tr>
<tr>
<td>Dual</td>
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<td>30</td>
<td>55</td>
</tr>
<tr>
<td></td>
<td>28</td>
<td>34</td>
<td>57</td>
</tr>
<tr>
<td></td>
<td>32</td>
<td>40</td>
<td>56</td>
</tr>
<tr>
<td></td>
<td>36</td>
<td>44</td>
<td>62</td>
</tr>
<tr>
<td>Triple</td>
<td>18</td>
<td>24</td>
<td>58</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>26</td>
<td>58</td>
</tr>
<tr>
<td></td>
<td>22</td>
<td>28</td>
<td>58</td>
</tr>
<tr>
<td></td>
<td>24</td>
<td>30</td>
<td>58</td>
</tr>
</tbody>
</table>

Adapted from Bibliography Source No. 30.

* Percent recovery is based on allowing 6 to 8 inches of coal thickness for droop of auger flight and an 8 inch pillar between holes.

NOTE: Values courtesy of Salem Tool and Applied Manufacturing

Augering of a seam can also potentially result in the sterilization of coal reserves beyond the penetration depth of the auger holes. Second cutting by surface methods is often conducted on abandoned cuts when the coal market value justifies mining the higher strip ratio material. However, previous augering will usually cause this type of operation to be
AUGER PRODUCTION

FIGURE 2

Range of Single Head Drive

Range of Dual Head Drive

Range of Triple Head Drive

TONS OF COAL PER 100' OF HOLE

HOLE DIAMETER IN INCHES

52
44
36
28
20
12
0
8
16
24
32
40
48
56
64
72

1 Coal density is assumed to be 82 lbs. per cu. ft. Output will vary with specialized auger characteristics and coal geology.
economically unattractive. Underground reserves can also be sterilized by previous augering in steep slope terrain if access to the reserves cannot be technically or economically accomplished. This is due to the fact that drift entries cannot usually be driven through old auger holes. Underground reserve sterilization will be discussed in a later section of this report.

In order to maximize revenue from their property holdings, coal owners wish to maximize recovery from mining operations with minimal sterilization of potential future reserves. Because auger mining can result in both low coal recovery and reserve sterilization, many lessors are now stipulating in their leases that auger mining is not to be allowed.

Web Thickness Effect on Auger Coal Recovery

An integral part of maximizing auger coal recovery is the proper selection of web thickness. The web thickness required to support the overlying rock is a function of auger hole diameter, the coal strength and the downward pressure exerted by the overburden. Downward pressure increases as penetration depths become greater. This relationship is shown in Figure 3.

Web thickness is related to coal recovery because if the web dimension is too wide, coal that might otherwise be recovered is lost. If too thin a web is utilized, maximum penetration may not be realized because collapse of overlying strata will become more likely as hole depth increases.
When a web is broken through, coal being transported by the flights can be deposited in the adjacent hole and thus lost.

**Highwall Curvature Effect on Auger Coal Recovery**

Contour mining operations follow the outcrop of a coal seam along the side of a hillside and sometimes completely encircle a ridge. The end result is a highwall which has numerous inside and outside curves. As the number and sharpness of curves along a highwall increase, the expected recovery for an auger operation decreases.
On inside curves, the web thickness between auger holes will increase with penetration depth. The sharper the curve, the greater the increase in web thickness per foot of penetration. Because of this, the amount of coal left in webs near the end of the auger holes is greater than required, and maximum recovery is not achieved.

When an outside curve is encountered along a highwall, auger holes drilled perpendicular to the highwall will advance toward the focal point of the curve. In this situation, web thicknesses will decrease as the penetration depth increases. Thus, auger holes will eventually cross if they are drilled to the maximum depth. On outside curves that are very sharp, auger holes can only be drilled short distances to avoid the intersection of holes.

If the curvature of a highwall is not severe, a skilled auger operator can begin the hole on a slight angle to the highwall and thus keep the auger hole close to parallel to the adjacent hole. By operating in this manner, excess coal left between holes will not be as great as if the auger holes were all drilled perpendicular to the highwall. However, coal recovery will still be reduced. For these reasons, auger recovery rates are usually higher from pits which are relatively straight.

**Economics of Augering**

In spite of the low recovery factors associated with augering, the economics of auger mining make it an attractive method to many operators.
Due to the large availability of used augering equipment and relatively low cost of new auger equipment, auger mining requires a low capital investment. In many instances, augering does not necessitate much supporting equipment since it is incorporated into an ongoing operation or is conducted on an unreclaimed abandoned bench. A typical augering operation may only require the auger machine, a two man crew, a dozer, a dozer operator, and a truck fleet to economically recover coal. Depending on the factors listed below, the average operating costs to produce augered coal range from $4.00 to $6.00 per ton (see Appendix A).

In general the following factors will affect the operating costs for an auger operation:

- Auger ownership costs
- Auger operating costs
  - Fuel
  - Bits
  - Grease
  - Parts
  - Maintenance labor
- Auger operating labor
  - Crew size
- Move-in and Erection Costs
- Insurance Cost
- Pit Preparation and Reclamation Costs
  - Amount and type of equipment needed
  - Percent of time on auger related work
  - Surface mining method utilized to create bench
  - Equipment and labor costs
- Auger Production Rate
  - Recovery rate
  - Penetration rate
  - Operator Skill
  - Auger machine condition
  - Auger machine availability
  - Delays due to stripping operation
  - Pit conditions
  - Truck availability

If mining cost was the only factor considered when choosing a coal recovery method, augering would always be the selected method to recover coal if it is technically feasible to use. With surface mining operating costs averaging $12 to $25 per ton in the auger mining regions, augering can be utilized in a stripping operation to effectively reduce the overall operating cost per ton. Underground costs in the same region average $20 to $25 per ton. Even though these figures may vary greatly, they still give a relative indication of the cost effectiveness of augering.
ASSESSMENT OF REGULATORY IMPACTS ON AUGERING
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ASSESSMENT OF REGULATORY IMPACTS ON AUGERING

With the passing of U.S. Public Law 95-87 on August 3, 1977, the auger industry will now be faced with another major deterrent. These federal regulations establish performance standards for the surface mining industry. In addition to imposing restrictions on the types of surface mining methods that are associated with auger mining, the federal regulations have set special performance standards for auger mining operations. 30 CFR, Part 819 delineates these standards for the augering industry.

The prime objective of the auger mining regulations is to prevent adverse environmental effects and any unnecessary loss of coal reserves that may occur due to augering. The regulations attempt to achieve this objective by imposing barrier pillar and hole sealing requirements on augering and by prohibiting auger mining under certain conditions. A synopsis of the special performance standards for auger mining in each of the concern areas follows.

BARRIER PILLARS

The intent of the barrier pillar requirements is to provide access for removal of those reserves recoverable by underground methods by leaving areas of undisturbed coal. Pillars also prevent accidental breakthroughs between active and abandoned underground workings and the surface. The barrier pillars left intact must be:
- a minimum of 250 feet wide at any point between each group of auger holes to the full depth of the hole (Part 819.11 [d]);

- no more than 2,500 feet apart, measured from the center of one pillar to the center of the next pillar (Part 819.11 [a]);

- an additional 50 feet wider for each subjacent seam in multiple seam operations. The centers of all barrier pillars must be aligned vertically (Part 819.11 [a]) – see Figure 4.

- 500 feet wide measured horizontally between any part of the auger hole and any active or abandoned underground workings (Part 819.11 [b]).

Part 819.11 of the Federal Regulations does allow for exceptions to the requirements in certain instances. If the operator can present technical evidence which indicates that the objectives the auger regulations require will be maintained by his practices, a variance may be granted. The regulatory authority will determine whether the evidence presented is accurate and cause enough to permit the exception. Any variations from the requirements of the regulations must be fully documented in the permit application. The conditions upon which the requirements may be waived if proper evidence is provided follow:

- Barrier pillars between groups of auger holes need not be left if evidence proves that the coal reserves have been depleted or are limited in thickness or extent to the point that it will not be feasible to recover the remaining reserves by underground methods. (Part 819.11 [a]).

- Barrier pillars may be greater than 2,500 feet apart (center to center) if a greater distance is set forth in the permit application and approved by the regulatory agency. (Part 819.11 [a]).
LEGEND

- Barrier Pillar
- Area to be Augered

MINIMUM BARRIER PILLAR SPACINGS FOR AUGER MINING

FIGURE 4

Adapted from Bibliography Source No. 28
- Augering may be conducted closer than 500 feet in horizontal distance to underground workings if:

  . The nature, timing, and sequence of the operations are jointly approved by the regulatory authority, MSHA, and the state agency responsible for mine worker safety; and

  . The activities result in improved resource recovery, abatement of water pollution, or elimination of health and safety hazards. (Part 816.79 [a]).

AUGER HOLE SEALING AND RECLAMATION

The performance standards require each auger hole to be plugged in order to prevent the discharge of water from the hole and the access of air to the coal. These actions are intended to avert surface and groundwater pollution and to reduce fire hazards. Sealing of auger holes must be accomplished to the extent that:

- Auger holes discharging water containing toxic-forming or acid-forming material are sealed within 72 hours after completion by backfilling and compacting non-combustible and impervious material into the hole to the extent required to form a water-tight seal or the discharge shall be treated commencing within 72 hours after completion to meet applicable effluent limitations and water quality standards until the hole is properly sealed. (Part 819.11 [c]).

- Auger holes not discharging water shall be sealed within 30 days following completion by backfilling and compacting non-combustible and impervious material into the hole to the extent required to form a water-tight seal. (Part 819.11 [c]).
Exemptions to the auger hole sealing requirements are allowed under Part 819.11 of the Federal Register in certain instances. Auger hole sealing is not required if the regulatory authority finds that:

- sealing of the auger holes would result in impoundment of water which may create a hazard to the environment or public health (Part 819.11 [d]).

- drainage from the auger hole will not pose a threat of pollution to surface waters and will comply with applicable federal and state water quality standards and effluent limitations. (Part 819.11 [d]).

CIRCUMSTANCES OF AUGER MINING PROHIBITION

The last section of the auger mining special performance standards sets forth the circumstances under which the regulatory authority shall prohibit auger mining. The aim of this section of the auger regulations is to forbid augering in situations where adverse environmental effects or unnecessary loss of coal reserves cannot be prevented even if the performance standards previously set forth are complied with. The regulatory authority shall prohibit auger mining in situations where:

- adverse water quality impacts cannot be prevented or corrected. (Part 819.11 [e]).

- stability of auger sealings cannot be achieved. (Part 819.11 [e]).

- augering will not maximize the utilization, recoverability, or conservation of the coal reserves. (Part 819.11 [e]).

- subsidence resulting from an auger operation may potentially damage powerlines, pipelines, buildings, or other facilities.
REVIEW OF THE STATES' AUGER MINING REGULATIONS

In order to assess the impact of the federal regulations on the auger industry, the applicable regulations of the various states where augering is practiced must also be examined. Prior to the enactment of Public Law 95-87 only eight states had regulations pertaining to auger mining. Alabama did not issue augering permits but planned to adopt the federal regulation requirements. Table 5 summarizes the specific augering requirements for those states which had regulations prior to P.L. 95-87.

Because all surface mining regulations apply to augering, many states have utilized the general surface mining requirements to restrict augering. For example, Pennsylvania's requirement to maximize recovery of coal reserves has been used to prohibit augering in many cases because of augering's low recovery rate. Surface mining water quality requirements are strictly enforced in West Virginia. The direct result of this is the prohibition of augering in upward dipping seams in the state.

Examination of Table 5 reveals that no state barrier pillar requirements are as strict as the federal requirements. Auger mining can be prohibited in more situations under the federal provisions than under any states'. However, the sealing and backfilling timing requirements of many states are comparable in severity to those of the federal regulations. Ohio, Pennsylvania, West Virginia, Tennessee, Maryland, Kentucky and Illinois regulations all specify that auger holes must be plugged to some
<table>
<thead>
<tr>
<th>STATE</th>
<th>BARRIER PILLAR REQUIREMENTS/PROXIMITY TO UNDERGROUND WORKS</th>
<th>AUGER MINING REGULATIONS</th>
<th>AUGER HOLE SEALING REQUIREMENTS</th>
<th>TIMING OF BACKFILLING</th>
</tr>
</thead>
</table>
| FEDERAL | • 500' barrier between auger holes and active or abandoned underground works.  
• Minimum 250' wide pillars on maximum 2500' centers between groups of auger holes. Pillar width increases by 50' for each subjacent seam. | • Must be conducted so as to maximize recovery.  
• Prohibited where adverse water quality impacts cannot be prevented or corrected.  
• Prohibited where subsidence may disturb or damage utilities or buildings.  
• Prohibited where fill stability cannot be achieved. | • A watertight seal of impervious and non-combustible material must be used.  
• All holes discharging toxic or acid water must be treated or plugged within 72 hours.  
• Holes not discharging water must be sealed within 30 days. | • Contour mines - 60 days or 1500 linear feet.  
• Area mines - 180 days and no more than 4 spoil piles.  
• Open pit mines - in accordance with approved time schedule. |
| OHIO | • If breakthrough into underground mine impounding water occurs, it must be sealed with impervious compacted material to a depth 3x the greater dimension of the opening.  
• Seal must be inspected and approved. | | | |
| PENNA. | • If breakthrough to underground works occurs, augering must cease until seal is in place.  
• Seal must be approved. | | | |

**TABLE 5**

**SPECIFIC AUGER MINING REGULATIONS**
<table>
<thead>
<tr>
<th>STATE</th>
<th>BARRIER PILLAR REQUIREMENTS/PROXIMITY TO UNDERGROUND WORKS</th>
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<th>AUGER HOLE SEALING REQUIREMENTS</th>
<th>TIMING OF BACKFILLING</th>
</tr>
</thead>
<tbody>
<tr>
<td>VIRGINIA</td>
<td></td>
<td>· Auger mining must follow stripping within 90 days.</td>
<td></td>
<td>· Backfilling must follow augering within 30 days.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>· No more than 350' of active pit.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>WEST VIRGINIA</td>
<td>· Must maximize recovery.</td>
<td>· All holes must be sealed with an impermeable and non-combustible material.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>· Auger must follow stripping within 60 days.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TENNESSEE</td>
<td>· Leave 15' barrier between hole and underground mine.</td>
<td>· Force spoil into hole by machine.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>· If breakthrough into underground mine, report in 24 hours and seal within 30 days.</td>
<td>· Backfill 10' above hole and grade.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
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<td></td>
</tr>
<tr>
<td>MARYLAND</td>
<td>· One barrier at least 200' wide must be left if operator intends subsequent deep mining.</td>
<td>· Partitions between auger holes may not be recovered unless approved by Director of Bureau of Mines.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>· Auger holes must be backfilled by compacting with nonbituminous material to a depth of 2x the hole diameter.</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>· Backfilling must be completed as augering progresses.</td>
</tr>
</tbody>
</table>
### TABLE 5 (Cont'd.)

**SPECIFIC AUGER MINING REGULATIONS**

<table>
<thead>
<tr>
<th>STATE</th>
<th>BARRIER PILLAR REQUIREMENTS/PROXIMITY TO UNDERGROUND WORKS</th>
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</tr>
</thead>
<tbody>
<tr>
<td>ALABAMA</td>
<td>Plan to adopt OSM's regulations</td>
<td>Plan to adopt OSM's regulations</td>
<td>Plan to adopt OSM's regulations</td>
<td>Plan to adopt OSM's regulations</td>
</tr>
<tr>
<td>KENTUCKY</td>
<td>Auger mining must follow strip mining within 30 days, grading and backfilling within 15 days; with a maximum of 1000' of exposed bench. Highwalls must be reduced to a 45° slope or less. If underground mine or acid drainage is found, it must be reported to DNR. No person may enter auger hole without permission by DNR.</td>
<td>Auger holes must be securely blocked with spoil before they are abandoned.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ILLINOIS</td>
<td>Leave 50' minimum barrier to boundary of active underground mine.</td>
<td>Must keep a current map of augering operations with depth and direction. Must be inspected before startup. No person may enter hole. No work may be done on highwall in vicinity of auger.</td>
<td>All holes must be plugged with spoil or other suitable material before abandonment.</td>
<td>Grading must be completed within 11 months after June 30th of the fiscal year in which mining occurred.</td>
</tr>
</tbody>
</table>
degree. The time period allowed to accomplish sealing in Ohio is stricter than the period allowed by the federal regulations. Virginia allows a maximum of 350 feet of active pit at any time during stripping. This is less than the federal limit of 1,500 feet.

Overall, the federal augering performance standards are much more stringent concerning barrier pillar requirements and prohibition of augering than any state regulations. The federal sealing requirements are comparable to most state requirements. However, depending on the interpretation of "impervious material" and "water-tight seal", the federal requirements could be much more difficult to achieve.

Clay is to be the most readily available material to mine operators that can be used to plug auger holes and stop the discharge of water. However, if water was being discharged from an auger hole prior to sealing, then the possibility exists that pressure can build up behind the plug due to accumulated water. This may even occur in seams which dip slightly downward. Under these circumstances, it is possible that any seal, even if constructed of pure clay, may leak in time. Prediction of this event cannot be accurately made beforehand. Thus, interpretation of the long term sealing requirements of the federal regulations will greatly affect the degree to which plugging must be accomplished and the decision to possibly prohibit augering.
The impact of the federal regulations on any auger operation will be dependent on many factors. These factors include: current state regulations; nature of the stripping operation being conducted to create the auger's working bench; the site specific conditions on the site; and the possibility of obtaining variances to the federal regulations. The impact of the federal regulations can be broken into several categories. These are effects on auger productivity, recoverable resources, and auger mining prohibition. Because of the site specific nature of regulatory impacts, an overall estimate of the regulation's impact on each of the categories cannot be made. However, the potential impacts of each of the auger mining performance standards can be predicted for various situations that can occur in the regions where augering is practiced.

Impact of Barrier Pillar Requirements

The barrier pillar requirements, as set forth in Part 819.11(a) of the Federal Regulations are intended to allow for the maximum recoverability of coal reserves remaining after augering has been conducted. An evaluation of the success of the barrier pillar regulations in fulfilling their objective will be discussed in the last section of this report. But regardless of the degree to which future coal reserve recovery is maximized, the barrier pillar requirements will reduce the potentially recoverable reserve base for all augering operations. The only exception to this will occur if underground workings are not within 500 feet.
of the auger operation and a variance waiving the pillar requirements between groups of holes has been granted.

There are only a few possible augering situations that would not lose reserves in the barrier pillars. The absence of underground workings in an area usually indicates that some amount of underground reserves are present. If this is the case, a variance waiving the barrier pillar requirements may only be granted if:

- The thickness of the coal seam is too thin for underground mining to be technically feasible. For all practical circumstances, this will be all seams less than 26 inches in thickness. However, roof conditions, seam partings, and seam dip are also factors that will determine the technical feasibility of underground mining of thin seams.

- The total recoverable tonnage is so limited that underground methods would not be economically feasible. Under the present economics, reserve tonnages as low as 100,000 tons are economically removed.

The thickness of the coal seam to be recovered could be a technical limitation to underground mining in both the Appalachian and Eastern Interior Regions. Faults, or pinching out of seams, may limit the amount of recoverable underground reserves in both augering regions. However, the nature of seam occurrence on the mountaintops of steep slope Appalachia often isolates small pockets of underground reserves.

If underground mining has already been conducted in the immediate vicinity of a proposed auger operation, obtaining a variance to eliminate the requirement for barrier pillars between groups of auger holes should not be difficult. However, augerable reserves will probably be sterilized
due to the barrier pillar requirement between auger holes and underground workings. If a 150-foot auger penetration was planned, occurrence of underground workings within 650 feet of the highwall will reduce the recoverable auger reserve. Workings within 500 feet will cause augering to be prohibited unless a variance is granted.

The circumstances under which variances for augering within 500 feet of underground workings will be granted are difficult to assess. Under the regulations, increased resource recovery is grounds for a variance. Increased reserve recovery will always be a product of increased penetration depth under these conditions. However, it is unlikely that variances will be granted on this basis alone. Exact location and condition of the underground workings will most likely have to be known before any variance is allowed. In the case of abandoned workings, this information may not be easy to obtain. Another deterrent to augering is the fact that most underground mining conducted prior to the 1969 Health and Safety Act came well within 500 feet of the outcrop, especially in the Appalachian Region. Since drift mining is not nearly as prevalent in the Eastern Interior Region, the presence of underground workings within 500 feet of an auger operation will not be as common.

The circumstances delineated above indicate that the barrier pillar requirements of the federal regulations will result in lower recoverable reserves in almost all augering situations. A methodology for determining the amount of reserves that may be lost to augering due to barrier pillar requirements follows.
Quantification of Sterilized Reserves

The amount of reserves that may be lost to augering depends on both the overall augering situation and the site specific characteristics of the coal seam, auger machine, and overburden. The calculations and methodologies presented in this section to determine the amounts of coal left in barrier pillars assume that no variances have been granted. Coal seam, auger machine and overburden characteristics will all have an effect on the penetration depth that can technically be realized by an auger operation. If the maximum penetration depth attainable is not within 500 feet of underground workings, the potentially recoverable reserve base will not be reduced due to the underground workings barrier. However, when the difference between the distance to the underground workings from the highwall and the penetration depth is less than 500 feet, the recoverable reserves are reduced. The following relationship can be used to estimate the minimum volume of recoverable reserves that will be lost due to barrier pillar requirements for a single seam augering operation along a straight highwall.

Input Variables

\[
\begin{align*}
\text{OUT} &= \text{Outcrop Length to be Augered (feet)} \\
\text{PD} &= \text{Penetration Depth Attainable (feet)} \\
\text{DUG} &= \text{Distance to Underground Workings from Highwall} \\
\text{THK} &= \text{Coal Seam Thickness (inches)}
\end{align*}
\]
Input Variables (Cont.)

DEN = Density of Coal Seam in Pounds Per Cubic Foot

RR = Percent Recovery for Auger Operation in Virgin Block Based on Web Thickness, Seam Diameter, Auger Diameter, and Other Factors

Output Variables

SRUG = Cubic Feet of Recoverable Coal Sterilized Due To Presence of Underground Workings

TOTSR = Cubic Feet of Recoverable Coal Sterilized Due To All Barrier Pillar Requirements

TONSR = Tons of Recoverable Coal Sterilized

POTON = Tons of Recoverable Coal if Barriers Not Utilized

RECNB = Tonnage Recovered if Barriers Not Left

RECWB = Tonnage Recovered When Barriers Left

RECST = Recoverable Tonnage Sterilized in Barriers

SRBB = Cubic Feet of Recoverable Coal Sterilized Due to Barrier Pillar Requirements Between Groups of Auger Holes

DS = Depth Sterilized Due to Presence of Underground Workings (feet)

Quantification Equations

SRBB = \((\text{OUT} \div 2500) \times 250 \times \text{PD} \times \text{THK} \div 12\)

DS = 500 - (\text{DUG} - \text{PD})

IF \((\text{DS} \leq 0)\) DS = 0

SRUG = DS \times ((\text{OUT} \div 2500) \times 250)) \times \text{THK} \div 12
Quantification Equations (Cont.)

\[
TOTSR = SYRBB + SYRUG
\]

\[
TONSR = TOTSR \times \text{DEN} \div 2000
\]

\[
POTON = PD \times \text{OUT} \times \text{THK} \div 12 \times \text{DEN} \div 2000
\]

\[
\text{RECNB} = \text{POTON} \times \text{RR}
\]

\[
\text{RECW} = \text{RECNB} - (\text{TONSR} \times \text{RR})
\]

\[
\text{RECST} = \text{TONSR} \times \text{RR}
\]

The tonnages calculated by these equations are for a straight highwall. The lost tonnages will increase with the increase of highwall curvature due to irregular web thicknesses left between holes. The additional amounts lost will depend on the number of curves and their severity. An allowance for highwall curvature can be made by lowering the percent recovery (RR) input for the above relationships. To estimate the recoverable and lost tonnages due to barrier requirements for the second seam in a multiple seam operation, the following equation substitutions should be made:

\[
\text{SRBB}_2 = (\text{OUT} \div 2500) \times 300 \times PD \times \text{THK} \div 12
\]

\[
\text{SRUG}_2 = \text{DS} \times (\text{OUT} - ((\text{OUT} \div 2500) \times 300)) \times \text{THK} \div 12
\]

For tonnage calculations for the third subjacent seam in a multiple seam operation, the equation changes to become:

\[
\text{SRBB}_3 = (\text{OUT} \div 2500) \times 350 \times PD \times \text{THK} \div 12
\]

\[
\text{SRUG}_3 = \text{DS} \times (\text{OUT} - ((\text{OUT} \div 2500) \times 350)) \times \text{THK} \div 12
\]

In order to illustrate the use of these equations and the potential
reduction in recovered tons due to the barrier pillar requirements, calculations will be made utilizing data from an actual auger mine in operation prior to the enactment of the federal regulations. The following production data was reported by the mine.

Penetration Depth = PD = 100 feet
Percent recovery = RR = 30%
Seam thickness = THK = 40 inches
Distance to underground workings = DUG = (none present)
10,000 feet used
Outcrop length = OUT = 10,000 feet (assumed)
Coal density = DEN = 82 lb./cubic feet

Results:
SRBB = 333,333. cubic feet
DS = -9,400. feet
DS = 0
SRUG = 0 cubic feet
TOTAL = 333,333. cubic feet
IONS = 13,667. tons
POTON = 136,667. tons
RECNB = 41,000. tons
RECWB = 36,900. tons
RECS = 4,100. tons

In this augering situation, 10 percent of the recoverable reserves would have been lost in barrier pillars if the federal regulations had
been in effect. However, this reserve loss was totally accountable to
the barriers left between groups of auger holes since underground work-
ings were not present in the highwall area. If underground workings
were 580 feet from the highwall, the following tonnages would have been
calculated if variances were not granted.

\[
\begin{align*}
SRBB &= 333,333. \text{ cubic feet} \\
DS &= 20. \text{ feet} \\
SRUG &= 600,000. \text{ cubic feet} \\
TOTS &= 933,333. \text{ cubic feet} \\
TONS &= 38,267. \text{ tons} \\
POTON &= 136,667. \text{ tons} \\
RECN &= 41,000. \text{ tons} \\
RECE &= 29,520. \text{ tons} \\
RECST &= 11,480. \text{ tons}
\end{align*}
\]

The presence of the underground workings caused an additional
7,380 recoverable tons to be left in pillars. In this case, a total of
28 percent of the recoverable reserves were lost to augering. However,
it should not be difficult to obtain a variance waiving the need for barriers
between groups of auger holes when underground workings are present
close to the highwall. If this variance is granted the necessary equation
substitutions become:

\[
\begin{align*}
SRBB &= 0 \\
SRUG &= DS \times OUT \times THK \div 12 \text{ (all seams)}
\end{align*}
\]

The approximate tonnage of reserves lost in barrier pillars can be
estimated with these equations. The maximum penetration depth will be restricted by the location of underground workings. Since the depth of the auger holes usually varies between a few feet and the maximum penetration depth, the tonnage of reserves lost may be even greater than is estimated by these equations.

The barrier pillar requirements will result in reduced auger tonnage unless variances are granted. The direct impact of this will be less revenue for the auger operator. The loss in revenue may be great enough to discourage an operator from augering. In any case, it will surely increase mineral rights owners' dislike for augering since the effective recovery rate will be lowered more.

Barrier Pillar Regulation Effects on Productivity

Although the most significant effort of the barrier pillar requirements on augering will be reduction in reserves, these regulations may also decrease productivity and increase operating costs in some instances. The nature of augering mandates that it follows primary overburden and coal removal operations along a bench. The strip ratio of the site, the efficiency of the operation, and the size and number of prime movers will determine the advance rates for overburden stripping along the bench. A well planned and executed strip/auger operation will have matched advance rates for overburden stripping and augering. When this occurs, men and machinery are utilized to their maximum potential. The auger operation will have no delays waiting for stripping to advance, and re-
grading can be kept close behind augering.

The barrier pillar requirements will have an adverse effect on the productivity and operating cost of a strip/auger operation of this type. The auger operation will advance at a faster rate if reserves are sterilized due to underground workings because the average penetration depth will be decreased, causing the auger operation to have to wait on the strip operation at times before an operating place can be prepared for the auger. The result of the delay is decreased production per man hour and increased cost per ton.

The same result occurs due to the barrier pillar requirements between groups of auger holes. An efficient auger operation will have to wait on the strip operation every 2,500 feet until it advances past the 250 foot barrier. Again, productivity will decline and costs per ton will increase.

In some instances, an augering operation may be capable of advancing faster than the strip operation even if barriers are not left. Delays in this case are unavoidable. However, if barriers are left, the delays will become longer, thus adversely affecting both productivity and operating costs. The magnitude of this adverse effect will vary depending on the specifics of the operation. The primary factors determining delay are:

- strip ratios on the site;
- bench width;
- production rate of prime mover;
- decrease in auger penetration due to underground workings;
- auger penetration rate;
- auger set-up and move times;
- grant of variance waiving or decreasing barrier pillar requirements.
Variables needed to estimate decreases in productivity and increased operating costs are:

- production rate of auger;
- total production time per shift (no barriers left in place);
- delay time due to barrier pillars;
- crew size;
- recovered tons (no barriers left in place);
- recovered tons (barriers left in place).

The number of dependent factors required for quantification indicates that the productivity effects will vary from site to site. In some cases, barrier pillar requirements may affect productivity only slightly. Productivity decrease may only be attributable to increased move and set-up times. If the presence of underground workings limits the penetration depth, a higher percent of the total operating time will be spent on non-productive aspects of augering. This causes productivity to decrease, and consequently, costs per ton to rise.

The impact of the barrier pillar requirements on productivity will generally be higher in the Appalachian Region than in the Eastern Interior Region. In Appalachia, where contour mining is predominantly practiced in conjunction with augering, grading must be within 60 days or 1,500 linear feet under the federal regulations. Since auger holes must be drilled and sealed prior to grading, the auger operation must be much closer to the stripping operation than the grading limits. Also, in a haulback operation it is to the operator's advantage to keep grading as close as possible to stripping to reduce haulage costs. These factors make it essential for augering to be conducted close behind stripping and coal removal. Therefore, any increase in the auger operation advance
rate caused by barrier pillar requirements may result in increased delay and non-productive time, because the auger crew will have to wait for overburden stripping and coal removal operations to advance past the barrier pillar.

When augering is conducted in the final pit of a modified mine area; the timing of grading is not such a limiting factor. The federal regulations stipulate that regrading in these situations must be within four spoil ridges or 180 days. This allows the augering operation to remain well behind coal removal, and thus delays will not be a main factor. Underground workings should not be as great a factor in the Eastern Interior Region due to the nature of its underground mining. Therefore, the overall productivity impacts of the barrier pillar requirements will be greatest for contour strip/auger operations.

Impact of Auger Hole Sealing Requirements

Almost all auger mining states required some type of auger hole plugging prior to the advent of Public Law 95-87. However, only Ohio regulations approach the federal stipulations in severity. The aspect of the federal auger hole sealing regulations that can potentially impact the productivity and economics of augering the greatest is the requirement that holes be plugged with a non-combustible and impervious material. If impervious materials, such as clays, are not readily available on the mine site, suitable material would have to be trucked in to seal the holes. This would obviously be very expensive and would drastically
increase the overall cost per ton of augering.

The auger hole sealing requirements do not specify clear-cut parameters that indicate the degree of backfilling required for each hole. For example, the depth of plugging is not given as a constant value nor is a methodology given to compute the necessary plugging depth. The regulations only specify that backfilling be accomplished to the extent needed to create a water-tight seal. Therefore, prediction of the cost and productivity impacts of sealing each auger hole cannot be accomplished until the final auger hole conditions are known. Overall, the federal sealing requirements will adversely affect auger productivity. The extent to which productivity will be affected will depend on the following factors:

- status of state sealing requirements prior to P.L. 95-87;
- availability of non-combustible and impervious material on site;
- attitude of the regulatory authority in defining "water-tight seal" and "impervious material";
- discharge rate from hole;
- seam dip;
- hole diameter.

The status of the sealing requirements in each state prior to P.L. 95-87 determines the regions that will be most adversely affected by the federal sealing regulations. Since Illinois and Western Kentucky do not have as strict sealing requirements as the Appalachian states, it is likely that the impact of the sealing requirements will be greatest in the Eastern
Interior Region. However, for any given site, the impact of the plugging requirements will also depend on the site's specific conditions.

If the regulatory authority determines that suitable sealing material is not available on the site, the economics of sealing the auger holes will depend on the volume of material needed for plugging and the distance it must be transported. It is unlikely that the economics of augering would be favorable under these circumstances.

The discharge rate from the hole, seam dip, hole diameter, and the regulatory authority's definition of "water-tight" will all affect the extent of the plugging required. As the potential water storage capacity of a hole increases, the volume of material required to plug the hole becomes greater. In seams that dip downward, material may tend to slough off toward the back of the hole, thus requiring more material to be used for plugging. The degree of sloughing is a function of the dip angle, the sealing material's characteristics, and the hole diameter. Generally, sloughing will increase with increasing:

- dip angle;
- hole diameter;
- moisture content of the fill material.

If a seam dips upward, much water pressure can build up behind the plug. Under this situation, even a large seal may not be capable of preventing seepage indefinitely, and leakage could occur from fractures in the coal ribs. For this reason, augering permission will probably be refused by the regulatory authority on upward dipping seams.

Although it is much more common in upward dipping seams, discharge
can occur on horizontal and slightly downward dipping seams that are below the water table. If water is discharging from a hole prior to sealing, it is logical to assume that after sealing, water is probably collecting behind the seal. As pressure builds the seeping action of water increases. Therefore, it is possible for auger holes to begin leaking long after they are sealed. If the regulatory authority determines that seals should be designed to prevent this possible future seepage, seal requirements and depths could be quite extensive.

Because of the uncertainty of the extent of backfilling that will be required by the regulatory authority to create a "water-tight" seal, exact quantification of the productivity impact of the federal sealing requirements is nearly impossible. The fact that much of the fill material available to auger operations may not be classified as impervious adds to the difficulty of determining the impacts of the sealing requirements.

However, the higher operating costs for auger hole sealing will increase the overall augering cost per ton and decrease output per man-hour. The presence of additional equipment in the pit for backfilling the auger holes, and possibly for hauling impervious material, will cause scheduling and congestion problems in the pit. This could have the effect of increasing both stripping and augering costs.

If a variance waiving auger hole sealing requirements is granted, there would not be any adverse productivity impacts. Examination of the conditions under which exemptions can be made will show that obtaining a variance may not be an easy task.
The federal regulations stipulate that auger holes need not be plugged if sealing would result in impoundment of water which may create a hazard to the environment or public health and safety. However, if a hole under these conditions is not plugged, the discharged water must be treated to meet applicable effluent limitations and water quality standards. The discharge must be treated as long as it continues to flow from the auger hole. Therefore, if the discharge does not meet the necessary standards, the associated costs of long-term treatment will have an adverse impact on the productivity and economics of the auger operation.

If the operator can prove to the regulatory authority that drainage from the auger holes will not pose a threat of pollution to surface waters and will comply with applicable water quality standards, treatment is not needed. This type of proof will require evidence that shows these standards will be met in both the short and long terms. Obtaining information to substantiate that discharge will meet the effluent limitations and water quality standards in years to come may be a most difficult endeavor. However, if the variance is attained without excessive cost to the operator, the sealing requirements will not have a negative effect on the auger operation.

**Impact of Prohibition Restrictions**

The regulatory authority has the power to prohibit augering under the circumstances defined earlier in this section. If the regulatory authority exercises this control often, the augering industry may suffer se-
verely. Production would decline and operators may decide the supplemental coal recovery may not be great enough to compensate for the additional compliance problems and costs. The conditions under which augering may be prohibited are specific. However, prediction of the occurrence of these events which shall prohibit augering cannot be easily accomplished.

Auger mining shall be prohibited if adverse water quality impacts cannot be prevented or corrected. The possibility exists that in time any auger hole which was discharging water could begin to leak. This possibility in many cases will be very unlikely. However, if the possibility exists, this could be used to prohibit augering.

The requirement that auger mining be prohibited if fill stability cannot be achieved can also be interpreted in a few ways. Since a degree of fill stability to be achieved is not indicated, any deterioration of or leaking from an auger seal could be considered an instability. The occurrence of this cannot be accurately predicted beforehand in most situations. However, the possibility that any auger hole which has been sealed may begin leaking in time always exists.

Since the average recovery rate of augering is lower than the recovery rate of surface and underground methods, prohibition may often be on the grounds of maximizing the utilization, recoverability or conservation of the coal reserves. Auger reserves usually lie under overburden depths that are greater than can economically be stripped at the time when augering is to occur. It could be argued that, in time,
coal market conditions would make surface mining of those reserves economi
cal. Therefore, many potential auger operations may be
on the basis that maximum recovery of reserves would not be achieved.

Summary of Federal Regulatory Impacts

Interpretation of prohibition requirements and prediction of future
augering impacts by the regulatory authority will have a great impact
on the future of the augering industry. The requirements of the fed-
eral regulations can be used to prohibit augering in many cases. In
any event, the auger industry will have to operate with a reduced
reserve base, lower productivities, and increased operating costs
brought on by the federal performance standards for auger mining.
The summarized impacts of the federal requirements assuming no var-
iances are granted follow.

Barrier Pillar Requirements

- Decreased recoverable reserves by a minimum of 10%
- Decreased productivity depending on the increase in
delay and non-productive times.
- Increased operating cost per ton depending on the
amount of reserves sterilized in barrier pillars and
decrease in productivity.
- Possible prohibition of augering if underground
workings are within 500 feet of the highwall.
Hole Sealing Requirements

- Decreased productivity based on the availability of impervious material to the site, the extent of sealing required, the discharge treatment needed, the sequencing delays due to increased pit congestion, and previous state requirements.

- Increased operating costs depending on the decrease in productivity and the additional expenses for hole sealing and water treatment.

Auger Mining Prohibition Requirements

- The prohibiting of auger mining in many situations, based on site specific conditions and the attitude of the regulatory authority.

In summary, the federal augering regulations have already begun to further hinder the auger industry. The primary characteristic of current auger practices that does not conform with the objective of the regulations is its low recovery rate. The circular shape of auger holes and the lack of guidance controls cause a large percent of the recoverable auger reserves to be sterilized. The barrier pillar requirements will serve to reduce the recoverable reserve base; and thus, mineral right owners receive even less revenue from an auger operation. The stricter sealing requirements have increased the costs of augering, and consequently, have made augering an even less desirable extraction method. Unless technological improvements can increase the recovery and productivity rates of current augering practices, the federal regulations will depress and possibly eradicate the auger industry.
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NEW AUGERING
TECHNIQUES
NEW AUGERING TECHNIQUES

The standard machine now used in auger mining is a relatively small, simple machine designed to remove the coal quickly and inexpensively from abandoned and/or exposed highwalls. Its size and capacities are based primarily on the arrangement of the major design components.

Auger machines built for mobility (lighter, fewer flights to store and transport) are lacking in potential maximum penetration depth. Conversely, the large production-oriented augers are slower to transport from pit to pit, limiting multiple seam/site applications.

The drawbacks of present augering practices, with respect to OSM regulations and the concerns of lessors over potentially lost royalties include:

- low recovery figures and large, unattainable blocks of reserves, due to lack of adequate steering/guidance systems;

- magnified environmental hazard potentials due to acid drainage from auger holes;

- lost web coal due to the circular shape of auger holes;

- limited penetration depths.

To reverse the current decline in the augering industry, technological improvements must be aimed toward efficiently meeting the federal augering performance standards and improving the recovery ratio. The apparent key to this problem involves the upgrading or development of new auger machines, cutting heads and/or guidance systems. A more controlled and selective mining approach is needed to insure production
and environmental safety and thus the future of the industry. The following sections describe recent developments in each of the key areas and will ultimately evaluate each, according to its potential for complete compliance with OSM's regulations.

AUGER MACHINE DEVELOPMENTS

The first attempts to develop more capable augering machines were directed toward improving the materials and designs of components used in the standard augers. Larger engines for more power and deeper penetration, lighter or stronger auger flights for more control, and improved rock/interface detection sensors for better alignment and quality of coal mined have been added to the basic auger design with varying degrees of success. However, the most obvious achievements in improving auger machinery are seen in the new innovations for deep penetration and steeply pitching seam extraction. Five of the more promising developments are detailed below, including: two (2) extended depth augers, a high angle (non-horizontal) auger, a continuous mining auger, and a tower (vertical) auger.

Extended Depth Auger (SWRI)

Development of an extended depth auger is one of several auger mining technology improvement projects which is being funded by the Department of Energy and the U.S. Bureau of Mines. The Texas-based firm South West Research Institute (SWRI) has been contracted to design
and construct an auger machine that can achieve increased penetration depths. SWRI has utilized new innovations such as specialized smaller auger flights (10.5 feet long) and a new sensor system to achieve greater penetration depths as well as selective handling. These two features will be mounted behind twenty-four (24) inch diameter dual cutting heads. Each head is designed with a central breaker and replaceable drag bits on the outermost perimeters.

Aside from the cutter head, few other standard auger parts will be utilized in the machines composition. High strength lightweight steel will be used to construct the auger flights. This has been proposed to diminish overall flight weight; and therefore, the downhole friction on the longer (extended depth) flight line. Less resistance will allow for increased penetration and manageability. SWRI predicts depths of up to 490 feet in typical Appalachian coal fields and nearly 600 feet in the horizontally extensive seams of the Eastern Interior Province will be attainable with their auger machine.

SWRI has developed a scanner/probe drill which will provide guidance for the extended depth auger. The scanner is placed into a thin cut in the roof of the coal, and by insertion and withdrawal movements, it records the relative reflectance of the coal and roof rock. These values will be printed out on a recording chart in order that the operator knows the relative distances between the cutting mechanism and the roof rock at all times. The effectiveness of this system was successfully proven in the laboratory, but in the field it encountered major problems with
both the system's impedance of coal flow and with difficulties in thinning seams or unexpected floor rock contact. Additional guidance data will be supplied by an extendable probe that measures web thickness between each flight completion. This information will be used to prevent breakthrough to adjacent holes.

In conjunction with the guidance system, the extended depth auger will be powered by two large diesel engines; a primary, six-speed, 1200 horsepower engine and a 300 horsepower back-up system. These sources will supply the crowding force to the auger flight to obtain an average penetration rate of 12 feet per minute. A set of hydraulic jacks mounted on the main auger platform provides the vertical leverage and direction angle by which the cutting head is steered. The SWRI model has been designed so that it can be operated by two men. Training is necessary for one of these men to operate this system (Figure 5).

During the designing, building and testing of the auger, major emphasis will be placed on mobility and production. The self-contained unit is designed so that it can be moved from pit to pit with little time loss and essentially no land disturbance since it can be broken down into 3 major components that can be fixed with axles and wheels for transport. The sensor system and extended depth capabilities will allow for increased utilization of reserves in addition to higher and faster production rates. Additionally, the increased control of web thickness offered by this auger design should result in a higher recovery rate than can be obtained by a standard auger.
SOUTHWEST RESEARCH INSTITUTE'S
EXTENDED DEPTH AUGER SYSTEM

FIGURE 5

Adapted from Bibliography Source No. 31.
Extended Depth Auger (RAHCO)

In the past few years, the R.A. Hanson Company, Inc. (RAHCO) of Spokane, Washington, has been developing another type of extended depth auger. This machine is significantly different from the SWRI model. The Hanson Company Miner was developed independently under the auspices of the United States Bureau of Mines which later transferred control of the project to the Department of Energy. Design emphasis here is placed on achieving the highest possible production and recovery attainable for a machine with extended depth capabilities (Figure 6).

The component construction of the machine consists of:

- a large platform base with an in-pit (hole-to-hole) tramway;
- thirty (30) auger flights and sufficient racks for horizontal storage and loading;
- lead flight or cutting head with attached guidance package; and
- steering assembly.

The most crucial components of the auger are the guidance package and flight design. Their introduction into the system is expected to promote consistent mining of coal to depths greater than 600 feet. The guidance system is a form of pulse radar designed for non-contact, continuous monitoring of the coal/rock interfaces (both roof and floor) and of adjacent web thickness. The guidance system was developed for RAHCO by Battelle Pacific Northwest Laboratories. The guidance system is designed to provide the operator with a screen display of the
RAHCO'S EXTENDED DEPTH AUGER SYSTEM

FIGURE 6
cutter head and its relative position (distance) to the roof and floor rock. This information, coupled with constant surveillance of web thickness, is essential for selective handling of in-place reserves.

The cutting mechanism to be utilized by this auger is a dual 30 inch head equipped with interchangeable drag bits and central breaker unit. The subsequent flight will be constructed to include the guidance package and steering system directly behind the head. The 30 inch diameter conveying flights will be lifted off the floor of the hole by spider brackets, which are intended to reduce downhole friction. However, these brackets have proven to impede coal flow somewhat during lab tests but succeeded in reducing drag on the flights. The flights are constructed of heavy-duty steel, as opposed to the lightweight steel of the SWRI auger flights, to withstand the increased crowding pressure and frictional forces encountered with extended depths.

Powering the RAHCO auger will be three variable-speed diesel engines. The primary engine will be a 750 horsepower hydraulic transmission unit. It is designed to deliver sufficient torque to drive the heavy auger flights at 80 to 160 rpm to depths in excess of 600 horizontal feet. The expected penetration rate is approximately 15 feet per minute. The secondary operations of stacking and handling flights, as well as moving and positioning the auger machine, will be handled by two auxiliary diesel engines mounted in tandem on the auger platform.

As for transportation, the RAHCO machine design is too massive for unassisted movement. It was designed for maximum production at the
expense of overland mobility; and therefore, must be disassembled for pit-to-pit movement. This will entail a time-consuming process of breaking the machine down into its five major components which will then be moved by flat bed trailer. The larger machine size may also necessitate construction of a wider bench on which to set and assemble the components for operation. These features are major drawbacks to a machine's value if sufficient reserves are not present at the mine site to allow a long term uninterrupted operation.

In light of OSM regulations, the Hanson Company's extended depth auger provides two basic advantages over standard augering practices. The first is a highly sensitive guidance system. Theoretically, this will enable the operator to "see" where he mines, so as to promote selective and maximized extraction with decreased reserve sterilization. However, actual field testing is needed to prove this system's worth. The second feature is the designed combination of adequately powered engines with friction-reducing spider brackets to promote rapid penetration to the projected 600 foot depths.

**Variable High Angle Auger**

This concept was developed for the Department of Energy by Skelly and Loy in Harrisburg, Pennsylvania, in response to a need for new methods to reach "technologically sterilized" reserves (those coal seams which dip too severely for mining/augering by conventional methods). Examination of recent reserve studies has revealed that approximately
sixty billion tons of coal are contained in steeply pitching seams. The Skelly and Loy auger was conceived to extract reserves which dip at any angle from horizontal to ninety (90) degrees by utilizing an adjustable (variable angle) mast with hydraulic supports (Figure 7).

Major emphasis in the conception of this machine was placed on simplicity (using stock components, where possible) and system designs that would not necessitate excessive operator training. Construction consists of a self-contained unit with sufficient platform space for:

- the angled (variable) tower;
- the drive system;
- flight loading and storage system;
- coal conveyors.

The unit is mounted on crawler treads for movement and alignment within the pit.

The main feature of this angle auger concept is the flight tower. The flight tower is hinged at the base platform and is tilted by hydraulic support rams until the desired augering angle is achieved. The rotational drive and crowding force required to cut and convey coal at variable angles are provided by diesel engines whose capacities are determined by the angle and depth of augering, and by the inherent characteristics of the coal (i.e. density, swell).

The main drive consists of two (2) diesel engines with hydraulic pump combinations. The primary engine has a 700 horsepower V-12 design that will power all hydraulic operations, including positioning.
FIGURE 7. SKELLY AND LOY - HIGH ANGLE (VARIABLE) AUGER.
rotating, extracting, uncoupling and stacking the auger flights. The secondary motor is a smaller diesel capable of producing 200 horsepower and is designated to run all electrical systems on the auger.

Although this machine is a design concept with no particular cutting tool or guidance package specified, a suggested head design is one of the recently researched "square hole" cutters - discussed in more detail in the following sections of this report. This hole configuration allows higher recovery rates to be achieved than can be realized with the standard auger head. Using any single cutting head and one of the many standard guidance packages, this auger may be capable of achieving up to a 250 feet penetration depth in seams dipping from the horizontal to 90 degrees. As such, this particular machine is more responsive to the environmental concerns of the Office of Surface Mining than standard augers since down-dip augering greatly reduces the potential for acid drainage. Incorporation of more sensitive guidance apparatus or more efficient cutting heads will allow this machine to obtain a higher recovery rate than conventional augering.

Guided Continuous Miner (RSV)

A Dutch mining equipment manufacturing firm, Rhine-Schelde-Vevolme (RSV) Mining, has devised an augering machine with continuous head cutters and extended auger conveyance. Its objective in this effort was to develop a maximum recovery/high production, selective mining apparatus. Laboratory tested and proven, this auger is soon to
undergo field demonstration in or near Buchanan, West Virginia, in conjunction with Coal Systems, Ltd.

The machine is engineered into three major components, which can be broken down and transported by low-boy trailers considerably faster and easier than the SWRI or the RAHCO extended depth augers. The basic components include:

- cutter head module with base frame;
- power supply module; and
- push beams and conveyor system.

In the pit the unit is affixed with tracks or crawlers, as is the independent power supply module. This allows hole to hole mobility and a turning radius of 180 degrees for alignment (Figure 8).

The most impressive design of this system is that of the cutter head-push beam assembly, or the cutting string. A continuous mining cutter utilizes two (2) hydraulic motors, which power twin cutting chains, gear boxes, and drive shafts. It measures 80 inches in width and will swing up and down on hydraulically controlled swing arms to accommodate coal heights of 18 to 40 inches. The hole produced is roughly rectangular in shape and accounts for the removal of 80 - 85% of the reachable coal. The hydraulic motors within the head produce 200 horsepower (enough to turn the cutting chain assembly at 140 rpm). Each subsequent auger flight (or push beam) measures 20 feet long x 16 inches high x 6.6 feet wide. These beams are shielded to prevent damage to the high pressure hydraulic lines contained within and convey
FIGURE 8. SURFACE STRUCTURE FOR GUIDED CONTINUOUS MINER.
coal cuttings by means of dual 16 inch diameter augers (Figure 9). Although the original machine is equipped with sufficient push beams to penetrate to 220 feet (beams are stored on the ground) the developer has estimated achieving depths of 300 to 600 feet within the next few years.

Also contained within the cutting head module is the guidance system. It is located 10 feet behind the cutting mechanism and consists of three backscatter-sensors, which measure roof, floor and rib coal thickness. The operator is warned of an approaching interface of coal/rock or coal/void by red and green lights on the control panel. Steering is accomplished by means of a hydraulically activated, side shoe for horizontal movements and a top and bottom pusher system (hydraulic cylinders) for vertical direction. This system most effectively complements the swing-arm cutter head by allowing the efficient removal of the entire coal height and by measuring remaining pillar and support web thicknesses.

The power source employed by the continuous mining auger is a mobile diesel generator and hydraulic pump set. It produces 760 horsepower and a maximum hydraulic pressure of 3000 psi, which is carried from the engine to the hydraulic swing arms at the cutting head in a specially constructed one-piece hose. This unit will run all major functions of the auger, including loading push beams, providing crowding force, powering auger rotation and supplying conveyor power. A secondary 200 KW electric generator is included to run all electrical functions (lighting, control panel, sirens, etc.).
FIGURE 9. CUTTER HEAD CONFIGURATION FOR GUIDED CONTINUOUS MINER.
A system of this caliber has several advantages, especially in light of the OSM regulations. Some of the more notable points of this machine include:

- The rectangular holes afford maximum recovery with minimum sterilization.
- The depth (including future projections of 600 feet) permits greater productivity and could be considered a primary mining system in many instances.
- As a primary mining system, health and safety hazard potentials are substantially decreased in comparison with other mining methods.
- Compared to other augering methods production and percent recovery are greatly increased without sacrificing personnel or environmental safety.

Several problems have been encountered during development of this auger. The most restrictive of these problems is that of coal flow. Once cut, the coal is collected by a scoop pan. Any coal escaping the scoop is left on the floor and forces the cutting mechanism upward toward the roof. Back-tracking and undercutting is then required to remedy the situation. Similar problems may or may not be encountered by the box-like structure of the push beams since there is not much space for entry of larger sized coal cuttings.

**Square Hole Drill**

This augering method was conceptualized in 1976 by James C. Justice and Frank A. Delli-Gatti, Jr., of Coaltex, Inc., Beckley, West Virginia. It was designed specifically to maximize coal recovery by capitalizing
on the significant amounts of web coal unnecessarily left between holes by standard auger practices. It achieves higher recovery due to its square hole design.

The machine itself is based on the addition of side or wing cutters behind a standard single cutting-head (Figure 10). These wings are comprised of continuously rotating drums which are equipped with and driven by cutting chains. They are attached to the main auger shaft by a cylinder control block which is mounted directly behind the cutting head but remains stationary while the rest of the machine is torqued. This cylinder block contains the adjustable hydraulic rams which control the extension and retraction of the wing cutters. Stability against overturning or skewing in the seam is provided by 3 ski-brackets arranged in triangular fashion around the wing cutters.

As the machine enters the coal seam, the wings are retracted and aligned behind the main cutting head. Vertically, the drums measure approximately equal to the diameter of the single cutting head. The diameter of the drums is such that when retracted, the drums cut a square hole equal in width to the single cutting head's diameter. In this retracted position, the wings are continuously rotating and cutting thereby squaring-up the hole as the auger penetrates the seam.

Once the maximum depth has been reached in a hole the wings are hydraulically extended in the horizontal direction and additional coal is backreamed, to both sides of the cutter head, equivalent to the width and height of the wings. The name "square hole drill" then
COALTEX BACK-REAMING CUTTERHEAD

FIGURE 10
becomes somewhat of a misnomer since the resulting down-hole configuration is actually rectangular. As the extraction of the auger head nears the entranceway, the wing cutters are once again folded in behind the head in order to leave more coal near the highwall for additional support.

The disadvantages of this system are caused by the complexity of the system and the potential for down hole damage to the additional parts exposed to roof fall and binding forces. Here again, as in most cases of auger machines containing extra cutting equipment, a problem is also encountered with coal flow. The coaltex auger attempts to compensate for this by having the accessory cutters rotate outwards, thus throwing the bulk of the cut coal around the congested area and back toward the auger flights.

SUMMARY OF NEW AUGER TECHNIQUES

To determine which of the innovative augering techniques are congruous with present OSM regulations and merit continued research, it is necessary to review the characteristics of each machine in light of production and recovery potentials as well as environmental compatibility. Table 6 has been constructed to provide a comparative listing of machine specifications. The summarized data in Table 6 and the following discussion of the virtues and problems associated with each new augering technique provide the basis for determining the candidate systems for further research, development and testing. These systems may provide an economic and environmentally acceptable alternative to the standard
<table>
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<tr>
<th>AUGER TYPE</th>
<th>TYPE AND SIZE OF CUTTING HEAD</th>
<th>GUIDANCE SYSTEM</th>
<th>DEPTH</th>
<th>FLIGHT LENGTH</th>
<th>POWER SOURCE</th>
<th>AUGER STORAGE</th>
<th>MOBILITY</th>
<th>MANPOWER</th>
</tr>
</thead>
<tbody>
<tr>
<td>SWRI: EXTENDED DEPTH AUGER</td>
<td>Dual head with drag bits. 24&quot; dia.</td>
<td>Light reflectance sensors for roof/coal interface. 17&quot; probe drill to monitor web thickness.</td>
<td>490' in typical Appalachian mines. 600' in trench-strip.</td>
<td>10.5'</td>
<td>Primary: 1200 hp, 6 speed diesel. Secondary: 300 hp diesel.</td>
<td>Mounted vertical storage racks.</td>
<td>Self-contained transport and alignment system.</td>
<td>2 men; full shift, minimum training.</td>
</tr>
<tr>
<td>RAHCO: EXTENDED DEPTH AUGER</td>
<td>Dual head with drag bits and central breaker. 30&quot; dia.</td>
<td>Pulse radar monitoring. Roof, floor and ribs visible on screen for operator.</td>
<td>600' in extensive flat-lying seams. Up to 800' in trench/strip augering.</td>
<td>20'</td>
<td>Primary: variable speed diesel w/hydraulic drive-750 hp. Secondary: 300 hp electric.</td>
<td>Mounted in horiz. storage racks.</td>
<td>Must be dis-assembled and moved via trailers from pit to pit. In-pit movement by machine mounted push rail.</td>
<td>2 men; full shift, one operator, must be trained.</td>
</tr>
<tr>
<td>GUIDED CONTINUOUS MINING AUGER</td>
<td>Continuous mining head with chain cutters. 18&quot;-40&quot; Dia.</td>
<td>3 sensors using back scatter radar to monitor roof, floor and ribs.</td>
<td>220' at present. 300'-500' projected in next 2 years.</td>
<td>20' length 16' height 6.6' wide (push beam)</td>
<td>Primary: 760 hp diesel w/hydraulic drive. Secondary: 200 kw electric.</td>
<td>Stacked on the ground.</td>
<td>Must be broken down into 3 movable components. In-pit mobility.</td>
<td>2 men; full shift, both men require operator training.</td>
</tr>
</tbody>
</table>
techniques hampered by present regulations.

The continuous mining auger has high potential for maximizing coal recovery. The combination of an extremely efficient cutting mode with a capable scanning/guidance device (such as backscattering radar) will provide for very high production and selective mine design. Additionally, this machine is engineered to allow the guidance system to be adaptable to site conditions. This permits the replacement of guidance systems in areas where another design is more efficient than the radar sensors in the original design.

This method limits the environmental hazard potential because the rapid penetration rate allows the coal seam to be exposed to outside elements for only a limited amount of time before the hole is sealed, thus restricting the volume of acid drainage that can flow from the hole. This fact, the comparatively high projected recovery rate (greater than 80%) and the ability to avoid reserve sterilization designate the continuous mining auger as a technique with very great potential as a primary mining method for flat-lying seams.

Both types of extended depth augers have been developed to the laboratory testing phase, but neither has been extensively tested in the field. Though different in design, both are efficient in their own right. The SWRI auger shows ideal suitability for limited highwall lengths and multi-seam jobs requiring increased mobility. Its guidance system is sound, but due to packaging and comparative performance, it is not competitive with radar types. Both extended depth auger designs show
a marked improvement in performance over standard auger equipment. However, only minor advancements have been made toward limiting environmental risks and maximizing recovery.

The Hanson auger is also geared for high production rates (15 feet penetration/minute). It is ideally suited for extensive highwall augering or trench strip and auger techniques in or near horizontal seams. Although it possesses a more sophisticated guidance system (pulse radar), optimum efficiency of the unit has not yet been achieved. The design of the radar scanner permits it to be adversely affected by excessive coal dust which can easily cause it to malfunction. This problem complicates selective handling and can result in "frozen" reserves. The Hanson Company feels that it can improve the telemetry and signal feedback to overcome these problems in the immediate future. However, packaging the system to avoid coal flow impedance must still be accomplished.

Since the environmental risks and coal recovery percentage associated with the extended depth augers are not much improved over those connected with standard augering practices, these extended depth augers have only limited potential to become effective primary mining systems.

The High Angle Auger System is presented as a specialized auger concept. This concept has more flexibility than the other auger approaches but does not have their production potential. Maximum proposed penetration (in ideal conditions) is about 200 feet for this machine which does not compare with the 400 feet to 600 feet projections of the previous models.

The design of the system does, however, permit downdip augering
from any angle (0 to 90 degrees from the horizontal). A variety of cutting heads and guidance packages can be incorporated into the concept design. These options may allow high recovery rates to be realized. Additionally, the steep dips of many of the seams that potentially can be augered by this technique provide a natural impoundment for acid water which prevents drainage from the hole prior to sealing. In these situations, the High Angle Auger system is superior in maintaining the quality of the environment compared to other systems. Properly equipped, this proposed auger machine could be an effective and economic means for recovering coal from steeply pitching seams that were originally considered unmineable. Further research and development work may also produce extended augering capabilities in steeply pitching seams increasing the potential value of this concept considerably.

Finally, the Coaltex Square Hole Drill has several design advantages over standard coal augers. Because the final auger hole is rectangular in cross-section, the Square Hole Drill will potentially increase coal recovery (by as much as 35%) by extracting significant amounts of web coal unnecessarily left between holes by standard augers. Also, since the additional web coal is recovered during auger flight extraction via backreaming, sufficient web coal is always present to support the roof during auger cutting head penetration. Because the wing cutters are retracted before the auger head is extracted from seam, additional web coal is left for support near the highwall. This will add to the safety of the auger crew working below the highwall. However, the environmental risks of traditional
auger practices are also incurred with the use of the Square Hole Drill for highwall coal recovery.

The Square Hole Drill has a great potential for increased coal recovery with reduced chance of head damage due to superior roof support. Even more important may be the fact that cutter wings of this type could theoretically be mounted on the sides of a dual head auger. This would allow backreaming capabilities in conjunction with extended penetration depths. The increase in recovery would not be as great as that for a single head auger, but the increase should still be significant.

**Auger Heads**

Development of specialized cutting tools for auger machines has been a continuous process since the industry’s inception. Beginning with horizontal drills (which for the most part pulverized or ground up the coal) and continuing to the development of such techniques as early chopping heads and chain cutters, many methods have been attempted. Recently, augers have been utilizing various single, double, or triple headed cutters of a barrel shape. These heads are peripherally lined with interchangeable, tooth-like drag bits for breaking up the coal. Some improvisations on these cutting heads have been made in the past few years, such as the addition of a central core breaker, but generally they have remained the standard of the industry.

The following sections discuss several of the more promising developments in auger head design.
Expandable Back-Reaming Auger

This system, although finalized and tested by Southwest Research Institute, is based on a concept designed and developed under the auspices of the Department of Energy. It utilizes standard cutting head(s) and supporting auger flights but differs from standard augers in the construction of the first flight adjacent to the cutting element. This flight is five (5) feet long and is equipped with hydraulic accumulators or expansion joints so that the metal screws comprising the auger flight are segmented or interspersed with flexible fittings (Figure 11).

During penetration into the seam, the first five (5) foot long flight is contracted and performs as a normal auger. However, once withdrawal of the cutting string begins, the first flight is expanded progressively outward (towards the cutting head), using the hydraulically operated flexible joints. Small drag bits similar to those on the cutting head are arranged along the outer perimeter of the expanded flight and affect the back-reaming during withdrawal.

The expansion of the first flight is adjustable to any thickness up to double the original diameter of the flight screw. This allows for complete augering of most seam thicknesses without costly auger flight interchange or replacement. As the expanded segment of the flight line approaches the highwall opening, the spiral is contracted to normal size in order to leave more coal for highwall support.

Some noted disadvantages of this unit include the lack of back-reaming
FIGURE 11. EXPANDABLE BACK-REAMING AUGER.
guidance, and therefore, selective mining. Since the standard auger tends to wander in an up and down fashion inside the seam, there is no way to keep a consistent distance between the center of the hole and the roof/floor. Once back-reaming is begun, the expanded sections will (while following the course taken into the seam) several times contact and cut portions of the roof/floor thereby decreasing coal quality and leaving unmined coal behind. An additional drawback is that the expandable segments can only be used behind a single-head auger.

**Corner Reaming Auger Head**

Also included in the testing of the United States Bureau of Mines prototypes, this system was redesigned by SWRI to increase productivity. It employs a standard auger head(s) and mounts an additional set of cutting elements behind the cutting and guidance packages (Figure 12). These elements consist of four (4) conical reaming devices, located in the corners. The purpose of each is to break-out the bypassed roof and floor coal, giving a square appearance to the hole.

The cones rotate on their own shafts, which are independently connected to the auger flight, but they do not have the helix design for coal transport. Although this apparatus produces far more coal, it has several drawbacks. The most obvious difficulty of the system is encountered with recovering the coal reamed out of the corners. This type of auger also requires extra bracing to support the reamers and reduce head friction. Not only is this bracing an encumbrance to coal flow, but
it also increases the horsepower requirements of the drive.

Square Hole Auger Head

Following the established principle that squared-off holes maximize recoverable coal, the USBM developed a "s quar ing" apparatus that is mounted behind a guidance package for use with a standard single-head auger (Figure 13).

As opposed to the Corner Reaming Auger Head which employed conical cutters in each corner of the hole, this system utilizes a Reuleaux triangle cutter. The triangle rotates by the power of the main auger flight and reams out the corners of the originally round hole due to it's elliptical orbit. The result is a "square hole" with four rounded corners. This achieves a higher recovery rate; but several problems still exist with this approach.

The disadvantage of the Square Hole Auger, as with most devices utilizing this principle, concerns the amount of coal lost using a round auger to transport coal out of a square opening. Additionally a problem exists with down hole spacing. The difficulty with which originally mined coal bypasses the guidance system is compounded when a secondary cutting element is mounted directly behind the first flow barrier. However, the system has functioned and shown promise in field tests so far.

Although a square hole auger head can be utilized with a standard auger flight, a truly efficient system could possibly be created if an effective and compact guidance system is included in the machine design.
FIGURE 13. SQUARE HOLE AUGER HEAD.
Not only are selectivity and production increased with the addition of a steering package, but by limiting its size, the problem of coal flow may be significantly decreased. Numerous types of guidance systems have been developed, but recent advances have been made in only a select few. The following sections will give a brief summary of their descriptions and potentials.

**New Guidance System Approaches**

Control of auger machinery is the primary objective of these new developments. It is the key to compliance with recent regulations as well as to greatly increasing recovery. The Department of Energy has selected a few of the more promising guidance theories and funded their research and development. This discussion will deal with the most favorable of the recently designed and tested guidance systems. It will also attempt to illustrate the progress being made toward consolidating and/or compacting these units to alleviate coal flow problems and downhole damage.

Based on past experimentation, the most suitable sensors are those measuring the non-mechanical properties of the coal and roof/floor rock, (i.e., resistivity, conductivity, reflectance). However, they have experienced common difficulties in receiving and delineating the proper coal/rock interface signal due to numerous signals from other surfaces. Thus a major obstacle in the development of these guidance systems is fine-tuning and background elimination. Despite these disadvantages the
following coal-interface detectors (CID's) have been recognized as the most compliant with modern needs.

**Pulse Radar**

This CID is based on the principle of electromagnetic wave reflectance. Simply put, the amount of time for a wave to reflect off a material and return, along with the measured size of that wave on its return, are indicative of the material type and thickness. The equipment necessary for this type of sensor are short horn antennae - one to transmit the signal and the other to receive. An advantage of the system is that it is non-contact, limiting the risk of damage and allowing for convenient placement on the auger. Presently, manufactured models can measure the coal interface from 0 - 11 inches with plus or minus one inch error.

A related system called the Frequency Modulated Continuous Wave Radar (FM-CW) applies the same principles but uses different transmitting waves and larger antennae. A typical horn antenna for this system measures 13 inches by 10 inches and may become a problem to protect.

Both radar systems have been studied extensively by ENSCO, R.A. Hanson Co., SWRI, Foster-Miller, NASA and Britain's National Coal Board (NCB). They have found radar to be very effective in given situations. However, all agree that more research is necessary to overcome:

- short target range;
- signal thinning and fluctuation;
- multiple wave returns.

Gamma Backscatter Sensors

The Gamma Backscatter Sensor uses a directed radiation source to infiltrate the coal/rock interface and measures the time required for gamma rays to "bounce" back to the unit. An acceptable gamma source material for this CID is Cesium 137 or Americium 241, both of which have been tested. The principal of the return is a process called Compton scattering, which directs some rays back to their source. The quantity of measured backscatter is inversely proportional to the coal/rock density.

Continued research of this method has provided some improvement. Signal clarity was found to increase through tilting of the source and detector's positions. It was found that the number of measurable counts or returns was significantly improved by increasing the source strength. A major advantage was the development of a smaller, 2-point floating-head sensor exhibiting the potential to measure up to 8 inches of thickness with a plus or minus 1/2 inch accuracy.

The disadvantages of this system include measuring errors from air gaps between the device source and coal surface and receiving back-scattering interference from impurities found in the coal seam. There are also potential hazards associated with working near unshielded radiation sources even though the radiation source used for the gamma backscatter sensor is not strong and does not have to be licensed by the Nuclear
Regulatory Commission (NRC). Research is continuing by all developers of this system to study the potential safety problems associated with long term exposure.

Natural Gamma Radiation Sensors

The third CID to be examined is a natural radiation detector which measures gamma radiation inherent in the coal/shale relationship due to the high gamma concentrations in potassium. Radiation from potassium-rich shales is absorbed to an extent by adjacent coal beds. The amount of radiation measured reveals the coal thickness and coal/shale interface.

Some of the more attractive features of this sensor system include non-contact and compact design. The accuracy claimed for the N.G.R. Sensors is 0 to 6 inches of coal thickness with a plus or minus 1/2 inch error. Additionally, there is essentially no outside interference to these measurements from dust or air gaps. However, the accuracy of the unit will depreciate to plus or minus one inch as a result of low radiation counts.

The safety factor in this design is obvious in that there is no additional radiation source incorporated into the system. This feature also adds to the Natural Gamma Radiation Sensor's compactness. The unit consists essentially of a gamma counter and its relays and filters.

Since steering and guidance systems are the key to advancing remote mining techniques, further research and development programs are necessary to improve upon these systems to overcome their drawbacks.
Companies and agencies such as Foster-Miller Associates, Waltham, MA; Southwest Research Institute, San Antonio, TX; R.A. Hanson Company; ENSCO, Inc.; U.S. Bureau of Mines; National Aeronautics Space Administration; and Great Britain's National Coal Board, are presently working independently or in conjunction with the Department of Energy to develop these specialized guidance systems.

The augering research being conducted is directed toward making auger mining a much more acceptable method for coal recovery under the regulations. Guidance systems and square hole augering will allow auger recovery rates to be comparable to those obtained by underground, and possibly even surface methods. Increases in productivity and recovery rates will make augering more favorable to mineral rights owners. Therefore, if the auger industry is to survive under the restrictions of the federal regulations, the current research efforts of government agencies and private companies must be continued.
IMPACT OF BARRIER PILLAR REQUIREMENTS ON INCREASED UNDERGROUND MINING
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IMPACT OF BARRIER PILLAR REQUIREMENTS ON INCREASED UNDERGROUND MINING

The intent of the barrier pillar requirements between groups of auger holes is to provide areas of undisturbed coal for workable access to those reserves mineable by underground methods. This will allow resource recovery to be maximized. This section of the report will:

- Examine the types of underground mining that can potentially benefit the most from these barrier requirements;
- Determine the mining regions where increased underground activity is likely to occur;
- Delineate the possible underground mine development alternatives when barriers are and are not present (for three development situations);
- Present a methodology to determine the extent to which underground reserves will be maximized due to barrier pillar requirements; and
- Evaluate the success of the barrier pillar requirements in enhancing resource recovery through increased underground mining on three test sites.

UNDERGROUND MINING METHODS

Basically, underground mining operations can be divided into two categories. The first includes those mines which have many operating sections and vast recoverable reserves. The expected life of these operations is usually in excess of 10 years. Large underground operations of this type require enormous amounts of mining equipment, extensive surface facilities, and consequently, vast capital requirements.
Because of the extent of the reserves required for an operation of this magnitude, mines of this size do not often occur in the higher elevations of steep slope Appalachia where augering is common. Large underground mines in Appalachia usually occur in lower seams that do not outcrop along a hillside. In the Eastern Interior Region, large underground operations are very common. In most cases, these mines also occur in seams which do not outcrop on the surface.

Access to large underground mines is predominantly accomplished by driving a slope or shaft from the surface to the seam to be mined. The large capital required to develop slope or shaft access is offset by the total market value of the vast recoverable reserves and the long depreciation period for the operation.

At times, extensive underground reserves can outcrop at some point on the surface making them accessible by drift entries. Drift entries are horizontal headings driven into the outcrop of the coal seam that follow the inclination of the coal bed. Since driving entries through coal is easier than driving them through rock and since the creation of drift entries results in the recovery of coal, the capital expense required to drive and maintain drift entries is considerably less than the expense for slopes or shafts. This fact makes drift entries the most attractive method of coal seam access.

The second category of underground mining includes those mines which have only one or two operating sections and limited recoverable reserves. The mine life of those operations can be anywhere from one
to a few years. Because of the small revenue recouped from an operation of this type and the short mine life over which capital investments can be depreciated, total capital requirements to initiate mining must be kept to a minimum. In order to keep capital needs low, used mining machines usually comprise the equipment fleets used to extract the coal.

Development costs must also be kept as low as possible. The large capital costs for slope or shaft access could not possibly be absorbed in an operation of this size if a profit is to be made. This necessitates that drift entries be utilized for initial mine development. Therefore, these smaller underground mines can only exist where coal outcrops on the surface or at the base of a highwall. Because these mines are characterized by short drift access entries from an outcrop, they are commonly referred to as punch mines.

Punch mining is very common in the steep slope areas of Appalachia. Coal seams often outcrop the entire way around a mountain ridge. The entire ridge is sometimes surface mined by a mountaintop removal method. In many cases, however, the strip ratio on the site is too excessive to justify complete mountaintop removal. If this situation exists, contour mining to the limiting economic highwall is commonly practiced along the seam outcrop. This leaves a limited tonnage of reserves under the core of the mountain. Auger mining is commonly practiced to recover additional reserves; however, limited reserves under the center of the ridge often remain after augering is completed. These reserves can potentially be recovered by a punch mining operation if the economics are favorable.

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In the Eastern Interior Region limited amounts of contour outcrop mining is performed. The contour mining practiced primarily occurs in the rolling hills of Western Kentucky. The reserves that remain in place following contour or modified area mining in this region are usually more extensive than those remaining after contour mining in Appalachia. This can be attributed to the fact that seams are usually more continuous in the gently rolling terrain of the area, and entire ridges are seldom encircled by an outcrop. Because of this, punch mining is not practiced very often in the Eastern Interior Region.

Small scale punch mining in the steep slope terrain of Appalachia can potentially benefit the most from the barrier pillar regulations. The primary reasons for this are:

- Auger mining is practiced the most in eastern Kentucky, West Virginia, Tennessee and Virginia.

- The nature of the coal deposits and topography cause isolated pockets of limited reserves to remain in place following contour stripping.

- The steep and rugged terrain make shaft and slope development even more costly or impossible.

- Underground reserves beyond an augered highwall in the Eastern Interior Region are usually more extensive and thus higher capital requirements for other methods of seam access can be justified.

- Slope and shaft development costs are lower in the Eastern Interior Region because of less rugged terrain (more level areas and shorter entry distances to access surface mineable areas.)
UNDERGROUND MINE DEVELOPMENT ALTERNATIVES

After the economic limiting highwall has been reached in any surface mining operation, augering can be conducted to recover additional tonnage. Following augering, sufficient reserves may still remain to be recovered by underground mining methods. Yet, the tonnage remaining may not be sufficient to justify slope or shaft development to access the coal bed. Also, in steep terrain, slope or shaft construction may be technically infeasible. If these conditions exist, drift entries may still be utilized to access the coalbed and recover the remaining reserves. However, if the auger operation is conducted along the entire length of the outcrop without leaving barrier pillars between groups of auger holes, drift development is extremely difficult or even impossible. Unless another economic method of accessing the reserves can be utilized, the remaining reserves will not be recovered.

Development of drift entries to access underground coal reserves through solid blocks of coal is not a technically difficult task if the seam is of sufficient thickness and roof conditions are adequate. However, if auger mining is conducted without leaving solid blocks of coal for entry development, accessing the underground reserves is extremely difficult and costly. If large amounts of underground reserves remain and surface topography is not rugged, development of a slope or shaft entry may be economically feasible. Barrier pillars will not serve to increase underground mining activity on a site where the underground reserves are substantial enough to justify slope or shaft development.
To evaluate the degree to which underground reserve recovery will be maximized on any given site due to the barrier pillar requirements, the economics of reserve access must be examined. Barrier pillars left after augering may allow maximum resource recovery to be achieved by providing the only means of economic access to underground reserves on sites where:

- the remaining coal reserves are not great enough to compensate for the high cost of slope and shaft development (slope and shaft economically unfeasible);

- the surface terrain is too steep and rugged to allow slope and shaft development (slope and shaft technically infeasible).

To estimate the extent to which underground mining activity is increased due to barrier pillar requirements, the extent of underground mining that would take place if barrier pillars were not required must be known. If the revenue generated from underground reserve recovery is great enough to compensate for operating and mine development costs, underground mining may be economically attractive. Therefore, to evaluate the degree to which reserve recovery will be maximized on any site, the economics of reserve access must be compared when:

- barrier pillars of the dimensions specified by the federal regulations are left between groups of auger holes;

- augering was conducted without leaving barrier pillars between groups of auger holes.

On steep slope sites where barriers were not left, there are a few possible methods that can be used to gain access to underground
reserves. Shaft and slope development will not be considered as viable means of underground access on steep slope sites for the reasons previously noted in this section.

One possible method to access underground reserves through a completed augered outcrop involves cribbing auger holes to provide roof support. If subsidence has not occurred and the auger hole diameter is greater than 36 inches, cribs can be constructed for the entire length of the auger hole to support the roof. The first crib is constructed at the entrance to the auger hole. Subsequent cribs are built directly behind the previous crib until the entire hole has been cribbed. This is a very slow and dangerous process. Cribs must be constructed from the front to the back of the hole one at a time so that the worker is always under supported roof. Due to the restricted work space, the difficulty in cribbing an auger hole becomes greater with decreasing auger hole diameter. To insure the roof is supported adequately, crib construction is accomplished concurrently in a block of adjacent auger holes. In this way, an entire false pillar is advanced toward the back of the auger holes. This process continues until an entire false pillar has been created. Depending on the number of drift entries needed, several cribbed pillars must be constructed. Four cribbed pillars would be required to support the roof for three entries. The pillar width required will depend on overburden conditions on the site. Entries can be driven between cribbed pillars to access the solid seam.

Construction of cribbed pillars to provide roof support for entries
can only be accomplished if specific conditions exist on the site. The roof above the auger holes must not be subsided. In many states, the regulatory authority must grant permission before anyone can enter an auger hole. The difficulty of crib construction will increase with decreasing auger hole diameter. Holes less than 36 inches in diameter may be too small to crib. Although auger hole cribbing is not a common practice and can be very hazardous, it has been utilized successfully in the past to gain access to underground reserves. However, the federal auger hole sealing requirement will make cribbing of auger holes impossible in the future if a variance waiving sealing requirements is not granted. For this reason, cribbing will not be considered a viable method for development of underground reserve access where barrier pillars are not present.

Underground reserves can also be reached by excavating a sufficiently wide corridor back to the end of the auger holes with surface mining methods. Once the solid block of coal is reached, underground development can begin in the seam. This excavation must comply with all surface mining regulations, and therefore, the spoil must be disposed of in a head-of-hollow fill, valley fill, or suitable excess spoil disposal site. The depth of overburden above the auger holes will be great since it is beyond the economic stripping cut-off. The width of the cut required must be great enough to allow a minimum of three entries to be developed in the solid coal block.

If mine development costs for excavating overburden back to solid coal are low enough to allow underground reserve recovery to be profitable,
barrier pillars left on the site will not serve to maximize recovery since underground mining would be economic without them. Therefore, to determine if leaving barrier pillars will increase reserve recovery, the mine development costs must be estimated for the following situations:

- Access to underground reserves is achieved by driving drift entries through barrier pillars left between groups of auger holes.
- Access to underground reserves is achieved by excavating the overburden back to the full depth of the auger holes.

Mine development costs are also dependent on the overall mining conditions that exist at the time when mining is initiated. In particular, underground development can be initiated from the working bench in an active strip/auger mine, after reclamation of a strip/auger mine has been accomplished, or from an abandoned bench on an unreclaimed site. The underground mine development rationale and the factors that affect the development costs are examined for each of these situations to evaluate the barrier pillar impact on reserve maximization.

**Underground Mine Development From An Active Pit**

During the progression of an active strip/auger mine, a decision may be made to develop an underground punch mine from the working bench to recover additional reserves. After the decision has been made, development of underground access will be a major concern of the mine operator. In this situation, the mine operator will always leave a sufficient barrier between groups of auger holes at the point along the
highwall where he wishes to begin underground development. It would be very unwise for an operator to auger the outcrop completely and attempt underground access by some means other than driving drifts through a solid pillar. Figure 14 illustrates that a minimum of 20 percent of the coal will be recovered from a 250 foot wide pillar by the mine operator when it is used for entry development. This is based on development of three 16.5 foot wide entries without any crosscuts. If auger hole lengths approach or exceed 100 feet, crosscuts are turned approximately every 50 feet, and coal recovery from entry development increases,

Even though the recovery from this block is usually lower than the recovery achieved by augering, the savings in underground access costs by driving drifts rather than excavating overburden to create a 250 foot wide passage back to solid coal are much greater than the revenue obtained from the slightly higher recovery. A cost estimation for excavating a passage of this type will be presented for the next underground mine development situation.

The barrier pillar requirements of the federal regulations will not result in increased reserve recovery when the underground mine development is to be initiated on a bench of an active strip/auger mine. This is because barrier pillars would be utilized for entry development even if the federal requirements did not exist. However, reserve recovery may be greatly increased by barrier pillar requirements in other mine development situations.
FIGURE 14. MINIMUM DRIFT ENTRY COAL RECOVERY.
Underground Mine Development on a Reclaimed Strip/Auger Mine Site

The economic feasibility of developing an underground punch mine on a reclaimed mine site is dependent on many factors. Assuming shaft or slope development is not economically or technically feasible under steep slope and limited reserve conditions, other access methods must be examined. If barrier pillars were not left between groups of auger holes, a passage to reach the solid coal block will be excavated. However, if unaugered barriers were maintained, these barriers will be utilized to drive drift entries to reach the underground reserves.

On an active site, a working bench was present from which underground mine development could be initiated. A reclaimed site does not possess this feature. Because a bench is required at the mine mouth to facilitate haulage and support activities for the mine, the reclaimed spoil will have to be excavated back to the old highwall regardless of whether barrier pillars are left or not. At this point, the factors that affect the cost of underground access development are presented for both development methods. The costs associated with excavating reclaimed spoil back to the old limiting highwall are the same for both development methods.

These site preparation costs are dependent on the following factors:

- permitting cost for the surface excavation;
- access road construction cost to reach the reclaimed mine bench;
- sedimentation control costs;
- drainage control costs;
- consolidation of the old spoil;
- excess spoil disposal site location;
- haul road length needed;
- clearing and topsoil handling costs;
- volume of spoil to be excavated;
  - old pit width
  - slope of reclaimed spoil
  - width of excavation (at least 250 feet)
- spoil revegetation costs;
- surface excavation equipment fleet owning and operating costs;
- labor costs.

The development costs for accessing the solid coal seam by excavating a passage to the depth of the auger holes are based on the following site specific conditions:

- volume of overburden to be excavated for passage;
  - depth of auger hole
  - width of block to be exposed
  - slope of terrain
  - highwall angle needed for stability
- excess spoil disposal site location;
- additional sedimentation control costs;
- drainage control costs;
- haul road length needed;
- clearing and topsoil handling costs;
  . vegetation type and density
  . topsoil thickness and removal method
- consolidation and type of overburden;
  . drilling and blasting costs
  . ripping costs
- spoil revegetation costs;
- surface excavation equipment fleet owning and operating costs;
- labor costs.

If barrier pillars are left between groups of auger holes, underground reserves access is achieved by driving drifts through the pillar. These development costs depend on the following parameters:
- depth of auger holes;
- number of drifts driven;
- width of drifts;
- seam thickness;
- roof and floor conditions;
- water handling costs;
- underground equipment owning and operating costs;
- material and supply costs;
- labor costs;
- revenue generated from coal recovery.

The overall development cost depends on the access method utilized and the respective site parameters that have been listed. However, the
total mining cost also includes the operating costs for the underground mining, taxes, royalty, administrative and overhead costs, bonding costs, and union benefits if they apply. The revenue generated from the recovered coal on a F.O.B. basis depends on the following:

- in-place reserve tonnage;
- underground recovery rate;
- coal market value.
  - steam or metallurgical grade
  - ash content
  - sulfur content
  - moisture content

The total mining cost compared to the total market value of the recovered coal for each development method gives a general indication of whether the mining venture will be undertaken. However, additional factors may enter into the decision-making process. Inflation rate expectations, increases in coal market values, the discount rate, and present worth factors, are sometimes utilized by companies to determine the internal rate of return or discounted selling price required for a venture. Punch mines are sometimes developed to boost a company's production to meet contract requirements. In these instances, companies will sometimes incur a slight loss on a per-ton basis at the punch mine to avoid losing more money by buying the additional coal needed on the spot market.
Estimation Methodology To Determine Impact of Barrier Pillar Requirements on Reserve Recovery

To estimate the success of the barrier pillar requirements in maximizing resource recovery after augering, the economics of underground mining on a site must be examined for the cases where pillars are and are not left between groups of auger holes. The methodology developed utilizes site specific data to estimate the economics of underground mining for both development situations. The operations which are common to both underground mine development situations are costed in the same manner. Surface and underground mining operating costs are input as average values, since they can vary depending on site specific conditions. The major difference in the final break-even cost per ton for the two situations is due to the differences in capital requirements for access to the underground reserves.

Three drift entries are utilized to access the coal reserves through the barrier pillar. This number of entries is sufficient to support a punch mine operation. One entry is used for intake air, and for transport of men and materials. The second entry is a neutral split used for coal transport (belt). The last entry is for return air. The main intake serves as the principal emergency escapeway, and depending on the state law, either the return air entry or neutral split can be utilized as the secondary escapeway.

Assuming a 250 feet barrier width, three 20 feet wide entries permit
pillar widths between entries to be 47.5 feet. This width pillar should be ample for roof support; however, the required pillar strength will be examined. The following pillar stress and strength relationships were taken from a publication written by Robert Stefanko entitled "Coal Mining Technology - Theory and Practice".

To determine the pillar width required, the maximum compressed stress that is on the pillars must be known. This pressure can be determined from the following relationship:

Virgin Stress (psi) = 1.1 x Overburden Depth in feet

Because the maximum overburden depth above the pillars varies for each site, the maximum overburden depth occurs above the end of the auger hole and depends on site slope, penetration depth, and pit width. The equation to calculate the maximum overburden is:

Maximum O.B. Depth = (Pit Width + Penetration Depth) x Tan (site slope)

A pit width of 100 feet, a penetration depth of 200 feet, and a site slope of 50 degrees will be assumed in order that the overburden depth is higher than would normally be encountered.

Maximum O.B. Depth = (100 + 200) x Tan (50) = 357 feet

Based on the overburden depth, the maximum virgin stress will approximately equal:

Virgin Stress = 1.1 x 357 = 393 psi

The average stress on the pillar is related to the virgin stress and the recovery rate by the relationship.

Pillar Stress = Virgin Stress x (1 - recovery rate)
The recovery rate for individual chain pillars is 50 percent based on three 20 feet wide entries in a 250 feet wide barrier pillar (Figure 15).

Therefore, pillar stress becomes:

\[
Pillar\ Stress = 393\ psi \div (1 - .50) = 786\ psi
\]

The compressive strength of the pillar must at a minimum equal the average pillar stress to support the roof. A safety factor of two will be used to insure adequate support. Using a safety factor of two, the compressive strength of the pillar should be at least 1572 psi. The actual compressive strength of the pillar is dependent upon its minimum horizontal dimension \((w)\), the pillar height \((h)\), and the compressive strength of the coal \((k)\). The relationship is:

\[
Actual\ Pillar\ Strength = K \times \sqrt{\frac{W}{H}}
\]
Where the dimensions are in inches, the minimum dimension of the pillar is 47.5 feet. However, pillar height will change from site to site. As pillar height increases the pillar strength decreases. Therefore, a relatively large entry height of 6 feet is used in the equation to minimize the effective pillar strength. The variable $K$ is a coefficient which relates a unit (1") coal cube's compressive strength to the actual pillar's compressive strength. Solving for $K$ the relationship becomes:

$$K = \frac{1572 \text{ psi} \times (6' \times 12)}{\sqrt{47.5 \times 12}} = 4740 \text{ psi}$$

Allowing for a safety factor of two, the compressive strength of a one-inch cube must equal 4740 psi for the mine opening to be stable. The average compressive strength for bituminous coal sample cubes is between 4000 and 5000 psi; therefore, the pillar dimensions are probably adequate to support the opening.

These pillar and entry dimensions were utilized in the following methodology to estimate the cost of entry development.

**Input Variables**

- **AC** = Access road, surface facility, and move-in costs for mine site ($)
- **PW** = Pit width of reclaimed site (feet)
- **SB** = Slope of graded backfill (degrees)
- **SV** = Slope of virgin ground above highwall (degrees)
- **HA** = Highwall angle needed for stable conditions (degrees)
- **BW** = Bench width desired at mine mouth (feet)
- **PD** = Auger hole penetration depth (feet)
- **THK** = Seam thickness (inches)
UR = Underground mining recovery rate
RA = Underground reserve area (square feet)
DEN = Coal density (lbs./cubic foot)
SCCY = Assumed stripping operating costs per BCY for reclaimed spoil ($/BCY)
SCVCY = Assumed stripping operating costs per BCY for virgin material ($/BCY)
UGT = Underground mining operating cost per ton ($/ton)
PMS = Surface mining permit cost ($)
PMU = Underground mining permit cost ($)
ROY = Royalty per ton ($/ton)
AD = Administrative and overhead costs per ton ($/ton)
MRK = Market value of the coal ($/ton)
FEDR = Federal reclamation tax per ton ($/ton)
BEN = Union benefit cost per ton ($/ton)
SEV = Severance tax per ton ($/ton)
BLK = Black Lung tax per ton ($/ton)

Output Variables

SPCOST = The site preparation cost for access roads, surface facilities and stripping old spoil to access the previous highwall and barrier pillar. The equation used to calculate this value is based on the trigonometric solution of oblique triangles/input site dimensions, spoil stripping costs per BCY, and site development costs. This cost is incurred by both underground mine development methods.
EXCOST = The excavation cost for stripping the virgin material above the augered coal seam to the full depth of the holes. The width of the passage is a user option, however, it should be at least 250 feet to allow for sufficient pillar width for entry development in the solid coal block. The calculated value is dependent on the trigonometric solution of oblique triangles, input site parameters, and virgin ground stripping costs per BCY.

DECOCT = The development cost for driving three 20-foot wide entries through the 250 foot barrier pillar for the full depth of the auger holes. The equation is based on input site dimensions, coal density, and underground operating costs per ton.

OPCOST = The total underground operating costs for the mine. Based on the area of the reserve base, the coal thickness, the underground recovery rate, and underground operating costs per ton. This total cost is incurred by both development systems.

TONE = The total tonnage of coal recovered by the mining system employed when barrier pillars are not left on the site.

TOND = The total tonnage of coal recovered by the mining system which utilizes drift entries through barrier pillars to access the underground reserves.

AUXCOST = The auxiliary costs for both mining systems. Based on royalty, administrative, severance tax, federal reclamation tax, union benefits, black lung compensation, and permit costs for the mines. Zeros can be input for these values if the user does not want to consider them in the overall mining cost.

MCSTNB = The overall mining cost per ton to recover the underground reserves remaining after augering. No barriers left for drift development. Overburden is stripped to end of auger holes to provide access.
MCSTWB = The overall mining cost per ton to recover the underground reserves remaining after augering. Barrier pillars are utilized for drift development.

REQTNB = The total tonnage of in-place reserves that are required to break even on the site. No barriers are left after augering. Revenue is based on input coal market value.

REQTWB = The total tonnage of in-place reserves that are required to break even on the site. Barrier pillars are used for entry development.

Cost Estimation Equations

SPCOST = \[ AC + ((PW \times PW \times \sin (SB) \times \sin (180 - HA)) \div (2 \times \sin (HA - SB))) \times (BW + (PW \times 0.66 \times \tan (SB) \div \tan (HA)))) \div 27 \times SCCY \]

EXCOST = \[ ((PD \times PW \times \sin (SB) \div \sin (HA - SB) \times \sin (HA)) + (PD \times PD \times \sin (SV) \times \sin (180 - HA) \div (2 \times \sin (HA - SV))) \times (BW + (PW \times 0.66 \times \tan (SB) \div \tan (HA)))) \div 27 \times SCVCY \]

DECOsT = \[ ((3 \times THK \div 12 \times 20 \times PD \times DEN \div 2000) + (PD \div 70 \times 100 \times 20 \times THK \div 12 \times DEN \div 2000)) \times UGT \]

OPCOST = \[ RA \times THK \div 12 \times DEN \div 2000 \times UR \times UGT \]

TOND = \[ (3 \times THK \div 12 \times 20 \times PD \times DEN \div 2000) + (RA \times THK \div 12 \times DEN \div 2000 \times UR) + (PD \div 70 \times 100 \times 20 \times THK \div 12 \times DEN \div 2000) \]

TONE = \[ RA \times THK \div 12 \times DEN \div 2000 \times UR \]

AUXCOST = \[ (ROY + AD + BEN + SEV + FEDR + BLK) \times TONE + PMS + PMU \]

MNCSTNB = \[ (SPCOST + EXCOST + OPCOST + AUXCOST) \div TONE \]

MNCSTWB = \[ (SPCOST + DECOsT + OPCOST + AUXCOST) \div TOND \]

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Barrier pillar regulations will have the greatest impact on increasing underground mine activity in situations where underground mining will not be economical unless a low cost method of seam access can be utilized. Stripping overburden to the end of the auger holes can be an economically acceptable means of access under certain conditions. In order to determine the impact of the barrier pillars on maximizing reserve recovery on previously stripped and reclaimed sites, the mine costing equations are used to determine the economic feasibility of developing and operating an underground mine on test sites. The overall mining cost per ton and the underground reserve tonnage needed to break even are generated for mine development with and without the aid of barrier pillars. Table 7 presents the mine data utilized for the three test mines.

In order to show the regional importance of the barrier pillar regulations, data for Mine No. 1 represent data typical of a steep slope Appalachian contour strip/auger mine. Mine No. 2 is a modified area mine in gently rolling terrain. The third set of mine data is tested to determine the relative difference in the economics of mine development
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<td>2,000,000</td>
<td>2,000,000</td>
</tr>
<tr>
<td>DEN</td>
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<td>82</td>
<td>82</td>
</tr>
<tr>
<td>SCCY</td>
<td>2.10</td>
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<td>2.10</td>
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<tr>
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<td>1.80</td>
<td>2.60</td>
</tr>
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<td>22</td>
</tr>
<tr>
<td>PMS</td>
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<td>5,000</td>
<td>5,000</td>
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<tr>
<td>PMU</td>
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<td>5,000</td>
<td>5,000</td>
</tr>
<tr>
<td>ROY</td>
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<td>2</td>
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<tr>
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</tr>
<tr>
<td>MRK</td>
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<td>29</td>
<td>29</td>
</tr>
<tr>
<td>F6DR</td>
<td>.35</td>
<td>.35</td>
<td>.35</td>
</tr>
<tr>
<td>BEN</td>
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<td>1.35</td>
<td>1.35</td>
</tr>
<tr>
<td>SEV</td>
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<td>.50</td>
</tr>
<tr>
<td>BLK</td>
<td>.25</td>
<td>.25</td>
<td>.25</td>
</tr>
</tbody>
</table>
with and without barrier pillars, when site conditions are adverse. Mine No. 3 data are identical to the site data used for Mine No. 1 with the exception of terrain slopes.

The cost values utilized in the models for surface and underground operating costs are representative of the costs incurred by active mining operations today. In reality, these values will change based on site conditions. However, because they are used in the economic costing for both mine developmental methods, the relative difference in the overall economics of the two systems is the same in spite of operating cost values used.

A stripping cost of $2.60 per bank cubic yard is assumed for excavation of virgin material in steep slope terrain. This value is based on reported operating costs from industry, in-house cost analysis studies; and output from numerous steep slope mine simulator tests. A value of $2.10 per bank cubic yard is used for the reclaimed spoil stripping cost. This assumes drilling and blasting does not have to be accomplished; however, some ripping may be necessary. For the modified area mining site, a cost of $1.80 per bank cubic yard is used for stripping virgin material. The cost of excavating reclaimed spoil is $1.55 per yard due to the lack of a need for drilling and blasting. These costs are lower than the costs for the steep slope site because of the following steep slope mining factors:

- increased overburden haulage costs
  - steep slopes
  - valley fill costs
  - more trucks
- increased drilling and blasting costs
  - more dozer work needed
  - higher powder factors needed
  - tighter drilling patterns
- steep slope affect on all operations
  - overburden stripping
  - topsoil removal
  - reclamation

Underground mining costs are kept constant for all tests. A value of $22.00 per ton is used for the underground operating costs. This varies depending on seam and roof conditions, the mine life, and the ability of the labor crew. The results for the mine development and operating cost evaluation can be seen in Table 8.

Examination of the cost evaluation results verifies the relative impact of the barrier pillar regulations in the two mining regions. The access costs incurred in steep slope Appalachia where barriers are not left are much higher than the access costs in the Eastern Interior Region. The steep slopes of Appalachia require huge amounts of overburden to be stripped from above augered areas to access solid coal. Lesser volumes must be stripped in modified area mining situations due to the gentle slope. However, in the modified area situation high costs are incurred for site preparation because of the wide pit width. The difference between the mining costs per ton with and without the use of barrier pillars for Mine 1 and 2 illustrates that the barrier pillars have a greater impact on mine economics in Mine 1. Overall mine costs are $2.63 per ton higher when barrier pillars are not utilized in Mine 1.
### TABLE 8
**TEST RESULTS - BARRIER PILLAR IMPACT ON MINE ECONOMICS ON A RECLAIMED SITE**

<table>
<thead>
<tr>
<th>OUTPUT</th>
<th>MINE 1</th>
<th>MINE 2</th>
<th>MINE 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>* SPCOST</td>
<td>$83,950</td>
<td>$103,518</td>
<td>$177,350</td>
</tr>
<tr>
<td>EXCOST</td>
<td>$446,060</td>
<td>$224,390</td>
<td>$1,769,820</td>
</tr>
<tr>
<td>DECOST</td>
<td>$41,940</td>
<td>$41,940</td>
<td>$55,920</td>
</tr>
<tr>
<td>* OPCOST</td>
<td>$3,788,400</td>
<td>$3,788,400</td>
<td>$3,788,400</td>
</tr>
<tr>
<td>TOND</td>
<td>174,000 ton</td>
<td>174,000 ton</td>
<td>174,742 ton</td>
</tr>
<tr>
<td>TONE</td>
<td>172,200 ton</td>
<td>172,200 ton</td>
<td>172,200 ton</td>
</tr>
<tr>
<td>* AUXCOST</td>
<td>$862,390</td>
<td>$862,390</td>
<td>$862,390</td>
</tr>
<tr>
<td>MCSTNB</td>
<td>$30.08/ton</td>
<td>$28.91/ton</td>
<td>$38.31/ton</td>
</tr>
<tr>
<td>MCSTWB</td>
<td>$27.45/ton</td>
<td>$27.56/ton</td>
<td>$27.95/ton</td>
</tr>
<tr>
<td>REQTNB</td>
<td>439,030 ton</td>
<td>274,720 ton</td>
<td>1,591,200 ton</td>
</tr>
<tr>
<td>REQTWB</td>
<td>65,530 ton</td>
<td>81,440 ton</td>
<td>137,850 ton</td>
</tr>
</tbody>
</table>

* Costs incurred by both development methods
for the given reserve base. Overall mine costs are only $1.35 higher without pillars on Mine 2. Assuming a coal market value of $29.00 per ton, underground mining would probably not take place on Mines 1 or 3 if barrier pillars are not left after augering.

The required in-place tonnages required for break-even mining further illustrate the importance of barrier pillars in steep slope regions. If less than 439,000 tons of underground reserves are present at Mine 1, mining is not economic if barriers are not utilized. It should be noted that these tonnage figures and mining costs are all based on the economic costs input into the model. As these input costs change, so do the results. However, the relative differences in costs for the same mine conditions remain the same.

Mine 3 conditions are more extreme than Mine 1 conditions. Steep slopes and deeper auger holes are utilized. Because the height of highwalls rise with increasing slope, a 50 degree highwall angle is used to insure stability. These parameters cause higher site preparation costs to be experienced on the site for both development situations. The excavation costs for removing overburden from above auger holes are much higher because the volume of material to be moved is enormous. This large volume is due to the steep slopes and deep auger penetration on the site. The conditions of Mine 3 make the presence of barrier pillars essential for economic mining. A $10.36 difference in overall mining costs per ton exists for the two mine development situations, and 1,592,000 tons of reserves would have to be present before mining
without utilization of barrier pillars for entry development would be economic. Only 137,850 tons are needed for break-even mining if barrier pillars are utilized with the assumed mining costs and parameters.

If the necessary site conditions and average mining costs are known for a reclaimed mine site, the methodology presented can be used to estimate overall underground mining costs and reserve tonnages required for break-even mining for both mine development techniques. The relative differences in costs and reserve tonnages from the tests indicate that barrier pillars have more impact on increasing underground mining and maximizing reserve recovery on reclaimed sites if:

- slopes increase;
- previous pit widths decrease;
- auger penetration depths increase;
- necessary highwall angles for stability decrease;
- stripping costs per BCY increase;
- underground reserves are limited;
- coal market value is low;
- auxiliary costs per ton are high;
- underground mining costs increase.

**Barrier Pillar Impact on Mine Economics on an Abandoned Site**

The cost of underground mine development from an abandoned strip bench is also lower if solid blocks of coal are available for the placement of drift entries. Without the barrier pillar regulations, coal
seams on abandoned sites may be augered completely, thus eliminating the possibility of utilizing drift entries to access underground reserves. Although it is unlikely that many augering operations will be initiated on abandoned sites, the barrier pillar requirements will provide a means by which underground reserves can be easily accessed. The degree to which reserve recovery will be maximized because of the barrier pillar regulations once again depends on the economics of mine development with and without the aid of the barriers. The cost of mine development varies based on the site conditions of each abandoned strip pit. For this reason, the mine costing equations are used to determine the relative impact of the barrier pillar requirements on the development and operating costs of three underground mining operations.

On an abandoned stripmine site, it is not necessary to create a bench for the mine portal since one already exists. Because of this, the site preparation costs are much lower on an abandoned site than on a reclaimed site. However, some lesser amount of bench preparation may be required depending on the conditions of the site. Therefore, the site preparation cost equation for mine development on abandoned sites becomes:

$$SPCOST = AC + BPREP$$

The access road and surface facility construction cost (AC) remains the same in the equation, and a bench preparation cost (BPREP) is added to it. The bench preparation cost will include machine costs for cleaning up the abandoned bench and highwall stabilization costs.

To illustrate the impact of barrier pillars on underground mining
economics in the regions where augering is conducted, the development and operating costs of underground mining are estimated for the same three test sites. This allows the relative importance of the barriers for different mining situations to be seen. The pit conditions for the following test sites are assumed to be good. Minimal work is required prior to the initiation of underground mine development. All underground and surface mining costs are assumed to have the same values as in the cost estimations for reclaimed sites. The results for the mine development and operating cost evaluation can be seen in Table 9.

The overall mining cost per ton incurred when barrier pillars are utilized for entry development (MCSTWB) is almost identical for the three mine sites. Since a working bench existed prior to mine development, site preparation costs for bench construction are very low. However, where barrier pillars are not present to be utilized, overall mining costs for all test mines were estimated to be much higher. The increased mining costs are due to high excavation costs for stripping to the end of the auger holes to access solid coal. Once again, the barrier pillar requirement has the greatest impact on the economics of underground mine development on the site with the steepest slopes and deepest auger holes.

The relative impact of the barrier pillar regulations can also be seen by examining the reserve tonnage required for break-even mining for each site. If barrier pillars are utilized for entry development, the minimum reserve tonnage required before mining is profitable
TABLE 9  
**TEST RESULTS - BARRIER PILLAR IMPACT ON MINE ECONOMICS ON AN ABANDONED SITE**

<table>
<thead>
<tr>
<th>OUTPUT</th>
<th>MINE 1</th>
<th>MINE 2</th>
<th>MINE 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPCCOST</td>
<td>$25,000</td>
<td>$10,000</td>
<td>$25,000</td>
</tr>
<tr>
<td>EXCOST</td>
<td>$446,060</td>
<td>$224,390</td>
<td>$1,769,820</td>
</tr>
<tr>
<td>DECOST</td>
<td>$41,943</td>
<td>$41,943</td>
<td>$55,924</td>
</tr>
<tr>
<td>OPCOST</td>
<td>$3,788,400</td>
<td>$3,788,400</td>
<td>$3,788,400</td>
</tr>
<tr>
<td>TOND</td>
<td>174,000 ton</td>
<td>174,000 ton</td>
<td>174,742 ton</td>
</tr>
<tr>
<td>TONE</td>
<td>172,200 ton</td>
<td>172,200 ton</td>
<td>172,200 ton</td>
</tr>
<tr>
<td>AUXCOST</td>
<td>$862,390</td>
<td>$862,390</td>
<td>$862,390</td>
</tr>
<tr>
<td>MCSTNB</td>
<td>$29.74/ton</td>
<td>$28.37/ton</td>
<td>$37.43/ton</td>
</tr>
<tr>
<td>MCSTWB</td>
<td>$27.11/ton</td>
<td>$27.03/ton</td>
<td>$27.07/ton</td>
</tr>
<tr>
<td>REQTNB</td>
<td>391,100 ton</td>
<td>198,690 ton</td>
<td>1,467,330 ton</td>
</tr>
<tr>
<td>REQTWB</td>
<td>17,600 ton</td>
<td>5,410 ton</td>
<td>13,990 ton</td>
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</table>

* Costs incurred by both development methods
(REQTWB) on all sites is very low. However, when barriers are not present, the reserve tonnage needed for a profitable operation increases dramatically. The required reserve base for profitable underground mining without the use of barriers for development increases as the surface terrain gets more rugged.

**Overall Impact of Barrier Pillars on Increasing Underground Mining Activities**

Whether the presence of barrier pillars on a previously augered mine causes underground mining to be economical depends on the specific conditions on the mine site. If underground reserves can be economically accessed without the utilization of barrier pillars for drift entry placement, the barrier pillar requirements will not serve to maximize recovery. However, underground mining will not be economically feasible in many instances unless solid coal blocks are available for low cost drift development. In these cases, the barrier pillar regulations will serve to maximize resource utilization.

The methodology developed can be used to estimate the overall cost of underground coal mining on a site when coal blocks are and are not available for entry development. This methodology was used to determine if barrier pillar requirements would result in maximized reserve recovery on three test sites. The results from the cost estimations indicate the relative impacts of the barrier pillar regulation for various mining conditions and situations. If exact mining data is known, the costing methodology gives an indication of the potential barrier pillar
requirement impact on reserve recovery. However, the test results indicate that barrier pillars have the greatest impact on maximizing resource recovery on steep slope sites that have already been reclaimed. The following general statements regarding the impact of the barrier pillar regulations on the economics of underground mine development are also inferred from the test results.

- The barrier pillar impact becomes greater as the total revenue that can be obtained by mining decreases. The revenue is based on total reserve tonnage recoverable and the coal's market value. Therefore, small mining operations will gain the most from the barrier pillar requirements.

- The barrier pillar impact increases as the cost of mine development without the aid of barrier pillars for entry development rises. The cost of mine development rises as:
  - slopes increase;
  - auger penetration depth increases;
  - highwall stability decreases;
  - stripping costs per bank cubic yard increase.

- The barrier pillar impact increases as the total operating and auxiliary costs of underground mining rise.

- The barrier pillar impact decreases as the ratio of site preparation costs to mine development costs increases. This situation occurs as the previously reclaimed bench widths increases and the slope decreases, such as with modified area and area mine augering operations.
RECOMMENDATIONS FOR EASING THE IMPACTS OF THE FEDERAL AUGER REGULATIONS
RECOMMENDATIONS FOR EASING THE IMPACTS OF THE FEDERAL AUGER REGULATIONS

This report has shown that the federal augering restrictions increase auger operating costs, decrease the recoverable reserve base due to barrier pillar requirements, adversely affect auger productivity, and may prohibit augering in many situations. In order to lessen these impacts, research must be aimed toward developing new auger mining techniques and machines that can increase the productivity, recovery rate, and environmental acceptability of current industry practices.

The most important research area that must be pursued involves the development of new auger machines, cutting heads, and guidance systems. More powerful machines allow higher production rates and deeper penetration depths to be achieved. The Extended Depth Augers, Variable High Angle Auger, and especially the Guided Continuous Miner all have the potential for achieving these increased operational features and should be further researched and tested. In addition, the Variable High Angle Auger can recover reserves from steeply pitching seams—those dipping in the range of 25 to 90 degrees. Extraction of coal from these seams is frequently not attempted because of the mining and reclamation problems inherent to working on steep dips. The potential for acid drainage is also reduced due to the severe seam dip; and therefore, the Variable High Angle Auger has the potential for effectively complying with the federal regulations.
The design of the Guided Continuous Miner offers the power needed for increased penetration rates and depths. Since a rectangular hole is achieved, recovery rates in the range of 80% to 85% may be realized. These recovery rates are comparable to those achieved by surface methods, and thus, maximum resource recovery could be obtained with the Guided Continuous Miner.

In addition to these innovative auger machines, several basic auger components show promise for increasing augering recovery rates. Several "square hole" auger heads are currently under development and have the potential for increasing recovery rates. A number of guidance system approaches are also being investigated. Both of these areas should be researched and tested further in order that these selective coal removal and higher coal recovery components can be incorporated into existing machines.

All of the above mentioned auger machines and components can increase the productivity levels and recovery rates of current auger practices. This will result in making augering more attractive to mineral right owners and regulatory agencies who wish to maximize resource utilization. However, many of the environmental consequences of augering still exist with these techniques.

To make auger mining more environmentally acceptable, new methods of sealing auger holes must be investigated. In conjunction with this, an evaluation of the suitability of materials available to mine sites for creating water-tight seals should be undertaken. Research should also examine
the possibility of mixing quantities of materials not available on a site with clay to create a more impervious seal. For example, lime mixed with clay will form a harder material. Concrete can be mixed with clay to form a type of soil cement. Bentonite expands to a few times its original volume when saturated with water. It could potentially be used with other clay materials to form a plug that would expand as the amount of water builds up in the hole.

Any plug would be more effective if it could be compacted to a greater degree. Therefore, some type of expandable form set in each hole prior to sealing may provide the resisting force to compact material against. In any case, new sealing materials and methods must be investigated to lessen the environmental effects of augering.
BIBLIOGRAPHY
BIBLIOGRAPHY


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APPENDIX A
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### APPENDIX A

#### AVERAGE HOURLY AUGER OPERATING COSTS

<table>
<thead>
<tr>
<th>COST CATEGORY</th>
<th>Single Head 34&quot; Dia.</th>
<th>Dual Head 24&quot; Dia.</th>
<th>Triple Head 22&quot; Dia.</th>
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<td>$ 74.22</td>
<td>$ 78.37</td>
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<td>$ 14.84-29.69</td>
<td>$ 15.67-31.35</td>
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<td>Operating Costs</td>
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<td></td>
</tr>
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<td>Fuel @ $1.10 per gallon</td>
<td>22.00</td>
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<td>11.00</td>
</tr>
<tr>
<td>Bits (4-6 per hour @ $3.00 each)</td>
<td>12.00-18.00</td>
<td>12.00-18.00</td>
<td>12.00-18.00</td>
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<td>2.50-3.00</td>
<td>2.50-3.00</td>
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<tr>
<td>Maintenance</td>
<td>3.00-6.00</td>
<td>3.00-6.00</td>
<td>3.00-6.00</td>
</tr>
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<td>Auger Labor (2-3 men @13.60 per hr.)</td>
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<td>27.20-40.80</td>
<td>27.20-40.80</td>
</tr>
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<td>Total Owning and Operating</td>
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<td>184.38-254.33</td>
<td>189.36-260.14</td>
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<td>Average Hourly Production (Tons)</td>
<td>41-45</td>
<td>39-43</td>
<td>43-47</td>
</tr>
<tr>
<td>Average Cost per Ton</td>
<td>$ 3.69-5.64</td>
<td>$ 4.29-6.52</td>
<td>$ 4.02-6.05</td>
</tr>
</tbody>
</table>
APPENDIX A (Cont'd.)

COST DESCRIPTION

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital Cost</td>
<td>Hourly capital costs were based on machine cost less five (5) percent salvage value depreciated as a straight line over 4 years at 2,000 hours per year. Machine costs used were $420,000, $625,000 and $660,000 respectively.</td>
</tr>
<tr>
<td>Overhead</td>
<td>Represents insurance, record keeping, licenses, and support facilities charges for equipment. Based on average of 20% to 40% of fixed costs.</td>
</tr>
<tr>
<td>Fuel</td>
<td>Based on average consumption rate of 20 gallons per hour for the 510 h.p. single head auger and 10 gallons per hour for the 250 h.p. dual and triple head auger.</td>
</tr>
<tr>
<td>Lubrication and Maintenance</td>
<td>Charges based on average figures reported in sources 30 and 31 of the Bibliography.</td>
</tr>
<tr>
<td>Pit Preparation and Hole Sealing</td>
<td>Based on cost for a front-end loader and bulldozer to accomplish all pit preparation and hole sealing activities. Assumes all sealing materials are available on the site. Equipment spends 50% of time on auger related activities. Minimum cost based on use of 3.5 yard F.E.L. and 105 h.p. dozer. Maximum cost based on use of a 10 yd. F.E.L. and 300 h.p. dozer.</td>
</tr>
<tr>
<td>Average Hourly Production</td>
<td>Based on the average production figures in source number 14 of the Bibliography plus and minus five (5) percent.</td>
</tr>
</tbody>
</table>
COST DESCRIPTION

Average Cost per Ton-

The average cost range per ton of coal recovered in-pit. Based on maximum and minimum costs from ranges for auger owning and operating costs. These costs are average projections and do not represent all possible costs that could be incurred. Larger diameter (greater than 36 inches) single head augers have lower average costs per ton, but because of their low recovery and their rapidly declining use by industry, they were not considered in the cost estimation. Also, average costs per ton will increase if special hole sealing or pit preparation activities must be accomplished.
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The introductory material in this document presents the objectives and approach by which this project was directed. In order to ensure that this work satisfies the original purpose of the task, the following scope of work, reprinted from the signed task order, has been included for comparison:

15. OBJECTIVE

The objective of this task order is to evaluate techniques for minimizing the impact of federal mining regulations on the production of coal by highwall mining techniques (auger mining). To meet this objective, the contractor will identify significant performance standards in the permanent regulatory program and project their effect on current auger mining practices. Additionally, the feasibility of using new auger machines and techniques to comply with the regulations will be assessed.

16. TASK STATEMENT

Accomplishment of the stated objective will require the contractor to be: 1) familiar with the federal regulatory program of the Office of Surface Mining (OSM); 2) have a working knowledge of highwall mining methods and equipment; and 3) be knowledgeable of coal geology. The following tasks will be performed to meet the study objective.

Task 1 - Review Current Highwall Mining Operations and Economics

The contractor will conduct a comprehensive review of highwall mining operations in the United States. This review will include a literature survey of applicable highwall mining studies and contacts with active operators and contractors. The results of this task will provide an evaluation of auger applications and recovery rates.

Task 2 - Assess Regulatory Impacts on Performance of Highwall Mining

This task will provide an assessment of the effect of the federal performance standards on the productivity. Productivity impacts will be predicted for actual mining operations representing the major coal regions where highwall mining is practiced. Primary factors to be included in this evaluation are scheduling problems and production losses with current methods of augering.
APPENDIX B (Cont'd.)

Task 3 - Evaluate the Feasibility of New Augering Techniques

This task will provide for the gathering of information on new augering machines and techniques. The feasibility of these new methods complying with the OSM regulations will be evaluated. Emphasis will be placed on their ability to replace lost production due the impact of the regulations on existing augering practices. Additional emphasis will be placed on the feasibility of new methods increasing productivity while minimizing environmental impact.

Task 4 - Evaluate the Feasibility of Increased Underground Mining

The mandate for barrier pillars stems from the intent of the law to maximize recovery of reserves not strippable or augerable under present economics. The barriers are intended for future underground entries. In this task, the contractor will investigate the feasibility of using these barriers for future mine entries. Particular emphasis will be placed on the cost and engineering requirements to place entries both during the active stripping operation and following reclamation of the site.

Task 5 - Reports

Technical and financial letter reports will be submitted monthly to report study progress and expenditures. At the end of the seventh month of the project, a Draft Final Report will be submitted containing all findings, conclusions and recommendations.

Upon approval of the Draft Final Report, a Final Report will be submitted within 30 days along with all back-up data, charts, drawings, and pictures.