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SAFETY AND HEALTH IN UNDERGROUND MINE WASTE DISPOSAL

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16. Abstract (Limit: 200 words) Results of a comprehensive investigation of the impact of underground mine waste disposal on the health and safety of miners are presented. Information was gathered through an extensive search of American and foreign literature and personal communication with professionals in private industry and government. All conceivable health and safety hazards directly or indirectly related to underground mine waste disposal are analyzed, categorized, and ranked on an industry-wide basis. Positive health and safety effects are analyzed and ranked in a similar way. Both potential and known hazards and positive impacts are included. Recommendations on abatement techniques for the various hazards are presented. Case histories of a fill-related accident in a metal mine and a health hazard associated with coal waste backfilling are included and causes and possible abatement procedures are discussed. The role of management in the promotion of health and safety in backfilling operation is discussed.				
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EXECUTIVE SUMMARY

It has become apparent in recent decades that returning coal mine and preparation plant wastes to the mine voids not only provides support for the overburden but also can be a viable alternative to surface disposal. The hazardous conditions and environmental problems that have resulted from mine waste disposal on the surface over the past century or more are well known. Unfortunately, as the relatively new practice of backfilling coal mine voids becomes more widespread, especially in active mines, many foreseen and unforeseen health and safety problems associated with the backfilling activities will become evident. To begin with, the underground mine environment is recognized as a most hazardous working place. The imposition of a backfilling procedure upon the existing mining cycle will inevitably add to health and safety problems by creating congestion of miners, material, water, dust and equipment.

In the United States, more backfilling has been done in metal mines than in coal mines in recent years. As metal mining operations have extended deeper underground to recover the ores, the use of sandfill in the newly made openings has become indispensable for providing the ground support needed for safety and better ore recovery. Although backfilling has not been as prevalent in the coal mining industry, over the past decade underground waste disposal has begun to be an economically attractive disposal alternative for active coal mine operations.

The need for a current study to define health and safety problems relating to the mine backfilling process and to identify methods for controlling those problems is justified in view of the trend toward greater use of backfilling, especially in active mines. This rising trend has paralleled the rising cost of surface disposal in the coal regions. In metal mining areas, the increased use of backfilling coincides with penetrations to greater depths to recover the ores.

The various methods of backfilling that are in use in coal and metal mines are described in this report. These vary with mining methods, condition of the mines, and the purpose for which the backfilling is done. Backfilling in both active and abandoned mines is covered. The applications of hydraulic filling, pneumatic stowing, and mechanical injection of the waste in relation to room-and pillar mining, longwall mining, and stope filling are considered. The compositions of the various fill materials, their effectiveness in providing strata support, and the dangers that may be inherent in their chemical nature are discussed.

Data on all possible types of known and potential health and safety problems relating to the backfilling process were collected and evaluated. Because of the complexity involved in identifying and ranking such health and safety hazards as they relate to methods of mining, methods of backfilling, and composition of the fill itself, it was deemed advisable to discuss problems that are peculiar to coal mines separately from those that are associated with metal mines. In most instances the problems encountered in active mines are more important than those involved with blind filling abandoned mines.

An extensive search of domestic and foreign literature was conducted on underground mine backfilling to obtain technical data on stowing systems as well as on documented health and safety incidents that could be directly or indirectly attributed to the backfilling process. A significant finding of the literature search was that there is a dearth of useful statistics on health problems and accidents relating to underground mine waste disposal. Accident statistics pertaining to backfilling activities in the United States have never been systematically compiled. Computer searches for information on backfilling-related accidents identified very few accident reports, and accident reporting methods are inadequate for meaningful research on backfilling accidents. For example, the metal mine accident case study described in this report was not located by any of the computer searches, even though the accident was directly related to backfilling. This lack of statistical information required that the evaluation and ranking of hazards in this report be based more upon professional judgement than upon documented facts.

In an effort to supplement the minimal published information, numerous professionals in government and private industry were canvassed for their views on health and safety in underground mine waste disposal. In general, these professionals had a favorable opinion of the overall health and safety impacts of underground mine waste disposal. Although the number of presently active mines in the United States where backfilling has been done is limited, visits were made to two of these mines. Interviews with engineers at these mines revealed no occurrences of important safety problems, but there was concern about the potential safety hazards associated with slurry line spills.

In order to evaluate the relative seriousness of potential backfilling-related health and safety hazards, it was necessary to develop a systematic method for classifying these hazards. For this purpose, a hazard classification system was adapted from the Accident Prevention Manual for Industrial Operations

by the National Safety Council (39)¹. This system provides for the two part classification of a hazard based on: (1) its likelihood of producing an accident or health problem, and (2) the relative severity of the accident or health problem. Classifications assigned using this system were incorporated into the development of non-site specific hazard rankings as well as hazard matrices which allow the user to account for site-specific conditions when assessing the hazards associated with backfilling at an individual coal or metal mine.

The ranking of hazards related to coal mine backfilling was based on foreign and domestic literature, foreign accident statistics, and information from people in the industry. Because of the dearth of accident statistics pertaining to backfilling and the need to generalize the ranking for all types of coal mine operations, professional judgement was needed to develop the overall ranking. Hazards associated with underground coal mine backfilling were ranked as follows from most hazardous to least hazardous:

- 1) roof falls when stowing at the working face,
- 2) spontaneous oxidation of fill,
- 3) dust generation when pneumatically stowing at the working face,
- 4) waste haulage on the working level,
- 5) explosions while stowing at the working face,
- 6) congestion while stowing at the working face,
- 7) pipeline spillage,
- 8) haulage from surface to working level,
- 9) fall of fill material through lining,
- 10) quick conditions during placement,
- 11) waste haulage on the surface,
- 12) roof falls when remote stowing,
- 13) pillar punching,
- 14) quick conditions of inplace fill, and
- 15) inadequate filter design.

In order that potential backfilling hazards can be described on a site-specific basis they are also listed in a matrix format which accounts for mining method, stowing method, equipment used, fill material, purpose for filling, and location of deposition in the mine.

The ranking of hazards related to metal mine backfilling was developed in the same way as the ranking of hazards in coal mine backfilling. This ranking is as follows from most hazardous to least hazardous:

¹ Numbers appearing in this report in parenthesis and underlined refer to publications listed in the reference section at the end of this report.

- 1) spillage from pipes and bulkheads,
- 2) toxic or reactive compounds,
- 3) unstable rock and fill,
- 4) oxidation and combustion,
- 5) water pollution from mill tailings,
- 6) construction injuries,
- 7) operation of stowing equipment,
- 8) drilling operations,
- 9) liquefaction of fill, and
- 10) electrokinetic treatment.

This ranking is also generalized on an industry-wide scale, and should be refined when a specific site is being considered.

A hazard matrix for metal mine backfilling was also developed which takes into account filling method, mining method, purpose of fill, and type of fill.

As stated above, the hazard rankings are necessarily subjective because of the lack of good statistical data and the need to generalize the importance of a hazard on an industry-wide scale. The hazard matrices, however, allow the reader to refine the ranking according to operational and situational factors. The hazard classifications entered in the matrices can be arranged in order of importance for any combination of these factors. Further refinement can be done if a specific mine is being considered.

In both metal and coal mine backfilling, the liquefaction (or quick surging) hazard is ranked quite low in importance. This is because no important liquefaction accidents in recent years were discovered in the course of this research. This is not to say that the liquefaction hazard is of little or no concern. Factors such as fill compaction, size distribution, hydrostatic pressure, dip of workings, and stress in the fill can favor liquefaction in certain instances. Serious liquefaction problems can be avoided by determining the physical characteristics of the fill material in the laboratory and providing adequate drainage and design of the areas to be filled.

Spontaneous oxidation of fill is ranked rather high in importance in both metal and coal mining. This chemical reaction causes danger to miners in three ways: (1) oxygen depletion, (2) harmful gas production, and (3) heat and fire. The most important effect, and the one that most often causes serious problems from fill oxidation is the fire hazard. Fire can occur in timbers and other combustible materials, and extreme oxidation of fill can itself be considered a fire. Oxidation rates are not a function of one or two circumstances but are the result of a complex combination of factors. It was

found that there are low incident rates of major disasters from excessive oxidation, but there is little documentation on the minor accidents.

A case history of a backfill accident in a metal mine in the United States is described in the report. Three deaths were caused by a fall of backfill material that had been emplaced several years prior to the accident. Contributing causes included a delay in the mining cycle caused by a slurry line spill and the excessive height of the stope where the accident occurred. A decision to muck the broken ore and complete the permanent timber supports before cleaning up the slurry spill might have averted this accident.

Another case history included in the report describes a health hazard situation in which coal wastes being injected into a coal mine were possibly mixing with domestic water supplies.

Known and potential benefits to the mine environment and to the workers' health and safety are also presented in the report. These positive effects are analyzed and ranked on a generalized basis in order of their importance. The site specific positive health and safety effects will vary because a positive effect in one mine may not apply in other mines. For example, protection of the mine from inundation from overlying bodies of water can only be realized if there is a body of water overlying the mine.

Structural support of mine workings is probably the greatest overall health and safety benefit to be realized from backfilling. This support helps prevent falls of ground, surface subsidence, and damage to overlying aquifers and surface waters. However, it is important to recognize the limitations of sandfill as a support medium. Sandfill will probably never be the complete solution to ground support problems in deep mines.

Other benefits of backfilling include provision of a safe working platform, fire hazard suppression, reduced ventilation problems, reduced damage to the groundwater regime, and reduced damage to the surface environment because less waste would be deposited on the surface.

The recommendations on health and safety in underground mine waste disposal presented in this report are intended to provide a sound basis upon which mine management can initiate safety training for backfillers. A great deal can also be done in the planning and design stages, such as designing uncrowded layouts of equipment and mine workings. Phone communication

between sandfillers and slurry operators is very important to avoid large spills while backfilling. The role of management in maintaining a safe backfilling operation is also discussed in a special section of this report.

While it is most important that the miners and management be made aware of all known real and potential health and safety backfilling problems and the methods for dealing with them, it should be remembered that the use of backfilling during active mining on an industry-wide scale may uncover many as yet unforeseen problems.

I. INTRODUCTION

It is apparent that the growing problem of mine waste disposal on the surface can only be alleviated through an accelerated program to develop suitable solid waste management practices and through research to find methods for further utilizing existing and future accumulations. One important alternative to future accumulations, of course, would be the discovery and use of a safe and economical system for disposing of mine and processing plant waste into the underground voids from which it was taken.

The inclusion of regulations pertaining to the underground disposal of coal processing waste that were developed after passage of The Surface Mining and Reclamation Act of 1977 may be attributed to a 1975 study conducted by the National Academy of Science (NAS) for the National Science Foundation (43). This study addressed the state-of-the-art technology for mine backfilling concurrent with coal extraction, and provided an overview of the technical and economic constraints on underground disposal of coal mining wastes. The NAS study recommended that underground waste disposal be demonstrated at sites representative of U.S. coal mining practices in order to establish the feasibility of this method of disposal of coal mining waste in the United States.

In response to the NAS recommendation, the U.S. Bureau of Mines contracted with HRB Singer, Inc. to conduct a detailed study of the technical, economic, and environmental constraints on underground waste disposal in active coal mines. The results of that study indicated that while the concept of underground disposal done concurrently with mining is technically feasible, it is not competitive economically with surface disposal.

There are a number of coal mines in Appalachia where underground waste disposal is being practiced. Although it previously had not been feasible from a cost standpoint, the economics are changing because of the expenses incurred in complying with government regulation of surface disposal.

Aside from avoiding the costs of surface disposal, including the additional costs of addressing bank and impoundment stability, underground disposal of the preparation plant waste has other benefits. Underground disposal, in supporting the overburden above the mine, reduces the incidence of subsidence, reduces surface-water seepage into the mine voids (generation of acid mine water), and helps to avoid disruption

of ground water tables. By lessening surface accumulations, the problems of unstable waste pile slopes and leachate production through contact with surface water are reduced.

Underground disposal, in providing support of the strata above the working places, adds to the mine's stability and increases safety for the workers. Proper use of the system can result in greater recovery of the coal reserves.

Regardless of the method of backfilling used (pneumatic, hydraulic, or mechanical) technical and safety problems develop as the waste moves underground, often using the same passageways used to transport the coal to the surface.

Excess water from an hydraulic system or excess dust from mechanical or pneumatic systems, to mention only two hazards, create additional problems in the management of a safe and efficient mine environment.

Whether the greater part of any backfilling procedure is implemented at the surface or underground, and regardless of the method employed, the potential for injury to the workers and their health is always present. The purpose of this investigation is to identify such hazards and recommend a program that will provide for their alleviation.

A. Purpose and Scope of Study

As backfilling of underground mine voids becomes more widespread in the mining industry, it is important that the health and safety problems associated with the practice are identified and solved.

The main purposes of this research were to (1) list, define, categorize, and rank all conceivable health and safety hazards directly or indirectly related to the backfilling of underground mine voids, with special emphasis on active coal mines, and (2) analyze these hazards and suggest research and control methods which will provide solutions suitable for incorporation in industry practice.

The scope of the work included (1) investigation of accidents and effects to the mining environment related to backfilling, (2) relating health and safety criteria to the purpose and method of fill, type of fill, and mining method, (3) establishing causes and discussing methods for prevention of fill liquefaction, gas emission, fires and failures, and (4) development of health and safety recommendations for underground mine backfilling including safety provisions on fill equipment.

B. Background

1. Outlook for Underground Mining and Processing of Coal and Metal Ores in the United States

Waste materials that have resulted from mining and processing mineral ores and preparing solid fuels for market during the last century and a half have drastically altered the American landscape. Now, as our population and standard of living continue to rise, we must produce even more minerals to meet nationwide demands for manufactured goods and energy.

The waste produced from mining and processing currently amounts to about 2.3 billion tons annually and consists of overburden spoil, tailings, and refuse (54). The total volume of such accumulations on the surface is not known, but it is believed that most of it is deposited near the estimated 100,000 abandoned and active mines from which it was taken.

The total number and volume of sizable active and abandoned waste piles and impoundments in the eastern coal fields alone is conservatively estimated at 3,000-5,000, cumulatively containing over 3 billion tons of refuse (54). Coarse coal refuse accumulations generally resemble conical or ridge-shaped mounds that may extend up to 700 feet in height and over one mile in length. The fine refuse is often impounded in settling ponds or is pumped into the hollows behind waste piles.

The history of metal mine tailings disposal is similar. Like the coal industry, many mill operators, until recently, dumped the tailings into the nearest stream. This is no longer acceptable, and active tailings ponds now cover from as little as one acre to as many as 5,000 acres, attaining heights of 300 to 400 feet.

Waste piles and impoundments produce acute social as well as environmental problems. In the coal regions they have been the direct cause of the death of mine workers and hundreds of mining community inhabitants, as well as considerable property damage. Such accumulations are also the source of severe local air pollution, stream and ground water pollution, and regional economic, psychological, and sociological impacts. In the Anthracite region for instance, the vast bulk of the refuse is located within two miles of the traffic centers of incorporated communities which have a total population of 625,000 (37). In general, metal mine tailing ponds have been better engineered than coal refuse piles, but some of these have also failed.

Recognition by the Congress of the severity of the solid waste problem in the United States resulted in passage of the Solid Waste Disposal Act (Public Law 89-272) in October, 1965. This Act required economic and resource-evaluation studies aimed at delineating factors causing and contributing to waste-disposal problems in mineral and fossil fuel industries, as well as scientific and engineering research to find ways of utilizing, or otherwise disposing of, a variety of inorganic waste materials. The first federal regulations governing the surface disposal of coal wastes were promulgated pursuant to the Federal Coal Mine Health and Safety Act of 1969 (Public Law 91-173). Under this Act the Secretary of the Interior was required to develop health and safety standards for surface disposal of waste.

The laws enacted by Pennsylvania, West Virginia, and Kentucky regarding coal waste disposal were strengthened in 1968 as a result of the Aberfan disaster in South Wales. In the aftermath of impoundment failures in the Buffalo Creek area of West Virginia in 1972, an inspection and inventory of all waste impoundments was conducted in order to determine their stability. Under the authority of the Dam Safety Act, Public Law 92-367, enacted August 1972, the Army Corps of Engineers conducted a survey of all waste impoundments in the Appalachian region and reported the results to the state governors. Because of the potential hazards to miners and the public from improperly constructed coal waste piles and impoundments, the Department of the Interior in 1974 proposed new and expanded regulations controlling waste piles and published them in the Federal Register.

Despite legislation and regulations intended to ensure environmentally acceptable disposal of mine waste, dangerous and improper practices persisted. Consequently, Congress enacted laws such as the Federal Water Pollution Control Act of 1972, the Resource Conservation and Recovery Act of 1976, the Surface Mining Control and Reclamation Act of 1977, and the Federal Mine Safety and Health Amendments Act of 1977. While these laws resulted in more stringent waste disposal control, they also provided for research related to the safety, health, and environmental impacts of waste management.

2. Rising Costs of Surface Disposal

Until the last decade the cost of coal refuse disposal was a relatively minor part of the total mining investment at a given mine. During the last 10 years, however, the imposition of government regulations on disposal and reclamation has resulted in an impressive rise in such costs. In 1978, the

costs of reclaiming coal refuse disposal areas ranged from \$3,600 to \$17,900 per acre. The costs included contouring and grading, installation of drainage systems, transporting, spreading and compacting topsoil, establishing vegetation, and other miscellaneous reclamation activities such as grubbing. Assigning a median cost of \$10,700 per acre for reclamation, the estimated cost of reclaiming the approximately 174,000 acres affected by nonburning waste banks in the U. S. would be \$1.86 billion (32).

3. History and Extent of Mine Waste Disposal Underground

a. Coal Mines

Hydraulic backfilling of coal mine voids was developed in the late 1800's and in the 1900's and was used in about one fourth of the anthracite mines in northeastern Pennsylvania to extinguish mine fires, to arrest the development of progressive pillar failure known as mine squeeze, to permit the reclaiming of pillars, to dispose of unwanted mine refuse, and to protect the surface (57). The total area backfilled in the anthracite region was actually quite small when compared to the total area mined. Three methods of hydraulic placement of backfill material in underground mined-out spaces have been used in the anthracite region. With these methods, granular solid material was sluiced down from the surface, usually through boreholes, by jets of water. Occasionally, when convenient, the slurry was transported in pipelines to the underground voids through vertical or inclined shafts.

Controlled hydraulic backfilling is possible in mines (active and abandoned) in which workers can safely enter and gain access to key areas to conduct the filling operations. Bulkheads are built in mine passages around the periphery for containment of the fill. Drain boxes may be used in these structures to facilitate rapid removal of water. The injection boreholes, generally about one borehole for 4 acres, are cased from the surface to the mine opening. At the base of each hole, large radius 90° pipe elbows are placed through which slurry is diverted to horizontal pipes and distributed into the mine workings. Horizontal dispersal ranges from 300 to 1,000 feet, depending on the vertical distance from the ground surface to the mine opening (static head) and the solids concentration of the slurry.

Many abandoned mines are inaccessible because of flooding or extensive caving. Prior to 1970, blind gravity-feed flushing was the only method that was used for these mines. The fill material was injected underground through boreholes as

in the controlled method. In the mine, conical-shaped piles formed under each borehole providing minimum roof support. Hundreds of such boreholes were used in each project. In inhabited areas these boreholes were usually located in streets and alleys and not under buildings or yards where easements could not be obtained. Consequently, the support given was of only indirect benefit to existing structures.

A technique for the blind filling of inaccessible mine workings, the "pumped-slurry injection process," was first demonstrated in 1970 at Rock Springs, Wyoming (57). This system differs from the blind gravity-feed method in that pumping energy is used to achieve a suspension of the solid particles in water and the system is closed from the mixing tank to the bottom of the injection borehole. The energy provided by the pump and the static head in the borehole give the velocity required to keep the solid particles in suspension and to transport them. In Scranton, Pennsylvania, the site of the first large-scale pumped-slurry demonstration in 1972-73, only five boreholes were used to inject 450,000 cubic yards of mine refuse into two coalbeds beneath a 30-acre residential area. Nearly 200,000 cubic yards were injected through one borehole from which the material moved into the mine workings on all sides; the injected material reached a maximum lateral distance of 640 feet and filled flooded mine workings from floor to roof. This method of backfilling has also been used successfully in mine workings above mine-water pool level.

The practice of backfilling by the coal industry in the United States decreased after the First World War with the decline of the anthracite industry. Its use fell even more during World War II when production rose sharply in the remaining mines to supply space heating needs on the East coast. To combat the growing subsidence problem in the anthracite region, the Federal Government and the Commonwealth of Pennsylvania joined in a program authorized by Public Law 87-818, 87th Congress (October 15, 1962), and Act 443, Pennsylvania Assembly. The program, called "Operation Backfill", involved going back to fill underground mine voids in certain localities of the anthracite coal region where subsidence threatened public health and safety. Under this authority, four subsidence control projects were completed between 1962 and 1965 and the cost of the work was shared equally by the Federal and State Governments. The Appalachian Regional Development Act of 1965, Public Law 89-4, included authorization to fill voids in abandoned coal mines within the Appalachian region. Costs under this Act are shared 75 percent by the Federal Government and 25 percent by the cooperating state. By the end of 1978, 15 subsidence control projects had been completed under the Appalachian program and additional projects were in progress in the anthracite region of

Pennsylvania. Under the same program, one project in Maryland and one in West Virginia have also been completed.

Under the authority assigned to the Department of Interior's Bureau of Mines by the Organic Act (May 16, 1910), the Bureau conducts scientific and technologic investigations concerning mining and its related problems. By the end of 1978, twenty-one subsidence-control demonstration projects had been conducted under this authority, including the Rock Springs, Wyoming projects and others in Pennsylvania, Maryland, West Virginia, and Illinois. The vast majority of the U. S. coal mine backfilling projects conducted by industry in active mines and conducted by government in abandoned mines, have utilized some form of hydraulic backfilling.

b. Metal Mines

Backfilling of underground mine voids with various types of solid waste has become a quite useful means of providing ground support not only in coal mines, but also in metal mines. Hydraulic backfilling after the extraction of metal ores, termed "sand filling", began in the western United States about the same time as similar activity in the anthracite region.

In addition to the purposes of backfilling noted for the Anthracite region, sand filling in metal mines was also found to be useful in, (1) providing immediate support of the working face during stoping, (2) support for access openings, (3) enabling the mining of parallel, hanging-wall orebodies, and (4) reducing rock-burst hazards. Despite the problems created by excess water in the mine, hydraulic sand filling was found to be helpful in reducing the cost of mining metals. During recent years, the prime producers of gold, silver, lead and zinc have used sand fill to completely fill the openings produced by ore excavations in underground mines.

It has become apparent during the last two decades that returning waste to the underground metal mine is done primarily for the purpose of providing the ground support needed for better recovery. However, as the mining effort has reached deeper for the ores, ground pressures became greater and the need for a sand fill with less compressibility was obvious. Consequently, the mining companies and the U.S. Bureau of Mines began a research program to study hydraulic sand fill and its support potential. Results of some of this research have included the determination of the physical properties of sand fill, how these properties vary with the use of chemical additives and compaction methods, the influence of various factors on water percolation rates, and field measurements of stope wall deformations and pressures within the fill. Other research included related rock mechanics studies.

4. Foreign Experience with Underground Mine Backfilling

The information for this section was obtained from a National Academy of Science study (43).

While the United States may have originated the idea of backfilling, the European mining industry perfected its use. Europe has a highly developed infrastructure that is rather sensitive to mine subsidence. As a result, backfilling in underground coal mining was chosen as a solution for the problems of mine subsidence from underground coal mining. Backfilling reached its peak in the late 1950's and has declined in use since then. For instance, in 1954 Great Britain used some form of backfilling whether road packing or stowing methods, in 81% of its underground coal mines. In 1973, no backfilling was being practiced in Great Britain.

The decline of backfilling was directly attributable to its extreme cost and because it inhibited the rapid advance of a longwall face. For instance, in the wake of the tailings impoundment failure at Aberfan, South Wales (October 21, 1966), the Aberfan Tribunal appointed to inquire into the disaster concluded that backfilling as an alternative to surface disposal was not economically feasible.

The European coal mining industry has practiced four backfilling techniques.

1. Standard pneumatic backfilling
2. Pneumatic lateral discharge backfilling
3. Hydraulic backfilling
4. Mechanical backfilling

Because most European mining uses the advance longwall mining method, backfilling must be done adjacent to the working face in coordination with the production schedule. The most widely used backfilling techniques over the last few decades have been the Standard Pneumatic and Hydraulic Backfilling Systems. With both systems, backfilling cannot be done concurrently with the mining, therefore these activities must be rotated. Scheduling is either in three 8 hour shifts, with mining during the first shift, backfilling during the second shift, and equipment movement during the third shift, or in four 6 hour shifts alternating mining with backfilling. These rotating schedules cause expensive mining equipment to sit idle for alternate shifts, limit the production from each face, and require considerable man-hours per ton of coal mined, hence the high cost of backfilling.

The pneumatic lateral discharge system is much more cost effective in that backfilling is run concurrently with longwall

mining. The system is fairly automated with little delay of mining activities to advance the equipment. However, the equipment is costly. The first of these systems was installed at the Nordstern Mine, Germany in 1968.

Mechanical backfilling involves mechanically slinging waste material into the mining void. It has been fairly unpopular because it has not proven very effective in reducing subsidence, due to poor void filling and poor density of the pack. Germany discontinued its limited use of mechanical backfilling in 1958, France in 1962, and by 1970, Poland reported less than 1% of their mines using it.

Backfilling with shortwall mining must be the same as with longwall mining using standard pneumatic or hydraulic backfilling systems. Poland is the only reported country using backfilling with shortwall operations.

Table 1 indicates the amount of backfilling that was being practiced in 1972. For the countries reporting backfilling activities, on the average, 24% of their underground coal mines were using backfilling practices. These consisted of pneumatic or hydraulic stowing methods only. Of those countries which differentiated between their pneumatic and hydraulic stowing operations, 87% were pneumatic while hydraulic represented the remaining 13%. Poland has the most widespread use of backfilling comprising 57% of the backfilling operations that are reported in Table 1. Poland has very stringent regulations on

TABLE 1. - The Amount of European Underground Coal Mines That Practice Backfilling, 1972 (43)

<u>Country</u>	<u>Total Number of Underground Coal Mines</u>	<u>Percentage of Mines Which Backfill</u>		
		<u>Pneumatic</u>	<u>Hydraulic</u>	<u>Stowing Method Unknown</u>
Poland ²	78	34%	3%	-
France	40	-	-	28%
Germany	61	10%	1%	-
Belgium ¹	24	4%	12%	-
Netherlands ²	4	-	-	25%
Great Britain	289	-	-	0%
Total	496			

¹ 1970 Statistics

² 1973 Statistics

surface disposal of coal mining wastes and outlaws surface disposal in some regions. France was the second largest practitioner of backfilling accounting for 22% of the reported backfilling operations. The pneumatic lateral discharge backfilling system is the only backfilling system that can operate concurrently with longwall equipment. While being very cost effective, it was used only in 24% of the pneumatic backfilling systems in 1972. By 1974, there were only 10 reported pneumatic lateral discharge systems in use in Europe and only one in Poland. Most of the lateral discharge systems were divided between Germany and France.

A review of the European backfilling situation reveals that some countries, such as Poland, are devoted to underground backfilling while others, such as Great Britain, have abandoned its use. All of these European countries are highly concerned about mining subsidence effects and recovering their coal resources, but their opinions of backfilling as the solution to these problems are quite divergent.

II. UNDERGROUND DISPOSAL OF COAL WASTES

A. Current Backfilling Practices in Coal Mines of the United States

The two main methods of underground coal mining in the United States are room and pillar and longwall. Room and pillar accounts for 88 percent of the current underground coal production in the United States, while longwall is the principal method used in Europe. There are many variations in room and pillar mining depending on geologic conditions, thickness of the bed, and the nature of the coal. Shortwall mining is the only variation of longwall mining, a method that may become popular in the United States because it combines some of the advantages of both longwall and room and pillar.

The few techniques of backfilling developed in Europe to be used with the various methods of mining involve pneumatic or hydraulic emplacement of the fill material. Mechanical backfilling is done only rarely. Although popular in Europe, there are very few applications of pneumatic backfilling in the United States. Hydraulic backfilling has been used in the United States mostly to fill voids in abandoned mines and inactive portions of coal mines. Backfilling of mine voids is done primarily to provide surface subsidence control, support the mine workings, and dispose of the waste.

In the following discussion, several safety and health factors relating to various applications of hydraulic and pneumatic backfilling are identified, principally with reference to room and pillar mining.

1. Blind Gravity Flushing

Solids in slurry form are introduced into abandoned coal mine voids through boreholes from the surface when the old workings are inaccessible to workers due to flooding or other hazardous conditions. A large hopper is mounted over each borehole into which water from fire hoses is mixed with the solids and flushed into the mine voids by force of gravity. Safety and health problems associated with this type of backfilling evolve from the use of heavy earth-moving equipment which is used to load the solids at the waste bank, borrow pit, or preparation plant and transport them to the hoppers over the large number of boreholes that are required with this system. Water used to flush the solids underground may be obtained from a municipal source or pumped from a nearby lake or stream. The potential for accidents is always present when mobil equipment,

drilling rigs, pumps, piping, hoppers, and hoses are utilized. Health problems can develop from the ever present dust and noise created during the progress of the work. The most important positive aspect of this type of backfilling is the fact that workers do not enter the mine.

2. Blind Pumped-Slurry Injection

Blind pumped-slurry injection differs from the gravity-feed method in that a solids suspension is created in a mixing tank by agitation and is pumped into the mines through boreholes. This method is more efficient than the gravity method because the lateral extent of fill in the mine per borehole is much greater.

While the pumped slurry injection method has a more complex equipment arrangement than the gravity fed system, the types of health and safety hazards and benefits for both are similar in most ways. For instance, both encounter the risks involved with drilling activities and materials handling with front end loaders. In addition, both are situated on the surface so that no personnel are exposed to hazardous underground conditions.

It should be noted that because of the head generated by the pump, the potential for a return eruption through the borehole, pipeline, and pump is possible after injection ceases. Under the right conditions, air entrained with the slurry can accumulate under pressure above the rising mine pool level. After injection ceases the level of the pool may recede to the borehole opening allowing the compressed air to return to the surface with considerable violence carrying water, mud, and other debris. An incident of this nature occurred during a backfilling demonstration at Rock Springs, Wyoming in 1973. A similar occurrence at Scranton, Pennsylvania in the same year resulted when the pumped slurry encountered high resistance in seeking to open up new outlets through the packed fill and escaped with considerable violence through a monitor hole. At Rock Springs, no injuries resulted and damage was minor. At Scranton, however, a few nearby houses were splattered with mud which required a lengthy clean up effort. With this process, workers are not required underground.

3. Controlled Flushing

This method of filling mine voids is possible when men can safely enter the abandoned mine and direct the operation. Bulkheads are built in mine passages on the periphery for

containment of the fill. On the surface, facilities for this type of work are similar to those used in both the gravity and pumped slurry methods. For controlled gravity flushing, a long radius heavy duty elbow is anchored at the foot of the borehole to change the direction of slurry flow from vertical to horizontal to the various points of stowage. Water drains through the pervious bulkheads and drain boxes leaving a compact mass of solids. Pumped slurry in the controlled flushing process may be taken underground the same way or transported in long pipelines from the surface along the main entry used to bring coal to the surface, or along the main air return. These methods have been used to fill abandoned mines and inactive portions of an active mine.

Safety and health problems with controlled flushing may be divided into two categories. On the surface, conditions are similar to blind flushing. Underground, however, the workers are exposed to many of the hazards experienced by miners. In addition to this, the men often work in knee deep water removing sections of slurry pipe and adding drain box sections as the work progresses. A critical situation could develop under these conditions if the pipeline becomes uncoupled behind the workmen allowing the loose slurry to build a mound through which the men could have difficulty escaping. The long slurry line used with the pumped slurry process could extend a mile or more from the surface to the points of disposal. A break in such a slurry line along the main entry could disrupt the movement of men, coal, and supplies. If placed in the main air course, a break could disrupt the ventilation.

4. Pneumatic Backfilling

Blind and controlled applications of this injection process have been used occasionally in the United States to fill voids in abandoned or inactive portions of room and pillar mines. Pneumatic packers are installed on the surface and connected by pipes to a borehole through which the fill material is injected blindly into the voids. Another form of blind pneumatic injection involves the use of pneumatic tank trucks which haul fly ash to the site and blow it down boreholes. Safety and health impacts involve the use of drilling equipment, material haulage, and injection of the solids into the boreholes. Where men are used in the mine with pneumatic backfilling, the solids are transported underground in cars or hydraulically from the surface to a prepared site where dumping, drainage, and loading facilities transfer the solids to the blower which impels the material up to 1000 feet in a pipeline to the storage points.

Safety and health aspects of controlled pneumatic backfilling relate mostly to the personnel who operate the dumping, drainage, loading, and blowing equipment and also to those who direct the flow of material at the face. Commonly with pneumatic stowing systems, the blower is located near the point of deposition. This requires the wastes to be brought to the stower through main haulageways adding to the equipment and congestion in these drifts. A health concern involves the presence of dust with the material handling and blowing system especially at the end of the pipeline. The supply of fresh air from the pipeline together with sparks created by the impact of solids moving at high velocity against the roof and sides could ignite methane. Spontaneous combustion could occur in the deposited waste the same way it does in waste banks on the surface. Workers at the face are exposed to considerable ear-damaging noise. Also, because of such noise, the workers are not likely to detect warning sounds in the top before a fall of roof.

5. General

It seems apparent that some of the safety and health problems arising in room and pillar mining probably are related to attempts to adapt backfilling methods to mine layouts where such activities were not included in the original plan of mining. There is little flexibility in the close confines of any mine to accomodate major changes in transportation when the major thrust is to move the coal to the surface. If an adequate disposal system were incorporated in the total mining plan before a given underground mine is opened, more positive safety and health measures could result.

The best application of backfilling in the room and pillar situation would involve depositing the fill in rooms immediately after the coal is removed, just as in longwall mining. Unfortunately, while such a technique could result in better roof control and increased production, it would necessarily produce greater congestion of men, machines, dust, or excess water in the face. In some mines the stratum under the coal bed contains clay which becomes slippery in the presence of water, a condition that would aggravate the congested environment at the mining face. Excess water in the mine from hydraulic backfilling may also weaken pillars, and underlying strata, and pollute ground water.

6. Longwall Backfilling

Many of the safety and health aspects of pneumatic and hydraulic backfilling in room and pillar mining also apply to

longwall mining because the same type of equipment is used to gather, prepare, and transport the solids from the surface to the points of stowage. Whether the final injection is done pneumatically or hydraulically, the work is done concurrently with the longwall mining. Pneumatic disposal is more flexible than hydraulic in the longwall situation because it can be adapted to more than one shift per day and is not dependent upon the direction of bedding dip. The main health problem, of course, involves creation of dust as the solids are blown behind brattice walls near the face. For the 24-hour mining cycle, additional waste material over and above that produced at the mine must be acquired elsewhere as in the case of filling abandoned room and pillar mines. This again brings in to play the use of heavy earth-moving equipment with the related safety and health problems on the surface as explained earlier.

Hydraulic backfilling in the longwall situation is rarely conducted in the same shift as the mining because of the constant danger that the slurry may breach the protective brattice and invade the area where the coal is being cut.

A most serious safety problem associated with longwall backfilling is roof control when this type of mining is being conducted on the advance-direction of mining from the portals to the limits of the property. With retreat longwall mining, problems of roof support in the backfill area are less severe because the main direction of mining is from the property limits to the portals leaving the roof hazards in the wake of the mining.

B. Health and Safety Hazards of Underground Disposal of Coal Mine and Preparation Plant Wastes

In order to determine the nature and degree of health and safety hazards associated with backfilling, accident statistics for backfilling operations should be compared to a norm for mining operations not employing backfilling. Unfortunately, accident statistics are usually compared to a wide range of norms often making such data confusing and inconclusive. The objective of this study is to determine if the use of backfilling will present any high risks or unforeseen hazards to personnel or the environment. This includes identifying and dispelling any misconceptions. The use of accident statistics for this purpose helps to qualitatively clarify the degree of risk but does not allow an absolute quantitative level of risk to be established. This chapter deals specifically with the health and safety hazards inherent in backfilling operations in underground coal mines (metal mines are discussed in Chapter III).

In general, the degree of risk incurred is dependent upon the type and location of the activity (unit operation) taking place. Studies by Mueller, 1965, and Wanat, 1963, 1969 reviewed by Freid, et. al. (21), have shown that roughly 40 to 60 percent of all coal mining accidents are a result of human error, depending upon the severity of the environment. In addition, Mueller, 1965 (21) concluded that only 7 percent of all mine accidents exhibited a complete absence of human inadequacy as a cause. Although it is somewhat of a simplification, it can be said that where you have people you will have accidents. For the purposes of this study it must be assumed that human error will make essentially the same contribution to backfilling accidents as it does to accidents associated with other mining activities.

Backfilling is an additional activity in a mining operation. As such, it requires additional personnel and equipment for its implementation. The amount of personnel time and equipment required to backfill is dependent upon the method of backfilling and site specific requirements.

Backfilling can be broken down into a series of unit operations. Some of these unit operations are common activities that are employed for other purposes within the mine, while other unit operations are unique to backfilling.

For some unit operations, backfilling does not influence the degree of risk. These include unit operations which are needed for other mining activities as well as instances when the waste does not exhibit any of the adverse qualities which normally influence the amount of risk associated with a given unit operation.

In other situations, backfilling can influence the degree of risk of a unit operation. Such conditions would include instances when the quality of the fill material affects the risk of an activity, when the activity must be performed in a situation or location that would not be encountered by normal mining activities, or when the activity is unique to backfilling and consequently imposes new risks to backfilling personnel. Determining the degree of risk for these situations can become more vague and subjective unless accident statistics for such activities are available.

This study will attempt to point out the hazards involved with backfilling and indicate those which are unique to the backfilling activity and those which are not.

1. Hazards of Backfilling

Backfilling underground coal mines is a costly activity with a related potential for accidents. Therefore, the use of backfilling for the express purpose of waste disposal is justified only when the costs and hazards of surface disposal warrant it. A study conducted by Bucek (9) evaluated the environmental, technical, and economic problems of surface coal waste disposal across the country. This study located those regions which exhibited severe problems with surface disposal. The Appalachian region was the only area within the country that warranted this severe rating (Figure 1). As such, the Appalachian region has the highest potential for backfilling and can benefit the most by its use. Consequently, the reduced hazards to people on the surface and to the environment by placing coal wastes underground in the Appalachian region will likely offset any increased risk to personnel underground.

The advantage of Bucek's work is that it orients the hazard analysis to conditions which are similar to the Appalachian region.

To simplify the analysis of potential backfilling hazards, the hazards are classified as those occurring during waste haulage, those occurring as a result of stowing, and those associated with the stowed waste.

a. Waste Transportation Hazards

Coal wastes, being more inert than the coal itself and exhibiting physical characteristics fairly similar to coal, do not pose any significantly different risks in their handling than does coal. In fact, coal wastes may be more trouble free. As a result, the degree of risk that a miner encounters in transporting coal wastes is essentially the same as if he were transporting coal.

In the underground disposal of waste material, the waste must be transported from the preparation plant across the ground surface, from the ground surface to the working level, and along the working level to the disposal room. The waste may be transported by a different form of equipment for each leg of the trip or one type of haulage equipment may be used for the whole trip. The possible combinations of equipment used for waste haulage are numerous and the equipment chosen is dependent upon the mining method, stowing method, and other site specific factors. Table 2 indicates the potential combinations of haulage equipment that can be used. In some cases, the production equipment that is used to transport the coal can also be used to return the waste to the stopes,

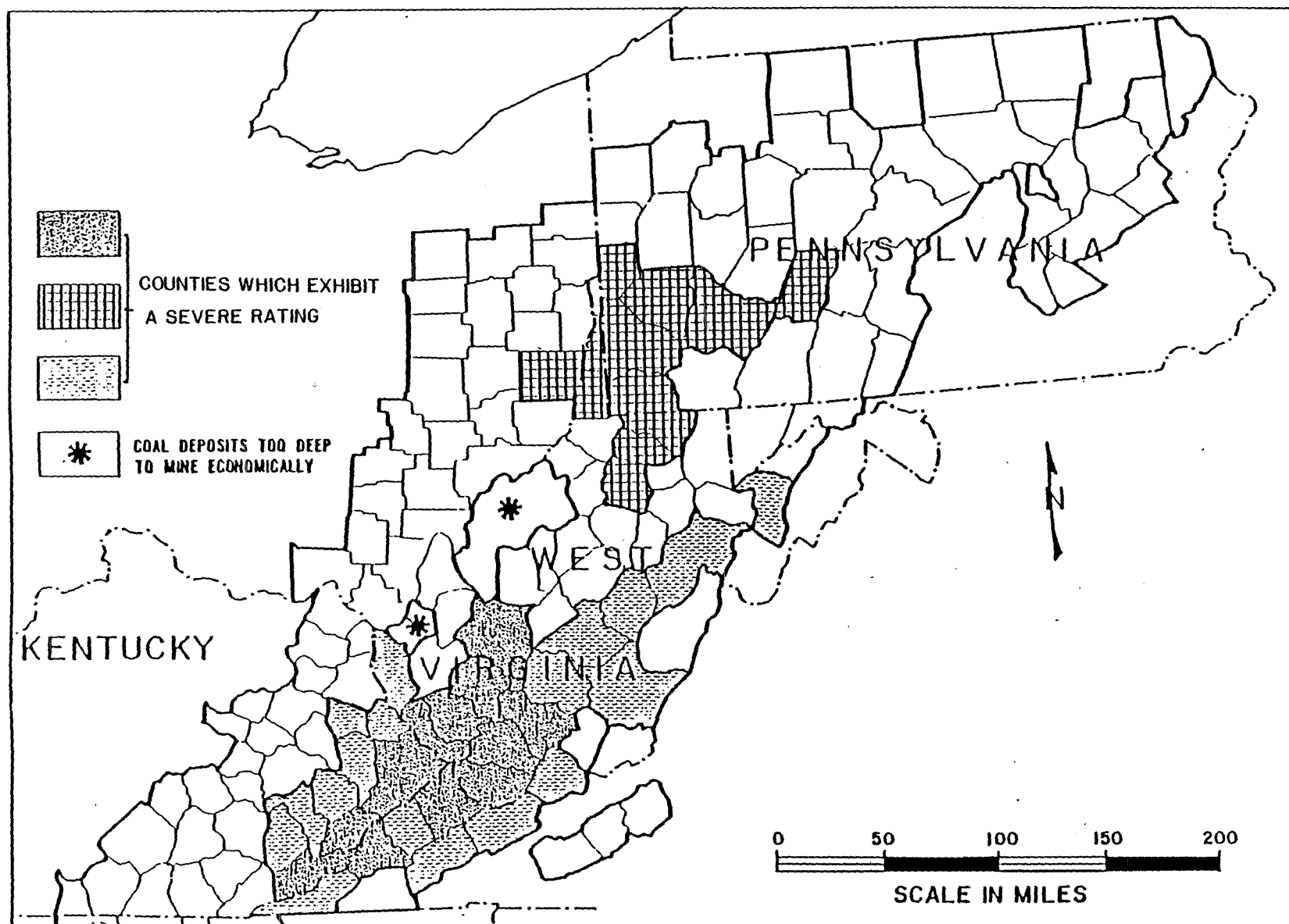


Figure 1. Regions in which environmental, technical, and economic problems of surface coal waste disposal are most severe (9).

however, these cases are few. No matter what haulage equipment is used to move the waste, it has to be compatible with production equipment and schedules. The actual haulage systems employed for backfilling are few in variety, usually consisting of slurry pipeline transport or mechanical transport with pneumatic or hydraulic stowing.

TABLE 2. - Combinations of Haulage Equipment That are Used to Transport Mine Wastes from the Preparation Plant to Stowing Room

<u>Principals of Stowing and Transport</u>	<u>Surface Transport</u>	<u>Surface-Working Level Transport</u>	<u>Working Level Transport</u>
Gravity	- - - -	Borehole	- - - - -
Mechanical	Rail Truck/FEL Conveyor	Rail Hoist Conveyor	Rail LHD Conveyor
Hydraulic	Pipeline	Pipeline Borehole	Pipeline

It is commonly assumed that underground activities are more dangerous than surface activities around an underground coal mine. Confirming this, Wanat, 1970 (21) determined that accident frequency (per ton of production) was on the average 2.5-3 times greater underground than on the surface. This indicates that activities which place people underground increase the frequency of accidents. Therefore, limiting the number of personnel underground for backfilling by limiting the length of underground haulage definitely reduces the risks. However, there are economic limits to minimizing underground haulage distance.

1.) Surface Haulage of Backfill Materials

The preferable way to compare accident statistics is through a comparison of incidence rate or accident frequency (accidents per worker time or accidents per ton of production). Unfortunately, most accident statistics provide inadequate data for such rates to be calculated. Instead, what is normally provided is the number of occurrences per category of accident. Such accident data are not correlated to tonnage production or worker hours. This means that a percentage of the accidents can be credited to a particular cause, activity, or location but nothing can be said about an individual worker's potential for having a certain type of accident.

For instance, both rail haulage and truck haulage of coal are labor intensive and have a high occurrence of accidents. Because accident statistics are not related to tonnage hauled or worker hours, it is difficult to determine which activity is more hazardous to a particular employee or what the expected accident rate would be if an operation were just starting up. As a result, generalizations about accident potentials are all that can be stated.

Wanat, 1969 (21), reported that the pattern of accidents on the mine surface was different from the underground pattern. The most pronounced differences were attributable to human and organizational factors. While these comprised 43% of all underground accidents, they represented 62% of the above ground accidents. Thus, to minimize the potential for an accident with surface haulage of waste materials, one should reduce the potential for human error by choosing a haulage system that requires few personnel to operate and maintain it. Since there are no accident statistics on surface haulage of coal wastes for backfilling of underground mines, it was felt that accident statistics at surface coal operations might provide some comparative information.

Grundy (25) reported that for the period 1972 through 1976 haulage at surface coal mines ranked seventh worst in terms of number of injuries when compared to other activities. However, it ranked second for number of fatalities, representing 26% of the deaths. This indicates that while accidents associated with haulage on the surface do not commonly occur, the consequences can be very severe.

Equipment used for rail haulage of coal wastes back underground would most likely be the same as, or similar to production rail equipment. As such, backfilling rail haulage workers would encounter the same hazards as the production rail crew. However, the total hazard to both crews might be increased due to congestion, spillage, or tighter scheduling. Yelensky, 1965 (21), found that for the period 1946-1964, severe or fatal rail haulage accidents in surface coal mines of the Ural Mountains in Russia represented 43% of all severe and fatal accidents. While this statistic may reflect the fact that the predominant haulage system was rail, it also indicates that rail haulage crews faced a relatively high hazard rate. In all, surface haulage of backfill materials by rail is probably the riskiest form of haulage, as long as the surface haulage distances are short.

Truck haulage of backfill material on the surface is probably the second riskiest form of haulage. Like rail haulage, the method is labor intensive to operate and maintain, mobile, subject to motion related accidents, involves many moving parts, and significantly adds to congestion. Seals (48)

stated that for the period 1972-1976 in U.S. surface coal mines, truck haulage represented almost 80% of the haulage related deaths. Here again, this figure tends to be biased because of the popularity of truck haulage. Truck haulage can easily become the most dangerous of backfill transportation methods if backfill material must be hauled along public roads for any great distance. This is primarily due to congestion on the roadways.

Conveyor haulage is similar to rail haulage in that material can be moved the whole distance from the preparation plant to the face by one system. In addition, conveyors must be run parallel to the production system through the main haulage drifts. However, this is where the similarity ends. Conveyor haulage is significantly safer than rail or truck haulage systems because it is stationary and requires fewer people to operate and maintain. In addition, there is less potential for an operator to incorrectly operate a conveyor; either it is on or it is off. Grundy (25) reported that for the period 1972-1976, conveyors were credited with only 7.5% of the surface coal mine fatalities. Because of its compatibility with many production systems and its low requirement for personnel, surface haulage of waste material by conveyor has good possibilities.

Slurry transport of coal wastes across the surface is the safest method by far. It is stationary, requires very few personnel to operate and maintain, has few moving parts, and can be routed over all kinds of terrain. There is a high potential for a spill, but on the surface the consequences are not severe. These advantages are reflected in the fact that slurry transport of backfill materials is the most popular method of haulage in the United States.

2.) Transport of Backfill Materials from Surface to Working Level

When material is transported beneath the surface, the potential for and the consequences of an accident increase. As stated earlier, miners have a 2.5 to 3 times greater accident frequency underground than on the surface. This is primarily the result of entering a hostile environment. Human and organizational factors comprise only 43% of the underground accidents as compared to 62% for above ground accidents. While Wanat, 1970 (21) stated that 57% of all underground accidents occurred at the face he also concluded in 1969 (21) that underground accidents which were primarily due to human factors mainly involved transport. Therefore, as with surface haulage of backfill materials, to minimize the potential for an accident when transporting waste underground the number of

personnel involved with operating, maintaining or working adjacent to the haulage equipment should be limited. This applies to hauling the waste from the surface to the working level as well as hauling the waste along the working level.

Backfill materials transported from the surface to the working level can be transported via the main production haulageway, ventilation drift/shaft, or through a borehole. The most versatile haulage system is slurry transport which can be used in all three openings. The other haulage systems (hoist, train, or conveyor) are usually relegated to the production haulageways. A hoist can, of course, only be employed in a shaft or slope mine, a conveyor in a slope or drift mine and a train in a drift mine.

As would be expected, the main haulageways, which are the most congested with personnel, have the greatest potential for accidents. Ventilation drifts/shafts exhibit a much lower risk potential for backfill transport than production haulageways because there are much fewer personnel in them. However, a large slurry spill in such a drift/shaft can still reach actively traveled workings and interfere with ventilation. A drill hole, if practical, is by far the safest location to run a slurry line to the working level. A drill hole is inaccessible to personnel and it can be placed so that underground routing of the slurry line can be in seldom used drifts.

Factors which make a haulage system hazardous on the surface are magnified for underground operations because of congestion, clearance, and spillage limitations. Trains are the most hazardous for hauling waste underground. This is because trains are mobile, require a larger crew to operate and maintain, must be operated in the highly traveled main haulageways, must be tightly scheduled to be compatible with production haulage, and must have a sufficiently complex rail system underground for the wastes to be transported where they are needed. Thus, it is a very labor and organizationally intensive haulage system, providing the right conditions for haulage accidents.

Despite the fact that it must be routed through the main production haulageway and that it has many moving parts, conveyor haulage of backfill materials to the working level is much less hazardous than using trains. This is because conveyors require fewer personnel to operate and maintain, are stationary systems, and operation is independent of the production schedule.

Slurry transport of backfill from the surface to the working level is, as on the surface, the safest method to return wastes underground. It requires few personnel to

operate and maintain, has few moving parts, is stationary, is independent of production scheduling, has much greater flexibility in its routing, and best of all, takes up very little space. In addition, the upper portion of the slurry line which runs from the surface to the workings usually operates at very low pressures. This minimizes the potential for breaks in the upper portion. This hazard is further discussed in the section on Slurry Transport Spillage.

The hazards involved with hoist transport of backfill from the surface to the working level are not clear. On the negative side, a hoist is a mobile haulage system, requiring a moderate amount of personnel to operate and maintain, and it is heavily tied to production scheduling. On the positive side, personnel are not usually near the moving equipment, and the hoistway does not get congested. Significantly, in 1979, hoist related accidents in underground coal mines represented only 0.14% of all underground coal accidents in the United States (14). Consequently, the degree of hazard associated with hoist haulage of backfill material to the working level is probably very low.

3.) Transport of Backfill Materials on the Working Level

The degree of hazard encountered in haulage on the working level is relatively the same as in hauling the waste to the working level from the surface, with a few notable exceptions.

One, with rail haulage there can be considerable car handling on the working level, increasing the labor involved with its use. This of course directly increases the potential of an accident.

Two, a slurry line which extends a considerable vertical distance to reach the working level builds up a very high pressure over a considerable portion of the working level leg of the pipeline. This increases the potential for a break in this portion of the pipeline. High pressure problems do not exist if the pit pump is located on the working level or if there is little vertical drop in the pipeline.

Third, if a slurry line must extend down a shaft, it must make a sharp bend onto the working level at a point where the pressure in the line is at its greatest. This is a section of high wear in the pipe, further increasing the potential for a spill.

4.) Slurry Transport Spillage

Because of the popularity of slurry transport to return coal wastes back underground and the high potential for slurry lines to leak, it was felt that a special subsection was needed to investigate slurry line spills. Hydraulic stowing requires that slurry transport lines be installed in mine entries or boreholes to the workings that are to be filled. These openings can be ventilation routes, main production shafts, or slope passageways. When the slurry lines are installed in mine openings, the line usually must run along main haulageways or other highly traveled drifts. While coal waste in slurry form is not particularly abrasive, it can be expected that sooner or later the line is likely to break from wear, incorrect coupling at pipe joints, abuse, or from water hammering the slurry line. If such spills are not detected immediately, especially when the pitch of the seam is steep, or the spill is in a crucial drift, the consequences can range from equipment damage to loss of personnel.

Hydraulic stowing is sometimes used in room and pillar mining for filling the mined out panels, whereas hydraulic stowing with longwall mining is used right next to the working face. Therefore, the consequences of a spillage accident affecting personnel or equipment is greater with the longwall mining system even though the filling can be more closely monitored.

Generally, when a slurry line breaks, the flow rate through the pit pump increases causing an increase in the power drawn by the pump. However, this is not always a reliable warning sign. If the breakage is not large, there is very little increase in the flowrate and there is no warning that there is a spill. Sometimes a major break can take place but due to the orientation of the pipe, sufficient back pressure at the break can mask the problem so that it is not noticeable at the pit pump.

An operator in Colorado who had run his slurry backfill lines down the production drift said that a ruptured slurry line had leaked unnoticed for four hours. This spill nearly stopped the production belt. The mine was relatively horizontal so that the spillage did not spread very far (18). However, if the pitch had been steep, a quick surge could have knocked out equipment or killed personnel. The same danger exists in a vertical shaft.

When a slurry pump is started, there is very little back-pressure at the discharge point and the slurry rushes through the empty pipeline. This water can have considerable momentum and can yank pipes off their mounts or break couplings if the

water surge is required to make a sharp bend. Once the pipeline is full of slurry, resistance to flow produces considerable backpressure slowing down the flowrate. This does not mean that every time a pipeline is started this problem is encountered, but if the pump is started at full power, such an event is possible.

Flyash is much finer than preparation plant waste, therefore it can be transported at a much lower velocity and with much less water. As a result, flyash presents a much lower potential for a spill because there is less pipeline wear and because there are fewer operational problems when hydraulically transporting a fine material. In addition, the consequences of a spill are less severe because the leakage rate from a broken pipeline is lower and there is less transportation water that has to be handled. However, a flyash spill will flow a greater distance because of its fineness.

Whether hydraulic stowing is used for increased stability, subsidence control, waste disposal, or a working platform, the potential for a spill is not significantly different.

a.) Water Hammer. - While water hammer is commonly associated with closing a valve too quickly in a pipeline causing a temporary high pressure condition, water hammer in a slurry line usually occurs through a different mechanism. Water hammer in a slurry line is usually the result of a very sudden and temporary blockage, usually at the suction inlet of the pit pump. When the pump suction is temporarily blocked causing the net positive suction head (NPSH) to drop below the required pressure, the pump total dynamic head (TDH) will drop to near zero. A sudden unblocking of the suction causes the pump TDH to instantly jump back to its normal level. This causes a high density slug of slurry to slam into the back of the slurry already in the pipeline creating a high pressure hydraulic shock wave that travels down the line. Booster pumps in the slurry line are the usual weak points for these hydraulic shocks, commonly resulting in a ruptured pump. However, the line could break at any weak point.

While a steel pipe can handle high pressure surges, brittle pipes such as PVC are more likely to break. A water hammer could occur if a large slug of solids were to slide into the pit pump suction as shown in Figure 2. Such a problem could be remedied by using a sloped bottom feed box. If the pit pump suction is as shown in Figure 2, a water hammer could be created by getting the suction too close to the bottom causing it to be temporarily blocked by the floor of the pit.

b.) Wear. - With a slurry line, wear is a constant problem. The line should be inspected regularly and the pipe rotated to distribute the wear uniformly. A wear hole can make a considerable mess without showing much change at the pit pump. It usually is not as catastrophic as a blown line from water hammer.

The operations of the Armutcuk Coal Mine in Turkey, which has a thick, steeply pitching coal seam implemented hydraulic stowing of borrow material in 1957. The following statement concerning slurry pipelines at this mine indicates the

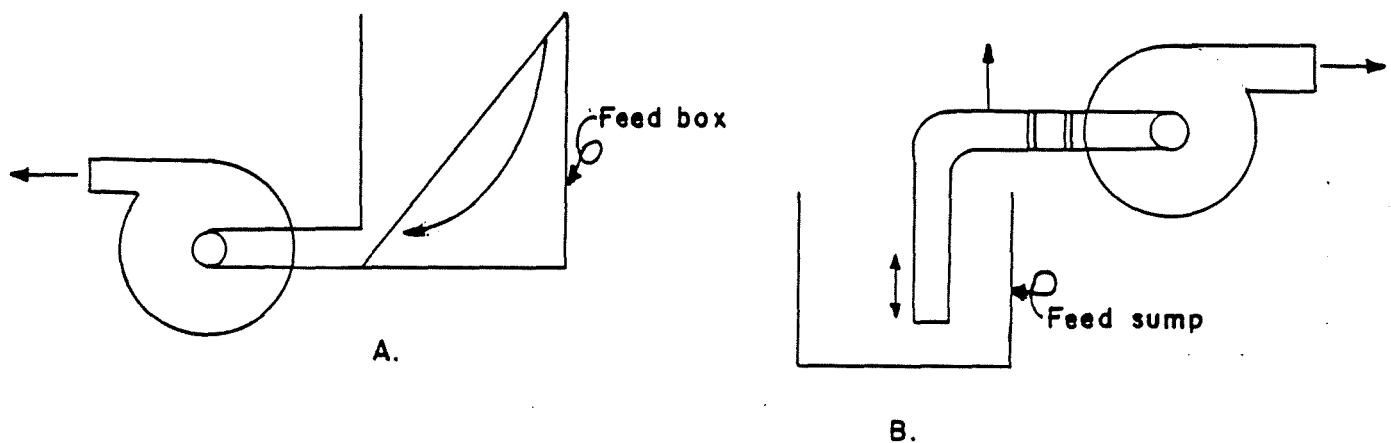


FIGURE 2. - Situations which can cause a water hammer from temporary blockage of the sump pump suction.

potential problems caused by pipeline wear (26): "Experience has shown that for greater efficiency, special attention must be paid to the maintenance of the stowing plant and pipeline network; and for this regular inspections are essential. The success or failure of this method depends to a large extent on the attitude of mine management to the working operations."

c.) Recommendations to Limit Spill Problems. -

1. Frequent inspections of slurry line.
2. Rotate pipe for more even wear.
3. Patch leaks immediately.
4. Try to route slurry lines through drifts that are not heavily traveled.
5. Care must be used during start-up and during operation to prevent water hammer of the slurry line.
6. Protect the slurry line from abuse by equipment.

b. Hazards in the Stowing Area

Backfilling personnel who go underground face a greater hazard than those on the surface as described above. The question is, what hazards do they face and are these hazards any greater for backfilling crews than for other miners who must go underground? As with transportation, there are some activities whose degree of risk does not change when backfill materials are involved. In other cases, special techniques for handling or placing of the wastes can create a hazard that is not normally encountered elsewhere in the mine, or not encountered to the same degree. This section is a discussion of those hazards that exist in stowing the waste.

Mine wastes can be stowed in sealed areas of the mine, in mined out but accessible areas of the mine, or next to the active production face. The degree of hazard that backfilling crews will encounter will be dependent upon where they are working, what their activities are, and the materials they are dealing with. For instance, Wanat, 1970 (21) reported that in the hard coal mines of Poland, 57% of all underground accidents took place at the face. This is not surprising as most of the men are concentrated at the face, but it also indicates that backfilling near the face is more risky.

To better understand the hazards that will be encountered during stowing, they will be discussed according to the location of filling; at the working face or in mined out panels.

1.) Stowing at the Working Face

Backfilling adjacent to the working face has predominantly been practiced in Europe. In almost all cases, backfilling has been hydraulic or pneumatic at a longwall or shortwall face. There has been no mention of backfilling adjacent to a room and

pillar working face. While backfilling is becoming unpopular with the European mining industry because of its expense, it is still an accepted practice.

Even though the use of backfilling in Europe is declining, the use of backfilling in Poland is not. This is primarily because Poland has stringent surface disposal criteria and in some cases, all mine wastes must be returned underground (43). As a result, accident statistics from Poland are probably the most representative accident information that can be acquired for backfilling at a longwall or shortwall operation. Wanat, 1970 (21), reporting on hard coal mining in Poland, provided accident rates (accidents/100,000 man-days) at various underground working faces for 1967-1969 as shown in Table 3.

TABLE 3. - Accident Frequency Rates at Various Types of Faces, 1967-1969 (21)

<u>Number</u>	<u>Type of Face</u>	<u>Number of Accidents per 100,000 Man-days</u>		
		<u>1967</u>	<u>1968</u>	<u>1969</u>
1.	Longwalls, total	36.4	43.3	50.4
1.1	Longwalls with caving	30.3	44.5	51.3
1.2	Longwalls with hydraulic filling	32.7	40.8	49.6
1.3	Longwalls with dry filling	50.6	49.1	46.2
2.	Shortwalls, total	19.5	33.7	30.9
2.1	Shortwalls with caving	15.5	17.8	21.1
2.2	Shortwalls with filling	22.8	37.7	36.5
3.	Gate ends, total	12.6	14.8	20.6
3.1	Rock gate ends	3.8	4.4	5.4
3.2	Rock-coal and coal-rock gate ends	11.7	12.0	15.7
3.3	Coal gate ends	22.2	29.8	44.6

Table 3 indicates the potential of an accident based upon the type of face that is being worked. From this table, the following conclusions might be made.

1. The degree of risk that a longwall miner faces is independent of whether hydraulic stowing, dry stowing, or caving is used.
2. Shortwall mining with backfill is significantly more hazardous than shortwall mining with caving, even though shortwall with backfilling is much safer than longwall mining.

While Table 3 gives the accident potential for various faces, it does not state what the major hazards are or the proportions of the accidents attributable to each hazard. Wanat, 1970 (21) further clarified these hazards by compiling a distribution of accidents at the faces according to the type of hazard (See Table 4).

While he grouped his hazards into 10 categories, they can be simplified into three classifications: fall of roof or side rock (No. 1 and 2), fall of material through the lining (No. 4), and accidents influenced by the presence of personnel (No. 5, 6, 7, 8, and 9). These hazard classifications are covered in the subsections below entitled fall of rock, fall of fill, and congestion. While Wanat had reported on catastrophic accidents in his work, he failed to cover conditions hazardous to health. Consequently, these are covered below in subsections on dust generation and dust and gas ignitions with pneumatic stowing.

a.) Fall of Roof, Face, or Rib. - According to Galloway (22), in U. S. coal mines during 1980, 71% of the fatalities occurred underground. Fall of roof, face, or rib accidents accounted for 24% of the total number of fatalities for the coal mining industry. Eighty-four percent of roof fatalities occurred in by the last support. Consequently, roof falls are the number one killer of U. S. mining personnel, with a majority of these fatalities happening under unsupported roof. Therefore, the face is where the most dangerous roof fall potential exists. It is obvious that even if backfilling does not have an effect upon the roof fall potential, the placing of additional personnel at the face will expose more miners to roof fall hazards resulting in additional accidents and injuries.

It is important to understand how backfilling adjacent to the working face affects the potential for roof falls. The effect of backfilling upon the roof fall potential can be evaluated by comparing roof fall accident frequencies for mining with and for mining without backfill. If the accident frequency is relatively unchanged, then backfilling has had no effect upon the roof fall potential. Using information from Tables 3 and 4, roof fall accident frequencies were determined according to the type of working face in Table 5.

TABLE 4. - Percentile Distribution of Accidents at Faces According to Type of Hazard (21)

		<u>Longwalls</u>		<u>Shortwalls</u>			<u>Headings</u>		
		With	With	With	With	With	Coal	Rock/	Rock
		Caving	Hydraulic	Dry	Caving	Hydraulic		Coal	
			Filling	Filling		Filling			
1.	Fall of rock from roof	21.78	17.34	17.05	20.93	25.06	18.05	18.58	13.52
2.	Fall of rock from side walls	12.24	16.10	9.38	25.58	20.48	17.54	14.86	6.76
3.	Fall or sliding of objects	24.62	22.39	21.58	6.98	17.35	15.80	13.31	20.27
4.	Fall or sliding of winnings or rock from behind the lining (Except 1 and 2)	11.49	7.06	23.29	9.30	9.88	7.88	17.96	18.91
5.	Fall, stumbling, or slipping of persons	2.82	6.18	5.12	2.33	1.50	9.20	9.12	6.67
6.	Blows by work tools	4.49	8.30	7.10	6.98	7.33	7.14	5.88	4.06
7.	Protruding objects	6.12	6.46	5.40	9.30	5.78	6.60	6.50	12.16
8.	Touching transport machinery and installations in motion	4.54	4.70	3.13	2.33	1.45	8.10	4.96	6.25
9.	Touching working machinery	4.03	2.33	0.85	4.64	0.48	2.77	3.72	4.06
10.	Other hazards	6.87	9.14	7.10	11.63	5.69	6.66	5.11	7.29
		100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

TABLE 5. - Roof Fall Frequencies According to Working Face

<u>Face</u>	<u>Roof Fall Accidents/100,000 Worker Days¹</u>
Longwall with Caving.	17.5
Longwall with Hydraulic Stowing.	16.6
Shortwall with Caving	9.8
Shortwall with Filling.	9.72

¹ Derived from 1969 statistics

² Assuming that most shortwall mining uses dry filling

From Table 5, two conclusions can be made. One, that backfilling adjacent to the working face appears to have no effect (<5%) upon the roof fall potential for longwall or shortwall faces. The last shortwall statistic however uses the assumption that most shortwall filling is done dry. Two, shortwall mining has a much lower potential for roof fall accidents than longwall mining.

To summarize, accident statistics have shown that backfilling adjacent to the working face has no effect upon the potential for a roof fall. However, there normally is a high potential for roof falls at or near the face, so bringing backfill crews into these areas exposes them to a hostile environment. This potential for roof fall injuries to backfill crews can be minimized by using a shortwall mining method versus a longwall mining method.

b.) Fall of Material Through Lining (brattice). - The backfilling of an unconsolidated waste material adjacent to an active face creates the potential of this fill material sliding into the crew at the face. Such a potential is a function of the mining method, stowing method, strength of the pack, how high the pack must stand, and the strength of the lining (brattice) which retains the fill. There is very little information available to address this topic. This is primarily because filling adjacent to the face is not a common practice except in Poland. Using Wanat's, 1970 (21) accident statistics, it was possible to calculate the accident frequency for fall of material through brattice (Table 6). In the case of a backfilling method, this means a fill failure through the lining and in the case of a caving method, this means gob (i.e., caved material) invading the working face.

TABLE 6. - Accident Frequency for Fall of Material Through the Lining According to Working Face

<u>Face</u>	<u>No. of Accidents/100,000 Worker Days¹</u>
Longwall with Caving.	5.89
Longwall with Hydraulic Filling.	3.50
Shortwall with Caving	1.96
Shortwall with Filling.	8.50 ²

¹ Derived from 1969 statistics

² Assuming that most shortwall mining used dry filling

Table 6 indicates that there is a significantly lower accident frequency in longwall mining with backfilling than with caving. However, shortwall mining showed the inverse effect but to greater extremes. From Table 6 it is apparent that backfilling changes the potential for material penetrating the lining, but it also is apparent that the mining method has a significant impact on how backfill influences such a risk. With longwall mining, the inclusion of fill apparently reduces the catastrophic failure of the roof behind the lining thus reducing the amount of material that can penetrate the lining. On the other hand, shortwall mining with caving has the lowest accident frequency while shortwall mining with backfill has the highest accident frequency. Shortwall mining with caving has the lowest accident rate with lining failure because the face is perpendicular to the lining instead of parallel as with long-wall mining. The shortwall crews have more room and they are not working as close to the lining as with longwall mining. However, when backfilling with shortwall mining, the perpendicular orientation of the face to the lining appears to create more lining breakage problems than it solves.

Wanat, unfortunately, did not provide sufficient accident information to evaluate whether lining failure accident rates were different for hydraulic stowing as compared to pneumatic stowing. It therefore, must be assumed that the fill's potential for failure will govern this hazard. Such a risk is investigated in the section below entitled "Quick Potential of Inplace Waste Backfill."

To summarize, the hazard of material penetrating the lining and causing an injury is less than for roof falls. With longwall mining, the inclusion of backfill reduced the potential for lining failure but with shortwall mining, it accentuated the hazard. This inverse relationship is primarily due to the orientation of the working face for these two methods.

c.) Face Congestion. - It has been the concern of some that backfilling activities adjacent to an active face cramp quarters sufficiently to increase the potential of an accident due to congestion. However, accident rates at the working face due to congestion are hard to quantify. For instance in 1963, Wanat (21) stated that only 2.5% of the accidents at 10 Polish hard coal mines were due to congested headings and workplaces. However, given the congested conditions at the working face, it must be assumed that there is a high potential for human and organizational accidents. This can be substantiated by the fact that underground haulageways, which usually have tight clearances, primarily have human related accidents.

To help simplify our evaluation we will assume that the human and organizational hazards listed by Wanat in Table 4 (Nos. 5-9) are a result of congestion. If the accident frequencies of these hazards are different for filling as compared to caving, then it might be deduced that backfilling does affect congestion related accidents. Table 7 shows these accident frequencies as determined from the data in Tables 3 and 4.

TABLE 7. - Congestion Accident Frequencies According to Working Face

<u>Face</u>	<u>No. of Accidents/100,000 Worker Days¹</u>
Longwall with Caving.	.11.3
Longwall with Hydraulic Filling.	.13.9
Shortwall with Caving	5.4
Shortwall with Filling.	7.9 ²

¹ Derived from 1969 statistics

² Assuming most shortwall mining was with dry filling

From Table 7, it can be seen that longwall mining exhibited 23% more congestion related accidents with filling than with caving. In addition, there were 46% more congestion related accidents in shortwall mining with backfilling than with caving. Longwall mining also had twice as many congestion related accidents as shortwall mining. This is understandable because as we stated in the previous section, the working face of a shortwall operation is perpendicular to the lining allowing for more room to work.

To summarize, backfilling adjacent to an active face apparently increases the potential for human and organizational accidents due to congestion. However, such accidents can be greatly minimized by using a shortwall method rather than a longwall method. Since backfilling has not been applied adjacent to a room and pillar mining face, this situation could not be evaluated for its ability to create congestion related accidents.

d.) Respirable Dust Generated by Pneumatic Stowing. - Pneumatic stowing is the only stowing method that exhibits a dust generation problem. This problem is the worst when pneumatically stowing adjacent to an active face, although there is some dust dispersion involved with blind pneumatic stowing at the stower. The dust generation problem is not easily solved as there are a number of influencing factors. The following subsection will point out these factors and discuss the severity of the dusting problem backfill materials.

(1.) Current Dust Regulations. - The current maximum allowable concentrations (MAC) for dust in coal mines according to MSHA (6) is as follows in Table 8.

TABLE 8. - Maximum Allowable Concentration of Respirable Dust in Coal Mines

<u>Material</u>	<u>Maximum Allowable Concentration¹</u>
Coal or coal wastes (<5% SiO ₂)	2 (mg/cm ³)
Coal or coal wastes (>5% SiO ₂)	(10/%SiO ₂)(mg/cm ³)

¹Average for 8 hour exposure at the working face

The above regulations are in units of mg/cm³, which makes it difficult to correlate with data that is reported in particles/volume. However, 2mg/cm³ is roughly equivalent to 200 particles/cm³ or 6 million particles/ft³ assuming specific gravity = 2.65 and the mean particle size is 2 microns.

As is indicated in Table 8, the presence of quartz (SiO₂) can make the dust requirements very stringent. It was determined by MSHA that coal mine wastes must meet all of the dust requirements in underground workings applicable to coal despite the fact that the carbon content of the waste is low.

(2.) Dust Hazard. - Considering that the silica content of coal wastes can be high if the roof, floor, or partings are sandy, some wastes could be totally unsuitable for pneumatic stowing unless the amount of dust can be stringently controlled.

A study by the British National Coal Board (NCB) (35) was conducted in 1958 to determine dust levels from pneumatic stowing and to find a way of reducing them. It was found that concentrations of respirable dust ranged from 260 to 3000 particles/cm³ (7.4-85 million particles/ft³) during stowing and that the most important sources of dust were in the stowing area and at the stower. While the moisture content of the material was an important factor, there were other large differences between stowing systems.

Other tests have been conducted by the British National Coal Board (35) and in Germany (35) to determine the factors causing dust generation. Considering the range of reported dust concentrations it is obvious that a pneumatic stowing system unless operated in a correct fashion, could far exceed dust requirements in underground U.S. coal mines. Therefore, it is quite important to understand those factors which reduce or produce the generation of dust from pneumatic stowing. As with any mining activity, pneumatic stowing can be employed in a safe manner or a dangerous manner, or can be used for an inappropriate application. The safety of mine personnel is dependent upon several factors that are discussed below.

(3.) Dust Sources in Pneumatic Stowing. - Respirable dust comes from the discharge end of the pneumatic stower, from leakage at the stowing machine, and from impact of the stowed material on the face of the pack. However, the amount of dust suspended will be dependent upon the manner in which the pneumatic equipment is operated, preparation of the fill material, and the fill material properties.

The German studies (35) determined some interesting information on fill properties which influence the amount of dusting in pneumatic stowing. After testing with shales, sandy shales, and sandstone, they found that sandy shales and sandstones produced more respirable dusts and that these respirable dusts contained a higher proportion of quartz. This would indicate that it could be difficult to meet dust requirements underground if pneumatic stowing were used with a very sandy waste.

Size distribution had important effects upon dusting and pneumatic stowing. Excess fines, as a result of weathering or too much grinding, not only increased the amount of suspended particulate, but within certain moisture limits, exhibited a marked degree of stickiness requiring the pneumatic stower to be operated at a higher flowrate. The NCB's suggestions

included screening out of the fines, addition of dry material to lower the moisture content, or addition of water to raise the moisture content. The German studies also showed that increasing the top size of the stowed material increased the dust dispersion (particles/ton of stowed material) at a constant airflow rate and also increased the minimum flowrate for the stower, therefore, there appears to be an optimum size distribution for a pneumatically stowed material to minimize dusting.

The Germans found that while there was considerable breakage of material with pneumatic stowing, there was no correlation between production of fine material by breakage and airborne dust. Therefore, it must be concluded that a greater degree of dustiness exhibited by weathered material was due to the smaller size distribution and not to increased friability.

Results of the investigation of controlled pneumatic stowing by the NCB determined many of the operational factors that control dust generation but little was concluded relating to the amount of fines that were present in the fill material or their chemical composition. Table 9 may help in comparing dust potential of several common coal mine wastes. Table 9 lists the amount of -200 mesh and -7.1 micron (μ) material present in representative size distributions of these wastes. Minus 7.1 μ was chosen because the dust collectors used by the NCB in their study collected particulates in this size range. Included is an appropriate range of quartz concentrations from sampling of bituminous waste piles done by the U.S. Bureau of Mines at some western coal mines.

TABLE 9. - Amounts of Respirable Dust from Common Coal Wastes

<u>Wastes</u>	<u>-200 mesh</u>	<u>-7.1μ</u>	<u>SiO₂</u>
Anthracite Coarse ¹	3%	----	
Bituminous Coarse ²	5% - 13%	Trace - 6%	14% - 47% ⁴
Bituminous Fine ²	29% - 36%	7% - 12%	
Flyash ³	70% - 90%	10% - 35%	40%

1 (57)
2 (10)
3 (23)
4 (5)

What becomes apparent is that wastes which have many fines such as preparation plant fine wastes or flyash with a high SiO₂ content would be extremely difficult to pneumatically stow and still meet MSHA dust regulations. This excessively fine waste could be blind pneumatically stowed provided there was good exhaust ventilation at the stower. Coarse preparation plant wastes, on the other hand, may be very suitable for pneumatic stowing, especially if the SiO₂ content is low.

The NCB studies found that there was an optimal range of material moisture content to minimize dusting. Their experimental work with various shale wastes showed this range to be 6%-9% by weight. Obviously if the material was excessively dry, the fine particles would suspend much easier. However, at moisture contents greater than 9% and when stowing at high air flowrates, the dust dispersion increased. The higher moisture contents created visibility problems from fogging and more material handling problems from stickiness. It was also found that the addition of a little water to the compressed air supply aided in suppressing dust.

The air flowrate, or velocity, is the single most important parameter affecting dust dispersion in the stowing area. Dust dispersion increases with both volume and velocity of the air. The NCB found that in experiments using a 6" pipe, the dust dispersion in the stowing region doubled with every 700 ft³/min. flow rate increase if other operating parameters were optimal. If optimal conditions were not present, the dust dispersion could be doubled for every 400 ft³/min. increase in airflow. This means that if dust is to be minimized within the stowing region, the pneumatic system will have to be operated at the lowest possible air flowrate keeping in mind the minimum flowrate for efficient operation and good pack formation.

Dust dispersion at the stower is due to air leakage which is dependent upon back pressure and clearances of the stower. This means that adjustment of the stower to minimize leakage is necessary and frequent. It is suggested that dust laden air from the stower exhaust should be filtered.

Back pressure on the stower increased with an increase in material feed rate, the length of the stowing pipe, and its complexity. Increased air flowrates also induced a slightly greater backpressure. This supports the earlier conclusion that a pneumatic stower should be operated at the minimum allowable transport velocity. It also indicates that the conditions that increase the minimum optimum flowrate should be controlled.

The minimum pneumatic flowrate to transport a suspension is based upon several factors. The number of factors and their degree of influence can vary with the flowrate. The following discussion outlines some of these factors.

At high transport velocities it was found that dust dispersion could be minimized by using the maximum allowable throwing distance while still obtaining a high density fill. However, at the low transport velocities, short throwing distances can be used without increasing dust dispersion.

The use of a deflector shoe, while making fill placement easier, decreases the material velocity by a 25% thus decreasing pack firmness. The shoe also increases dust dispersion at higher airflows. It was reported that at 2800 ft³/min for a 6" pipe, the deflector shoe increased dust dispersion by 50% while at 1400 ft³/min it had no effect. The bottom line is that deflector shoes on the discharge of the pneumatic stowing line are undesirable.

The longer the pipe, the more bends there are in it, and/or the more friction causing wear there is in the system, the greater the minimum flowrate will be for stowing, thus creating more dust in the stowing region and at the stower.

Material feed rate to the stower has several effects with respect to dusting. The greater the feed rate, the lower the dust dispersion (particles/ton) but because a greater transport velocity is needed to carry the greater load, the reduction in dusting is negated by higher transport flowrates. Increasing feed rates also increases back pressure at the stower producing more leakage and dusting problems. What is important with feed rates is consistency. The more constant the feed rate the closer to the minimum transport velocity the system can be operated, thus minimizing dusting.

The main factor influencing the required airflow was "stickiness" rather than material size or type. Therefore, some moisture control to reduce stickiness may be necessary if transport flowrate is to be minimized for dust control.

It is apparent from reviewing the controlling factors that some of them increased dusting only at high flowrates; these were as follows:

1. High moisture content of the stowing material
2. Throwing distance
3. Deflector shoe on discharge of stowing pipe, and
4. Material top size

To maintain dust control in pneumatic stowing, it was found to be necessary to employ an exhaust duct adjacent to the pneumatic discharge as is indicated in Figures 3 and 4. It was

found that for stowing within a dead heading, the exhaust had to remove 150% of the air that was being introduced by the stower if dust levels were to be kept tolerable at the position of the deflector shoe. On a longwall face, dust was prevented from spreading into the main ventilation stream only by using a seal between the stowing region and the ventilation stream and by exhausting 50% more than the stowing air flowrate (see Figure 4). In this manner, dust dispersed into the airstream was reduced by 80% to 95% depending on whether the direction of stowing was with or against the direction of ventilation.

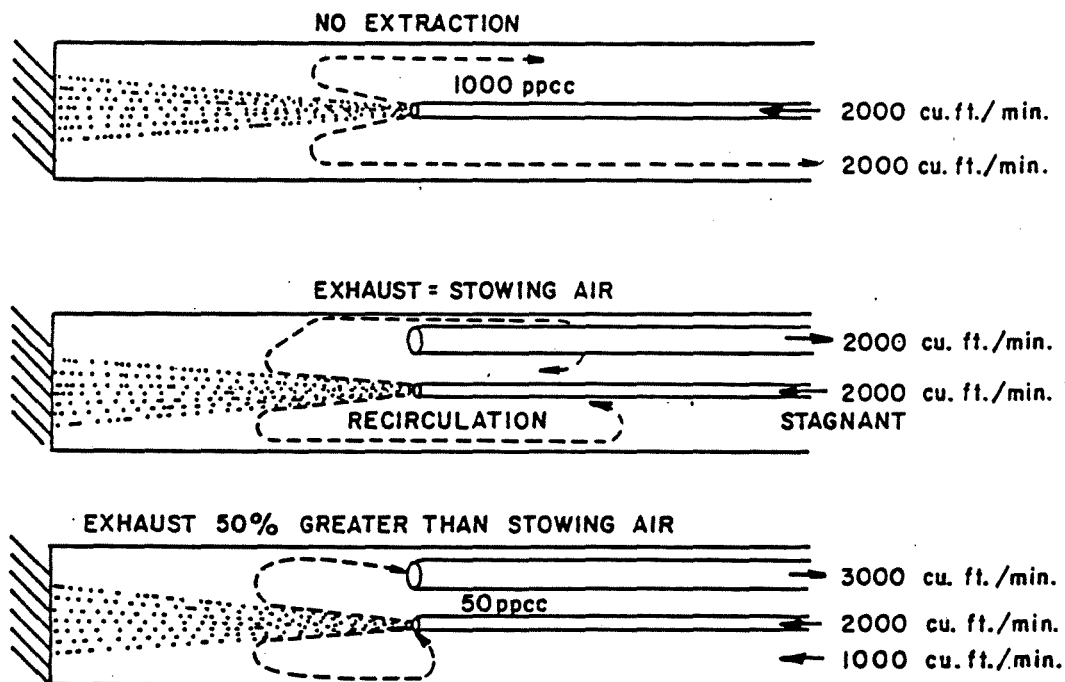
Filtration at the exhaust port of the stower was found to reduce dust at the stower by 50%.

(4.) Purpose for Backfilling. - Whether for room and pillar mining, longwall mining, shortwall mining, or controlled or blind flushing, pneumatic stowing has only two intended purposes, to reduce subsidence and to dispose of preparation plant wastes. Since the stowing techniques are the same if used for subsidence control or disposal, the potential for dusting with pneumatic stowing is independent of its intended purposes.

(5.) Conclusion. - Dusting can be a major problem when pneumatic stowing is used in an underground coal mine, especially when the waste material is very sandy. The dusting problem can be controlled by preparation of the fill material, by set-up and operation of the stower to minimize dusting, and by exhaust ducting at the stower line discharge and at the stower. Implementing these dust control measures can effectively control the dusting problem.

e.) Ignition of Gases or Dust During Pneumatic Stowing. - There has been concern that the use of backfilling, especially pneumatic stowing adjacent to the face, can accelerate the potential of an ignition of gases or dust by friction or static charge build up. This hazard potential is difficult to verify with accident statistics because no occurrences have been reported when backfilling. To compound this problem, Wanat (21) who had previously supplied such useful accident statistics for accidents at the working face, did not even list ignition or explosions as a hazard. To analyze this potential, the contributing factors to such an accident must be investigated because the accident statistics are inconclusive.

For an ignition to take place, an explosive mixture must be produced and an ignition source supplied. Common explosive mixtures in underground coal mines are methane gas concentrations or a dust suspension of combustible material. Unfortunately, pneumatic stowing of preparation plant wastes can supply all of the above.



Dust concentrations at positions of deflector shoe operator

FIGURE 3. - Effect of exhaust ventilation to control dusting in heading during stowing (35).

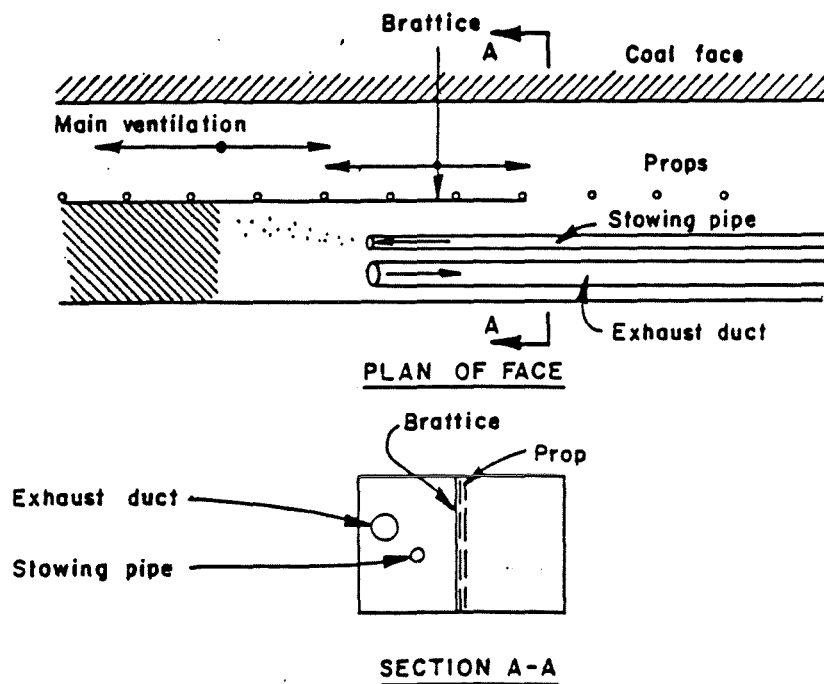


FIGURE 4. -- Arrangements for exhaust ventilation on longwall face (35).

Hartmann (29) concluded that electric arcs were the largest recent source of ignition for coal mine explosions. Therefore, the buildup of a static charge on a pneumatic stowing machine due to friction should be considered a viable source of ignition for such an explosion. A static charge buildup can be prevented by grounding the stowing machine.

MSHA regulations state that the methane concentration should be maintained below 0.5% for an 8 hour average and if the methane concentration reaches 1.0% the face must be evacuated. This requirement is considerably lower than the 5%-15% methane concentration necessary for an explosive mixture, but it is conceivable that isolated dead air pockets could reach this concentration. The working face usually has the highest gas emission rate, so this location receives the most monitoring. The ventilation rate is adjusted accordingly to maintain gas concentrations within limits.

The backfilling of waste adjacent to the working face can reduce the gas emission rate at the face, thus reducing the potential of a gas explosion. The fill limits the amount of roof strata fracturing, thereby limiting the amount of entrained strata gas that can leak out of the roof. While a preparation plant waste itself emits some methane, the quantity is negligible compared to what is being liberated at the face. On the other hand, a flyash emits no methane at all.

The real hazard that exists with pneumatic stowing of preparation plant wastes is a dust explosion. Flyash is totally incombustible and does not exhibit such a potential for explosiveness. Preparation plant waste which has been stock piled at the surface may be broken into finer particles and so present a more serious dust hazard.

Hartmann (29) stated that the potential for a dust explosion was based upon the particle size distribution of the dust, composition of the dust, amount of flammable gas present, quantity of dust, and the moisture content of the dust. The relationship between these factors is not simple, so the explosive potential of a preparation plant waste must be evaluated by two criteria. First, are there sufficient fines available for an explosion, and second, is the waste material sufficiently combustible to be explosive? Hartmann (29) described the maximum size particle that would contribute to an explosion as being 20 mesh. However, he stated that of this minus 20 mesh material, the proportion of minus 200 mesh determined the minimum concentration of suspended dust necessary for

an explosive mixture. This relationship is shown in Figure 5 for a bituminous coal dust. Because bituminous preparation plant wastes usually range from 14% to 47% SiO_2 , the maximum allowable concentrations of respirable dust allowed by MSHA would range from 0.2 to 0.7 oz/ft³. The percentage of

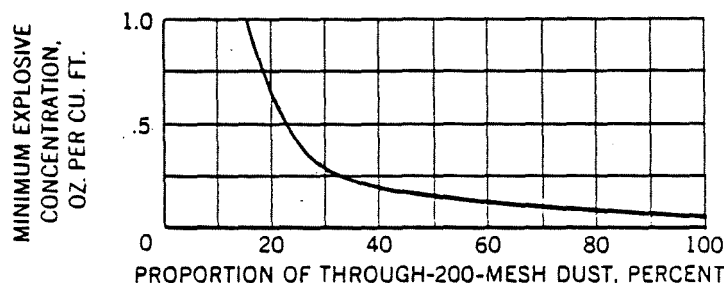


FIGURE 5. - Effect of various proportions of minus 200 mesh particles in through 20 mesh dust on minimum explosive concentration (29).

minus 200 mesh dust present within the explosive size range (minus 20 mesh) for a coarse bituminous coal waste is only 16%. Using Figure 5, this means that as long as MSHA maximum allowable concentrations for respirable dust are maintained when pneumatically stowing coarse bituminous coal wastes, there will be an insufficient concentration of dust for an explosive suspension. On the other hand, the percentage of minus 200 mesh dust present within the explosive size range (minus 20 mesh) for a fine bituminous coal waste is 39%. Using Figure 5, this means that bituminous fine coal wastes exhibit sufficient fines to produce an explosive suspension and still meet MSHA regulations on respirable dust.

Hartmann (29) stated that a dust was classified as explosive or nonexplosive based upon the relationship depicted in Figure 6. This classification is based upon the percentage of combustible material, percentage of flammable gas present, and a calculated value called the volatile ratio. The volatile ratio is indicative of the coal rank so that high rank coals have a low volatile ratio and low rank coals have a high volatile ratio. He concluded that for a volatile ratio below 0.12, coal dusts would be classified as nonexplosive. This is the equivalent of an anthracite coal. From Figure 6, it can be determined that an explosive dust can be avoided except for very low rank coal wastes, if there is a minimum of 70%

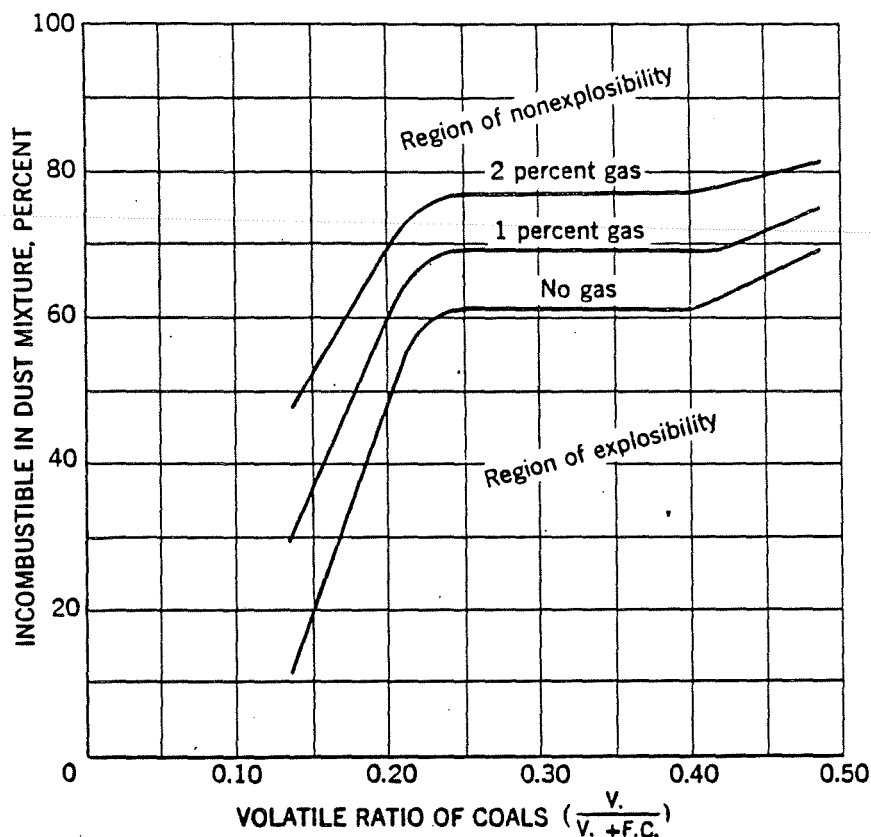


FIGURE 6. - Explosibility of mine-size coal dusts with and without gas in air current (29).

incombustible material in the dust. It is assumed that a 2% methane concentration will not be encountered. A National Academy of Science Study (43) reported that the incombustible content of bituminous wastes ranged from 70% - 90% for fresh wastes but only 40% - 85% for weathered wastes. It is assumed that the combustible component includes the fixed carbon, volatiles, and sulphides. It is also assumed that the volatile ratio of the fresh wastes is the same as the coal that it came from. From this it can be concluded that the fresh wastes are a nonexplosive material. The volatile ratio of the weathered waste is probably lower due to oxidation, so that it too might be considered nonexplosive. Because these preparation plant wastes just barely qualify as nonexplosive, before pneumatic stowing of a preparation plant waste it is best to determine the percent of incombustible material and the volatile ratio in the laboratory.

Hartmann also indicated that the explosive classification for a dust was affected by the amount of fines and moisture present. This relationship is depicted in Figure 7. This figure reconfirms that at least 70% of the dust must be incombustible for bituminous preparation plant fines.

To summarize, pneumatic stowing of bituminous preparation plant fines can produce a dust explosion not just because it can produce a dust suspension that is explosive, but also because it can ignite the dust suspension. The following suggestions should reduce the potential for dust explosions:

- 1) Ground the stowing machine and ducting
- 2) Screen the minus 200 mesh material out of the waste before stowing
- 3) Maintain the incombustible content above 70%, and
- 4) Control dust emission produced by stowing.

Anthracite, bituminous coarse wastes, and flyash exhibit no tendency for explosiveness.

Lastly, pneumatic stowing adjacent to the active face can reduce the gas emission from fractured roof strata.

2.) Remote Backfilling Hazards

Backfilling activities which are concurrent with production operations and adjacent to the active face require considerable planning. On the other hand, backfilling of mined out sections of the mine (remote backfilling) are independent of the production schedule and can be simpler to design. Almost all known cases of remote backfilling have been accomplished with either a controlled or a blind hydraulic stowing method. There has been a rare occasion of pneumatic blind flushing of a flyash material.

Usually, remote filling is used for purposes of disposal and commonly is an afterthought with an active operation. However, the South Africans have used a flyash to backfill a mined out seam for increased stability, so that nearby seams could be mined without any adverse interaction between the workings. The backfilling technique used by the South Africans was a typical controlled hydraulic stowing method. Consequently, the method chosen for remote backfilling appears to be independent of the intended purpose.

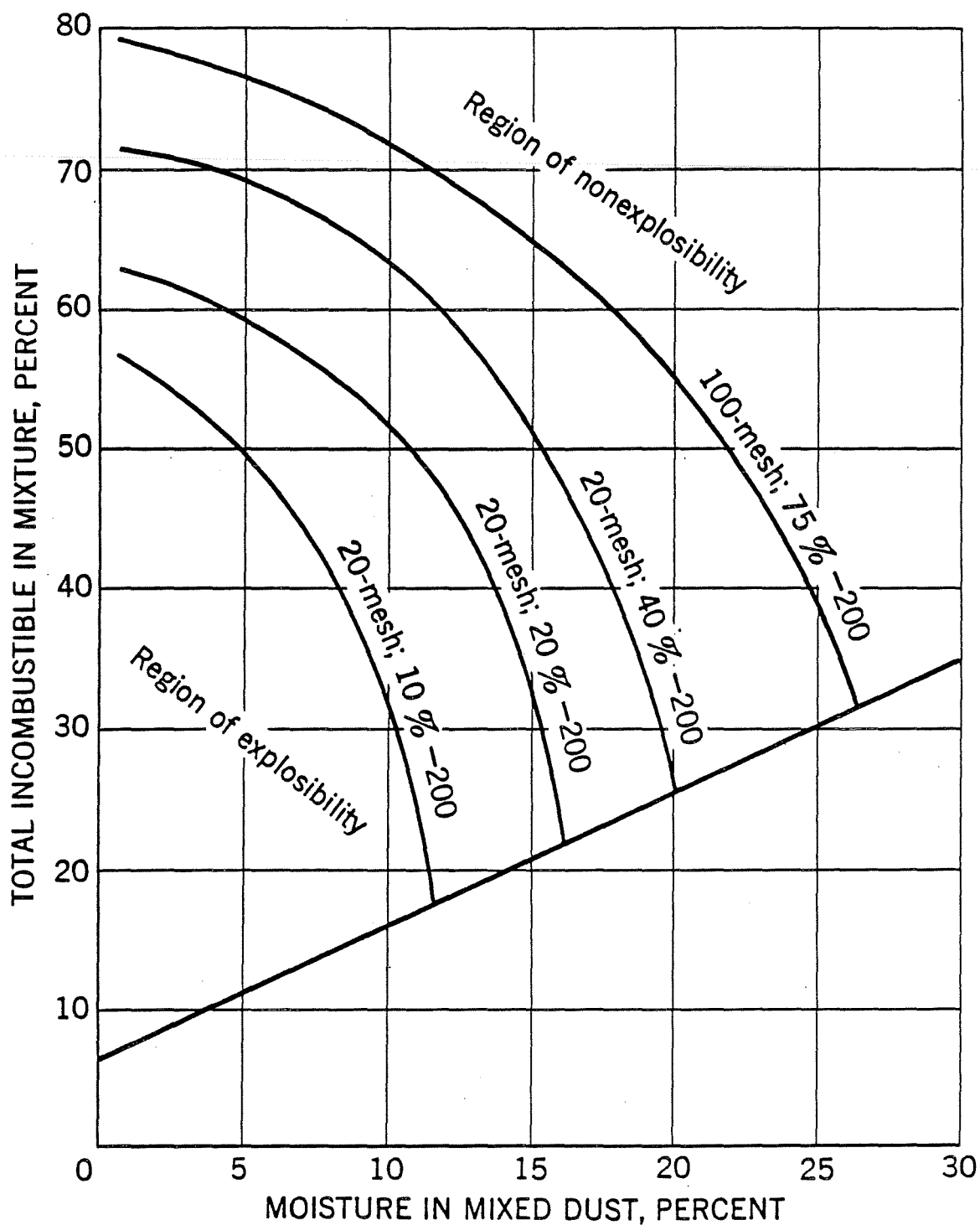


FIGURE 7. - Effect of moisture on explosibility of mixtures of Pittsburgh coal dust and rock dust (29).

Remote backfilling can take place in accessible mined out panels or in sealed areas of the mine. The backfilling methods for either are not very different. The primary differences are listed below.

<u>Accessible Areas</u>	<u>Sealed Area</u>
1. Bleeder entries left around filled panel	No or minimal ventilation of filled panel
2. Bulkheads do not always go to the roof	Bulkheads are well anchored and sealed
3. Much more control of fill placement	Filling is done blind with very little movement of discharge point in panel

Remote backfilling in general has much fewer hazards related to it than backfilling adjacent to an active face. Compared to the face, a remote mined out panel has more stable roof conditions, has less methane emission, has less congestion in the area of stowing and the haulageways leading to it, has looser scheduling, and because of its isolation, can experience more problems without causing injuries. Due to its trouble free nature, remote backfilling is the most utilized backfilling technique used in U.S. underground coal mines. While there are few accident statistics available to evaluate the accident potential of remote backfilling compared to backfilling adjacent to the working face or accessible remote backfilling to sealed remote backfilling, some inductive reasoning can still be applied to the hazard.

There are three hazards that might occur with a remote backfilling method; 1), roof falls, 2), quick flows of the fill during placement, and 3), pillar punching. Such problems as ignition and congestion will not be covered as they have no significant effect with remote filling. Dust generation with pneumatic stowing has already been covered.

a.) Roof Fall Hazard

As stated earlier, in the U. S. in 1980, 84% of roof fall fatalities occurred within 25 feet of the face and 69% occurred inby of the last support. Consequently, the roof fall potential is a result of recent mining activities and a lack of

adequate roof support. Mined out panels have had time to adjust to the redistribution of stresses in the roof strata and most large loose sections have fallen or been supported.

However, the potential for roof falls in mined out panels is time dependent. Roof supports deteriorate over time, that is, wood supports rot and crush and roof bolts loosen due to spalling or shifting of the roof. Consequently, the longer it has been since mining has taken place, the more remedial roof support work may have to be performed to guarantee a safe roof.

It is accepted that humidity causes expansion of water susceptible strata, such as shales, inducing compressive stress in these materials (27). In localities which normally have high humidities, such as regions in the Appalachians, the seasonal temperature changes can cause condensation and high humidities during the summer as compared to the winter. This large seasonal change of humidities in the mine air can cause considerable spalling of the roof strata during the spring, littering the floor with loose roof material and loosening roof bolts. While hydraulic stowing can increase the humidity in the stowing region and return airways, it has no apparent affect on roof spalling in these localities because it is overshadowed by the seasonal changes of humidity. This condition was verified by Wilson (59) for an underground coal mine in West Virginia that had been using blind hydraulic stowing techniques to backfill a mined out section of an active mine.

The seasonal spalling of roof strata is much less apparent in dry climates because condensation is less likely. Consequently, Fenwick (18) reported when controlled hydraulic stowing was initiated in an active underground coal mine on western slope Colorado, there was a marked increase of spalling from the roof in the stowing region.

Therefore, the following statements can be made about the potential for roof falls.

1. The roof fall potential in mined out sections is less than at the active face, however, this potential is based on the following factors.

- a. How long it has been since the roof was supported.
- b. The amount of moisture susceptible strata there is in the roof.
- c. How humid the mine air normally gets during the cycle of the seasons.

b.) Quick Surges During Placement

With hydraulic stowing in a horizontal to slightly dipping seam, the solids are brought into a remote area of the mine in a liquid state (slurry) at a concentration of only 35% solids by weight. The slurry is discharged in a mined out panel at the high end with clear water being removed at the low end of the room. If the discharge pipe is not moved and slurry is pumped for a while, a pile of saturated fill will develop. Once the pile gets high enough, it will slump and run a distance before stopping. A large percentage of fines (minus 200 mesh) in saturated fill, of course, adds greatly to the potential for creating quick conditions. Even the more coarse materials under the right conditions can fail and surge. Usually, such surges run a short distance and stop, depending upon the slope of the floor, height of the pile, and force of the discharging slurry on the back of the pile. Enzian (17) had indicated that quick surges during hydraulic stowing had caused damage to equipment and injured personnel. The same problem had been reported by a mine operator in Appalachia (59) who was filling a sealed section of an active mine. He stated that such a run would have invaded active workings were it not for a strong bulkhead. Despite the strong bulkhead design, pressure had to be relieved from the backside causing fill to be washed into open workings before a clear decant was achieved. Because backfilling is not a common activity and because most surges fail to result in injury, there are no accident statistics for this hazard. The information that is available to evaluate quick condition hazards is composed primarily of operator experience and what Enzian (17) reported in 1913. To say the least, such a hazard evaluation becomes necessarily subjective. The following discussion will point out the factors controlling such a potential.

The potential of such an accident occurring is dependent upon the shear stresses induced in the fill and the fill's ability to resist these shear stresses. Shear stresses in the fill are a result of the height and weight of the pile and pressure put on the pile as a result of the slurry line discharge. The weight of the pile is directly affected by the amount of water in the fill.

The ability of a fill to resist failure from induced shear stresses is dependent upon the amount of particle interlocking and the pore water pressures existing in the fill. When a slurry is introduced into a room, there is negligible inter-particle contact because of the relatively low solids content. As the solids settle and the fill dewater, the void ratio is reduced and the angle of internal friction of the fill (ϕ) increases. As would be expected, well graded size distributions allow for more interlocking and a lower void ratio

resulting in a greater angle of internal friction than a uniformly distributed material. However, until sufficient settling has taken place, the void ratio is high and consequently, the angle of friction of the fill material is relatively low.

Because the void ratio changes rapidly as the fill dewateres and the solids settle, it becomes very difficult to measure angles of friction. Thus the angle of friction of the materials under compacted conditions would not likely be any help in evaluating the strength of a fill during placement.

The yield strength of a fill is directly affected by the pore water pressure. Consequently, high pore water pressures in the pile can significantly reduce its ability to resist induced shear stresses.

The potential for failure is the greatest during placement for the following two reasons:

- 1) The freshly placed fill has had little time to settle and reduce the void ratio, consequently it has a very low angle of internal friction. Both Enzian (17) and a western U.S. underground coal mine operator who was hydraulic stowing stated that hydraulic stowing had to be interrupted periodically to allow for settling of the fill.
- 2) During placement, a pile of saturated fill will develop at the discharge of the pipe. This creates high shear stresses due to the height of the pile, and low shear strength because of hydrostatic pressure.

Enzian had observed this problem in the backfilling activities employed in the anthracite mines of Pennsylvania. As a result these backfilling operations had to move the discharge often to minimize the height of the pile built. However, this becomes rather difficult to do when employing a blind flushing technique.

Blind flushing on the other hand must rely on the pile failure for the pile to enlarge. This means that the area to be blind flushed must be able to withstand high pressures.

Quick surges are generally only a problem with horizontal or slightly dipping seams. With a steeply dipping seam, the solids quickly flow to the lowest point. Once deposited in the lowest level, there is very little gravitational induced shear stresses within the pile to cause any further movement.

c.) Pillar Punching

Pillar punching is the failure or squeezing of the roof or floor strata above or below a pillar. Not only does it cause the roof and floor to converge, it also reduces the load carrying capacity of the pillar, because the strength of the roof or floor at the pillar is reduced by its destruction.

Pillar punching results when the bearing capacity of the roof or floor strata is less than that of the coal pillar. Mines that have roof or floor strata which are clayey or shaley, and consequently susceptible to moisture, should be kept as dry as possible. This should be done because clays have a greater bearing capacity dry than they do wet. Coal mine operators, especially in the midwest, have worried, and rightfully so, that the introduction of wet fill could induce pillar punching. However, it is not clear how much moisture must be present in a fill material before it can affect the floor strata. For instance, a suitable fill material should be well graded with the fines (-200 mesh) probably ranging from 10% to 35% of the total material. These fines will hold water by surface tension, and according to Coates (12), this residual water content (w) commonly ranges between 15% to 30% where:

$$w = 100 \frac{W_w}{W_s} \quad \begin{array}{l} W_w = \text{weight of water} \\ W_s = \text{weight of solids} \end{array}$$

Therefore, water must be present in quantities greater than the residual water content for hydraulically stowed fill before any serious effects to the bearing capacity of a floor material would be expected.

The smaller the size distribution of a fill material is, the less water that is required for hydraulic transport and the less water that is available for affecting water susceptible strata. Unfortunately, the finer fills dewater much slower so that water retention time in the filled room is much longer. Because of these two offsetting effects, there probably is little difference in the potential for pillar punching based upon the fill used.

While water susceptible strata within a mine can preclude the use of hydraulic backfilling, whether blind or controlled, there is insufficient information on whether it precludes the use of pneumatic filling. If any such doubts exist as to the reduction of the bearing capacity of a roof or floor material, a few simple laboratory tests should determine how susceptible these strata are to moisture.

Backfilling for subsidence control, increased stability, or disposal in a room and pillar operation usually takes place after a panel has been mined with partial extraction. Using backfill for a working platform in a room and pillar operation or longwall operation, the filling takes place next to the working face. The bearing pressure on the floor or roof is greater with a partial extraction mined out panel than with longwall mining or before mining is complete in a particular room-and-pillar panel. Consequently, the potential for pillar punching is greater when backfilling mined out panels than when backfilling near the working face, provided there is water susceptible strata in the mine.

c. Hazards Associated With Stowed Waste

Backfilling of underground coal mines does not adapt well to high production mechanized mining. Consequently, the popularity of underground filling has decreased considerably, even among those European mining districts which had advocated its use. The United States has never really accepted the practice of backfilling and it only received notice in this country in the early part of the century. Consequently, within the United States there is a relative lack of knowledge about hazardous fill properties. This ignorance is further compounded by the fact that those countries that did use backfilling kept few if any accident statistics on their mining activities. Lack of accident data as related to backfill properties has made this part of the study somewhat subjective requiring this analysis to rely on experimental results and operator experience.

There are three topics of concern about stowed waste whose degrees of hazard are not well understood. These are oxidation heating of the fill, in-place fill becoming quick, and the special requirements of drainage filters in filled areas. These topics are evaluated using experimental data, and the degree of hazard still remains vague, but the controlling factors are presented here.

1.) Spontaneous Oxidation

Spontaneous combustion is an extreme occurrence of a more common problem known as spontaneous oxidation, spontaneous heating, or oxidation. Oxidation is the chemical combining of oxygen and unstable compounds producing a more stable compound and releasing energy in the process (exothermic reaction). It is called spontaneous because no stimulus is required to make the reaction begin or continue. If the heat from oxidation is

not dissipated but accumulates, the material temperature will increase to the kindling temperature; at this point combustion begins. Combustion, sometimes called burning or roasting, is defined as any chemical action which occurs so rapidly that both noticeable heat and light are produced. Spontaneous combustion is combustion which has started through excessive oxidation.

Excessive oxidation has been the cause of several hazardous conditions including high temperatures, high humidities, hazardous gas production, depletion of oxygen, and mine fires. While not thoroughly understood in the past, oxidation is an aspect of underground mining that has been dealt with for centuries.

The ultimate determination of whether or not a hazard exists is through accident statistics. This requires quite a bit of hindsight of which there is little at this time on back-filling in coal mines. To determine whether there is an excessive oxidation hazard, this chapter investigates the hazards from spontaneous oxidation of fill materials, the potential for a hazardous condition occurring, and provides a summary/conclusions of this investigation.

(a) Hazards. - The usual sequence of oxidation reaction events occurs as follows. Carbonaceous and sulphide compounds oxidize slowly producing acid mine drainage (AMD), carbon monoxide which reacts forming carbon dioxide, other products of combustion, and heat. If the gases are controlled, heat is dissipated into the surroundings, and the reactants are still in ready supply, the reaction will be slow and stable, and there will be no problems. If the reactant supply is stopped at any time, through subsidence compacting the fill or simply lack of oxygen, the oxidation stops, heat production is stopped, and most gas generation is stopped with the exception of evolving entrained methane and possibly some hydrogen sulphide production. This is usually the more long term solution to this problem. However, if the heat is not dissipated, the oxidation reactions accelerate, raising the temperature of the fill. At some point, the oxygen supply can not keep up with the oxidation rate and excess CO is produced. The temperature of the fill continues to rise if not checked and methane and other hydrocarbon gases are released. Eventually nitrous oxides and sulphur dioxides will be generated as well as combustion.

To best document these potential hazards, they are discussed individually even though in most cases they are interrelated.

(1.) Heat. - The Bureau of Mines, reporting on ventilation in coal mines in 1949 (20), stated that of the heat put into the ventilation air, 80% to 85% came from the rock, oxidation, and rock movement while the remaining 15% to 20% was created by adiabatic compression, man, machinery, blasting, and air friction. While this does not give an accurate description of the heat generated from oxidation, the report indicated that it was a significant proportion of the heat.

Heat generated by oxidation is generally a hazard when produced in extreme quantities. It poses both direct and indirect hazards to operating personnel. Directly, it can reduce worker efficiency and promote accidents. Indirectly, it accelerates oxidation rates and increases the other problems produced by oxidation reaction.

The production of heat is related to how fast the oxidation reaction is taking place. Fill materials, because of both physical and chemical factors which will be outlined below, can oxidize fairly quickly.

Heating of fill materials has been recognized as a problem for decades and was pointed out as early as 1913 by Enzian (17) when he stated that it was necessary to control heat accumulation in hydraulic fill materials of the anthracite mines of Pennsylvania. Since the oxidation rate is related to the fill temperature, the higher the fill temperature, the faster the oxidation rate proceeds and the faster that heat is liberated. The temperature of the fill itself is dependant upon how fast heat is being generated, how well it is dissipated into the surrounding rock and air, and the specific heat of the fill material. The temperature of the fill will increase until the rate of heat generation is balanced by the rate of dissipation. If the temperature rises above the kindling temperature, burning starts and large volumes of gas are produced. However, there is no widely accepted maximum allowable temperature for fill materials that can be used as a guideline for controlling combustion.

(2.) Humidity. - The humidity or the change in humidity of underground mine air can be a problem. Filling activities, especially hydraulic filling, have an impact upon mine air humidity.

As with high temperatures, high humidities in conjunction with high temperatures can have adverse effects upon personnel. "Because of the inability of a workman to produce at his normal rate in hot, humid surroundings, efficiency of work decreases. There is also an attendant increase in carelessness and accidents, because workmen are less alert. Both of these effects are costly in terms of production, dollars, safety and worker morale" (28). This statement, made by Hartman, while

tending to ignore the adverse health effects of high heat and humidity to those who are not acclimated or who are not physically well, is still basically true and does not need to be justified with any statistical data. While high humidity levels may be distracting and uncomfortable, they are seldom deadly.

(3.) Gases. - Workings in inactive portions of operating mines have always been hazardous to personnel who must periodically enter them or adjacent drifts. The hazard comes from the accumulation of explosive gases such as methane (CH_4), poisonous gases such as CO_2 , CO , H_2S , SO_2 , and NO_x , or the depletion of oxygen. These gases can be released from the strata or come from oxidation of materials.

The production of gases through oxidation of fill materials cannot compare in quantities to the release of strata gases, but in certain instances they can have important implications. Two common materials in fill, carbonaceous materials and sulphide materials, oxidize readily producing the above mentioned gases depending upon the fill temperature. The low temperature oxidation of carbonaceous materials initially forms carbon monoxide (CO) which reacts to form the more stable carbon dioxide (CO_2). With increased temperatures, the reaction rate accelerates and turns to incomplete combustion when there is insufficient oxygen available. This proves to be diagnostic of an oxidation problem. Pipes can be left connected through to these areas to assist with the removal of carbon monoxide and to provide early warning of any excess heating taking place. The bleeding of carbon monoxide from heated areas may increase the concentration of carbon monoxide in return airways of coal mines from typical values of 1 to 3 ppm to values within the range of 5 to 15 ppm. Concentrations higher than 25 ppm seldom occur before a characteristic odor (H_2S), sweating on coal surfaces (condensation), and other indications give warning of dangerous heat and gas conditions (24). Such heating should also start driving volatiles off from the coal wastes. Since the maximum allowable concentration of CO is 50 ppm, the presence of these visual and odorous warning signs cannot be taken lightly. At high fill temperatures, the more toxic gases start being produced such as SO_2 , NO_x , and even H_2SO_4 vapors.

The presence of plastics in these hot fills produces additional toxic gases. All plastics give off large quantities of carbon dioxide and carbon monoxide when heated. In addition, dangerous concentrations of hydrogen cyanide (HCN) are evolved from polyurethanes, nylon, urea-formaldehyde, and acrylonitrile at temperatures above 200°C (392°F); the rate of production increasing with temperature. PVC and PTFE are dangerous in fires because they release hydrochloric and hydrofluoric acid gases. Consequently, the presence of plastics in filled areas should be kept to a minimum.

Bacterial action has been known to produce hazardous concentrations of gases. For instance, methane may be generated by bacterial action on organic material, such as timber, and explosions have been caused by accumulated methane from this source while flooded mines were being dewatered (19). Autotrophic bacteria in flooded gold and coal mines have been known to modify soluble sulphates in the water to liberate hydrogen sulphide gas. Consequently, the presence of water, especially in flooding quantities appears to be a good condition for gas generation by bacterial action. This is an indication that a filled area should be well drained and ventilated or well sealed.

(b.) Spontaneous Combustion. - A study was conducted by McDonald in 1980 (37) in an attempt to develop a listing and comparison of mine fires in underground coal mines. Table 10 is a much condensed listing of these comparisons. They are listed by time period with the most recent period (1970-1977) being the most important. While none of these statistics were related to backfilling, some of their conclusions can be applied to backfilling. In the 1970-1977 time period, fires started by spontaneous combustion ranked second, representing 10.9% of all fires. Coal (not coal dust) and timber ranked significantly as ignition sources ranking second and fourth in the 1970-1977 time period.

As indicated, gob areas did not rank very significantly as the location of ignition. Even though gob areas, the likely location for waste disposal, are not prone to fires, there apparently are conditions in underground coal mines which promote spontaneous combustion of carbonaceous materials and timber. These same conditions may affect the potential for spontaneous combustion of backfilled coal wastes.

TABLE 10. - Analysis of Underground Coal Mine Fires in the United States from 1950 to 1977 (37)

Period	<u>1953 - 1961</u>		<u>1962 - 1969</u>		<u>1970 - 1977</u>		<u>1953 - 1977</u>	
	<u>%</u>	<u>Rank</u>	<u>%</u>	<u>Rank</u>	<u>%</u>	<u>Rank</u>	<u>%</u>	<u>Rank</u>
Fires by Ignition Source								
Spontaneous Combustion	7.6	3	5.0	3	10.9	2	7.0	3
Fires by Burning Substance								
Coal	23	1	17.6	2	22.2	2	20.6	2
Timber	10.7	4	7.5	6	8.9	4	9.2	4
Fires by Location								
Gob	8.2	5	5.5	6	9.3	5	7.3	5

(c.) Excessive Oxidation Potential - A major source of information for this section was Ninteman, D.J. (1978) (44).

The potential for excess oxidation is not easily determined because there are so many factors controlling the oxidation rate, and the degree each factor controls the rate is often not well defined. Therefore, to analyze the potential for excessive oxidation, each controlling factor must be investigated individually to determine its impact upon the total potential.

The oxidation process is controlled both by chemical and physical factors and both can have major effects upon whether oxidation of fill materials turns into a hazardous situation or not. The process consumes oxygen, produces heat, evolves gases, and produces both soluble and insoluble compounds. Some if not all of these changes can be harmful to personnel.

Some of the controlling factors in the reaction process are particle size distribution, permeability, porosity, moisture content, amount of ventilation, variations in fill properties due to weathering, carbon content, sulphide mineral content, and the amount of other combustible materials present in the fill. The following is a discussion of how these factors control the reaction rate and which properties enhance excess oxidation.

(d.) Particle Size. - Increasing the surface area of the oxidizing material by making the particles smaller will increase a fill's capacity for oxidation.

While the complexity of coal preparation plants varies, in many situations there are two wastes produced, a coarse and a fine waste. A survey done by the Bureau of Mines on surface disposed coal wastes in southwest West Virginia (10) produced the size distributions as shown in Figure 8 for bituminous coarse and fine wastes. In addition, the size distribution for the Eureka anthracite waste bank in Scranton, Pennsylvania (57) is shown; this material was used for backfilling an abandoned mine. According to the Unified Soils Classification System (USCS), both the anthracite and bituminous coarse wastes were clean, well graded gravels (GW) while the bituminous fines were classified as a dirty sand (SM or SC) containing 35% fines (minus 200 mesh). It was reported by a National Academy of Sciences (43) study that fine refuse amounts to only 10% of total refuse production. So if the coarse and fine bituminous wastes were combined, the fines (minus 200 mesh) would only amount to 12% of the total weight. There is no accepted critical particle size for spontaneous heating because there are too many other controlling factors. However, in the USCS a particle distribution is relatively clean if it contains less than 12% minus 200 mesh.

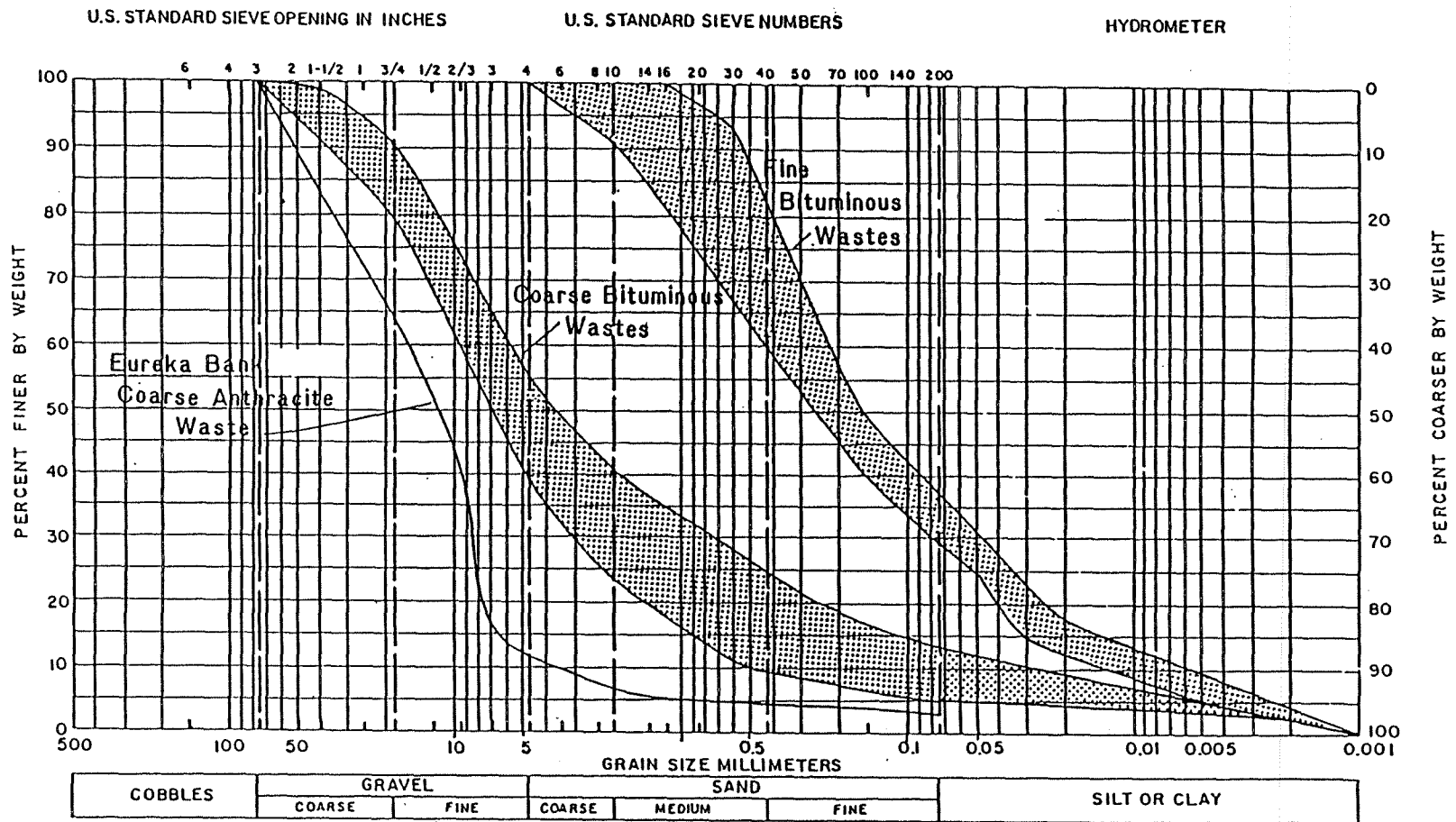


Figure 8. Particle size distributions for preparation plant wastes (10,58).

Laboratory tests have shown that the ignition temperature of sulphide minerals lowers with decreasing particle size, and this may also be true of carbonaceous materials. As of yet, there is no agreed upon critical temperature to which spontaneous heating should be limited, but suggested critical temperatures have ranged from 100°C to 150°C.

Considering the lack of fines (minus 200 mesh) in coal wastes, it might be assumed that unless poor placement techniques segregate the fines that are present in the fill material, the potential for excess oxidation due to fines is low. While the oxidation rate is dependant upon how much reactive surface is available (particle size distribution), it is also dependent upon how easily reactants are brought in and products of reaction removed (permeability).

(e.) Permeability. - While reactive surface area has a strong influence upon oxidation rates, permeability, or the ability to get reactants to these surfaces and products away from these areas, is important. Permeability of fill material is affected by the mode of placement, amount of subsidence upon the fill, particle size distribution of the fill, and amount of self-cementation or build up of reaction products in the fill. It has been recognized for years that once the roof has subsided upon a filled area, the fill becomes compacted sufficiently to control most oxidation problems. Because of other controlling factors, there are no accepted critical permeability rates at which excessive oxidation could be considered a distinct possibility.

Oxidizing fill materials can be self-cementing because of the build up of oxidation products. In most cases, it is the result of pyrites, other sulphides, or carbonates oxidizing with the products depositing out as insoluble materials. However, the amount of water present or percolating through the fill in addition to the quantities of reactant materials available will have large affects upon how the permeability will be altered. It can be safely assumed that wet fill with low percolation rates will cement more thoroughly, lowering the permeability more than would dry fill or fill having high percolation rates. The self-cementing of fills or the build-up of oxidation products is reduced or reversed if percolation of water through the fill is rapid. Consequently, it would not be wise to count on self-cementing processes to reduce the oxidation potential.

(f.) Porosity. - Increasing the porosity, like decreasing particle size increases the surface area for oxidation. However, there has been little work relating fill porosity or change in porosity to oxidation rates.

(g.) Moisture Content. - Moisture is a critical component for oxidation and without the presence of moisture at cool fill temperatures, it is doubtful whether much oxidation will take place.

Although the critical moisture range depends on factors such as type of mineral, mesh size, etc., it is generally found that a moisture content of from 3% to 8% creates the most ideal conditions for spontaneous heating. Below 2%, the little water that is available quickly evaporates as initial oxidation heat is generated, thus checking oxidation. Figure 9 shows laboratory test results on sulphide concentrates depicting this short lived heating of relatively dry material compared to more moist material. Above 8% moisture content, sufficient water exists to absorb heat energy by evaporation, to act as a heat sink, and to distribute heat throughout the fill, better minimizing local hot spots. The National Academy of Sciences (NAS) (43) study summarized the physical and chemical properties of bituminous coal and coal wastes. This study indicated that cleaning plant refuse ranged from 10% to 40% moisture by weight, while dry refuse ranged from 5% to 10% moisture. Consequently, dry refuse will have the higher tendency to oxidize.

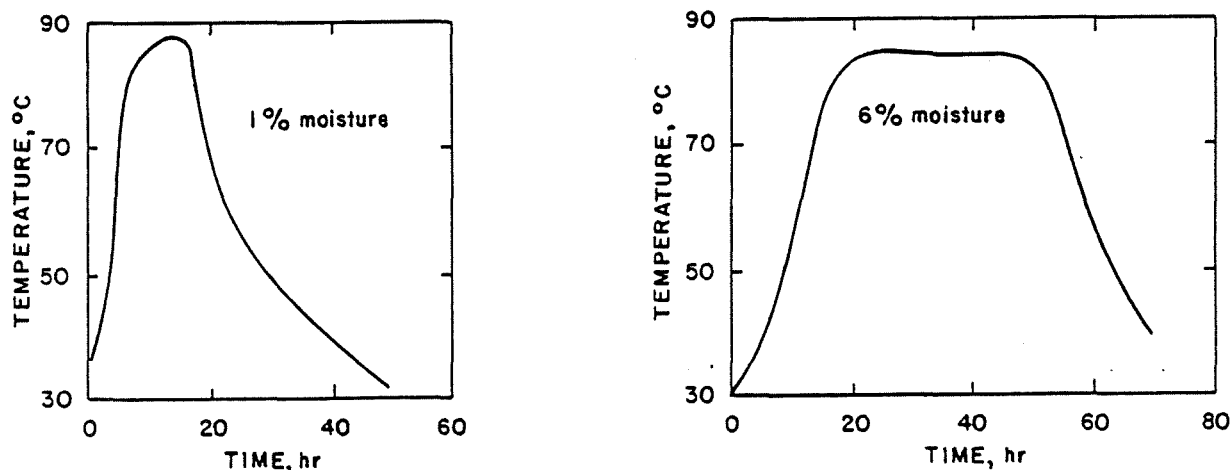


FIGURE 9. - Laboratory test results on sulphide concentrations depicting the short lived heating of dry material (44).

The water content of backfilled areas can vary based on mode of deposition, ground water hydrology, permeability of the fill, and drainage facilities in the filled area.

While a hydraulically placed fill can range from 50% to 80% water by weight during placement, most operations also provide for good drainage. Depending upon the amount of compaction, fines, and drainage facilities, the fill can be expected to drain to 10% to 40% moisture; not particularly conducive for oxidation.

Pneumatically placed fill, because of respirable dust requirements, will usually be placed at a moisture content from 6% to 9%. Thus, a waste which exhibits a high potential for oxidation should not be placed pneumatically.

If there is very little water in the mine and overhead strata is intact, the moisture content would not be expected to vary from these limits significantly. If on the other hand, the mine is very wet and the inflow of water is considerable, the water content of the fill would be expected to be high even if there were good drainage facilities.

Fill placed in a dry mine with dry ventilation air would tend to reach a lower moisture content on the ventilated faces. Conceivably, a wet fill placed in a dry mine could dry sufficiently to acquire a good oxidation potential. Consequently, a dry refuse or fill placed in a dry mine would have a higher potential for oxidation than a fill placed in a wet mine.

Oxidation processes have been noted to accelerate when the moisture content fluctuates, such as during weathering of waste banks. The alternate wetting and drying of coal wastes and sulphide minerals tends to dissolve oxide products exposing fresh surfaces for oxidation. Also, a capillary action is induced bringing more reactants to the reaction surfaces. Consequently, the percolation of water through the fill, especially if it is variable in rate, will tend to accelerate oxidation rates. Therefore, occasional wetting of hot fill to control heat of oxidation should only tend to accelerate the problem.

(h.) Weathering Alterations of Fill. - Characteristically, a weathered coal waste will have less sulphide minerals, be more friable, and have more fines. In addition, the low BTU, lower rank, carbonaceous compounds will have oxidized leaving the higher BTU and higher rank carbon compounds. This weathered waste will have a lower potential for oxidation, but the weathering activities usually affect the extremities of a surface pile leaving the core fairly fresh.

(i.) Ventilation. - There are two inverse effects upon fill material that vary with the ventilation rate, these are the cooling rate and the availability of oxygen. Increased oxygen availability from increased ventilation has been shown to accelerate oxidation rates and increase mine temperatures. However, this is dependant upon fill permeability. Inversely, there are cases where ventilation was removing spontaneous heat which would have built up quickly without the ventilation.

It is suggested by Kim (34) that there is a critical ventilation rate where sufficient oxygen for oxidizing reactions are being provided but heat is not being sufficiently dissipated. This has not been verified by experimental results.

Ventilation in a filled area under normal conditions will be required to maintain air quality and keep fill temperatures low. Which of these requirements is dominant will depend upon how gassy the mine is and the fill's propensity for oxidation.

Thus, it can be seen that the potential for oxidation problems will be dependant upon both physical properties and operational factors.

(j.) Carbon Content. - The oxidation potential of carbonaceous compounds is not so much dependent upon the carbon content as the form this carbon is in. Low rank coals have a higher potential for oxidation than do high rank coals. This holds true for wastes from high and low rank coals. Therefore, sub-bituminous coal wastes will have a higher oxidation potential than anthracite coal wastes. An analysis of a waste's potential for oxidation should include the carbon content and the rank of coal that it comes from.

The National Academy of Science (43) study reported that bituminous coal wastes contained 10% to 45% carbon in Appalachian wastes. While the minimum carbon content required for excessive oxidation has not been determined, and since coal in underground coal mines has ranked as the second greatest ignition source (29), carbon contents as low as 10% may still pose an oxidation problem.

(k.) Sulphide Mineral Oxidation. - The reactivity, or the tendency of sulphide minerals to react, is dependant upon the mineral composition (i.e., sulphide types), the number and types of sulphide minerals present, and the percentage of sulphides present in the waste.

The presence of large quantities of sulphide minerals in a fill with the correct moisture content can lead to excessive oxidation producing heat, sulphur dioxide fumes, acid mine drainage, and a reduction of the oxygen supply in the stopes. The Bureau of Mines testing at Pittsburgh, Pennsylvania found that self-cementing fill containing 3% to 10% sulphides by weight exhibited excessive oxidation. On the otherhand, back-fill samples from the Homestake Gold Mine in South Dakota ranging from 2% to 4% sulphides indicated no such tendency towards self-heating.

The oxidation of sulphide minerals is exothermic. It is well known that increasing the temperature of a material increases its oxidation rate. Laboratory experiments showed that in the temperature range from 30°C to 60°C, the rate of oxidation of pyrite doubled for every 10°C rise in temperature. These laboratory tests produced the oxidation temperature curve shown in Figure 10. As can be seen, the initial oxidation produced a sharp rise in temperature followed by a more gentle increase in temperature. These laboratory tests also showed that higher sulphide mineral concentrations caused a quicker initial heating than did lower sulphide concentrations. It should be understood that these lab tests were under ideal conditions for oxidation and do not necessarily indicate what will occur in the mine. However, it is obvious that the initial oxidation can produce quick increases in temperature, so that reopening of sealed backfilled areas could rapidly produce heating problems. The temperature drop off at the tail end of the curve in Figure 10 represents a build-up of oxidation products and oxygen depletion. This shows how the oxidation reaction can be choked off by oxidation product build-up provided that percolating waters and fluctuations of moisture content in the fill are not allowed to happen. For this reason, sprinkling of water to cool hot fill can accelerate oxidation. The amount of acceleration depends upon how much oxidation products have built-up, the drainage facilities, and how much water is used. A little water sprinkled on fill that is free draining can cause such an acceleration of oxidation.

While the heat generated by oxidation of coal wastes comes from oxidation of both carbonaceous materials and sulphide minerals, which component produces the greatest problem is not certain. The National Academy of Science (43) reported that bituminous coal wastes contained more carbon than sulphide material, perhaps twice as much (See Table 11). However, most if not all sulphide minerals found in coal wastes are iron pyrite (marcasite or pyrite). Peele (47) had reported that the heat of oxidizing iron pyrite per milliliter of oxygen consumed was twice that of coal. This suggests that heat generated by oxidation of sulphides could be as much as that generated by

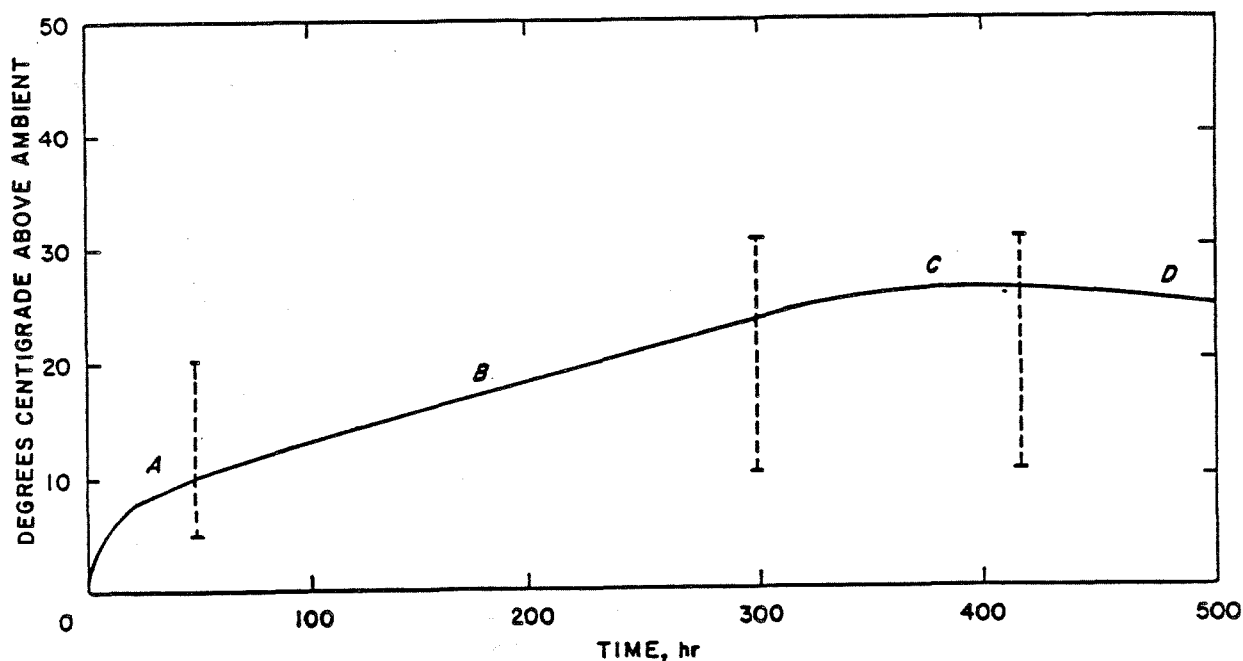


FIGURE 10. - Typical temperature-time profile for oxidizing conical-shaped dumps of sulphide concentrations (44).

oxidation of carbonaceous material. In cases of high sulphide content, sulphide oxidation could very well be the primary heat generator. This makes sulphide content an important evaluation criteria when investigating oxidation potential.

TABLE 11. - Heat Generated by Oxidizing Components of Coal Wastes

	Concentration in Coal Waste (by wt.) ¹	Heat of Oxidation (cal/cc of O ₂ consumed) ²
Iron Pyrite	5 % - 15 %	4.3
Coal	10 % - 45 %	2.1

1 (43)

2 (47)

As mentioned in the moisture content section, oxidation is highly unlikely in a totally dry material, but a totally dry fill is a rare exception. Oxidation of sulphide minerals requires a slightly acidic solution for the reaction to take place but as sulphuric acid is a product of oxidation, high acidities can retard oxidation. Consequently, a neutral solution or a very acidic solution will retard oxidation, so that it appears that there is an optimum acidity for oxidation, even though there is little test work detailing such requirements. The worst oxidation case would occur when sulphuric acid produced from oxidation was being neutralized or diluted by percolating waters.

Different sulphide minerals have varying oxidation potentials, with iron sulphides exhibiting the highest potential. The predominant sulphide minerals in coal wastes are iron sulphides, pyrite and marcasite; marcasite being common in low rank coals and pyrite common in the higher rank coals.

When any two sulphides are in contact and both are electrochemically connected by a solution, a current is generated which flows from the mineral of the higher electrochemical potential to the mineral with the lower electrochemical potential. This results in the lower potential mineral greatly increasing its rate of oxidation. It is reasoned that since pyrite has one of the higher rest potentials of all the sulphide minerals, sulphide reactions of other sulphide minerals would be accelerated in the presence of pyrite. While pyrite and marcasite are the primary sulphides present in coal wastes, in rare cases, copper, nickel, or zinc are present which could conceivably enter into such an electrochemical reaction. Preliminary tests on coal wastes should determine if such a problem would exist.

Nonsulphide minerals can also affect the sulphide oxidation rate. For instance, fine grained carbon has been known to increase sulphide oxidation. Whether the carbon chemically enters into the reaction or if the heat generated by the carbon oxidation speeds the oxidation of sulphide minerals is unclear.

On the other hand, some minerals which occasionally occur in bituminous wastes such as dolomite, decompose endothermically at high temperatures slowing down oxidation rates. This can be a plus when analyzing a material for its suitability for backfilling.

(l.) Other Combustible Material. - Other combustible materials present with the fill materials add to the hazard as they are potential sources of heat and combustion. Timber, especially when rotted, is by far the most dangerous and most widespread of these combustibles. Therefore, fill barricades made from wood can pose problems.

(m.) Index of Combustibility. - Kim (34) in her literature survey on spontaneous heating compiled the following discussion on combustibility indices.

A readily determined, universally applicable index of combustibility would be the preferred method of evaluating a coal's liability to spontaneous heating. Although several indices of combustibility are proposed in the literature, none are in general use. The most common indices have been:

1. Heating Rate
 - a. Relative Heating Rate
 - b. Dynamic Heating Rate
2. Cross-Point Temperature
3. Ignition Temperature, and
4. CO/ Δ O₂ Ratio

Combinations of the preceding indices have been used in an attempt to achieve greater accuracy.

All of the indices are determined by a laboratory procedure and require standard conditions to obtain reproducible results. In some studies, the index of interest is compared to some internal standard; oxygen content of the coal, for instance, without mathematical correlation. In other studies, a simple ranking system is used to evaluate the coal's combustibility. Indices determined in the laboratory have not been compared to the actual incidence of spontaneous heating.

Owing to the lack of an objective criterion and the diversity of experimental conditions under which the indices were developed, comparing various indices would be inaccurate and possibly misleading. No particular index has been shown to be significantly more accurate, and none is in general use. At present, the CO index is probably receiving the most interest in the United States. This is not because of demonstrated superiority as an index of combustibility, but because of its relatively simple adaptation to the detection of spontaneous heating. In many instances, evaluation of the hazards from spontaneous heating is based on previous experience with a given coal.

(n.) Analysis of Spontaneous Oxidation Hazard. - The problems that can develop from excessive oxidation ranging from minor levels of heating and low levels of gas generation to high temperatures, large quantities of gas generation and fire have been evaluated. The damage can range from minor problems to life and death situations, shutting down part or all of the mine. However, past experiences have shown that there are low incident rates of major disasters from excessive oxidation, and there is little documentation on the minor accidents.

The potential for such problems has been evaluated by looking at those factors that can control the oxidation rate or contribute to its acceleration. These controlling factors included fill properties such as permeability, porosity, particle size distribution, moisture content, index of combustibility, and degree of weathering of fill materials. Fill composition such as sulphide mineral content, carbonaceous material content, and other combustible materials present were investigated. Finally, operational factors such as ventilation were investigated. The wide variety of controlling factors has shown that oxidation rates are not a function of one or two items but an intricate combination of factors. No one factor can cause excessive oxidation to take place but if the combination of factors promotes oxidation, excessive oxidation can be an extreme problem.

Excessive oxidation in an underground mine is unlike other common underground coal mine hazards, such as explosions and roof falls, because it does not happen suddenly. The extreme case of a fire is the result of a gradual worsening of conditions.

Spontaneous combustion has a significant history of occurring in underground coal mines. The degree of damage from such a condition can be extreme in both property damage and lives lost. However, there is little history of backfilled areas spontaneously combusting. This is due to the limited amount of underground coal mine filling, the fact that those factors which promote oxidation are considerably less severe underground than on the surface, and because of the many avenues available for limiting the oxidation potential. Whether this hazard is realized or not will be dependent upon the awareness and safety consciousness of the mine management.

2.) Quick Potential of Inplace Waste Backfill

A quick condition occurs when a soil or fill behaves like a liquid. With a very fine fill, exceeding the liquid limit can cause the fill to behave in a liquid fashion (no shear strength). Slack coal, a mixture of coal dust and fine dirt particles in the fill adds to this potential.

When the shear strength of the fill is exceeded, failure will occur. If the fill is saturated and the mine workings are sloped, the failed material can flow a great distance.

It should be noted, however, that no known instances of liquefaction have been reported for fill material.

While shearing stresses might be induced in a fill by earthquake accelerations, blasting vibrations, or roof subsidence, the greatest source of induced fill stresses is from bulkhead failure. Bulkheads can fail due to deterioration or excessive pressure. Bulkheads constructed from wood are more susceptible to rotting and can serve as a source of ignition during oxidation heating. Therefore, the use of wood in bulkheads should be minimized. Bulkheads made from masonry with steel beam reinforcement are much less susceptible to deterioration or oxidation heating.

Excessive stresses on bulkheads are usually due to high hydrostatic pressures. High hydrostatic pressures are usually the result of plugged drainage facilities or a lack of drainage facilities. Therefore, it is very important to provide adequate drainage facilities and to maintain their correct operation.

Once a bulkhead has failed, the amount of material that will flow out of the filled room will depend upon the pore water pressure, the height of filling, and the dip of the seam. While the material's angle of internal friction and pore water pressure will determine at what slope a stable angle of repose will develop, the height of filling and the dip of the seam will control how much fill will fail before a stable slope is achieved. Thus, fill in a horizontal seam may fail to a lesser extent than fill in a steeply dipping seam.

Pore water pressure reduces the effective shear strength of a soil, so a saturated fill will fail more readily than a dry fill. Therefore, the presence of saturated conditions in a filled area can not only increase the potential for a bulkhead failure, but can also reduce the effective shear strength of a fill causing it to fail at lower shear stresses and to flow for greater distances than a dry fill. This problem is accentuated by a dipping seam or a high height of filling.

The fill material property that describes a fill's ability to resist shear is the angle of internal friction. The greater the friction angle is, the greater the fill material's ability to resist shearing stresses. The peak friction angle is dependent upon the composition of the fill (size distribution and hardness of the particles), the initial void ratio, and the initial confining stress.

The initial void ratio and initial confining stress are a result of the mode of deposition, dip of the seam, height of filling, and the amount of post fill subsidence upon the fill prior to bulkhead failure. The lower the initial void ratio is, the greater the peak friction angle will be. The greater the initial confining pressure is, the greater the fill's shear strength will be. Thus, a stowing method which compacts the fill well will reduce the void ratio and increase the density of the fill. This induces a greater confining pressure, thus making a stronger pack than a stowing method that makes a loose pack. While none of the stowing methods are very effective in compacting the fill, some authorities feel that pneumatic stowing is superior.

Roof subsidence upon the fill without failure of the bulkhead will compact the fill quite well, lowering the void ratio and increasing the confining stress in the fill. This is probably one of the better ways of increasing the strength of the pack.

A well graded size distribution will exhibit more interlocking of particles and a greater friction angle than a uniform size distribution. In addition, hard fill particles will resist crushing or deformation better than soft particles will, giving the fill a stronger peak friction angle.

In summary, the factors that control the potential for a failure of in-place fill are as follows.

1. Construction of bulkheads
2. Drainage facilities
3. Dip of filled room
4. Height of filling
5. Pore water pressure
6. Peak friction angle of the fill
 - a. Composition of the fill
 - b. Initial void ratio
 - c. Initial confining stress
7. Stowing method
8. Amount of post filling roof subsidence upon the fill without bulkhead failure.

The in-place conditions of a fill can be imitated in a testing lab to measure the peak friction angle. Such testing might be deemed necessary to help evaluate the potential of such a hazard if the consequences are considered severe. If the filling is considered to create an unacceptable risk, then the controlling factors for this type of accident can be modified to reduce the risk. Such modifications could include changing the location of stowing, changing the stowing method, increasing the capability of the drainage facilities,

compacting the fill, inducing roof subsidence on the fill, strengthening the bulkheads, cementing the fill, or modifying the filling material.

The following paragraphs present the expected potential of such accidents for the various fill materials.

Flyash, being very fine with a D₅₀ of roughly .027 mm has a good potential for behaving in a liquid fashion when transported and initially placed. However, it self-cements very well, greatly reducing the failure potential once in place. In addition, during placement, because of its liquid behavior, flyash will tend to fill the rooms more evenly so that a pile is not likely to build very high, thus minimizing the shear stresses that might build within the fill. As a result, flyash shows a low potential for quick behavior.

The most common waste materials for backfilling underground coal mines are preparation plant fine wastes or a combination of preparation plant fine and coarse wastes. A survey done by the Bureau of Mines on surface disposed coal wastes in southwest West Virginia (10) produced the size distributions as shown in Figure 8, page 79, for bituminous coarse and fine wastes. In addition, the size distribution for the Eureka anthracite waste bank (coarse waste) in Scranton Pennsylvania (57) is shown.

Well graded gravels, according to the Unified Soils Classification System (USCS), exhibit a high permeability and good shear strength. Thus a coarse waste, once in place would behave in a quick fashion only under high shear stresses. Such a condition could occur in a slightly dipping seam, but would be more serious in a steeply dipping seam filled with a saturated coarse waste where a bulkhead has failed. A quick surge created by such conditions would probably be rather limited due to the permeability of the coarse wastes allowing the water to run out of the waste. In a horizontal seam, such a quick potential is greatly reduced for a coarse waste because of the limited height of the fill.

Dirty sands, according to the USCS, exhibit fairly good shear strength but are impervious to semi-impervious when compacted. This implies that fine waste will exhibit a low potential for liquid behavior as long as it is kept well drained. Therefore, maintaining a low potential for quick conditions with fine coal wastes requires good drainage facilities and limited inflow of water into an area filled with these fine wastes.

Fines usually amount to 10%-15% of the total waste production, so if the coarse and fine bituminous waste were combined, the fines (minus 200 mesh) would amount to 12%-13% of

the total. The USCS classifies a particle distribution as relatively clean if it contains less than 12% minus 200 mesh. Consequently, combining the coarse and fine wastes would create a size distribution that is borderline clean.

Such a combined waste fill would have good strength and be semi-pervious to pervious after compaction. As long as drainage facilities are good, there should be a low potential for liquid behavior, especially for horizontal seams. The potential might be greater in dipping seams with poor drainage facilities.

Taking everything into account, the potential for quick behavior of inplace coal waste backfill is relatively low, as long as drainage facilities are maintained. The potential is the greatest for backfilling which is used with partial extraction room and pillar mining in a dipping seam. The fill is compacted very little because of minimal roof subsidence. The quick potential is the least with backfilling at a longwall or shortwall mine. Such mining methods create complete roof subsidence on the fill, compacting it well, and creating much greater shear strength within the fill.

3.) Filters for Permanent Drainage Facilities in Backfilled Areas

The necessity for good drainage from filled areas was noted in the previous section. Good drainage is necessary to keep hydrostatic pressure from building up on bulkheads, to keep pore water pressure from reducing the shear strength of the fill, and to minimize the potential for the inplace fill to become quick if the bulkhead or lining were to fail. However, inadequately designed drainage facilities can be as bad as not providing drainage at all.

While linings for longwall or shortwall mining with backfilling are designed to retain the waste and allow water to flow out of the waste, they are not intended to be permanent. The intention of this section is to cover the filter requirements of drainage facilities for permanent bulkheads.

When a permanent bulkhead retains backfill, drainage facilities are installed. A filter is needed due to the fill physical properties, and if it is not provided, fines can migrate through the drain. Fines migration can reduce the fill strength around the drain, plug the drainage facilities, and create muddy conditions in the open drifts downstream from the drainage facilities. Migration of fines can cause the fill to resaturate, contributing to the liquefaction hazard.

Figure 11 shows the size distribution for some representative mine wastes including: anthracite coarse wastes, bituminous coarse wastes, bituminous fine wastes, and South African flyash. When there is coarse material which is greater than 3 inches in size, there is a tendency for the fill to segregate or bridge during placement. Fortunately, most preparation plants crush all plus 3 inch material so that this should not be a problem.

If more than 5% minus 200 mesh material is present in the fill, then these fines will migrate into the drainage facilities causing the previously mentioned problems. As shown in Figure 11, coarse anthracite wastes are the only common waste material that contains less than 5% of 200 mesh material. Most coarse wastes will probably range between the particle size distributions which are shown for coarse bituminous and anthracite wastes.

It is beyond the scope of this study to specify the engineering details of a good filter design but a good description of filter requirements can be found in:

Earth Manual, First Edition - Revised Second Printing (55).

2. Coal Backfilling Hazard Ranking

Ranking of hazards provides a consistent guide for corrective action, specifying which hazardous conditions warrant immediate action, which have secondary priority, and which can be addressed in the future. To rank a hazard, one can evaluate several criteria, but a generalized ranking does not take into account site specific factors that could totally rearrange the ranking order for a particular mine.

Initially, it must be emphasized that the identification and ranking of some of the hazards, liquefaction of fill and spontaneous combustion for instance, are not based so much on real statistics as they are on knowledge of the physical and chemical properties of the fill and their relationships to a changing mine environment.

In ranking the hazards, a hazard evaluation system was used from the "Accident Prevention Manual for Industrial Operations" by the National Safety Council (39). With this system, hazards are evaluated on the potential of becoming a reality and the consequences of such an accident if it were to happen. Therefore, a particular hazard has a two part classification such as II B. Tables 12 and 13 depict this rating system.

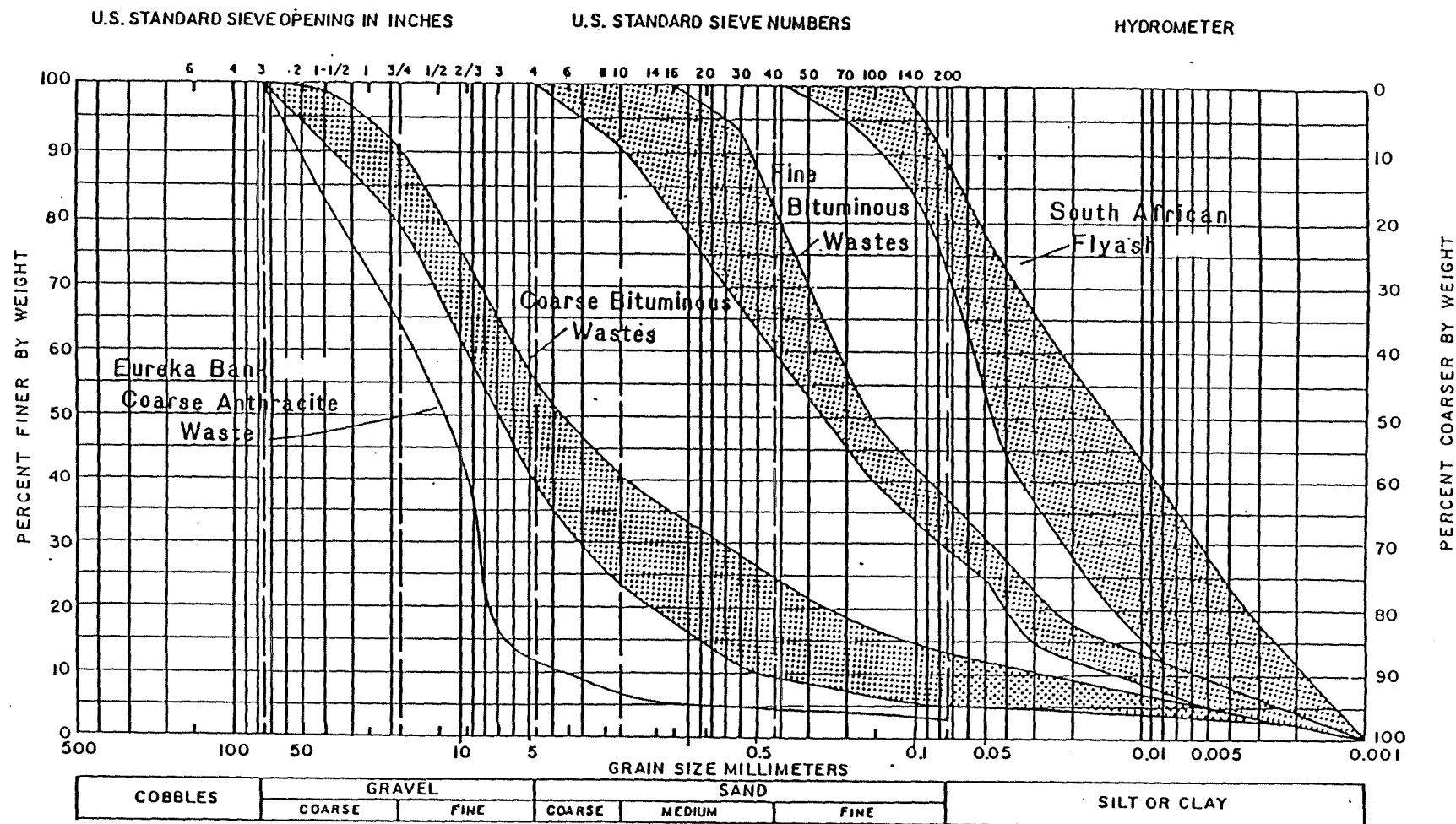


FIGURE 11. - Particle size distributions of coal mine wastes (10,57,23).

Table 12 is the classification of accident consequences. There are four classifications ranging from multiple deaths to minor first aid cases. It is realized that the magnitude of an accident from a particular hazard can range from large to small, but in this ranking of consequences, we are assuming that the most probable worst case, not the rare extreme case, would occur.

Table 13 provides a way to make a qualitative estimation of the potential for a hazard to cause an accident. It is qualitative because there are very few accident statistics to give such a classification any degree of accuracy. This probability classification is rather simplified and can be misleading. For instance, a hazard which has a high probability of occurrence but only under rare circumstances might be classified as being a remote (C) possibility.

TABLE 12. - Classification of Accident Consequences (39)

Accident Consequence Classification	Explanation
I. Catastrophic Effects	The hazard is capable of causing death, possible multiple deaths, widespread occupational illnesses, or loss of facilities
II. Critical Effects	Accident can result in severe injury, serious illness, or property and equipment damage.
III. Marginal Effects	Accident can cause injury, illness, and equipment damage, but the injury, illness, or equipment damage would not be serious.
IV. Negligible Effects	Accident will not result in a serious injury or illness. Damage beyond a minor first aid case is extremely remote.

TABLE 13. - Accident Probability Classification
(Qualitative Estimate) (39)

-
- A. Probable. Likely to occur immediately or within a short period of time.
 - B. Reasonably Probable. Probably will occur in time.
 - C. Remote. May occur in time.
 - D. Extremely Remote. Unlikely to occur.
-

Table 14 lists the hazards that might be encountered during backfilling activities according to their hazard classification and overall hazard ranking. As mentioned earlier, the hazards are classified according to the National Safety Council hazard evaluation system. However, this system has its limitations in that it indicates the probability of the worst probable case, not the probability of the less severe incidence. In addition, Table 14 classifies and ranks the hazards independently of the stowing method used. This can be misleading as some hazards are present only with particular stowing methods. While some of the hazards are documented with accident statistics, others are evaluated with assumed probabilities of occurrence. Last, some hazards which are documented are independent of the backfilling activities, so that the reader must be able to differentiate between those hazards caused by backfilling and those which may occur whether or not backfilling takes places.

The ranking system attempts to deal with all of the above mentioned deficiencies by giving priority to those hazards that are documented with accident statistics and those which are more likely to occur with lesser consequences.

To help clarify why the hazards were ranked as shown in Table 14, a short explanation of the ranking of each hazard is presented below.

a. Roof Falls With Stowing at the Working Face

Roof falls at the working face have been the number one killer of underground coal miners in the United States. The use of backfilling adjacent to a longwall or shortwall face does not affect the potential for roof falls as compared to caving techniques.

TABLE 14. - Ranking of Potential Hazards in
Underground Coal Mine Backfilling

<u>Classification</u>	<u>Transportation Hazards</u>	<u>Ranking</u>
I C	Surface Haulage	11
IC - ID	Surface - Working Level Haulage	8
IA - IIIA	Working Level Haulage	4
IIB - IIC	Pipeline Spillage	7
<u>Stowing at the Working Face</u>		
I A	Roof Falls	1
II B	Dust Generation	3
I B	Explosions	5
IB - IIIB	Congestion	6
II B	Fall of Material Through Lining	9
<u>Remote Stowing Hazards</u>		
IC - ID	Roof Falls	12
III B	Quick Surges During Placement	10
II D	Pillar Punching	13
<u>Hazards Associated With Fill</u>		
IC - ID	Spontaneous Oxidation	2
III D	Quick Conditions of Inplace Fill	14
IV D	Inadequate Filter Design	15

Therefore, even though backfilling has no effect on roof falls, because of the high incidence of roof fall fatalities, it is classified as having catastrophic effects (I) and is likely to occur within a short period of time (A). As a result, roof falls are ranked as the number one hazard.

b. Spontaneous Oxidation

Spontaneous oxidation was classified as a remote to extremely remote possibility for resulting in a catastrophic accident. The catastrophic effect in this case being a mine fire capable of causing multiple deaths and major damage to the mine property. While mine fires are definitely a hazard, the greater risk comes from the more likely probability of fill heating related problems and the difficulty in controlling them. Even though it is difficult to verify the potential for oxidative heating problems due to the limited amount of backfilling performed in the United States, the conditions which promote oxidative heating are prevalent enough to warrant ranking spontaneous oxidation as the number two hazard.

c. Dust Generation With Pneumatic Stowing

Pneumatic stowing is classified as having a reasonable probability (B) of causing a serious illness (II) from dust generation. While dust generation can be controlled if the stowing system is operated correctly, the amount of dusting is rather sensitive to operational factors. Therefore, during the operational life of the stowing system, it can be expected from time to time, the equipment will produce excess dust generation due to temporary improper operation of the equipment. Therefore, dust related problems are ranked as the number three hazard.

d. Work Level Haulage

Haulage accidents on the working level are classified as being likely to occur within a short period of time (A) causing anywhere from minor injuries to fatal accidents. While haulage of fill materials rather than coal does not affect the potential of a haulage accident occurring, it does pose a significant hazard to personnel underground, qualifying it to be ranked as the fourth worst hazard associated with backfilling.

e. Dust Explosions With Pneumatic Stowing

Pneumatic stowing produces dust concentrations which under certain conditions could be explosive. As a result, dust explosions are classified as having a reasonable probability (B) of creating a fatal accident (I). However, since such a potential is based upon the fill material properties, dust explosions are ranked only as the fifth worst hazard with backfilling.

f. Congestion When Stowing at the Working Face

It was determined that stowing activities adjacent to an active face increased the potential for human and organizational accidents. As a result, congestion was given a reasonable probability (B) of causing accidents ranging from minor (III) to fatal (I). Because of the increased potential for human error due to congestion, it was ranked the sixth worst hazard associated with backfilling activities.

g. Pipeline Spillage

Slurry transport pipelines will invariably have a spill during the lifetime of the pipeline and may have many such spills. While the consequences of a spill on the surface may be minimal, it can have extreme consequences if underground. As a result, pipeline spillage is classified as having a reasonable (B) to remote (C) probability of incurring serious (II) damage. Experience tends to indicate that spills underground are not very common so that slurry spillage is ranked only seventh worst as a backfilling hazard.

h. Surface to Working Level Haulage Accidents

As with other haulage accidents, human error is the major culprit. However, accident statistics indicate that haulage between the surface and working level do not account for a large portion of haulage accidents. Consequently, haulage accidents between the surface and working level are given a remote (C) to extremely remote (D) probability of causing a fatal injury (I). As such, this hazard ranks only as the eighth worst backfilling hazard.

i. Fall of Material Through Lining

Backfilling activities appear to affect the frequency of lining failure related accidents. With longwall mining it appears to increase it while with shortwall mining, it appears to decrease it. Since lining failure is a common enough problem, it is classified as having a reasonable probability (B) of causing a serious injury (II). Since shortwall mining is not common, lining failure accidents are ranked only as the ninth worst backfilling hazard.

j. Quick Surges During Placement

During hydraulic placement of fill material in mined out panels, there is a good possibility of the fill behaving in a fluid fashion causing damage. However, in such remote areas, the consequences of such a flow usually are not great. As a result, accidents from quick flows during placement are considered to exhibit a reasonable probability of occurrence (B) producing only minor damage (III). This justifies ranking this as only the tenth worst hazard of backfilling.

k. Surface Haulage Hazard

The haulage of backfill materials across the surface are the safest leg of the whole haulage route when transporting the materials back underground. Whenever personnel are around haulage equipment, there is always a possibility of a fatal accident. This hazard was thus classified as having a remote probability (C) of incurring a fatal (I) accident.

Because the surface is a much less hostile environment than to underground, surface haulage only ranks as the eleventh worst hazard involved with backfilling.

l. Roof Fall Hazards With Remote Backfilling

Roof fall accidents occur mainly at the face under unsupported roof. Consequently, the potential of a roof fall accident while backfilling a mined out panel was considered remote (C) to extremely remote (D). The consequences of such a roof fall are still just as deadly (I). Consequently, roof fall accidents while backfilling a mined out panel is only ranked the twelfth worst hazard for backfilling.

m. Pillar Punching

In some mines, the roof or floor strata are susceptible to weakening by the presence of water. Hydraulic stowing in a partial extraction mine panel can cause the failure of these beds producing structural damage to the mine. Consequently pillar punching is classified as having an extremely remote (D) probability of causing severe damage (II) to the mine. Because of the limited instances of this problem, it was ranked as the thirteenth worst hazard with backfilling.

n. Quick Conditions of Inplace Fill

Once a fill is inplace, the potential of the fill surging causing damage is low (D) with the damage caused by such a failure being marginal (III). The highest potential for such a failure exists in steeply dipping filled areas which are saturated when a bulkhead fails. Quick flows of inplace fill are ranked the fourteenth worst hazard with backfilling.

o. Inadequate Filter Design

When backfilling with considerable fines, the drainage facilities must contain a filter if fines migration is to be prevented. If such a filter were missing, the drainage facilities could plug leading to a saturated fill condition. The potential of such an occurrence is considered unlikely to occur (D) for creating minor damage to mine facilities (IV). Consequently, inadequate drainage filters are considered the least dangerous of the hazards associated with backfilling and are ranked fifteenth.

3. Hazard Matrix

There are a variety of backfilling techniques and each is related to a number of hazards. The degree of hazard is based upon many factors, such as backfilling method, equipment used, waste material, the type of mining, scheduling of the mining, and the location in the mine where the backfilling takes place. It is important to classify the degree of hazard for each backfilling situation encountered for better understanding of the hazards involved with backfilling.

Figures 12 and 13 depict these relationships. The degree of risk involved with transporting the waste material back underground is less dependent on the stowing method than the equipment being used. As a result, the transportation risks are evaluated in a separate matrix. On the vertical are the various combinations of haulage equipment for each leg of the trip back underground. On the horizontal are the materials being hauled and their destination. The degree of risk is evaluated for each type of haulage equipment and waste material combination using the National Safety Council hazard evaluation system. This system is a two part classification that rates a hazard on its potential of occurring and on the degree of damage it can cause. This ranking system is shown in Tables 12 and 13. Since this hazard ranking system is somewhat simplistic, it may tend to over simplify the implications of a hazard. The degree of risk for each haulage/material combination is further discussed in the hazard section of this study.

There are a number of hazards that are related to the combination of stowing and mining method. The second chart depicts their relationships. As with the transportation hazard chart, the National Safety Council hazard evaluation System is used to evaluate the hazards. On the horizontal are the hazards that might be encountered. On the vertical are the possible combinations of backfilling situations that might be used. These backfilling situations include the purpose for the backfilling, the waste being stowed, the stowing method, and the mining method.

The coal mining methods which have had backfilling incorporated in the operation are:

- *Room and pillar,
- *Longwall, and
- *Shortwall.

The stowing methods that have been used and which are likely to be used again are:

- *Controlled hydraulic stowing,
- *Blind hydraulic stowing,
- *Controlled pneumatic stowing, and
- *Blind pneumatic stowing.

The common waste materials used for backfilling are:

- *Preparation plant coarse waste,
- *Preparation plant fine waste,
- *Preparation plant coarse and fine wastes combined, and
- *Flyash.

FIGURE 12. - Transportation Hazard Matrix

Haulage System	Stowing Adjacent to Active Face				Remote Area Stowing			
	Flyash	Preparation Plant Wastes			Flyash	Preparation Plant Wastes		
		Coarse	Fine	Total		Coarse	Fine	Total
I. Surface Haulage								
A. Railroad	I.B-III.B	I.B-III.B	I.B-III.B	I.B-III.B	I.B-III.B	I.B-III.B	I.B-III.B	I.B-III.B
B. Truck	do	do	do	do	do	do	do	do
C. Conveyor	I.C-III.C	I.C-III.C	I.C-III.C	I.C-III.C	I.C-III.C	I.C-III.C	I.C-III.C	I.C-III.C
D. Slurry	III.D-IV.D	IV.B-IV.C	IV.C	IV.B-IV.C	III.D-IV.D	IV.B-IV.C	IV.C	IV.B-IV.C
II. Surface to Working Level								
A. Railroad	I.A-III.B	I.A-III.B	I.A-III.B	I.A-III.B	I.A-III.B	I.A-III.B	I.A-III.B	I.A-III.B
B. Hoist	I.C-III.C	I.C-III.C	I.C-III.C	I.C-III.C	I.C-III.C	I.C-III.C	I.C-III.C	I.C-III.C
C. Conveyor	I.B-III.C	I.B-III.C	I.B-III.C	I.B-III.C	I.B-III.C	I.B-III.C	I.B-III.C	I.B-III.C
D. Slurry	I.D-III.D	I.C-III.C						
III. Working Level								
A. Railroad	I.A-III.A	I.A-III.A	I.A-III.A	I.A-III.A	I.A-III.A	I.A-III.A	I.A-III.A	I.A-III.A
B. Conveyor	I.B-III.C	I.B-III.C	I.B-III.C	I.B-III.C	I.B-III.C	I.B-III.C	I.B-III.C	I.B-III.C
C. Slurry	I.C-III.D	do	I.C-III.C	do	I.C-III.D	do	I.C-III.C	do

	Stowing at Working Face					Remote Backfilling			Hazards Associated with Fill		
	Roof Falls	Fall of Material Through Lining	Congestion	Dust Generation	Dust Explosions	Roof Falls	Quick Conditions During Placement	Pillar Punching	Spontaneous Oxidation	Quick Conditions of Inplace Fill	Inadequate Filter Needed
C. Controlled Pneumatic Stowing Method											
1. Preparation Plant Coarse Water											
a. Increased Stability	N/A	N/A	N/A	III.C	IV.D	I.C-III.D	N/A	N/A	II.B-IV.C	N/A	N/A
b. Subsidence Control	N/A	N/A	N/A	do	do	do	N/A	N/A	do	N/A	N/A
c. Disposal	N/A	N/A	N/A	do	do	do	N/A	N/A	do	N/A	N/A
2. Preparation Plant Fine Waste											
a. Increased Stability	N/A	N/A	N/A	II.A-III.A	I.A-I.B	I.C-III.D	N/A	N/A	I.A-III.B	N/A	N/A
b. Subsidence Control	N/A	N/A	N/A	do	do	do	N/A	N/A	do	N/A	N/A
c. Disposal	N/A	N/A	N/A	do	do	do	N/A	N/A	do	N/A	N/A
3. Preparation Plant Coarse and Fine Waste											
a. Increased Stability	N/A	N/A	N/A	III.B-III.C	III.C-IV.D	I.C-III.D	N/A	N/A	II.B-IV.C	N/A	N/A
b. Subsidence Control	N/A	N/A	N/A	do	do	do	N/A	N/A	do	N/A	N/A
c. Disposal	N/A	N/A	N/A	do	do	do	N/A	N/A	do	N/A	N/A
D. Blind Pneumatic Stowing Method											
1. Preparation Plant Coarse Waste											
a. Subsidence Control	N/A	N/A	N/A	III.C-III.D	IV.D	N/A	N/A	N/A	III.B-IV.C	N/A	N/A
b. Disposal	N/A	N/A	N/A	do	do	N/A	N/A	N/A	do	N/A	N/A
2. Preparation Plant Fine Waste											
a. Subsidence Control	N/A	N/A	N/A	III.B-III.C	I.B-II.B	N/A	N/A	N/A	II.B-III.B	N/A	N/A
b. Disposal	N/A	N/A	N/A	do	do	N/A	N/A	N/A	do	N/A	N/A
3. Preparation Plant Coarse and Fine Waste											
a. Subsidence Control	N/A	N/A	N/A	III.C-IV.C	III.C-IV.D	N/A	N/A	N/A	III.B-III.C	N/A	N/A
b. Disposal	N/A	N/A	N/A	do	do	N/A	N/A	N/A	do	N/A	N/A
4. Flyash											
a. Subsidence Control	N/A	N/A	N/A	III.B	N/A	N/A	N/A	N/A	N/A	N/A	N/A
b. Disposal	N/A	N/A	N/A	III.B	N/A	N/A	N/A	N/A	N/A	N/A	N/A
c. Fire Control	N/A	N/A	N/A	III.B	N/A	N/A	N/A	N/A	N/A	N/A	N/A

FIGURE 13. - Underground Coal Mine Backfilling Hazard Matrix (Continued)

II. LONGWALL MINING METHOD
A. Controlled Hydraulic Stowing

1. Preparation Plant Coarse Water
 - a. Increased Stability
 - b. Subsidence Control
 - c. Disposal
 - d. Working Platform

Stowing at Working Face					Remote Backfilling			Hazards Associated with Fill		
Roof Falls	Fall of Material Through Lining	Congestion	Dust Generation	Dust Explosions	Roof Falls	Quick Conditions During Placement	Pillar Punching	Spontaneous Oxidation	Quick Conditions of Inplace Fill	Inadequate Filter Needed
I.A-II.A	II.B	II.B-III.B	N/A	N/A	N/A	N/A	IV.D	III.C-IV.D	IV.D	N/A
do	do	do	N/A	N/A	N/A	N/A	do	do	do	N/A
do	do	do	N/A	N/A	N/A	N/A	do	do	do	N/A
do	do	do	N/A	N/A	N/A	N/A	do	do	do	N/A
I.A-II.A	II.B-III.B	II.B-III.B	N/A	N/A	N/A	N/A	IV.D	I.B-III.D	IV.C-IV.D	III.B-III.C
do	do	do	N/A	N/A	N/A	N/A	do	do	do	do
do	do	do	N/A	N/A	N/A	N/A	do	do	do	do
do	do	do	N/A	N/A	N/A	N/A	do	do	do	do
I.A-II.A	II.B	II.B-III.B	N/A	N/A	N/A	N/A	IV.D	IV.D	IV.D	IV.C-IV.D
do	do	do	N/A	N/A	N/A	N/A	do	do	do	do
do	do	do	N/A	N/A	N/A	N/A	do	do	do	do
do	do	do	N/A	N/A	N/A	N/A	do	do	do	do
B. Controlled Pneumatic Stowing Method										
1. Preparation Plant Coarse Waste										
I.A-II.A	II.B	II.B-III.B	III.C	III.D	N/A	N/A	N/A	III.C-IV.C	IV.D	N/A
do	do	do	do	do	N/A	N/A	N/A	do	do	N/A
do	do	do	do	do	N/A	N/A	N/A	do	do	N/A
do	do	do	do	do	N/A	N/A	N/A	do	do	N/A
2. Preparation Plant Fine Waste										
I.A-II.A	II.B-III.B	II.B-III.B	II.A-III.A	I.A	N/A	N/A	N/A	II.B-III.C	IV.C-IV.D	N/A
do	do	do	do	do	N/A	N/A	N/A	do	do	N/A
do	do	do	do	do	N/A	N/A	N/A	do	do	N/A
3. Preparation Plant Coarse and Fine Waste										
I.A-II.A	II.B	II.B-III.B	III.B-III.C	II.B-III.C	N/A	N/A	N/A	IV.C-IV.D	IV.D	N/A
do	do	do	do	do	N/A	N/A	N/A	do	do	N/A
do	do	do	do	do	N/A	N/A	N/A	do	do	N/A

FIGURE 13. - Underground Coal Mine Backfilling Hazard Matrix (Continued)

III. SHORTWALL MINING METHOD
A. Controlled Hydraulic Stowing

1. Preparation Plant
Coarse Water
a. Increased Stability
b. Subsidence Control
c. Disposal
d. Working Platform

Falls	Lining	Congestion	Generation	Explosions	Falls	Placement	Punching	Oxidation	Fill	Needed
I.A-II.A	IIC-III.C	II.C-III.C	N/A	N/A	N/A	N/A	IV.D	III.C-IV.D	IV.D	N/A
do	do	do	N/A	N/A	N/A	N/A	do	do	do	N/A
do	do	do	N/A	N/A	N/A	N/A	do	do	do	N/A
do	do	do	N/A	N/A	N/A	N/A	do	do	do	N/A

2. Preparation Plant
Fine Waste
a. Increased Stability
b. Subsidence Control
c. Disposal

I.A-II.A	III.C	II.C-III.C	N/A	N/A	N/A	N/A	N/A	IV.D	I.B-III.D	IV.C-IV.D	III.B-III.C
do	do	do	N/A	N/A	N/A	N/A	N/A	do	do	do	do
do	do	do	N/A	N/A	N/A	N/A	N/A	do	do	do	do

3. Preparation Plant
Coarse and Fine Waste
a. Increased Stability
b. Subsidence Control
c. Disposal
d. Working Platform

I.A-II.A	IIC-III.C	II.C-III.C	N/A	N/A	N/A	N/A	N/A	IV.D	IV.D	IV.D	IV.C-IV.D
do	do	do	N/A	N/A	N/A	N/A	N/A	do	do	do	do
do	do	do	N/A	N/A	N/A	N/A	N/A	do	do	do	do
do	do	do	N/A	N/A	N/A	N/A	N/A	do	do	do	do

B. Controlled Pneumatic
Stowing Method

1. Preparation Plant Coarse
Waste
a. Increased Stability
b. Subsidence Control
c. Disposal
d. Working Platform

I.A-II.A	II.B	II.C-III.C	III.C	III.D	N/A	N/A	N/A	III.C-IV.C	IV.D	N/A
do	do	do	do	do	N/A	N/A	N/A	do	do	N/A
do	do	do	do	do	N/A	N/A	N/A	do	do	N/A
do	do	do	do	do	N/A	N/A	N/A	do	do	N/A

2. Preparation Plant
Fine Waste
a. Increased Stability
b. Subsidence Control
c. Disposal

I.A-II.A	II.B-III.B	II.C-III.C	II.A-III.A	I.A	N/A	N/A	N/A	II.B-III.C	IV.C-IV.D	N/A
do	do	do	do	do	N/A	N/A	N/A	do	do	N/A
do	do	do	do	do	N/A	N/A	N/A	do	do	N/A

3. Preparation Plant
Coarse and Fine Waste
a. Increased Stability
b. Subsidence Control
c. Disposal

I.A-II.A	II.B	II.C-III.C	III.B-III.C	II.B-III.C	N/A	N/A	N/A	IV.C-IV.D	IV.D	N/A
do	do	do	do	do	N/A	N/A	N/A	do	do	N/A
do	do	do	do	do	N/A	N/A	N/A	do	do	N/A

FIGURE 13. - Underground Coal Mine Backfilling Hazard Matrix (Continued)

Last, the purposes for which backfilling is used are:

- *Increased stability,
- *Subsidence control,
- *Disposal of the wastes, and
- *Working platform.

These hazards are covered in more depth in the hazard section of this study.

4. Case Study - Health Hazard

This case study does not depict an underground mine backfilling accident, primarily because there are no recent backfilling accidents in the coal mining industry. In fact, those accidents hinted at in the literature happened decades ago. Enzian (17) in 1913 had mentioned such accidents in the Pennsylvania anthracite fields, but he did not mention any particulars.

The information for this case study came from the following sources (8, 30, 51, 60).

The following case is a problem concerning underground disposal of mine wastes that developed in the Appalachian region, and as of yet is still under investigation and evaluation. However, the conditions surrounding the case are sufficiently common within the region that future problems of this type may occur. It is hoped that the presentation of this case study will make others sufficiently aware of the conditions surrounding the case so that other such problems may be avoided. The following is a description of the factors surrounding and influencing this case.

Coal mining in the Appalachian region has been going on for two centuries. Consequently, there are many abandoned underground workings which are in varying degrees of collapse. The rainfall in the region is high, and so the water table is also high. As a result, there are mine water pools in these abandoned mines that probably are interconnected in heavily mined areas.

The mining industry is mature in the region. This means that mining methods and techniques have become well defined and standardized. As a result, there has been little need for intense engineering, thus minimizing the technical staff needed.

The region is dotted with small mining operations and small mining towns. In many cases, mining is the only major

industry in the area, so these towns depend on the mines for their livelihood. Despite this mining activity, these regions can be economically depressed.

In the name of public safety, there are stringent water quality and waste disposal regulations set by the state and federal governments. However, the money available for public works in these economically depressed mining districts is rather limited. Over the years, private individuals and small communities have found the mine water pools to be a cheap and ready source of water. It is not an uncommon practice to tap these pools and use the water, in some cases without treatment. Unfortunately, others have found the abandoned mines to be ideal locations to dispose of wastes, ranging from raw sewage to coal preparation plant fines. Conceivably, there are cases in the Appalachian region where sewage and fresh water taps are common to the same mine water pool. While there are specific government regulations concerning the proper disposal of wastes and requirements for domestic water quality, the cost of providing adequate facilities for these small mining communities can be prohibitive. Hence, the widespread domestic use of water from mine water pools.

Surface impoundments or land fills are the most common methods of disposal of preparation plant fines. However, the high relief in the region, the limited capacities of impoundments, and the consequences of a failure of a surface impoundment have made the use of impoundments difficult. Consequently, local MSHA offices have been promoting the use of underground mine disposal of the fine wastes.

The underground disposal practices of mining companies in the region have been reviewed by MSHA for adequate design and safety but the protection of the local hydrologic scheme is left to OSM. In this case, the state has a review program that was accepted by OSM thus delegating the authority to the state. These regulations require that the impact of underground backfilling activities upon the hydrologic scheme must be evaluated. This is to protect the users of ground waters in the area from contamination.

A mining company which has several coal mines within the region had decided to pump its preparation plant fines into an abandoned mine near its preparation plant. The abandoned workings that the mining company chose were adjacent to other flooded workings that were tapped by a nearby small community for its fresh water supplies. This community did not treat the water before pumping it to residences for consumption.

Sometime after backfilling had begun, the people of the nearby town complained about the water quality. This resulted in several government agencies evaluating the water and the

state Department of Health subsequently condemned the water for domestic use.

The state department of health has reported levels of polyacrylamides ranging up to 5 mg/l in the drinking water of this local community, and cited this as the basis for their condemnation of the water supply. However, polyacrylamides are not on the EPA hazardous compound list, and neither are there any regulations about maximum allowable concentrations.

Polyacrylamides are flocculents for settling fine particulate matter. They have been used in both industrial and domestic water treatment plants. It has been suggested that polyacrylamides are so widely used in domestic water treatment plants that few fresh water supplies have absolutely no trace of polyacrylamides in them. However, the polyacrylamides used for fresh water treatment are usually a purer grade than the industrial grade. The industrial grade polyacrylamides can have small amounts of a toxic acrylamide monomer associated with them. This substance is on the EPA's hazardous compound list.

The management of the preparation plant that was disposing wastes underground has admitted using polyacrylamides as a flocculent in their treatment process, but said that they had discontinued its use.

Tests done on the water of the nearby towns' water supply had indicated the presence of acrylamide monomers but due to stringent testing requirements for detection of acrylamide monomers, there has been some doubt as to the validity of these water tests.

The state has allocated funds for a fresh water plant for this locality in an attempt to deal with the problem. As of the recent past, allegations have been made that the mining company, and state and federal agencies involved had carried out an inadequate investigation on the hydrologic impact of this underground disposal of preparation plant fines. Moreover, the case has not been resolved to date.

This case raises concern about how underground mine waste disposal can adversely impact ground water quality. If chemicals which are added to the washing process do not dissipate before being pumped into underground excavations, it could become necessary to treat wastes prior to pumping underground. The major problem in this case stems from the dumping of mine waste into mine water that may be taken for domestic use. As underground mine waste disposal becomes more widely practiced, special care must be taken to avoid inadvertent contamination of domestic water supplies.

C. Health and Safety Benefits from Underground
Disposal of Coal Mine Wastes

The purpose of backfilling should not be confused with health and safety benefits derived from the use of backfilling. In some cases, the health and safety benefits from backfilling are used as the primary purpose or contributing purpose for the backfilling, in other cases, these benefits are fortunate by-products.

The following sections outline the health and safety benefits that can be gained by the use of backfilling. These include the following topics.

Backfilling and stability

- Controlling structural instability in the mine
- Minimizing surface subsidence damage
- Controlling seepage and the potential for mine flooding
- Backfilling to control rockbursts
- Backfilling to prevent seal leakage
- Reducing the negative hydrologic impact of mining

1. Backfilling and Stability

Many of the rock mechanics principles in this section were taken from Coates (12).

It is sometimes desirable to put coal mining and preparation plant wastes back underground where they came from. While in many cases, the disadvantages of backfilling offset the advantages, there are situations where the advantages become dominant. One of the accepted advantages of backfilling is increased stability.

Backfilling for stability improvement is basically a safety measure. It is employed when mining conditions are considered too risky without the additional support or if the workings have begun to deteriorate requiring the additional support. On occasion, it is employed for greater resource recovery such as when trimming down the remaining pillars.

Backfilling for the purpose of stability improvement is also an aid to the following objectives.

1. Roof support so that greater pillar recovery could be achieved.

2. Roof and barrier pillar support to maintain the integrity of strata separating the active workings from flooded workings, bodies of water, or water bearing beds.
3. Protecting the integrity of roof, floor, pillars, and seals around sealed areas to minimize leakage.
4. Removing stress from the working face to minimize rock bursts.
5. Minimizing the effects of subsidence on the surface.
6. Protecting the integrity of barrier pillars around main haulageways and shafts.
7. Improving the stability of old workings so that further extraction can be accomplished.

While the history of backfilling is full of such examples, it is apparent that few authorities recommend such practices. Most authorities generally recommend lower recovery rates and larger pillars. Their reasoning is that filling does not stop subsidence but only limits it. However, it has been found through experience that some extraction ratios have been too great for a sound long term structural design. This has spawned the use of backfilling as a remedial technique. Most often this has been applied long after the mine has shut down and can be applied only as a blind technique. Blind flushing is covered elsewhere within this report.

Since it is probable that backfilling will be used for structural purposes in active mining, the safety of such practices are addressed in this study. However, it is beyond the scope of this study to delineate the engineering design procedures for a safe application. For this information, a well respected rock mechanics text should be consulted.

To address this topic without getting too involved in the engineering design, the following subsections will describe how filling can add stability to workings and then outline how it is employed in some of the situations previously mentioned.

a. Stability Improvements Through Backfilling

There are three situations where a fill is intended to provide structural support. The first is where the fill is intended to take the major axis stress. This commonly is vertical in sedimentary deposits and results from the weight of

the overburden. The second situation occurs when the fill confines a load carrying member (such as a pillar) thereby inducing a more compressive minor axis stress. This increases the member's load carrying capacity. The third situation is where the presence of the fill prevents caving or deterioration of adjacent strata, thus maintaining its ability to withstand stress.

The following subsections will discuss the effectiveness of fill to provide these three types of support.

1.) Major Axis Support

In the past, mine voids have been backfilled with the intention that the backfill will accept the major axis stresses. This has been primarily to prevent subsidence or take the load off other load carrying members for greater recovery of these load carrying members. However, this does not mean that the inclusion of fill can be expected to act as a surrogate pillar stopping any further failure of adjacent pillars or abutments. For fill to act as a pillar, it would be necessary for the stiffness of the fill material (modulus of deformation) to be as great or greater than the stiffness of the wall rock if the fill is to accept any loading without failure of the adjacent support members. Figure 14 shows the compressibilities of uncemented sand tailings and coal wastes. These curves are equivalent to secant moduli of deformation between 30 MPa and 100 MPa. It can be observed that a fill pillar, especially one of coal wastes, would be too compressible to accept any appreciable loading without failure of the adjacent strata and support members. From a practical point of view, this means that if walls or abutments fracture as a result of an excessive stoping span, then the inclusion of fill within this span as a remedial solution would have very little effect in preventing further fracturing. The stresses in the walls would be substantially the same as if no fill existed.

Cementing fill can improve the fill's ability to resist compression. However, it was stated by Coates (12) that while cemented fill has greater cohesion than uncemented fill, it is still essentially a fine fill. While it makes mining methods possible that would otherwise not be considered, it does not have significantly greater stiffness, or modulus of deformation. Therefore, the support provided against subsidence is not likely to be much different from that of an uncemented hydraulic fill. While cemented fill will limit closure it is still insufficiently stiff to replace a load carrying pillar.

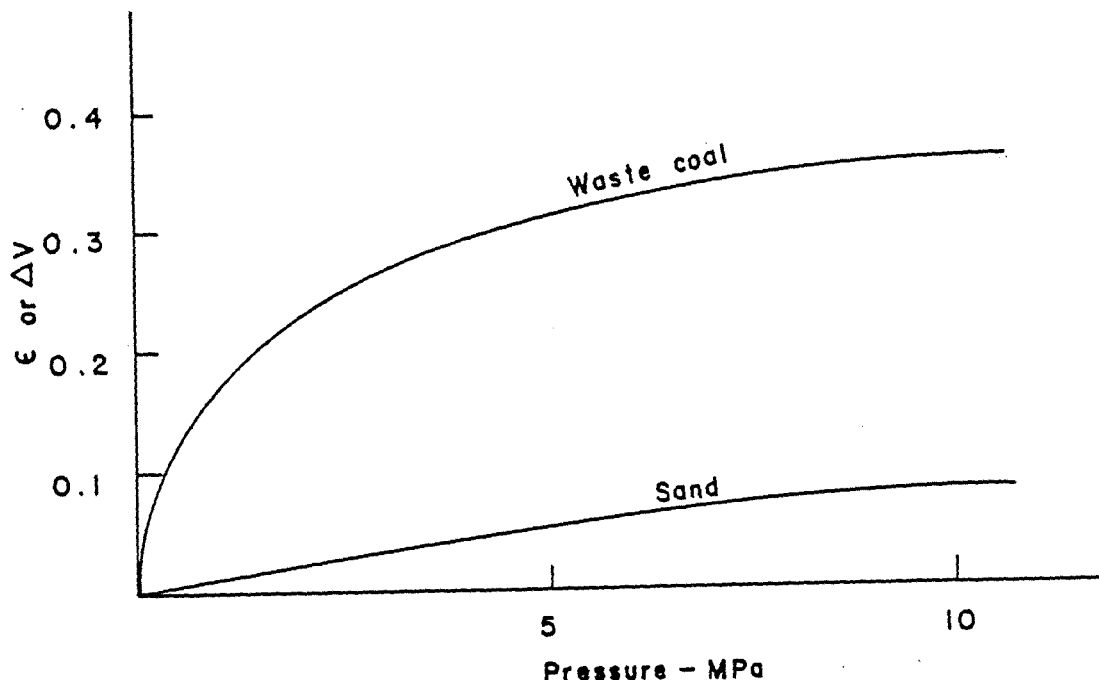


FIGURE 14. - Compressibilities of fills showing sand compressed less than 10% at a pressure of 10 MPa (1400) (12).

Therefore, the concept of a fill pillar supporting the overburden and replacing the load carrying member is a false and dangerous assumption.

This does not mean that a fill cannot carry the major axis stresses, but the roof and possibly the abutments must first fail allowing the overburden weight to compress the fill increasing its density until its bearing capacity is sufficient to carry the load. As Figure 14 indicates, the compaction under compression levels off after 10 MPa is applied to the fill. For coal wastes the volume under compaction can be reduced to as much as 60% of its original volume. This is why fill has been considered incapable of stopping subsidence, but capable of limiting the extent of it.

2.) Minor Axis Support

Providing minor axis support to structural members through backfilling has some theoretical basis and has had some reported successes. However, due to the expense and limited overall efficiency of backfilling for buttressing structural members, the application of backfilling for this purpose is not widely accepted.

Buttressing support to structural members is classified either as active support or passive support. Active support is application of confining pressures to the structural support while passive support relies on expansion of the rock to produce a restraining pressure on the support member. Consequently, backfill placed around a support member is considered passive. According to Coates (12), the pressure exerted by both active or passive support systems is small in relation to possible rock pressures, on the order of 0.01 to 0.1 MPa (1-15 psi). He therefore concluded that the buttressing support from fill was appropriate only to prevent deterioration (slabbing, loosening, or weathering) of the support member instead of being capable of significantly increasing a support member's carrying capacity. Galvin (23) refuted this opinion in his use of flyash as a fill material in the thick coal seams of South Africa. He showed that a strongly pozzalanic (self-cementing) flyash could increase the pillar load carrying capacity by 50%. The two following cases as reported by Galvin demonstrate the success of flyash backfilling to improve structural stability.

Workings at the Koornfontein Colliery in the Witbank Coalfield of South Africa were mined in 1956 and began to collapse in 1961. Flyash was hydraulically placed during 1963 to two-thirds of the mining height. The fill stabilized these workings so that there were no further major collapses throughout the life of the mine which closed in the mid-1970's.

Backfilling at the Springfield Colliery in the South Rand Coalfield of South Africa was implemented to improve the stability of two mined coal seams so that a third underlying seam could be extracted safely. This filling began in 1973 and in the four years during which the lower seam had been mined, no adverse interaction between the upper and lower horizon workings was noticed.

Galvin (23) stated that the effectiveness of such filling increased with improved self-cementing properties, pillar width, and curing time of the fill before deformation of the pillar. This meant that for a normally constrained pillar, fill had to be placed as soon as possible after mining and to at least two-thirds of the pillar height if maximum benefit was to be achieved.

Since backfilling is a passive support, situations which allow a greater amount of deformation will achieve the greater buttressing support. For instance, there is greater deformation laterally in a wide pillar than a narrow pillar before rupturing. Therefore, a deep mine with its correspondingly larger support pillars could take greater advantage of filling.

Planes of weakness within a structural member induce greater tensile horizontal strains at the weak zone. This induces dilation (slabbing and spalling) resulting in less pillar load capacity. Figure 15 depicts this condition by comparing a normally confined pillar's (A) horizontal stresses (σ_h) to pillars that are unconfined at the roof (B) and center-line (C). As coal is weak in tension, especially if there are cleats present, a plane of weakness can reduce a pillar's load carrying capacity.

While a pillar that is confined at both top and bottom will have the greatest horizontal expansion at the center, a pillar which is unconfined will expand the greatest at the point where the shear strength is the weakest. Consequently, a soft bottom which does not confine the base of a pillar will allow the most expansion to occur at the bottom of the pillar. Such a pillar would receive almost all of the benefit from a confining fill with only 50% filling. However, if the roof strata is soft, the greatest expansion would occur at the roofline requiring filling to the roof if any increased safety were to be gained.

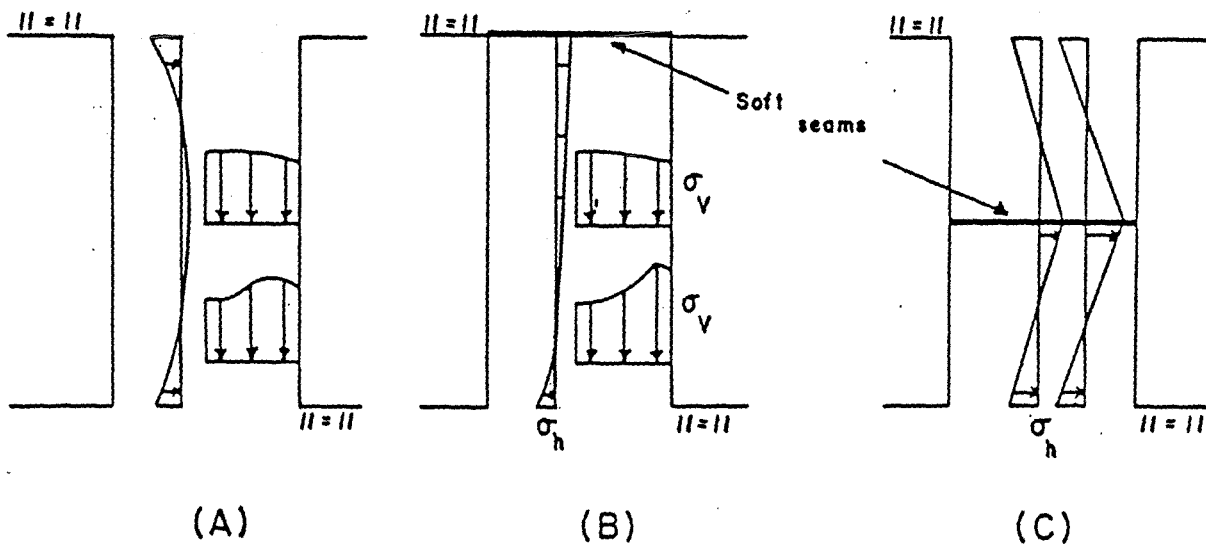


FIGURE 15. - Horizontal and vertical stress relationships in pillars with soft partings. (A) horizontal stresses tend to be compression near the walls and tension at mid-height; the vertical stresses tend to be higher in the center at mid-height and higher at the edges near the walls; (B) any soft seam or parting at the wall line that tends to be squeezed out will induce horizontal tension throughout the pillar; (C) soft seams at mid-height increase the horizontal tension in the center of the pillar (12).

Consequently, a pillar with a weak parting could benefit more from a buttressing fill than a competent pillar.

The physical properties that produce a good fill for buttressing pillars are:

1. Self-cementing
2. Low compressibility (high stiffness)
3. Well graded particle size distribution
4. Low friability

3.) Strata Integrity Support

Filling is used to reduce the amount of caving into mine voids where such rupturing of overhead strata or heaving of the floor would endanger the mine. Such dangers could include allowing large inflows of water, creating too much stress in the load carrying members, or disturbing the ground surface and mine facilities.

Essentially, this is buttressing the roof or floor strata thus providing minor axis support to this strata. However, this form of buttressing not only maintains the strength of these strata but also maintains low permeabilities perpendicular to their bedding plane.

Caving or roof falls themselves are not desirable events in a coal mine. Depending upon the major and minor axis stress orientation around a mine opening, caving can reduce the magnitude of stress around the opening or worsen the stress conditions. In addition, some strata are more prone to cave than other strata. Consequently, backfilling to prevent caving is applicable in some instances but ineffective and unwarranted in others.

Caving is dependent on the rock strength, geologic structure, and stresses around the opening. Caving might be initiated by two different actions. First, tensile stresses in the center of the roof span could sufficiently unload the rock allowing it to fall due to tension fracturing or the presence of previous fractures. Second, strong compressive stresses at the upper corners of support pillars could exceed the shear strength of the rock, causing failure. The orientation of the predominant stress fields with respect to the mine opening can have a strong effect upon the amount and extent of caving. Figure 16 (a) indicates the theoretical stress at the two above

mentioned points for caving in an excavation under predominantly vertical major stresses. This condition would be common in a horizontal single seam mine. As can be seen, as caving progresses upward the horizontal stress in the center of the room (σ_t) goes from tension to compression while the stress at the upper corner of the room (σ_c) is lowered from a high compressive stress to nearly that of the predominant vertical stress. Under these conditions, caving eventually produces a stable opening provided that the overhead strata is thick enough ($C > 4B$) before other excavations, water bearing beds, or the top horizon of the solid strata are encountered. Under these situations backfilling to prevent caving would be totally inappropriate. However, in the situations where the solid strata above the excavation is not very thick before an undesirable feature is reached, such as just mentioned, the integrity of this thin crown pillar is very important. Backfilling was used in the Pennsylvania anthracite mines in just this situation where it was important to maintain intact strata between the mine workings and the highly permeable water bearing "Buried Valley" (17).

Figure 17 indicates the stress relationship with respect to caving if the major axis stress field is predominantly horizontal. As indicated, the roof strata would be under compression so that the amount of roof falls should be considerably less. Any caving action in this case would probably consist of slabbing off the back due to the splitting action of the compressive stresses. Any weak or soft partings in the roof strata might facilitate such a slabbing because of their alignment. As Figure 17 indicates, as the caving

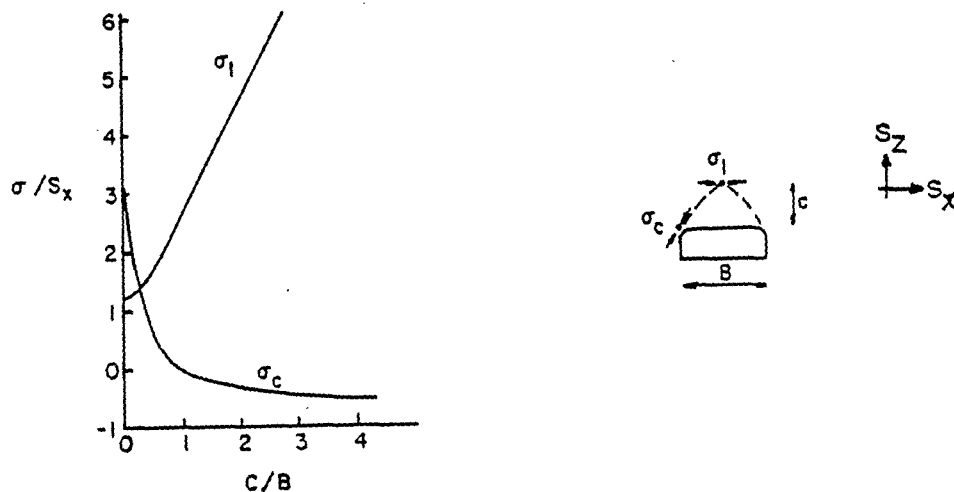


FIGURE 16. - Variation of stresses with height of caving or arching, C , for room width/height = 6. For $S_z = S_x/3$ the stresses tend to accelerate caving (12).

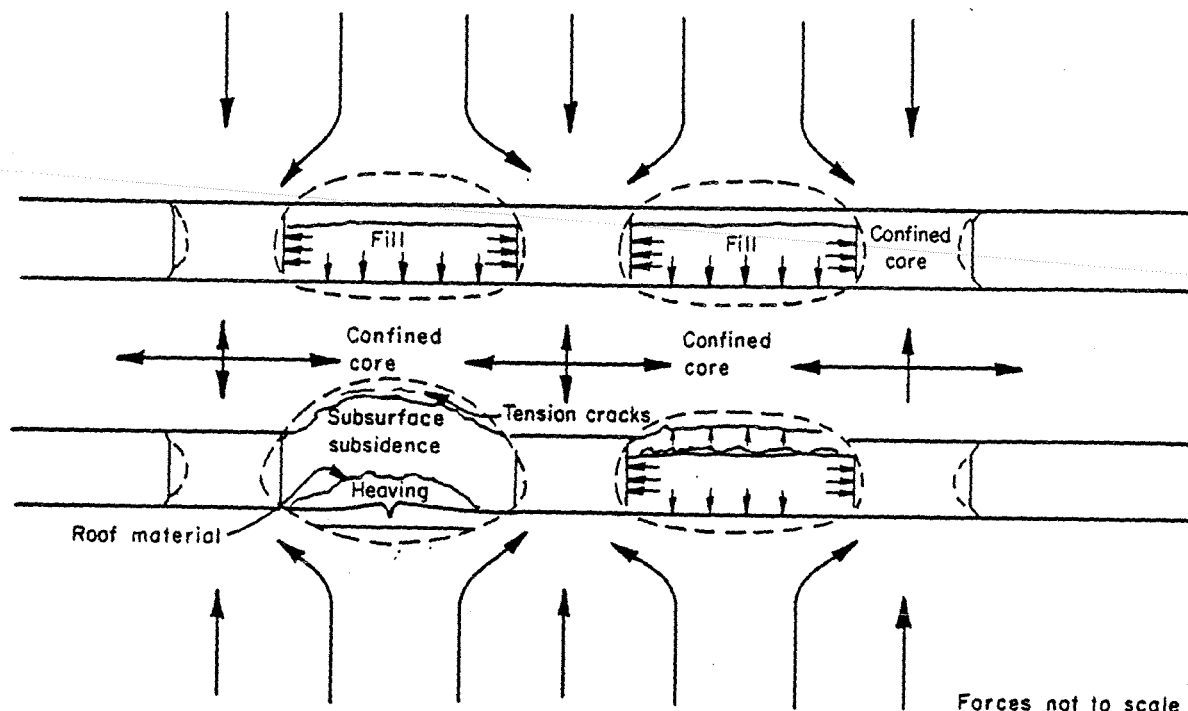


FIGURE 17. - Reduction of instability in sill pillars of multiple seam mines by filling mine voids.

progresses, the stresses at the top of the opening increase, creating a very unstable condition. Large horizontal stresses are not common in sedimentary deposits but such a condition can be induced in the sill pillars of a multiple seam extraction operation (Figure 17). Induced horizontal stresses promote failure along naturally occurring planes of weakness (partings, contacts, etc.). Such failure dramatically increases the stress induced at the roof line while reducing the size of the sill pillar which is able to carry the load. Caving could accelerate an unstable condition to complete failure. Consequently, the integrity of sill pillars can be extremely important, especially when the multiple seams are close together. The role of backfilling in limiting caving into the lower excavations can have a positive effect upon the safety of the whole operation. In addition, horizontal stresses can induce heaving of the upper excavation floor with equally disastrous effects. The weight of fill in the upper excavation while limiting heaving can also induce a bending moment in the sill pillar requiring more support to be placed in the lower excavation. Therefore, it is not clear whether filling the upper excavations would improve the safety or reduce it.

The appropriateness of filling to deal with this problem is based upon the thickness of the sill pillar and its integrity. The thicker the sill pillar, the less stressed it is and the less appropriate backfilling is for maintaining the integrity of the sill pillar.

b. Surface Subsidence Control

Surface subsidence results from overburden falling into mine voids. Due to elastic and inelastic deformation of this strata, the amount of surface movement will be dependent upon void size and shape, void depth, geologic, and physical factors. Subsidence results in horizontal and vertical displacement, compressive and tensile strain, and tilt of the surface. Surface facilities can withstand a certain amount of these kinds of movements before damage is done. Therefore, techniques which can maintain surface movement within tolerable limits can not only prevent costly repairs, but also maintain the safety of such structures.

By far, the most common structural use for backfilling is to protect surface structures such as buildings, highways, buried utilities and mine plant facilities including the shaft.

When talking about surface subsidence it should be understood that there are varying attitudes about what is considered appropriate protection and what are appropriate techniques. Most legislation in the United States aimed at subsidence control states that mining within the area of influence around a protected structure should be kept to a maximum of 50% extraction. Most of this legislation tends to ignore backfilling for subsidence control despite the fact that it has been used for such purposes over the last century. Backfilling is a viable alternative for subsidence control, but as with all prevention techniques, misapplication can limit the desired effects and the safety of the surface.

The intention of reduced extraction subsidence control programs is to reduce the amount of mine void into which overhead strata can cave and to increase the size of supporting pillars so that the stability of such workings will be greater. This works out quite well in a horizontal seam mine. As the roof falls into the smaller openings and fills them, the stresses around the mine opening become less and stabilize, and the caving stops, leaving the supporting pillars intact. The intact overhead strata is then protected and subsidence does not occur.

On the other hand, there are those who feel that partial extraction wastes resources, that it is a short term technique because support pillars will eventually fail, and that subsidence will eventually occur on the surface. Proponents of this view generally feel that the only way to prevent subsidence is to fill the voids. While the adequacy of partial extraction to prevent surface subsidence in the long run is questionable, it is widely accepted that full extraction with filling to the roof can only limit the total amount of surface subsidence.

The effectiveness of filling to limit surface subsidence is based on the percentage of filling, fill compaction, and the compressibility of the fill.

In general, backfilling adjacent to the active face of coal mines, as was widely done in Europe, is falling into disfavor because of its poor adaptability to mechanized mining. In the United States backfilling has rarely been employed adjacent to the active face with most of backfilling's success stemming from blind flushing.

c. Seepage And Mine Flood Control With Backfilling

Excess water in the mine workings makes conditions muddy, slippery, hazardous for electrical equipment and personnel and detrimental to any material susceptible to deterioration by water. It also softens the floor surface reducing its strength to hold supports, pillars, or equipment, and is uncomfortable and distracting. All of these conditions are known to promote accidents. In addition, the potentially catastrophic effects of mining too close to bodies of water create a hazardous situation to operating personnel and property. Excess water must, therefore, be controlled.

Inflows of water to the mine can range from minor seepage to mine flooding. Water control methods in underground mines have ranged from preventative to corrective methods, and employ such techniques as mine sealing, surface water control, backfilling, modified mining arrangements, reduced extraction ratios, dewatering tunnels, and pumping. While backfilling is not the only alternative for water control and by far the least popular, it tends to be a more long term solution.

The most popular and effective technique for seepage control is reduced extraction ratios. However, this can only be used as a preventative technique. Reduced extraction ratios are not always economical alternatives, or as in many cases, the water problem exhibits itself only after high extraction ratios have been employed. Consequently, backfilling has shown itself to be a viable technique for water control when high extraction ratios have been employed.

The benefits from backfilling unfortunately can only be gained after placement of the fill. Therefore, during placement, especially if the fill is hydraulically stored, the water problem can be more difficult.

Backfilling controls water problems by restricting the inflow of water and by protecting the integrity of adjacent strata from fracturing which results with lower resistance to inflows of ground water. How and where backfilling is used will be dependent upon geology, hydrologic conditions, mining method, and proximity to bodies of water. As can be deduced, a large inflow of water can be a result of naturally occurring conditions or the activities of man.

Backfilling to control inflows of water was most widely used in the deep anthracite mines of Pennsylvania. The northern field ranged in elevation from 700 feet above sea level to 1500 feet below sea level with 18 mineable beds in some localities. By the advanced stages of mining in the 1950's, overlying strata had been disrupted by subsidence, the surface subsidence had become a dangerous problem, and there were large underground water pools in abandoned mines which were no longer separated by competent barrier pillars. It was estimated that a third of the Lackawanna River watershed drained into the underground workings and had to be pumped out (3). There was an extreme danger of breaking into abandoned flooded mine workings or disrupting the strata separating the active workings from water bearing beds. According to the United States Bureau of Mines in 1947 (2); backfilling was being used to control subsidence and to buttress barrier pillars in the Pennsylvania anthracite mines. They reported 13 backfilling operations, 10 being conducted by private companies, with 12 using hydraulic methods. Seven of these operations were backfilling to maintain the integrity of overlying strata because of their proximity to water bearing beds. It was also mentioned that barrier pillars had been buttressed with fill when abandoned workings on the far side of the pillar were inundated. In these documented examples no mention was made of the effectiveness of the backfill to control water problems.

There were five conditions in the Pennsylvania anthracite mines that resulted in water related problems as listed below and in Table 17.

1. Barrier pillars which were too small, were deteriorating, or had been subjected to high hydrostatic pressure.
2. Fracturing of the roof or floor strata from squeezing, caving, or heaving around barrier pillars.
3. High seepage rates past barrier pillars because of naturally occurring high permeabilities of the pillar, roof, or floor strata.

4. Deterioration or caving of overhead intact strata separating the active workings from water bearing strata, inundated abandoned workings, or bodies of water.
5. Surface subsidence which catches surface runoff and adds it to the ground waters entering active mines.

When backfilling was employed, it was used in three different ways as shown in Figure 18. These were either buttressing a barrier pillar, filling mine voids to limit subsidence, or buttressing support pillars to reduce subsidence.

As indicated in Table 15, buttressing a barrier pillar with fill reduced deterioration of the pillar, roof and floor strata and provided additional strength to the pillar by providing minor axis support and prevention of slabbing or caving into the openings. In addition, it slowed seepage rates by placing more obstacles between the mine water pool and open workings (reduced permeability).

According to Table 15, filling mine voids to reduce subsidence effects maintained the integrity of overhead strata separating the active workings from water sources and limited surface subsidence depressions which increased ground water recharge rates. This was accomplished through limiting subsurface and surface subsidence, but unfortunately, some subsidence must take place before the fill accepts the full vertical stress.

Last, Table 15 indicates that buttressing support pillars prevented surface and subsurface subsidence thus protecting the integrity of overhead strata separating the active workings from sources of water and prevented surface depressions thus limiting the amount of ground water recharge.

d. Backfilling for Control of Bumps

Bumps or rock bursts in a coal mine are primarily due to high stresses from a thick overburden load. They can throw slabs of coal violently from ribs or sides, break down roof, rock or cause the floor to burst. Strata gas is sometimes given off with the bursting rock. Bumps are classified into two categories; pressure bumps or shock bumps.

Pressure bumps are the result of direct failure of overstressed rock in the pillars, abutments, immediate roof or immediate floor.

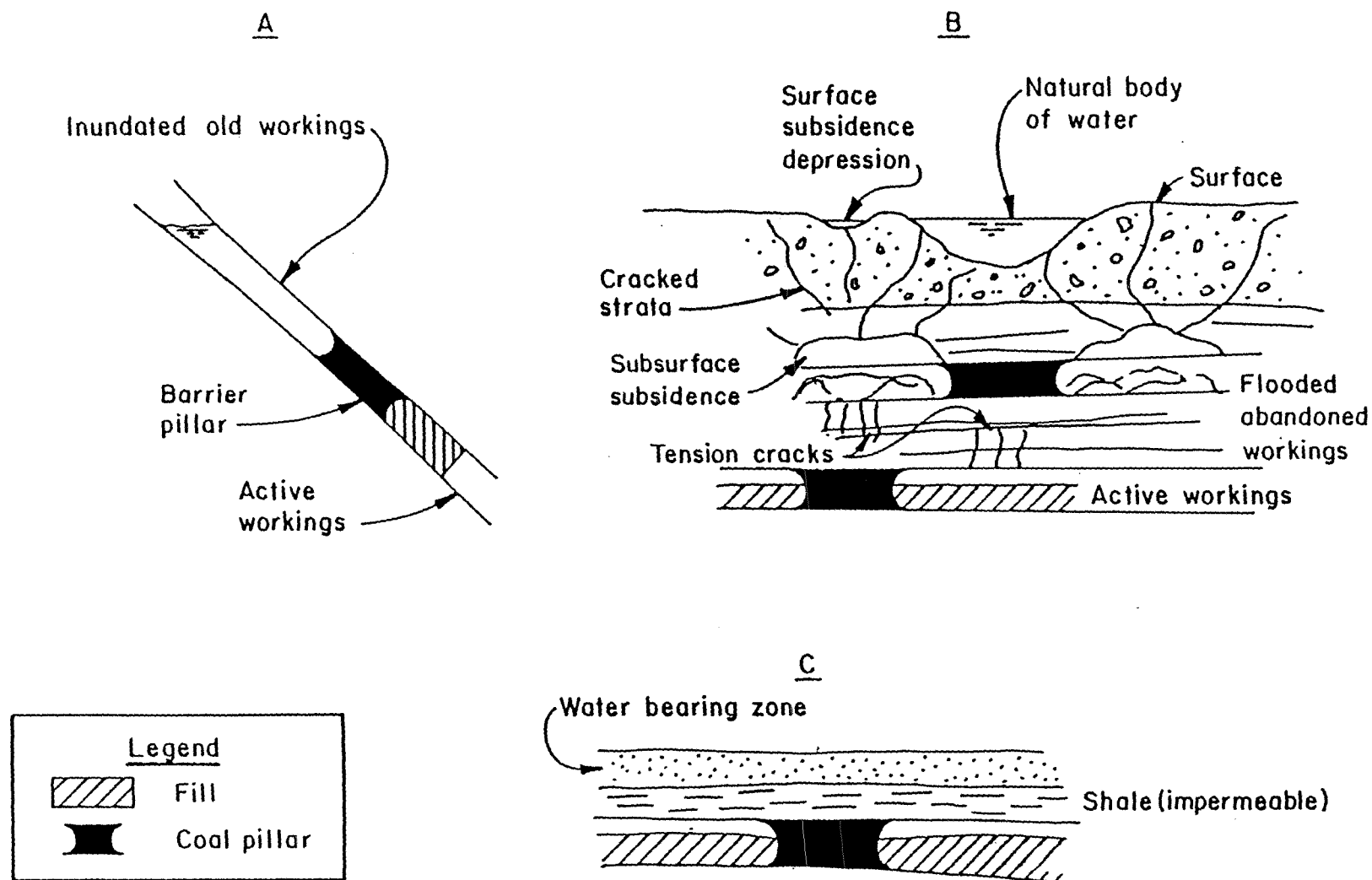


FIGURE 18. - Reduction of water seepage or flooding potential by filling mine voids.

TABLE 15. - Ways in Which Backfilling Applications Can Mitigate Water Related Problems

Problem	Application		
	A. Filling Against a Barrier Pillar	B. Filling Mine Voids to Reduce Caving	C. Buttressing a Support Pillar
Deteriorating Barrier Pillar	Minor Axis Support	-----	-----
Deterioration of Roof or Floor Strata Around a Barrier Pillar	Reduced Subsidence Minor Axis Support	-----	-----
High Seepage Rates at Barrier Pillar	Reduced Permeability	-----	-----
Deterioration of Overhead Strata Separating Workings from Water Sources	-----	Reduced Subsurface Subsidence	Reduced Subsurface Subsidence
Surface Subsidence Causing High Ground Water Recharging Rates	-----	Reduced Surface Subsidence	Reduced Surface Subsidence

Shock bumps are due to failure of a strong overlying or underlying strata. The sudden failure of this strata causes an intense impulse (in the form of a shock wave) creating a short lived high stress in the rock around the opening. This impact loading can cause rock to fail violently into the opening. Failure of the strong strata which creates the impulse can happen in two situations. One, the stope span can become too large, causing failure. Two, the strata can resist failure in a full extraction method creating a long cantilever until it fails suddenly (1).

While backfilling in hard rock mines has been shown to reduce the potential for rock burst, it apparently has not seen much use in coal mining. Bumps are the result of high stresses causing very strong strata to fail suddenly. Strong rock

usually does not bend or deform much before failure. Unfortunately, a fill material is too compressible to accept any loading before most strong strata fails (12). Consequently, the inclusion of a fill material has a questionable ability to reduce the potential for bumps in underground coal mining.

e. Backfilling And Sealed Workings

Sealing mine workings has fallen into disfavor as a useful procedure. However, the use of backfilling can improve the conditions under which sealing is practiced, making it a much safer activity.

Sealing old workings to prevent contamination of active workings has been used in coal mining for years, and it has been recognized for almost as long that seals are not always secure. Failure of seals can result from roof falls, blasting concussion, incorrect construction, pressure on the backside, abuse, or leakage through roof or floor strata. For this reason, the United States Bureau of Mines recommends the use of bleeder entries around mined out panels instead of sealing them.

This does not mean that sealing is not used. More often, large sections of a mine are sealed rather than sealing the mine panel by panel. Sealing is practiced so that dangerous areas within the mine can be separated from the active areas, to minimize the amount of airways that must be maintained, and most importantly to maintain good ventilation without adding extra ventilation facilities to the existing system.

It was stated by Hartman (28) that because of the caved and fractured roof strata created by a full extraction method, leakage past seals adjacent to the caved areas could never be stopped. This makes sealing more appropriate for a partial extraction mining method.

Why is it important to maintain seal integrity when an area is sealed?

1. The atmosphere in sealed workings becomes oxygen deficient in a very short time. If the seal leaks or the workings are mined into, personnel face a life endangering encounter with blackdamp. History shows many such accidents.
2. If oxygen is allowed to enter sealed workings, oxidation can begin and possibly create a heating and gas generation problem.

3. Operations which mine near bodies of water will quickly seal the workings after finishing extraction. This is a precautionary measure against flooding the whole mine if the intervening strata were to fail. It is quite obvious why these seals must remain intact.

How can backfilling affect the applicability of sealing?

1. Filling prevents caving adjacent to the seal, maintaining a low permeability at the seal and in the adjacent strata. This occurs not only because the fill reduces the amount of void space the roof has to cave into, but also because the fill can give additional buttressing support to the seal in case of pressure build-up behind it.
2. Backfill at a seal prevents concussion or abuse of the seal itself.
3. If closure causes the seal to squeeze and leak, the presence of a tightly packed fill can limit the amount of leakage.
4. Since fill replaces a void, there are fewer voids containing hazardous gases (black damp) or water which could inundate active workings if the seal were breached.
5. If backfilling promotes the use of sealing, then there are fewer drifts which must be inspected, sampled, and maintained. Therefore, less engineering is required to maintain adequate ventilation, and less ventilation capacity is needed. It is generally conceded that the more people there are underground, the greater the potential for an accident. Therefore, any activity which requires fewer people might be considered safer.

In conclusion, backfilling used in concert with sealing can improve the effectiveness of sealing and sealing of back-filled areas can reduce the hazard of fill oxidation. Therefore, while both activities exhibit a degree of hazard, A portion of the risks could be overcome by using these procedures in combination.

f. Backfilling to Arrest Mine Fires

The first instance of this application of hydraulic filling is reported to have been at a mine in the Schuylkill region in 1884.

Enzian in 1913 (17) reported the wide spread use of hydraulic stowing to seal off underground coal mine fires. It was primarily used if flooding the burning section of the mine with water was not possible. He reported that it had been successfully applied to sealing and extinguishing mine fires in abandoned mines or old workings of active mines.

On the other hand, McElroy (40) reported that hydraulic filling for controlling underground coal mine fires had been very limited. The fill when used as a seal was ineffective because of the difficulty in totally sealing a burning coal seam. When used to totally inundate and smother the burning area, it was effective in only 12 out of 24 applications being most successful with small fires. Even in these reported successful cases, only 6 were definitely extinguished and the remaining six may have been extinguished by water alone as there was inadequate drainage facilities. According to McElroy (40), hydraulic filling worked the best as a fire retardant. Thus, the advantages of hydraulic stowing to extinguish underground coal mine fires are limited.

g. Backfilling to Arrest Mine Collapse

Enzian (17) in 1913 had stated that hydraulic filling had been accepted as a technique to arrest squeezes in the Pennsylvania anthracite mines. However, his use of the term squeeze is not the same as it is used today. Enzian was referring to an unstable condition in the mine as a result of inadequate pillar support. For example, the potential for mine collapse is increased greatly where the pillars in one mined coal bed are not columnar (pillar above pillar) with those in a closely associated underlying bed. In such cases, there was a greater potential for collapse of the mine. According to Enzian, the use of hydraulic filling was a last ditch effort prior to collapse of the failing workings. As a result, it was applied rather hurriedly. As would be expected, the reserves within the collapsed area are no longer accessible because of the need for complete filling. Coal wastes are fairly compressible and the ability to fill a mine void under hurried and collapsing conditions may be rather limited. However, the presence of the fill should provide some strength to the failing pillars by buttressing them and limiting the void space which the roof can collapse into.

2. Hydrologic Effects of Backfilling

Hydrologic conditions surrounding a coal mine can be affected by backfilling in two different ways. The location of

and availability of groundwater can be changed or the quality of ground or surface waters can be altered. Restoring the hydrologic scheme to pre-mining conditions can be nearly impossible in some situations despite the fact that the Mine Safety and Health Act of 1977 requires such a restoration if possible. This includes the minimizing of acid mine drainage.

Acid mine drainage (AMD) is characterized by a low pH and a high concentration of metallic salts, chiefly iron. It is a common problem associated with coal mining. AMD seeps out of abandoned mine portals, through permeable strata to the surface, or into adjacent fresh ground waters that are actively being pumped. Stream pollution is the most common problem from AMD.

a. Waste Properties

It was reported by the National Academy of Sciences (43) that bituminous coal, which accounts for 95% of cleaned coal, generally has a sulfur content of 1%-5%. Fresh preparation plant wastes range from 3% to 15% sulfur with an average of 5% to 10%. Therefore, backfilling with preparation plant waste places a higher concentration of sulfur compounds underground than was naturally occurring. In addition, this fractured backfill has more fresh surface available for chemical reaction and a higher permeability than in-place coal. Moebs (42), performing a demonstration air-sealing project found that iron sulphides, the primary source of sulphur for sulfuric acid generation, were found primarily in the bottom portion of the coal bed and in the top layer of the floor material. The upper portion of the seam and the overhead strata were relatively low in iron sulphides. This indicates that sulphide compounds in the waste could possibly be reduced by being careful to avoid disrupting the floor material when mining near the bottom of the coal seam.

Another possible source of undesirable pollutants may be the presence of flocculation agents or chemicals added during the preparation plant process.

b. Acid Mine Drainage (AMD)

The primary technique for controlling Acid Mine Drainage (AMD) is to inundate the abandoned mine. This is sometimes called "air-sealing." The purpose is to rob the workings of air which is one of the necessary ingredients for oxidation and the production of AMD.

Since one of the primary ingredients for AMD is sulphide compounds, their presence in backfill increases the potential for AMD. Whether this potential is realized or not is dependent upon the effectiveness of air-sealing. According to Moebs (42), air-sealing is effective in reducing the mine effluent volume, effluent acidity, acid load, and fluctuations in acidity. However, its effectiveness is dependent upon purging the air from the mine indefinitely and reducing water percolation through the mine. If these criteria cannot be met in a post-mining situation, the placement of the fill can contribute to AMD. Air-sealing is most effective when the water table can be maintained above the mine level. This is easiest when the seam is deep, does not outcrop nearby, or dips away from the outcrop. In such instances, the additional sulphides introduced by the fill should not pose an AMD problem.

The appropriateness of placing a high sulphide waste underground when it is difficult to produce good air-sealing is subject to question. It must be determined whether the advantages of placing the fill underground outweigh the disadvantages.

The placement of a fill material underground can improve the effectiveness of air-sealing by restricting the flowrate of water within the workings and by maintaining the integrity of overhead strata and thus limiting the inflow of water into the workings.

An air-seal sometimes has a drain at the portal, and fill which restricts the flow of water towards the portal will restrict the amount discharged to the surface.

c. Hydrologic Scheme

Pre-mining hydrologic conditions can be at least partially restored by backfilling. Backfilling not only places a mineralogically similar material within the mine workings, but also can more closely approximate the original permeabilities than can unfilled voids.

In most sedimentary deposits, permeabilities are greater parallel to bedding planes than perpendicular to them. Disruption of the strata through caving increases vertical permeabilities (i.e., perpendicular to bedding planes). This can cause aquifers which occur over the mine and which were previously separated to become hydraulically connected. Such a connection can create changes in the water quality and/or the potentiometric surface associated with one or both of the aquifers. These changes can occur even if only one significant

water-bearing zone is present and becomes connected with previously isolated strata. By reducing the amount of caving and fracturing occurring in the roof of the mine, backfilling can reduce such effects.

An air-seal sometimes has a drain at the portal, and fill which restricts the flow of water towards the portal will restrict the amount discharged to the surface.

3. Ranking of Health and Safety Benefits from Underground Disposal of Coal Mining Wastes

While some of the health and safety benefits gained from underground disposal of coal mining wastes are very well known, other health and safety benefits are not so obvious and are based on conjecture. To understand and compare those benefits that might be gained from backfilling, each health and safety benefit is given a classification as to its importance, then is ranked from most to least positive for comparative purposes.

It must be understood that the reported successes of backfilling are based on its ability to achieve the intended purpose, which is usually monetary in nature. Seldom are its successes reported on the basis of improved safety or reduced numbers of accidents. Consequently, it becomes very difficult to rank the health and safety benefits from backfilling based on reported success. Instead, professional judgement must be used in determining the benefit ranking.

The classification system that is used is an adaptation of the National Safety Council hazard evaluation system. As such, each health and safety benefit is given a two part classification. The first part is a Roman numeral ranging from I to IV which describes the severity of the hazard that a benefit ameliorates (Table 16). The second part is a letter ranging from A to D which described the effectiveness of backfilling to reduce the health and safety problem (Table 17).

While this classification system is easy to understand and allows for some comparisons, it tends to oversimplify a complex situation. Backfilling is seldom employed for health and safety reasons alone. It is difficult to account for the frequency of each benefit because most are not well documented.

TABLE 16. - Classification of Relative Consequences
of Problems Which Backfilling Can Impact

<u>Problem Consequence Classification</u>	<u>Explanation</u>
I.	The problem is capable of causing a deadly working environment, major loss of mine facilities or equipment, or major long term environmental problems.
II.	The problem is capable of creating a working environment that can cause serious health problems, moderate damage to mine facilities or equipment, or moderate environmental problems.
III.	The problem is capable of creating a moderate to minor health danger in the working environment, minor damage to mine equipment or facilities, or minor long term environmental problems.
IV.	The problem will create minor to extremely remote problems with health in the working environment, minor short term environmental problems, or minor losses of equipment.

TABLE 17. - Classification of Backfill's Ability
to Abate a Health and Safety Problem

<u>Abatement Classification</u>	<u>Explanation</u>
A	Highest possible. Positive effect will likely eliminate or greatly reduce the problem that it was intended to control.
B	Positive effect will reduce the problems significantly.
C	Positive effect will reduce the problem to a small degree.
D	May not have any positive effect at all.

Because of the wide variation in site specific conditions, ranking health and safety benefits of backfilling becomes rather generalized and should not be assumed correct in all applications. However, the ranking system will attempt to compensate for deficiencies by giving a high ranking to those benefits which have been proven many times and those health and safety benefits which have a high frequency of occurrence. The classification and ranking for each positive aspect is depicted in Table 18. Each positive aspect will be discussed to clarify the classification and ranking.

a. Reduction of Subsidence

The most popular use for backfilling has been to control the damage caused by surface subsidence. This has been the predominant reason for backfilling in Europe, and thus, it is ranked as the number one positive aspect. Backfilling for subsidence control is classified as having a significant impact (B) on a problem that is capable of creating a major safety hazard to surface structures and major long term environmental impact (I). However, because of its inability to totally prevent the effects of subsidence on the surface, it has not been judged to be a total success in some European countries.

TABLE 18. - Ranking and Classification of Health and Safety Benefits From Underground Coal Mine Waste Disposal

<u>Rank</u>	<u>Classification</u>	<u>Aspects</u>
1	I.B	Reduction of Subsidence Damage
2	I.B	Improved Mine Structural Support
3	I.B	Control of Seepage and Mine Flooding
4	I.C	Reduction of Damage to Hydrologic Scheme
5	I.C	Backfilling to Arrest Mine Collapse
6	II.C	Improvement of Sealing Old Workings
7	I.D	Backfilling to Arrest Mine Fires
8	I.C	Control of Gas Emission at the Working Face
9	I.D	Control of Rock Bursts

b. Improved Mine Structural Support

Backfilling for structural support in mining activities has been successfully applied in the past. However, there are other techniques which have proven to be as successful and much less expensive. Because of the acceptance of backfilling for improving the structural stability of mine workings and its successful track record, it is ranked as the second most effective health and safety benefit gained from backfilling.

Backfilling for improved structural stability is classified as having a significant effect (B) in providing stability to the mine which is of major importance (I).

c. Control of Seepage and Mine Flooding

Backfilling was one of the techniques used in the Pennsylvania anthracite mines to control water seepage into the workings and to protect the mine from flooding. While it was successful in the extreme conditions encountered in Pennsylvania, it does not appear to have been used to a large extent for these purposes elsewhere. Consequently, backfilling to control the inflow of water into active workings is ranked third.

Backfilling for water control was classified as having a significant effect (B) to control a problem that could cause loss of life or loss of mine facilities (I).

d. Reduction of Damage to Hydrologic Scheme

The concern for fresh ground water supplies has become especially important within the last few years. Underground mining can have a major impact on the quantity and quality of fresh ground water supplies. Since there is likely to be much emphasis placed in the future on protecting ground water, backfilling for this purpose is ranked as the fourth most positive benefit.

Backfilling for purposes of mitigating mining damage to the hydrologic scheme is classified as having a small impact (C) on a situation that could create major, long term environmental problems (I).

e. Backfilling to Arrest Mine Collapse

The ability of backfill to minimize the effects of a collapsing section of the mine is moderate to minor. This is due to the compressibility of the coal waste and the limited ability to completely fill the collapsing void under poor conditions. Consequently, backfilling to arrest mine collapse was ranked fifth and was classified as having a small degree of success (c) against a problem that could do major damage to the mine or cause loss of personnel (I).

f. Backfilling to Improve Sealing

Sealing mined out areas that have caved is very difficult. The fracturing of roof strata creates leaks through the roof and seals that are difficult to correct. By minimizing the amount of caving using backfilling, especially near the seal, the amount of leakage past the seal can be reduced. Since backfilling for this purpose has not been documented, it is ranked as only the sixth most positive benefit from backfilling.

Backfilling for improved seals is classified as having a small degree of success (C) against a problem that could produce a serious health hazard (II) in the working environment.

g. Backfilling to Arrest Mine Fires

While backfilling was used at one time to arrest mine fires, its effectiveness was proven to be limited. At best, it worked as a fire retardant when the burning area was filled. Consequently, backfilling to control an underground mine fire is classified as having limited ability (D) to deal with a problem that could cause multiple deaths or loss of the mine (I). Thus, it is ranked as the seventh most positive benefit from backfilling.

h. Control of Gas Emission at the Working Face

Gas emission at the working face can be great if the mining rate is rapid. It has been stated that backfilling adjacent to the active face can minimize the amount of caving, thus limiting the passageways through which strata gas can escape.

This is unproven and in comparison to the emission from the face, the amount may be small. Consequently, backfilling to limit gas emission is ranked eighth most positive effect.

While the consequences of excess gas emission at the face can be deadly (I), the effectiveness of backfilling to control the problem is classified as small (C).

i. Backfilling for Control of Bumps

Bumps are found only under special conditions. While Obert and Duvall (45) stated that backfilling could reduce the potential for a bump, there is no positive evidence that it does. Consequently, backfilling to control rock bursts is ranked as the least most positive benefit.

While rock bursts are classified as creating a deadly working environment (I), it was determined that backfilling will exhibit little or no effect (D) in reducing the potential for bumps.

D. Health and Safety Evaluation Criteria and Suggestions to Minimize Hazards With Underground Disposal of Coal Mine Wastes

In the hazard section of this chapter, the degree of risk associated with backfilling of coal mine wastes and factors that can control it were evaluated for a number of hazards. The following is a compilation of these findings presented to help minimize the risks involved with backfilling.

In the evaluation of the hazards, the risk was determined using accident statistics or by considering the factors which influence the hazard potential. While accident statistics indicate the absolute risk involved, they do not necessarily indicate the factors which influence the risk. On the other hand, evaluating the factors which influence a hazard can show how to control the hazard, but it does not indicate the absolute risk adequately. Consequently, for some hazards, all that can be said is that one method or location is riskier than another while for other hazards, the factors which influence the risk can be stated.

The findings from the hazard evaluation will be discussed in the order that they appear in the hazard section.

1. Fill Material Properties

Before an adequate backfilling system can be designed or the degree of risk from such activities can be evaluated, it is necessary to determine the fill material properties of the waste. Table 19 lists the information that has to be gathered on the material. In discussing how the hazard potential can be evaluated, it will become apparent how this information is used.

TABLE 19. - Properties of Backfill Material That Must Be Determined to Evaluate the Hazard Potential

Particle Size Distribution
Rank of Coal that Waste came from
% Incombustible
% Quartz
% Fixed Carbon
% Volatiles
% Sulphur and Sulphides
% Moisture in Material

2. Personnel

The degree of risk involved with backfilling is directly attributable to the number of man-hours involved in the activity, especially man-hours underground. Therefore, to minimize the potential for an accident with backfilling, backfilling methods, equipment, and locations of operation should be chosen which minimize the number of man-hours underground. The influence of personnel upon particular hazards is noted in the following subsection.

3. Minimizing Risk With Waste Transportation

It was determined that haulage risk is no different for transport of coal waste materials than it is for coal. Therefore, the risk of using different pieces of haulage equipment was determined without evaluating the factors which might influence the risk for a particular piece of equipment. It was determined that haulage equipment selection might help to control the absolute risk more than equipment operation. The exception was with slurry transport because of its popularity and complexity.

Keeping in mind that the waste haulage system must be compatible with production haulage equipment and schedules, the following suggestions should help to minimize the risk involved with waste haulage.

1. Transport waste material on the surface as much of the route as possible before going underground.
2. Haulage equipment that requires the least amount of personnel to operate and maintain is always preferable to more labor intensive equipment.
3. The following list of haulage equipment is in order of its ability to minimize accidents (top to bottom).

- Pipeline
- Conveyor
- Hoist
- Truck/LHD/FEL
- Rail

4. Transportation routes that are less traveled are more desirable than the more traveled routes.

- a. The same holds for the size of the haulage drift; a larger, less congested drift is more desirable than more cramped quarters.

The above suggestions hold true for slurry transport as well as for other forms of transport, but slurry transport is sufficiently popular to warrant the following suggestions on its design and operation.

1. When laying out a pipeline route, the engineer should not only evaluate the consequences of a spill in the immediate location but also the consequences if the spill were to flow any great distance.

2. Minimize pipeline vibration by isolating the pumps with flexible pipe spools.
3. If possible, pipelines should be designed to withstand the expected pressures and abrasive wear in the pipeline for the life of the operation.
4. To minimize wear, the pipeline should be designed to operate at the minimum transport velocity.
5. In addition, wear can be handled better if long radius elbows and long wear pipe spools are placed in the appropriate locations.
6. During slurry operation, care should be taken to minimize the potential of a water hammer.
7. Pipe should be rotated regularly for even wear.
8. The slurry line should be protected from abuse by other equipment.
9. To minimize the consequences of a spill, the pipeline should be inspected frequently and leaks repaired.

4. Minimizing Hazards in the Stowing Area

There are two types of hazards encountered in the stowing area while actively backfilling. One type is hazards which are a result of adverse conditions and generally are hard to control and still perform the backfilling. These include roof falls, fall of material through the lining, congestion, and pillar punching. Therefore, to minimize the risk, the stowing method, mining method, and stowing location should be chosen which exhibits a low accident potential or utilizes fewest personnel. Another hazard type is hazards which result from incorrect operation of equipment or misapplication of a piece of equipment or technique. These include dust generation with pneumatic stowing, dust or gas explosions with pneumatic stowing, and filter requirements for drainage facilities. In these cases, modification of the technique or equipment can produce desirable effects.

The greatest risk to personnel is at the working face. Therefore, backfilling methods which operate adjacent to an active face are always more risky than backfilling in a remote mined out section of the mine.

a. Stowing at the Working Face

If backfilling does take place adjacent to an active face, the risk is minimized if the equipment and stowing technique are chosen which minimize the number of man-hours involved.

When backfilling adjacent to an active face, the best way to minimize the risk is through the choice of the mining method and backfilling method. While some of the risks seem to be related more to the mining methods, others seem to be related more to the backfilling method. Table 20 shows those hazards that are related more to the mining method and Table 21 shows those hazards which are related to the stowing method.

TABLE 20. - Risks Involved With Stowing Adjacent to the Active Face Which Are Affected by Choice of Mining Method

<u>Risk</u>	<u>Longwall with Filling</u>	<u>Shortwall with Filling</u>
Roof Falls	Greater	Less
Congestion	Greater	Less
Total Accidents	Greater	Less

TABLE 21. - Risks Involved With Stowing Adjacent to the Active Face Which Are Affected by Choice of Stowing Method

<u>Risk</u>	<u>Pneumatic Stowing</u>	<u>Hydraulic Stowing</u>
Dust Generation	Greater	Less
Dust Explosion	Greater	Less
Fall of Material Through Lining	Greater	Less

Table 20 indicates that longwall mining is much more dangerous than shortwall mining, a fact which is backed up with accident statistics.

Table 21 at first glance indicates that hydraulic stowing is safer than pneumatic stowing but this can be misleading. Accident frequencies for pneumatic stowing are roughly the same as for hydraulic stowing in longwall mining. This is partially due to the ability to control the dust related hazards of pneumatic stowing.

Factors that can control the problems caused by dust are outlined below.

1). Dust Generation from Pneumatic Stowing

Dust concentration regulations in underground coal mines are based on the percent of quartz in the respirable dust. Thus, it is necessary to determine the quartz content of the waste to be stowed.

The dust concentration in the underground workings is based on waste properties, stower operation, and dust ventilation measures.

The waste properties which will minimize dust generation problems are as follows.

1. Amount of Fines - It may be necessary to screen fines out of the wastes to meet dust regulations. However, there is no suggested maximum concentration of fines for a pneumatically stowed waste.
2. Moisture Content of Waste - The amount of dusting can be minimized by stowing wastes with moisture content ranges from 6% to 9%. Towards the high end, the fines get sticky requiring the pneumatic stower to operate at a higher transport velocity.

The operation of the pneumatic stower has significant impact on the dust generated. The following are suggested operational factors to minimize dusting.

1. Operate the stower at minimum transport velocity while observing the minimum velocity for good pack formation and pneumatic transport of the waste material. The following is a list of those factors that should be controlled so that low transport velocities can be achieved.
 - a. Stickiness of waste
 - b. Excessive top size of waste
 - c. Long or complex stowing pipe
 - d. Long throwing distances
 - e. Excess wear in the system
 - f. Feed rate should be very constant
2. The stower should be adjusted regularly to minimize clearances thus limiting leakage at the stower.

3. The use of a deflector shoe should be discouraged.

The following ventilation measures should be employed to control the dust that is dispersed because of pneumatic stowing.

1. A dust collection duct should be placed at the exhaust port of the stower.
2. When stowing in a dead heading, a dust collection duct should be placed adjacent to the stower discharge and should exhaust 50% more air than is being introduced into the heading from the pneumatic stower.
3. When stowing near an active face, dust should be prevented from spreading into the main ventilation system by placing a tight lining between the stowing region and the ventilation stream. In this manner, stowing is similar to stowing in a dead heading, with the same ducting and requirements for exhaust ventilation at a rate that is 50% greater than the stowing air flowrate. If possible, it is best to stow against the direction of ventilation.

2). Dust Explosions From Pneumatic Stowing

There are instances where requirements for respirable dust are met but pneumatic stowing of coal wastes can still produce an explosive dust suspension. Therefore, it is necessary to evaluate the potential of a waste producing an explosive suspension. If it does, then it must be modified so that such an explosive suspension no longer exists.

For an explosive suspension to exist, the dust that would enter an explosive reaction (-20 mesh) must qualify as combustible and be at the required concentration or greater. Generally, a dust is not considered combustible if:

1. Volatile Ratio ($\frac{\text{volatiles}}{\text{volatile \& Fixed Carbon}}$) is less than 0.12.
2. Incombustible content is greater than 70%. However, if the volatile ratio was greater than 0.40, the incombustible content would have to be greater than 85%. A preparation plant fine waste which is classified as a combustible dust cannot be explosive if the dust concentration is less than 0.19 oz/ft³.

If an explosive dust potential exists, it can be reduced by a number of methods as listed below.

1. Increase the incombustible content.
2. Screen the minus 200 mesh material from the waste.
3. Maintain dust levels below 0.19 oz/ft³.
4. Increase the moisture content of the waste.

It is always a good practice to ground the stower and duct work well to prevent friction induced static electricity.

b. Stowing in Remote Areas of the Mine

Stowing in remote areas of an active mine or in an abandoned mine is safer than stowing at the active face. However, there are hazards to contend with when stowing in these regions.

1). Roof Falls

Roof falls are much less prevalent in areas away from the active face. However, the older the workings, the more remedial roof control work that must be employed. In addition, workers should not be allowed to enter old workings which have not had roof conditions checked and supported.

2). Quick Flows During Hydraulic Stowing

Quick surges of saturated fill material during hydraulic stowing have been known to cause damage. It has been shown that such potentials can be reduced by periodically interrupting stowing for clarification and draining of the fill, and by moving the discharge point periodically to minimize the height of piles at the discharge.

3). Pillar Punching

Some mines have roof or floor strata that lose their bearing capacity when wetted. Therefore, hydraulic stowing should not be employed if such conditions exist in the mine.

5. Minimizing Risks Associated With the Waste

Certain fill properties can create a hazardous condition in the mine. The following is a summary of how to control the hazardous conditions.

a. Excessive Oxidation

There are four aspects to minimizing oxidation reactions:

1. Analyzing a fill's potential for oxidation.
2. Design of the backfilling scheme.
3. Operational preventative techniques.
4. Operational control techniques.

The following subsections will detail these aspects.

1.) Fill's Heating Potential

As a form of insurance, a backfilling operator should know the material that he is placing underground and its potential for oxidation. This knowledge of the material's properties can not only guide an operator in choosing an adequate material for filling purposes, if there is a choice of materials, but it can warn the operator if special attention must be given to a fill material. However, as mentioned in the index of combustibility section, there is no widely accepted criteria for evaluating a fill's potential for oxidation. We have also shown that there is a wide variety of factors that control oxidation that have nothing to do with the fill chemical or physical properties. Consequently, most oxidation potential evaluation must be comparative in nature.

In the oxidation sections we talked about those factors that can influence the oxidation rate and which characteristics promote or retard oxidation. Table 22 summarizes some of these physical characteristics.

If a proposed fill material exhibits many properties which promote oxidation, it is considered riskier than a fill which does not.

2.) Design Criteria of the Backfilling Scheme

The design of any mining system must not only produce an efficient operation but should anticipate and compensate for potential hazards. Backfilling as a mining activity is complicated and sizeable enough to impact other mining activities. Therefore, it is best coordinated with other mining systems by designing the mine plan with backfilling in mind. Design criteria to minimize oxidation problems fall into two categories: location and configuration of filled areas and design of operational factors.

TABLE 22. - Fill Characteristics Which Affect Oxidation

<u>Characteristic</u>	<u>Retards Oxidation</u>	<u>Promotes Oxidation</u>
Particle Size Distribution	Coarse, well graded few fines	Many fines, poorly graded
Permeability	Impervious (compacted)	Pervious
Porosity	Low	High
Moisture Content	<2% or >8% by weight	2%-8% by weight
Degree of Weathering	Weathered, however, must investigate whole pile	Fresh waste
Carbon Content	High rank coal waste, low carbon content	Low rank coal waste, high carbon content
Sulphide Minerals	<3% sulphides by wt., single sulphide mineral	>3% sulphides by wt., combination of sulphide minerals, pyrhotite present
Gangue Minerals	pH > 7, pH <<7, minerals exhibiting endothermic heating (dolomite)	ph < 7
Other Combustible Material		Timber

a.) Location and Configuration. - It is estimated that 25% of the material from an underground coal mine can be waste. This means that if you were to place all the wastes back in the mine, you would only fill a quarter of the mine.

Where this waste is placed is dependent upon the purpose for the backfilling. If the fill material is placed underground for purposes of structural support, the location of placement is dictated to the operator. If on the other hand, fill is placed underground for reasons of disposal, there is a fair amount of latitude in the choice of the placement location. In this case, locations can be evaluated on a number of factors, including the potential for oxidation. Oxidation produces heat and gases. The hotter and more polluted ventilation air is, the more ventilation that is required to meet standards. Proximity to the portal or ventilation inlet is desirable for enhancing ventilation effectiveness and minimizing its requirements for filled areas. This reduces the amount of change to the ventilation air before it reaches the filled area. The greater the distance that ventilation air must travel, the more heat that is added to the air from adiabatic compression, men, machinery, oxidation, air friction, and the surrounding rock. This reduces the air's cooling capacity. Some of these sources also reduce the oxygen content of the air and add poisonous and explosive gases to the ventilation air. These factors become doubly important if fill temperatures should start to increase, requiring increased ventilation through the filled areas.

Fill locations within the mine can also be dependent upon roof competence. The potential for excessive oxidation and the ventilation required to control this problem is greatly reduced if the roof strata subsides onto the fill and compacts it. Areas in the mine which are more prone to roof subsidence could be considered likely choices for backfilling. However, Kegel (33) indicated that weak roof which quickly fails makes it nearly impossible to fill the room before caving takes place in a longwall operation. Consequently, careful planning must be employed if such a backfilling location is chosen.

Backfilling has been more popular in dipping deposits than in horizontal deposits. Dipping beds are easier to fill because the solids will flow greater distances and the room can be filled to the roof. This reduces the potential for oxidation by producing better compaction and reducing permeability. Also, there is a reduction in the ventilation required for cooling and gas dilution. The ventilation design is simplified and the potential for dangerous gas accumulation is reduced. Enzian (17), reporting on the backfilling practices in the anthracite mines of Pennsylvania, stated that

hydraulic filling was used in beds from horizontal to greater than 25° dip. Even though ventilation to control heat and dissipate gases was easier and more effective for dipping beds, he did not suggest that horizontal rooms should not be filled.

The size and shape of a filled area may be dictated by the mining method, as with a longwall operation, or may be variable as with a room and pillar method. Since longwall methods induce caving upon the fill, the panels can be quite large without fear of heating in inaccessible areas of the fill. According to Enzian (17), when backfilling in room and pillar operations, the size and shape of the filled area in the mines varied depending upon the operator's choice. Filled areas varied from individual rooms to whole panels. The expected oxidation potential for a proposed room and pillar filling area can dictate the size and shape of the area filled if they are not to be sealed. When the oxidation potential is low, the area filled can be large without fear of oxidation problems within inaccessible areas of the fill. The ventilation then required for cooling and gas dissipation is considerably less. When the oxidation potential is high, the area filled should be small or long and narrow so that ventilation can adequately cool and dissipate gases. The expected oxidation potential for a proposed filling area is based upon the oxidation potential of the fill, dip of the seam, and whether the roof subsides onto the fill. Table 23 indicates these factors with respect to the oxidation potential of the filled area. Enzian (17), reporting on backfilling in the anthracite mines of Pennsylvania, suggested that backfilling could be employed advisedly even though there were cases where a high oxidation potential existed.

TABLE 23. - Factors Affecting Filled Area Oxidation Potential for Ventilated Room and Pillar Stopes

Fill Area Oxidation Potential	Low.....Med.....High
Bed Dip	>25° ...>10°.....Horizontal
Oxidation Potential of fill	Inert.....Low.....High
Roof Stability Suggested	Failure.....Intact
Size of Filled Area	Small or Long and Narrow.....Large

b.) Design of Operation Factors. - It is often the case that when a section of the mine is finished, it is sealed. This is after all active mining and backfilling activities are finished in the section. Therefore, design measures to control oxidation of fill materials should be able to contend with ventilated and sealed fill areas. Ventilation air for oxidation control should be cool, dry, and good quality, and there should be adequate capacity for both heat and gas dispersion.

There are a number of options available when designing ventilation systems for controlling oxidation in filled areas. Depending upon the mine design, some may be more economical than others, but the following suggestions are listed in probable order of choice.

1. Design the ventilation circuit for the filled slope to be as short as possible. This also means that ventilation of filled stopes is a once through flow pattern which goes directly to return airways and not for any other ventilation purposes.

2. If possible, the mine airways should be designed for large volume circulation of unconditioned air. This will allow for excess cooling capacity if the fill temperature rises. Such preparation of airways may include large cross-sectional areas and smoothing of walls.

3. In cases where the fill material has a high potential for oxidation, careful consideration must be given to how much ventilation air is routed to the fill area and how it is directed through the area. This is especially true when an air space is left above the fill and the area filled is large. Ventilation across the top of the fill will be necessary, not only for gas dispersion but for cooling. Methods for deflecting ventilation across the top of the fill may be necessary in this case.

4. Ventilation intakes to filled areas should be designed so that air quality is maintained. The best way, as previously mentioned, is to design short intakes. This minimizes the amount of contaminants added, temperature increases from mining activities, and reduction of the oxygen content of the air before it reaches the filled stopes. In addition, intakes should be designed so that they stay dry. Situations which will cause fluctuations in ventilation air humidity should be avoided. This means limiting those activities that would add water to the airways and providing drainage in the airways if ground water inflows are substantial.

5. If the previously mentioned modifications are inadequate or too expensive, the conditioning or pumping of air on a sectional basis within the mine may be necessary. If the volume of ventilation air available to filled stopes is insufficient, auxiliary fans with ducting may be necessary to meet ventilation requirements. If the ventilation air is already quite warm and the main purpose for the ventilation in filled stopes is for cooling, then section or stope cooling with refrigeration units may be necessary. The degree of cooling and the location of cooling units will be based upon the number of stopes that must be cooled and the degree of oxidation heating involved. It should be mentioned that evaporation conceivably could induce oxidative heating by bringing moisture content into optimum range for oxidation.

Sealing is the permanent solution to oxidation problems but cannot be implemented until all activities in the section are finished, provided the area is not deemed a sealing problem. The air in sealed workings becomes devoid of oxygen in short order, stopping oxidation reactions and heat generation. However, sealing is only effective when the seals are tight. Failure of seals can result from roof falls, blasting concussion, incorrect construction, pressure on the backside, abuse, or leakage through the roof or floor strata. Consequently, design of a sealing bulkhead for a backfilled area is just as sensitive as design of a seal for workings that are not filled. As with the design of any area to be sealed, the geologic strata must be investigated to guarantee that oxygen does not get into sealed workings along geologic anomalies from ventilated drifts or the surface.

While it is expected that an oxidation problem will not develop, the occurrence of such a problem must be planned for. Thus, excess ventilation capacity should be designed for filled areas while they remain open. In addition, it might be wise to specify portable chemical or water cars or waterlines to ventilated fill areas as a necessary precaution for fire. These devices should of course meet MSHA standards and there should be facilities for adding chemicals to the water supply. Alkali additives may prove effective for these measures.

3.) Operational Preventative Techniques

Preventative measures to curb oxidation problems include housekeeping, maintaining dry airways, and monitoring oxidation rates. Such common practices as housekeeping in filled areas can make a large difference. Keeping combustible material such as wood, rags, or plastic out of the entries and the fill can reduce the potential for an oxidation problem. Keeping intake

and return airways dry can reduce the potential for condensation heating and increase the effects of evaporative cooling of the fill. This means that a certain amount of housekeeping to maintain dry airways may be necessary.

All the best laid plans can fail if standards are not maintained and design procedures are not followed. One of the most important safety measures with backfilling, after an adequate design, is to monitor backfilled regions while they are being ventilated so that cheap and safe control techniques can be applied to hot fills before more catastrophic events occur.

Monitoring the temperature of the fill has not proven to be a reliable form of monitoring for excessive oxidation because equipment requirements and maintenance can be high. In addition, temperature monitoring can miss a local hot spot in the fill and provides no information on gas generation from the fill.

The more popular techniques for monitoring for excessive oxidation have been visual inspection of filled areas and measurement of the carbon monoxide levels in the return airways from the filled areas. As previously discussed, carbon monoxide production is indicative of incomplete combustion. The MSHA threshold limit value for an 8 hour exposure to carbon monoxide is 50 ppm (55 mg/m³), but commonly associated factors such as condensation on coal surfaces and the rotten egg odor of H₂S gas can be noticed by personnel in the return airways when carbon monoxide has reached 25 ppm. The carbon monoxide levels normally occurring in the return airways of coal mines can vary considerably from mine to mine. For monitoring of carbon monoxide levels, increases in CO levels are more important than the naturally occurring level of CO.

The U.S. Bureau of Mines, reporting on underground coal mine fires found that, excluding other unspecified categories, 64% of the fires were detected by an individual patrolling the mine or investigating an unusual occurrence such as equipment failure or smoke. This emphasizes the need for visual inspections as a preventative measure in detecting oxidation problems in fill material. Visual inspections can be quite simple. In most cases, excess heat generation is quickly noticed by personnel and low levels of oxygen as indicated by a hand held device will warn of oxidation problems.

4.) Operational Control Techniques

Control techniques are used once a problem has already developed. Considering that excessive oxidation is a gradually worsening condition, the control measures can vary in size and technique. Consequently, the extent of the problem must be known before appropriate measures can be taken.

The oxidation problem can be broadly grouped into three categories: heating of fills, excessive gas generation, and fire. Table 24 shows those control techniques which can be used for each category in order of desirability.

TABLE 24. - Control Measures Based on Oxidation Problems

<u>Heating of Fills</u>	<u>Gas Generation</u>	<u>Fire</u>
High Ventilation Rates	Water, Chemical Sprays	Sealing
Water, Chemical Sprays	High Ventilation Rates	Flooding
	Sealing	Water, Chemical Sprays
	Other (Foam, Rock Dust)	Other (Foam, Rock Dust)

The following discussion analyzes the control techniques for each problem and their application.

a.) Heating of Fills. - The increase of temperatures above what is considered acceptable can require the application of preliminary oxidation control measures. The most effective measure is to increase ventilation or to cool the ventilation air. This is why design of filled areas should include excess capacity in the ventilation circuit.

The application of chemical or water sprays is not as appropriate for a number of reasons. It is difficult to apply chemical or water sprays to the whole fill area, application of too little water can accelerate oxidation rates, it is more expensive, and in the early stages of oxidation it tends to be overkill. If it is felt that extra ventilation cannot control the problem, then the application of chemical or water sprays becomes appropriate. However, it would be better to apply the sprays in large doses than to apply a light continuous spray.

b.) Gas Production. - When oxidation heating is more than minor, fill temperatures become uncomfortably hot and excessive quantities of hazardous gases are generated. This condition should create a considerable amount of concern and usually will require more than one control technique to be employed. The most effective measure at this stage is the application of water and chemical sprays. Although spray application of water is commonly used in controlling rapid oxidation of sulphides in underground mines, its effectiveness is considered relatively small and short lived. Its best advantage is a quick reduction of fill temperatures when they are out of hand, especially local hot spots. Water application is only considered effective in the long term when applied in flooding proportions. Application of water is much more effective as a coolant when chemical combustion inhibitors are added to the water.

High ventilation rates should be employed as a control measure when dealing with excess heating along with other control measures. While extra ventilation may be sufficient at lower oxidation rates, as the oxidation problem increases, ventilation's effectiveness is reduced. Even though large rates of gas generation require higher ventilation rates, the primary purpose for extra ventilation is for cooling. Consequently, refrigerating ventilation air can have a significant effect in this situation.

Other techniques to control gas generation such as rock dusting and foam can be used, but their effectiveness against high oxidation rates is doubtful.

Sealing as a measure for controlling an oxidation problem is an extreme last ditch effort in preventing a mine fire. Since it is an extreme control measure which does not allow personnel to directly combat the problem, it is given a low priority as long as a fire has not broken out in the fill. Sealing techniques employed for controlling excessive oxidation would be no different than that used for sealing any mine fire.

c.) Fire. - A spontaneous combustion mine fire in filled areas is just as dangerous as any other fire. In fire conditions, combustion is usually starved for oxygen so that increasing ventilation would only fan the fire. At this point, the mine operator must decide whether direct fighting of the fire is more appropriate or sealing is more important. This discussion will be based on the extent of the fire. Small fires can be fought directly with chemicals, large doses of water spray, or inundation with slurried backfilling material. As mentioned, the effectiveness of foam or rock dusting in a fill fire is questionable because of limitations to getting the dust or foam to the burning front within the fill.

TABLE 25. Factors Affecting the Potential for and Extent of Failure of Inplace Fill

<u>Factors</u>	<u>Increased Failure Potential</u>	<u>Reduced Failure Potential</u>
Bulkhead Const.	Wood Construction	Masonry with steel beam const.
Drainage Facilities	No or inadequate facilities	Adequate facilities for expected lifetime of the mine
Dip of Room	Steep	Horizontal
Pore Water Pres.	High pore water pres.	Dry fill
Peak Friction Angle	Low peak friction angle	High peak friction angle
Composition of Fill	Uniform size distrib. soft, friable particles	Well graded size distrib. hard particles
Initial Void Ratio	High	Low
Initial Confining Stress	Low	High
Stowing Method	Mechanical	Pneumatic, hydraulic
Amount of Post-Filling Roof Subsidence Without Bulkhead Failure	None	Complete

Large fill fires must be dealt with through sealing or flooding. Sealing may be more desirable because of its ease of application and clean-up afterwards. Flooding on the other hand creates quite a mess and requires that the operator have the ability to flood the filled areas. Flooding does, however, quench a fire in very short order.

b. Potential for Failure of Inplace Fill

When backfilling is planned for an underground coal mining operation, it is advisable to investigate the potential for failure of the inplace fill. This investigation should include evaluating the potential for and the consequence of such an accident. If the consequences are considered more than minor, then a more thorough investigation of the potential for such an accident are warranted.

The evaluation of the potential for failure of a filled area should include evaluation of the factors that would induce failure and evaluation of the factors that would resist failure. Table 25 is a list of factors which affect the potential for and extent of inplace fill failure.

Since many of these factors can be modified, it might be stated that the backfilling conditions can be changed to reduce the risk of such a failure if necessary.

III. UNDERGROUND DISPOSAL OF METAL MINE AND MILL WASTES

The return of mine and mill wastes to the underground metal mine can offer economic, environmental, and safety advantages over surface disposal. Improved recovery rates, pollution control, and safer ground conditions are some of the more important advantages often realized with underground mine waste disposal.

This chapter deals with health and safety aspects of underground metal mine backfilling with tailings and development wastes. While classified mill tailings are the most common backfill material in metal mines, nonmetal mines which incorporate backfilling do so with alluvial sand and gravel, not waste from the mine. Underground nonmetal mines (not coal) do not ordinarily generate enough tailings or development waste to use as backfill material. For these reasons, nonmetal mines are not dealt with in this chapter.

Known and potential health and safety hazards, directly or indirectly associated with underground mine waste disposal in metal mines are evaluated. Known and potential positive health and safety effects of this activity are presented in a similar manner. This chapter also contains a case history of a backfilling accident and discussion of the role of management in controlling the hazards of underground mine waste disposal.

A. Current Backfilling in Metal Mines in the United States

Hydraulic backfilling is being practiced in numerous metal mines and is considered the most economic and effective support medium available in deep metal mines. According to the literature search and personal contacts made in this investigation, the pneumatic backfilling method is not being practiced nor is it being seriously considered for application in precious or base metal mines. For these reasons, pneumatic backfilling is not included in the discussion of metal mining.

The following is an overview of backfilling as it is being practiced in metal mines in the United States.

1. Purposes of Backfilling

The main reasons hydraulic backfilling is being done in metal mines are to provide ground support and a working platform. Many ore bodies could not be safely and economically

mined without the support attained with cut-and-fill mining methods. In overhand stoping operations, cemented backfill provides a hard, flat, safe working platform.

Backfill offers a number of other positive effects which can be very important in some cases. It can retard spontaneous oxidation and combustion of sulfides in wall rock and prevent timber fires where timbers are engulfed in sandfill. Underground tailings disposal can be an aid in pollution control and reduce reclamation problems associated with surface disposal. Backfilling mined-out stopes reduces ventilation requirements and so it can help maintain air quality.

The decision to use a cut-and-fill mining method is basically an economic one. In some cases it facilitates increased recovery rates and in other cases it is the only technique that can be used to extract ore because of sandfill's ability to support ground. It should be stressed, however, that all of the positive health and safety effects of underground mine waste disposal also have positive economic effects. Safety and health hazards can be costly to a mining operation in terms of production delay and loss of facilities and any degree of hazard abatement will have some positive economic effect. Reduction of fatalities and injuries is a major benefit to society in general and also an economic benefit to a mining operation.

2. Methods of Backfilling

The following is a brief discussion of how hydraulic backfilling is being applied in different metal mining situations in the United States.

a. Backfilling Active and Inactive Mines

The backfilling of inactive mines is usually accomplished by blind flushing through boreholes from the surface. This method is often used to fill inactive mines because they are often inaccessible or unsafe for personnel to enter for controlled filling. Where possible, controlled filling is used to backfill inactive mines because filling can be more complete and the completeness of filling can be verified by visual inspection. The effectiveness of backfilling inactive mines to minimize subsidence can be better evaluated with controlled filling because the completeness of filling can be verified. With blind filling, large gaps can remain in a filled area and if subsidence occurs it may not be known if it was due to such gaps or to compressibility or other inadequacies of the backfill.

Active mining operations which incorporate backfilling utilize controlled backfilling almost exclusively because complete, even filling is usually necessary for subsequent mining procedures. Also, the areas to be filled are often small and deep below the surface of the ground. Surface boreholes are not practical for delivering sandfill to small fill targets in deep mines.

b. Metal Mining Methods with Backfill

Hydraulic backfilling is an integral part of mining in cut-and-fill, undercut-and-fill, sublevel open stope and fill, post pillar and fill, and also sometimes with room and pillar mining methods in metal mines. The most common applications of filled stopes are in steeply dipping ore bodies with restrictive dimensions and weak walls where complete extraction or selective mining is desirable.

1.) Cut-and-Fill

Typical horizontal cut-and-fill stopes are overhand excavations in which ore is taken in horizontal slices. A cut of ore is mined first, then backfill is introduced to support the walls of the void. In addition, the backfill produces a flat, hard platform on which men and machinery can work with better safety.

Cut-and-Fill mining is applied to steeply dipping veins of strong ore with wall rock that will stand unsupported until the fill is in place. The method is flexible enough to permit use throughout highly irregular ore bodies. Ore pillars can be eliminated at times. Development is simple and conforms to that of most methods used in veins dipping between 50 and 90 degrees.

2.) Undercut-and-Fill

Undercut-and-fill mining simply is underhand mining used in conjunction with fill. After a slice of ore is taken, a timber and wire mesh floor is installed with a bulkhead at each open end. Then, waterborne cemented sandfill of a ratio of about 12 parts sand to 1 part cement is poured until it is about 3 feet thick. The rest of the stope is then filled with a mixture of about 25 parts sand to 1 part cement. After the water has drained and the cement is hardened, another slice of

ore is mined directly below. The timber and wire mesh floor, along with 3 feet of relatively strong concrete form a competent back while ore is mined below. Timbers are often installed immediately after blasting to provide temporary support. Permanent timber sets remain when the stope is backfilled.

3.) Sublevel Open Stope and Fill

There are several variations of this method. One involves ring blasting of several adjacent levels resulting in a large open stope which is subsequently backfilled. Another variation is called vertical crater retreat, in which blast holes are drilled downward to the draw point. Explosives are loaded from above and ore is drawn from below, eliminating the need for personnel to enter the stope. This also results in a large open stope which is subsequently backfilled. Mining and backfilling is not done in consecutive slices as with cut-and-fill and undercut-and-fill methods. This is a large-production overhand open stoping method that normally is confined to fairly regular ore bodies where both the ore and the country rock require little support during mining activities.

4.) Post Pillar and Fill

This is a variation of overhand cut-and-fill used for inclined ore bodies. Rib pillars and square post pillars are left in the ore. After each horizontal pass of mining, the stope is filled nearly to the top with cemented sandfill to support the walls, pillars and posts and to provide a working platform. Thus, tall pillars are only exposed over a short vertical distance at any time, improving their bearing capacity considerably. Mechanization with rubber-tired vehicles is preferred with this method. High recovery rates are made possible by backfilling because pillar sizes can be minimized with sandfill providing lateral support.

5.) Room and Pillar

Hydraulic backfilling has been used in room and pillar metal mining to improve rock stability. In one such case the uncemented sandfill became competent enough to stand unsupported when a drift was driven through it. Room and pillar mining can be used for tabular, near-horizontal metal ore bodies. Very few metal ore bodies are suitable for room and pillar mining.

6.) Comments

Filled stope methods are the most useful with respect to control of rock movement and to complete mining of steep ore bodies having a broad range of thickness and regularity. Various overhand cut-and-fill methods are low-cost high-tonnage methods because of recent trends in consolidated fill and mechanized mining. In overhand methods, the top few feet of tailings sandfill are poured with enough portland cement to form a hard mucking floor. Ore is blasted down onto the concrete floor and rubber-tired mucking machines remove the loose ore quickly with minimal dilution. The concrete floor eliminates the need for plywood or metal covers which are more labor-intensive, more hazardous alternatives for providing working floors and limiting ore dilution.

c. Hydraulic Backfilling Equipment

In metal mines with underground tailings disposal, tailings are hydraulically transported from the concentrator mill to the mined-out stope or to sand storage tanks either above ground or in the mine. In the sand plant at the mill, the tailings are almost always classified by means of a cyclone separator. A fraction of the slimes is diverted to surface disposal ponds and the remaining classified tailings are pumped to the stope or to the storage tanks.

Various pumps are utilized at the sand plant, for example, an impeller pump to feed the cyclone, another impeller pump to transport slimes to the disposal pond, and a piston pump to transport classified tailings to storage tanks. Electric motors are used for power. From the storage tanks, sometimes called silos, the slurry is usually motivated by gravity down to the mined-out stopes. Pumps are rarely necessary underground because of the considerable amount of vertical drop to the stopes in most metal mines.

Storage tanks assure a ready supply of classified sandfill when it is not available from the sand plant. Storage tanks are either the wet or dry type. Wet storage tanks have mechanical agitators which keep the sandfill in slurry form until it is piped to the empty stope. These agitators are usually powered by electric motors. Dry storage tanks hold the sandfill and allow the water to drain out. They can store more sandfill per unit volume than wet tanks, and they do not require as much mechanical maintenance or electric power as the wet tanks. Water jets at the bottom of dry tanks reslurry the sandfill when it is piped to the stope.

When cement is used it is usually stored above ground in a silo and fed by auger or conveyor into a tank where it is mixed with water. This cement slurry is piped into the sand slurry pipeline and the two slurries mix on the way to the stope. The rate at which cement is added to the sand slurry is carefully controlled to ensure a homogenous mixture of the desired proportions after emplacement.

Slurry pipe is usually steel, and PVC pipe is often used near the discharge end for ease of movement for subsequent pours of sandfill. Rubber-lined steel pipe is often used for long wear in vertical sections. Inclined or horizontal sections are sometimes rotated about a third of a turn for even wear because sand slurry friction is greatest at the bottom side of the pipe.

3. Types of Fill Material

Classified mill tailings are the most commonly used material for hydraulic backfilling in metal mines in the United States. Most metal mining and processing operations produce large quantities of tailings which can provide a ready supply of backfill material when various cut-and-fill mining methods are employed. These tailings tend to have a large fraction of slime-sized material (minus 200 mesh). Most of this fine material is usually taken out of the tailings with a cyclone separator and deposited in settling ponds. The rest of the tailings (classified tailings) are more suitable for use as hydraulic backfill because larger particle sizes promote greater permeability and shorter drainage time. Short drainage times are considered necessary to fit in with rapid production mining techniques.

Another advantage of classified tailings is that the particle size distribution is more nearly well-graded and therefore tends to achieve greater density and support performance.

Aside from particle size distribution, the most important characteristic of tailings sandfill is the amount of sulfide minerals they contain, especially iron sulfides such as pyrrhotite and pyrite which have significant potential for spontaneous oxidation and combustion. These minerals are present in many precious and base metal deposits. This is probably not an important consideration when cement is added to the fill because cement limits permeability and oxygen contact with sulfides after hardening.

Mine development waste is often dumped in mined-out stopes and it is important to remember that its support capability is very poor unless hydraulic sandfill is poured over it to fill the gaps between the large fragments.

B. Health and Safety Hazards of Underground Disposal of Mine and Mill Wastes in Metal Mines

Backfilling activities can introduce a number of hazards to a metal mining operation. Known and potential hazards are evaluated in this chapter. Anticipation of these hazards before they manifest themselves should facilitate the reduction of their incidence and severity.

1. Waste Transportation Hazards

The main concerns during the hydraulic transportation of sandfill are spillage of the sandfill and water and the direct hazards and indirect complications resulting from the failure of retaining structures. Other hazards during filling include ground and surface water pollution from backfill and the operation of equipment needed for the backfilling procedure.

a. Spillage From Pipes and Bulkheads

The most important hazard related to hydraulic transportation of backfill is spillage of water and sandfill due to broken pipes or gaps in bulkheads or other retaining structures. The smaller spills are generally regarded as a nuisance and the cleanup is accepted as a minor part of the cost of mining. Large spills, on the other hand, can present serious safety hazards and interrupt production by blocking haulage or service levels and burying equipment. Very large spills might trap miners, but spills of that size are rare.

Small spills usually result from pipeline leaks or leakage through fill and deteriorated burlap between bulkhead timbers. Bulkhead leaks tend to carry slimes and these can contribute significantly to slip and fall accidents. Drainage filters and plastic burlap virtually eliminate leakage of solids through bulkheads because filters prevent fines migration and plastic burlap will not rot.

Pipeline leaks are usually the result of abuse from equipment bumping into them, or internal wear caused by the friction of the slurry. In most hydraulic sandfill operations, system

controls are located at both the mill and at the sand storage tank control station. Startup and shutdown are controlled at either place at the request of the sandman in the stope. Phone communication between the stope, control station and concentrator plant should be kept open at all times so that the system can be shut down immediately when leaks or spills are noticed. Large spills from pipeline leaks can only happen if they go unnoticed for long periods of time. Pipe wear leaks should be minimized by rotating horizontal and inclined pipes for even wear. If possible, pipelines should be located so that they are less likely to be struck by mobile equipment, both under and above ground.

b. Water Pollution From Mill Tailings

Hydraulic backfilling with metal mine tailings may introduce chemical reagents from the mill process into groundwater and these chemicals may also eventually migrate into surface water. However, most of the water decanted from hydraulically emplaced backfill is usually pumped back to the surface along with groundwater that drains into the mine. When water is then discharged at the surface, chemical contaminants from the mill tailings may create a more difficult water treatment problem.

At a metal mine in Colorado, a small amount of cyanide left in the mill tailings forms a copper-cyanide complex in decant water. In order to meet surface discharge contaminant limitations, changes had to be made in the water treatment process to reduce the total copper in the discharged water(61).

Another way in which underground mine waste disposal can potentially contribute to water pollution is through the oxidation of sulfide minerals in the fill. In most cases, backfilling reduces the amount of sulfide oxidation, both in the fill and wall rock by restricting air circulation and helping to raise water levels. However, if water levels fluctuate and air circulation is allowed, oxidation of sulfides in backfill may occur and contribute to metal and sulfate pollution and acid mine drainage. This possibility is considered to be remote because of the reasons mentioned above. It should also be noted that surface tailings dumps containing metallic sulfides are prone to oxidation because they are exposed to air and rain. Therefore, poorly managed surface disposal has a greater potential to produce metal and sulfate pollution and acid conditions.

c. Drilling Operations

Boreholes are sometimes used to deliver sandfill to underground mine voids. This method is usually used when backfilling abandoned mines which are unsafe for personnel to enter. It is rarely used for backfilling active mines because slurry pipelines, an alternative to the use of boreholes, can be placed in existing shafts and passageways. Borehole delivery does not offer the flexibility and accessibility necessary for level and complete filling of small fill targets in deep mines.

Health and safety hazards of drilling operations are basically no different when performed for backfilling than for any other purpose. Drilling into mine voids does not increase these hazards except for an extremely remote chance of catastrophic mine subsidence. Drilling accidents are rarely fatal, but the risk of injury is always present during drilling operations.

d. Operation of Stowing Equipment

Equipment used in hydraulic backfilling can include water tanks, sand storage tanks (some with mechanical agitators), centrifugal or piston pressure slurry pumps with motors and controls, mechanical cement feeders, and possibly a fresh water pump. The hazards associated with this array of equipment include structural problems, mechanical hazards, and electrical hazards. Water and sand storage tanks might become unstable, mechanical agitators and feeders might cause injuries and electric motors may have electrical hazards.

The best way to control these hazards is through safe design of equipment and facilities. In some mines, sand storage tanks are built below ground in a convenient part of the mine, easing congestion at the surface while providing a stable, efficient way to store sandfill for use in the mine. Pumps can be designed to shut down automatically in case of an overload to prevent equipment damage. Mechanical hazards can be reduced with an efficient, uncrowded layout of equipment with the proper guards and warning signs. Electrical equipment must meet safety regulations and receive regular inspections.

When development workings are driven outside of the orebody, often the waste rock from these workings is dumped in mined-out areas of the mine with the same mechanical haulage equipment used to haul ore. It is important that the same safe procedures and degree of control used in the removal of ore are

also used when moving development waste. In addition, operators must watch for hazards which are likely to be found along seldom-traveled waste haulage routes.

2. Hazards in the Disposal Area

The largest number of important hydraulic backfilling hazards occur in the disposal area during preparation of the disposal site and the actual backfilling operation. The following is a discussion of hazards in the disposal area that occur during hydraulic deposition and draining.

a. Unstable Rock and Fill

Some hazards are intrinsic to underground mining, and one of these is the possibility of injury or death caused by unstable rock. This risk is incurred by anyone who visits or works in underground metal mines, including sandfill crews. A major purpose of backfilling is to improve the stability of mine workings, but it is very important to recognize the limits of sandfill as a support medium. The degree of support available from backfill is debatable, but it is regarded as a substantial improvement in ground control over the traditional square-set and waste-rock filling methods (41).

With increasing mining depth, ground conditions worsen and there is a growing need for sandfill of sufficient strength to minimize vein-wall closure, rock stress concentration upon vein pillars and rock burst events. Because of the difficulties involved in placing sandfill at maximum relative density, truly adequate sandfill support may never be achieved for deep mines with heavy ground conditions. Laboratory and field investigations have shown that modification of sandfill with vibratory compaction, cement and/or other additives can improve sandfill properties and reduce vein-wall closure and rock and pillar stresses. However, sandfill is typically placed at approximately 50 percent relative density, and at this density it cannot adequately support vein-walls in deep metal mines at depths exceeding 2,000 to 3,000 feet.

Although hydraulic backfill is usually the best means of stope wall support, fill material with inadequate compressive strength may permit yielding of the walls and lead to poor wall conditions or even rock bursts (56). Sometimes the strength of cemented sandfill is disappointingly low. Cemented fill strength can be adversely affected by the large amount of

excess water that is needed to place the fill, and the relatively uniform size of the material that is used as backfill material (52). Other materials that may weaken the cement are opaline, chalcedony, dacites, andesites and alkali and sulfate salts. Some of the worst chemical effects on concrete are from ammonium and aluminum sulfate, ammonium nitrate, hydrochloric, sulfuric and sulfurous acids, and the various chloride salts (not including halite). Cement mixing time in the slurry should be at least two minutes, but no more than six hours to avoid adverse effects on strength (12).

Quality control of both the composition and placement of sandfill is of greatest importance when maximum support strength is needed to maintain safe working conditions in an underground mine. The limits of the support capabilities of the sandfill as actually placed must be measured and compared to the support requirements in order to avoid dangerous rock-bursts and falls of ground. In some cases, rock stresses may be too great for any economic backfilling method to handle, and valuable ore may have to be left in place because of safety considerations.

In undercut-and-fill, the working stope is beneath the backfilled area and failure of the sandfill and supporting timber structure can have catastrophic consequences for miners and the mining operation (see Case Study - Fall of Fill, chapter III B. 6.). In other types of cut-and-fill operations, bulkhead failure can allow unconsolidated sandfill to flow down raises and into manways and haulageways, possibly trapping miners and/or delaying production.

In mining operations where ore pillars adjacent to back-filled stopes are mined, the fill must be able to stand in a vertical wall as the pillar is blasted. In 1973, an attempt to expose a vertical face of cemented backfill at the New Broken Hill Consolidated mine in Australia resulted in massive failure of the sandfill and dilution of the ore (4). The intention was to mine an ore pillar and expose an area of cemented backfill 57 meters wide and 48 meters high which was directly behind the pillar. Cement consumption records indicated that narrow bands of fill with low cement content were present and may have allowed the failure to occur. Quality control of cement addition and backfill placement was cited as critically important criteria for future attempts at pillar extraction.

b. Spillage From Pipes and Bulkheads

In the disposal area, spills from broken sandlines can have especially disruptive effects because they can block personnel and/or equipment from moving between the stope and

passageways. The remote chance of drowning also exists if miners are trapped and the slurry is not shut down promptly. These spills require cleanup work which can disrupt the mining schedule and can cause deviation from planned, safe procedures. According to experienced backfillers, spills of critical proportion are quite likely to occur, and related disruptions can be more dangerous than the spill itself.

Bulkhead drains and leaks in bulkheads can deposit fines from the backfill in drainage ditches and drifts requiring cleanup work and more underground man-hours caused by the backfilling operation. All man-hours spent underground carry risks that are inherent in underground mining, including hours spent by cleanup crews.

c. Toxic or Reactive Compounds

Underground backfilling operations may introduce a number of materials to the mine environment that are potentially harmful to miners. These compounds include portland cement, added to improve the support capability of the sandfill, and chemicals in the mill tailings used as sandfill that remain from the milling process. In some mines, chemical additives (flocculants) are used in the slurry to speed the settling of fine particles after placement, but in most cases these are not considered to be hazardous to miners, nor are they thought to be sources of water pollution.

1.) Cement

Skin diseases caused by contact between cement and skin are widely reported in the literature and have been said to account for about 25% or more of all the occupational skin diseases. These are more frequent among cement users than cement manufacturers. Cement burns are the most common backfilling accidents in metal mines found in MSHA accident reports.

Cement is composed of lime, aluminum, silica, and iron oxide with small amounts of magnesia, sodium, potassium, chromium and sulfur in combined form. The alkalinity of the cement presents a dermatitis hazard, and a cement eczema has been reported that is thought to be due to the hexavalent chromium in the finished product (11). Raw materials for cement do not usually contain chromium, but possible sources are volcanic rock, refractory lining of the kiln, steel balls in grinding mills and different tools used for crushing and grinding raw materials and clinker.

The effects on human skin include periungal erosions, inclusions in the skin, diffuse eczematous lesions and cutaneous infections (furuncles, abscesses, and panaritiums).

Cement has been described as a moderate irritant and an allergen. The allergic reaction is caused by chromium salts entering the dermal papillae and combining with proteins to produce a sensitization of an allergic nature. It has been stated that sensitization to chromium may be the leading cause of nickel and cobalt sensitivity and that the high alkalinity of cement is an important factor in cement dermatoses (31).

Skin burns from contact with alkaline cement water can be serious enough to require hospitalization. At one mine where cemented sandfill is used, waders have been acquired to stem this problem, and all sandfillers are required to use a recognized protective cream if contact with cement water is anticipated.

2.) Mill Chemicals

Milling processes for metallic mineral ores involve the use of chemicals that could cause problems for sandfillers and other underground miners. If pyrite is present in the tailings, sulfuric acid might be formed in enough quantity to be a hazard to miners through direct contact, or by degrading burlap and timber in bulkheads, causing spillage of sandfill. Acids used in milling processes may be left in tailings used as sandfill, but acids are quite easily neutralized with alkali materials such as lime.

The main substance of concern here is cyanide used in a gold leaching process. In South African gold mines where tailings are utilized as sandfill, tailings are taken directly from cyanide vats into the mine in order to minimize rehandling costs. If the tailings were first stored in piles on the surface, the cyanide salts would be made harmless by exposure to weather. In order to safely use tailings directly from the cyanide vats, an oxidizing treatment is used to destroy cyanide salts. Potassium permanganate and bleaching powder are commonly used, the amount depending on the strength of the last cyanide solution used, and on the moisture content of the sand from the vats (47).

d. Construction Injuries

The use of hydraulic backfill requires the construction of bulkheads and other retaining structures which may be rather labor-intensive. Injuries from handling construction materials and the use of hand tools are to be anticipated for such activities. Injuries such as cuts, bruises, and sprains can be anticipated. Construction of the sandfill system itself involves a similar risk of injuries when setting up pumps, motors, and storage tanks and fitting pipes.

Well-maintained tools which are appropriate for the task intended should be utilized along with safe work techniques to minimize construction injuries.

e. Electrokinetic Treatment of Mine Backfill

Most hydraulic backfilling operations in metal mines utilize classified mill tailings and dispose of a portion of the slimes in above-ground tailings ponds. This classified material dewateres faster in the mine because the slimes have been removed to improve permeability and increase particle settling rate. Incorporation of the slimes into the sandfill would increase the amount of available fill and probably eliminate the above-ground disposal requirements. The use of unclassified material would also result in a stronger, more cohesive fill after dewatering because of the large percentage of fine material.

The main problem with using unclassified tailings is the difficulty in achieving dewatering necessary to form a firm, competent backfill. Electrokinetic dewatering might be a practical solution to this problem and has had encouraging results in laboratory and mine-scale tests (50).

Electrokinetic treatment consists of imposing a direct current between electrodes placed in the slurry with drainage at the cathode. This method utilizes the negative surface charges on the solid particles in water suspension, and the positively charged metal ions in solution. The physical phenomena involved are electrophoresis and electro-osmosis. When the direct current is applied, the positive ions in solution are attracted to the negatively charged cathode (electrophoresis), and the water is carried along by the viscous drag of the migrating positive ions (electro-osmosis). Electro-osmotic flow is effective in dewatering dense slurries of fine particles because it is relatively independent of pore size while normal hydraulic flow is impeded by small pore spaces.

Research performed by the U.S. Bureau of Mines has shown this technique to be effective in dewatering unclassified mine tailings from north Idaho metal mines and a Mexican metal mine, mine drainage sediment in a Colorado molybdenum mine, thickener underflow from two Appalachian coal preparation plants (50), and materials from many other coal and metal mine sites for which results are not published. Electrokinetic dewatering has begun to be used in mines to treat backfill and sludge that accumulates in sump pits from mine and backfill drainage.

Potential safety hazards associated with electrokinetic dewatering include toxic and volatile gas emissions, electrical shock, accidental detonation of explosives, electrochemical corrosion of metal appurtenances, and possibly others (50).

Preliminary laboratory tests should be performed on the material to be used as backfill to determine its physical properties and predict the dewatering results. The physical properties can be used to predict the characteristics and quantities of emitted gases. Once identified, these gases should be evaluated in terms of quantities produced, toxicity, ignition, and detonation.

The U.S. Army Waterways Experiment Station Geotechnical Laboratory in Vicksburg, Mississippi conducted a study to develop safety practices for electrokinetic treatment of mine waste (53). The following is a partial list of recommendations from that report:

a. When used in deep metal mines, the electrokinetic dewatering process be properly monitored to obtain additional information on other potential hazards that possibly exist.

b. Laboratory tests to determine gas emissions and other pertinent properties be conducted on materials from any metal mines contemplating use of electrokinetics.

c. A computer model be prepared that could be used to determine electrode spacing and configuration, rate of dewatering, possible gas emissions, conductivity in and around the dewatering area, corrosion possibilities, etc.

d. Laboratory and field tests be conducted to determine the procedure to use for optimizing the effects of electrokinetic dewatering.

3. Hazards Associated With Stowed Waste

After emplacement and dewatering of sandfill in mined-out stopes, there normally is not much concern about hazards caused

by the fill. In some mines, however, a definite risk of spontaneous oxidation and combustion exists, and potential liquefaction of the fill should be considered in all mines.

a. Spontaneous Oxidation and Combustion

Large quantities of broken timber, trash, and other organic wastes present a spontaneous oxidation and combustion hazard in any underground mine. Prompt removal of these materials is, therefore, very important. In underground mines where cut-and-fill methods are used, sulfide minerals left in the mine waste used as sandfill can present a more complicated spontaneous oxidation and combustion problem. Sulfide minerals themselves are sometimes said to burn, not with open flames, but still emitting large amounts of heat and light.

If sandfill contains a large amount of reactive sulfides and has the needed amount of moisture and ventilation, accelerated oxidation may result. Heat liberated by oxidation serves to accelerate the oxidation reaction resulting in more heat, sulfur dioxide gas, acid mine drainage, and reduced oxygen supply. Other products include carbon monoxide, carbon dioxide and sulfurous acid gas (44). Also, if plastics are heated by the oxidation reaction, noxious gases may be produced.

Chemical and physical mechanisms and hazards associated with spontaneous oxidation and combustion are adapted primarily from Nineteman (44).

1.) Chemical Mechanism

Sulfide oxidation can be described in terms of four basic steps:

Step 1: The metal atom is released into solution. A slightly acidic solution is needed to break the predominantly ionic bonds in the crystal lattice of the sulfide. This increases the sulfur-to-metal ratio in the solid.

Step 2: Sulfur ions are released into solution.

Step 3: Sulfur ions quickly oxidize to form sulfate ion.

Formation of sulfate ions necessitates the formation of H^+ ions from water. Therefore, the solution becomes more acidic because of oxidation.

Step 4: The metal ion forms metal oxide, sulfate, carbonate, hydroxide, or chromate.

Chemical Factors Affecting Oxidation

a.) Mineralogical Composition Effects. - Reactivity, the tendency to oxidize, is a complex function of mineralogical composition which differs from one ore body to the next and in different parts of the same ore body. Iron sulfides, especially pyrrhotite, are most reactive. Russian research indicates that at higher temperatures, iron sulfides oxidize almost ten times faster than sulfides of copper, nickel, or cobalt. Pyrrhotite is by far most reactive where moisture is highly variable. Decreasing order of reactivity is: pyrrhotite >> pyrite-arsenopyrite > chalcopryrite > sphalerite > galena. Mineralogical composition is more critical than chemical assay of sulfide material. Two samples with identical iron assays may oxidize at completely different rates depending on the relative amounts of each iron sulfide present. Because of electrical effects, mixtures can be more reactive than solitary sulfides. Experiments have shown that in the presence of an equal amount of pyrite, samples of galena, sphalerite, covellite, and enargite oxidized 8 to 20 times faster than when allowed to oxidize alone.

Elemental sulfur may form during oxidation and increase sulfide reactivity as well as lower ignition temperature. Pyrrhotite contains varying amounts of free sulfur and is more reactive than other sulfides. Carbon has a similar effect as a fine-grained impurity in pyrite or copper sulfides. Some minerals, such as dolomite, decompose endothermically (absorb heat energy) at high temperatures and reduce the oxidation or combustion rate.

b.) Water Content Effects. - Sulfides will not oxidize without water unless they are above the boiling temperature of water. Water provides a solvent in which reaction products can be removed from the surface of the mineral. It has been suggested that hydrogen peroxide (H_2O_2), (present in very small amounts in water) is responsible for diffusional transporting of oxygen from air through water to oxidize metal ions. Water also acts as a solvent for other oxidizing catalysts such as ferric ions (Fe^{3+}).

At ordinary temperatures, water content from 3 to 8 percent is the most ideal moisture condition for spontaneous heating and combustion in metal mine tailings. Where water

content is below 2 percent, water quickly evaporates as oxidation starts and heat generation is checked. Completely dry sulfides probably will not oxidize. If the water content is above 8 percent, heat energy is absorbed by evaporation and the water acts as a heat sink, preventing hot spots. Experiments on 500 gram samples of sulfide ore concentrate showed that 3 to 9 percent water content produces the greatest heating.

Moisture fluctuations accelerate oxidation by dissolving oxide products that coat mineral grains and block the oxygen supply to the mineral surface. The reaction rate increases with increased frequency of fluctuations.

c.) Ventilation Effects. - Ventilation increases or keeps the partial pressure of oxygen from dropping, thus encouraging the oxidation reaction. However, ventilation also retards the reaction by carrying heat away from the reaction site. In some cases when ventilation is decreased, the oxidation rate increases because heat builds up and accelerates the reaction. The cooling effect of ventilation dominates once oxidation has started, but when oxidation has become excessive, oxygen availability is the dominating effect of ventilation. Ventilation effects are summarized on Table 26.

d.) Effect of Extraneous Materials. - Crushed, decaying timber mixed with sulfide backfill forms a very reactive combination. Wood has a lower kindling temperature than sulfide backfill material, and produces considerable carbon monoxide gas when heated by the oxidation reaction.

TABLE 26. Effect of Ventilation on the Oxidation of Sulfide Ores (44)

	No Oxidation	Some Oxidation	Excessive Oxidation and Combustion
Critical Effect	O ₂ Availability	Cooling	O ₂ Availability
Suggested Ventilation Action	Minimum Ventilation	Maximum Ventilation	Minimum Ventilation

e.) Temperature Effects. - An increase in temperature increases the rate of oxidation, provided that enough water and oxygen are available. Lab experiments have shown that in the temperature range from 30° to 60°C, the oxidation rate doubled for each 10°C rise in temperature (44). High background temperatures, as are found in deep mines, favor spontaneous combustion.

f.) Other Chemical Effects. - Various thermophilic bacteria accelerate sulfide oxidation by raising temperatures. Low pH in mine waters also encourages oxidation.

2.) Physical Mechanism

The physical mechanism of spontaneous oxidation and combustion of sulfides can be described in five steps, starting from the point where oxide products are being removed from mineral surfaces by circulating water:

Step 1: Sulfides are broken up, providing a large amount of surface area.

Step 2: Air is allowed to contact this large surface area.

Step 3: Heat produced is entrapped, but oxygen supply is maintained.

Step 4: Temperature increases to ignite elemental sulfur.

Step 5: Temperature increases to ignite fine, reactive sulfides.

a.) Fineness and Surface Area. - Finely divided sulfides are more easily oxidized and have lower ignition temperatures, and massive sulfide deposits rarely burn in place. Surface area per unit mass is inversely proportional to particle diameter, therefore, surface area is greatly increased when material is finely divided. However, critical particle size is variable depending on the sulfide involved, the crystal form, and the purity of individual grains. Critical particle size also depends on the combination of sulfide species and whether they are fresh or tarnished. Also, intact crystals resist oxidation more than broken ones.

b.) Porosity and Permeability. - Permeability, the capacity of a material to transmit a fluid, is dependent to a large degree on porosity, the ratio of void space to total volume. The ventilation rate in backfill material is determined by permeability and exposure to draft. Draft also has a cooling effect on the material.

c.) Electrochemical Effects. - The mechanism for the oxidation of metal sulfides is effectively summarized by Eh-pH diagrams for sulfide-water systems. These diagrams show that oxidation is favored at low pH. When two different sulfides are in contact and electrochemically connected by solution, current is generated and flows from the mineral of high electrochemical potential to one of lower potential. This is why sulfide mixtures, especially with pyrite, will oxidize faster than a sulfide found alone.

d.) Oxidation Products. - Insoluble coatings of sulfate or carbonate can accumulate from sulfide oxidation and stifle the oxidation reaction. If these products are not removed, the mass of material agglomerates and hard, relatively impermeable sulfate layers form.

e.) Heat Output. - Because of variables like oxygen availability, heat of reaction and thermal diffusivity, the intensity of oxidative heating cannot be predicted. Experiments with the material in question and monitoring in the mine environment provide the best information.

f.) Critical Temperatures. - The temperature at which combustion occurs and/or harmful gases are generated in sulfide backfill material is very unpredictable because of the many variables mentioned above. Critical temperatures ranging from 150°F (66°C) to 340°F (171°C) have been suggested for sulfide ore concentrates, but dangerous temperatures for backfill material should be determined on an individual basis.

3.) Gas Hazards

Spontaneous oxidation of sulfides causes fires and heat which can liberate dangerous gases. These gases include sulfur dioxide (SO₂), carbon monoxide (CO), carbon dioxide (CO₂), sulfurous acid gas (H₂SO₃), and gases emitted from heated or burning plastics.

a.) Sulfur Dioxide. - When heat from oxidation or other sources raises sulfide backfill temperatures above 125°C, significant quantities of sulfur dioxide will be released. Very large volumes are produced at temperatures above 1000°F (538°C) if sufficient sulfides are present in the backfill.

Sulfur dioxide is a very important gas to watch for in backfill fires in which iron pyrite is burning (19). Sulfide ore fires have produced mine atmospheres containing 0.04 to 0.12 percent sulfur dioxide. Air containing 0.1 percent sulfur dioxide is considered toxic for an 8 hour exposure, but lower concentrations are also strongly irritating and therefore hazardous.

b.) Carbon Monoxide. - Carbon monoxide is the gas responsible for more than 90 percent of the fatalities from mine fires. It is formed in the burning of any carbonaceous substance such as timber, explosives, or petroleum products, especially where there is smoldering or incomplete combustion.

Timber square-sets are often buried in backfill material as part of the mining plan. If spontaneous oxidation or other heat sources raise the temperature past the ignition temperature of the wood, incomplete combustion produces carbon monoxide gas. Combustion of the timber would be incomplete because of fill material covering the timbers and blocking the oxygen supply.

Carbon monoxide is poisonous even in low concentrations, and is explosive in concentrations of 12.5 to 75 percent. It replaces oxygen in the blood, and so acts as an asphyxiant.

c.) Carbon Dioxide. - Oxidation and combustion of organic materials produce carbon dioxide, a heavy, asphyxiating gas. Low oxygen content and temperatures above 80° F (27°C) are conditions caused by rapid oxidation and mine fires. These conditions increase the production of carbon dioxide.

d.) Sulfuric Acid Gas. - In extreme cases of sulfide oxidation and combustion, sulfuric acid gas is formed, making breathing apparatus necessary.

e.) Gases From Plastics. - When using backfill material that is susceptible to oxidative heating, it is important to remember that plastics give off noxious gases when they are heated to 250°C or above, regardless of the presence of oxygen. Polyurethanes, nylon, PVC and polyethylene all give off copious

quantities of carbon dioxide and carbon monoxide when heated. At temperatures over 200°C, polyurethanes and nylon evolve dangerous concentrations of hydrogen cyanide, the rate of production increasing with temperature. PVC releases hydrochloric acid gas when burned (24).

If the possibility of spontaneous heating exists, it is inadvisable to use plastic drain pipes, burlap, etc., in contact with the backfill material because of the dangerous gases that plastics produce when heated.

b. Liquefaction of Fill

Accumulations of saturated, loose, cohesionless materials, like some sandfills, are subject to liquefaction, a process by which the material takes on the characteristics of a liquid. If a "quick" condition such as this occurs in sandfill, excessive pressure could be placed on the bulkhead, causing it to collapse. This would result in tons of fluid sand flowing into working areas of the mine, causing hazards to miners (41).

1.) Mechanism

In saturated material, the pressure exerted by the water particles (i.e., pore water pressure) is referred to as the neutral stress. Since water has no shear strength, the neutral stress is equal in all directions. The grain-to-grain stress which exists in a saturated material is equal to the total normal stress that would exist between unsaturated sandfill grains minus the neutral stress. When the neutral stress becomes equal to the normal stress, the effective stress equals zero, and failure of the grain-to-grain contacts will occur.

2.) Susceptibility and Causes

Very fine and silty uniform sands and mill tailings with particle sizes in this range are the materials which are most susceptible to liquefaction failure. Susceptibility to liquefaction is dependent upon the void ratio of the material, the confining pressure, and the number and magnitude of vibrations to which the deposit is subjected (36). Some of the events triggering spontaneous liquefaction include high pore-water pressures and vibrations from blasting or natural seismic activity.

Repeated application of a shear stress on saturated material lowers the shear strength of that material, especially

when the direction of the shear stress reverses during each cycle of loading. This occurs because the excess pore pressures do not return to zero after unloading, but rather accumulate as shown in Figure 19. Increase in pore pressure is caused by progressive rearrangement of the soil particles during each successive cycle of loading. As this neutral stress increases, the grain-to-grain stress and resistance to shear decrease. In drained material, the result would be a volume decrease, but in saturated material the result is a much smaller effective stress and constant volume (36).

Catastrophic failures by liquefaction during earthquakes have been studied using repeated load triaxial tests. A typical set of results from these tests is shown in Figure 20. In the ninth cycle, large strains suddenly developed and within a few cycles these strains exceed 20 percent, implying total failure. Pore pressures built up to equal the confining stress so that the lateral effective stress dropped to zero.

If a sand has an in situ void ratio greater than the critical void ratio for that sand, the sand is highly susceptible to flow. The critical void ratio of uniform, fine sand with subrounded grains corresponds to a relative density of 20 to 30 percent for small confining stresses (up to 0.1 Kg/cm²) and a relative density of about 50 percent for an initial effective confining stress of 10 Kg/cm².

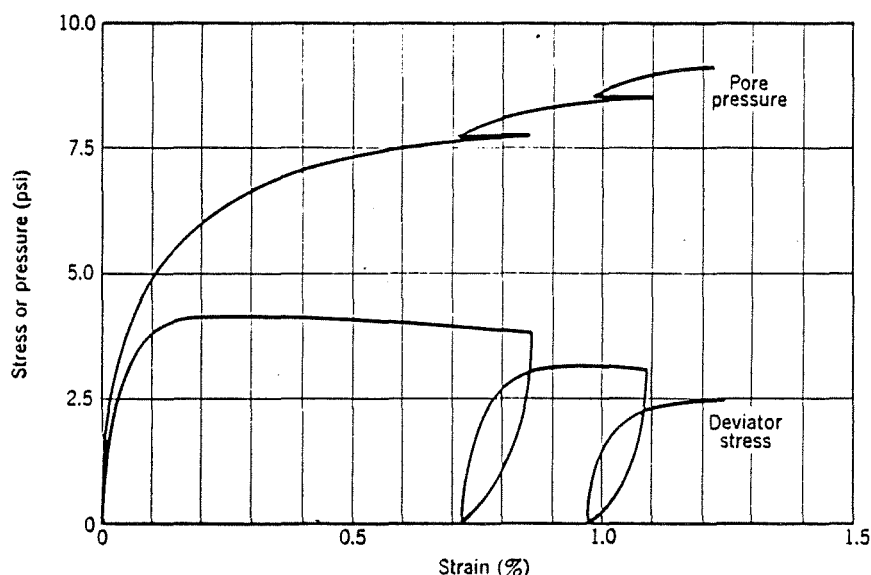


FIGURE 19. Effect of repeated loading on undrained strength of very loose saturated sand. Specimen consolidated to 10 psi; void ratio = 0.834 (36).

3.) Comments

In spite of the similarities of many backfilling materials to the materials described here as being susceptible to liquefaction, the authors have discovered no recent instance of liquefaction of backfill in an underground mine. In known cases where sandfill has flowed out of filled stopes, the flow was initiated by retaining structures inadequately constructed or weakened by rotting or fire. In these cases the sand flowed because it was uncemented or so lightly cemented that it flowed like a loose, unconsolidated sand. In many stoping operations, some or all of the backfill is mixed with enough cement to be too cohesive to flow, thus prohibiting liquefaction.

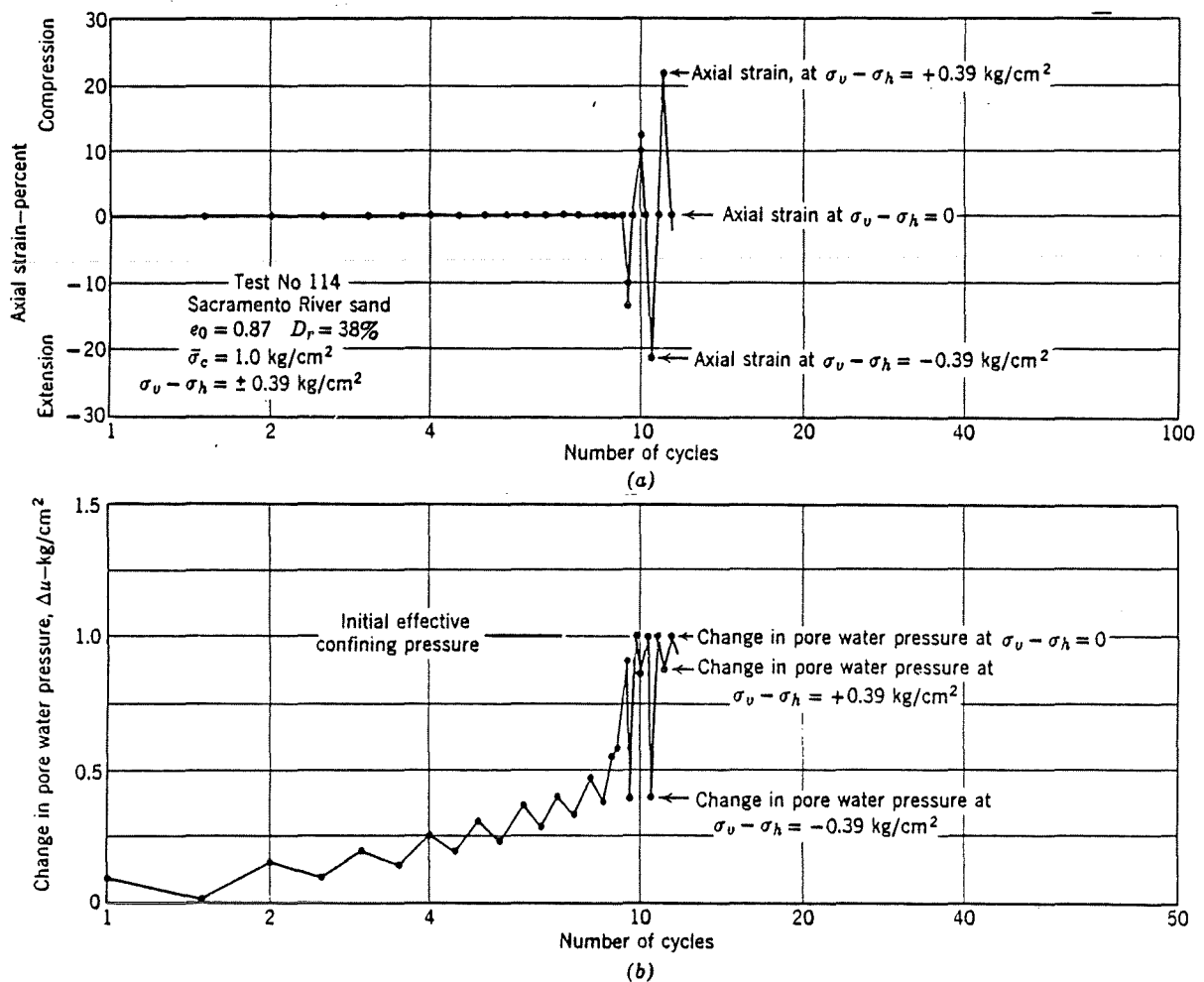


FIGURE 20. Pore pressure and axial strain versus number of cycles during repeated triaxial loading of loose saturated sand. (a) Axial strain versus number of cycles. (b) Observed change in pore water pressure versus number of cycles. (36).

4. Hazard Ranking

Classification and ranking of hazards related to hydraulic backfilling provides a rational method of assigning priorities and making decisions about which hazards demand more immediate attention. The classification of each hazard is based on the severity of its consequences and the probability of its occurrence (see Tables 28 and 29). This classification is used to rank the hazards in order of importance so that remedial action can be taken on a worst first basis.

The system of classification used here was taken from the "Accident Prevention Manual for Industrial Operations" by the National Safety Council (39), and is very similar to that used by MSHA and others. It should be remembered that the classification and ranking presented here is generalized for the industry as a whole and may not be adequate for some specific backfilling operations. It is suggested that mine operators apply this system of classification to their particular operation to refine their approach to the hazards of backfilling.

Classification according to the consequences of accidents is described in Table 27. A particular type of accident or health hazard may result in any degree of impact on safety or serious potential effects. For example, spillage of sandfill usually results in a mess which is only a minor nuisance to clean up, but it could also result in severe injury. Therefore, this classification is based on the most probable worst consequences of each particular hazard.

The probability of occurrence of a particular hazard is assigned a letter according to Table 28. The probability of occurrence applies to the metal mining industry as a whole. Therefore, a hazard associated with a particular backfilling procedure may have a low probability assigned here because the procedure is not widely used in the industry, but may have a somewhat higher probability of occurrence at a given mine where the associated procedure is employed. This rating is not based on actual statistics because there are none available, but rather it is a qualitative estimate based upon professional judgement and the material reviewed for this report. Again, it should be remembered that this rating may be different when applied to a particular mine versus the industry as a whole.

Once hazards have been assigned a classification according to consequence and probability, the classification is used to rank hazards according to their importance. A ranking of hazards associated with hydraulic backfilling, from most to least important, is presented in Table 29. A discussion of each hazard's classification and ranking follows.

TABLE 27. - Relative Consequences of Various Hazard Categories (39)

Hazard Consequence Category	Explanation
I. Catastrophic	The hazard is capable of causing death, possible multiple deaths, widespread occupational illnesses, loss of facilities.
II. Critical Hazard	The hazard can result in severe injury, serious illness, and property and equipment damage.
III. Marginal Hazard	The hazard can cause injury, illness, and equipment damage, but the injury, illness, and equipment damage would not be serious.
IV. Negligible Hazard	The hazard will not result in a serious injury or illness. Damage beyond a minor first aid case is extremely remote.

TABLE 28. - Hazard Probability Category (qualitative estimate) (39)

Probability Category	Explanation
A.	Probable. Likely to occur immediately or within a short period of time.
B.	Reasonably probable. Probably will occur in time.
C.	Remote. May occur in time.
D.	Extremely remote. Unlikely to occur.

a. Spillage From Pipes and Bulkheads

Spillage from pipe leaks and from bulkhead weirs, drains and gaps between timbers are common problems in many hydraulic backfilling operations. Such spillage creates congestion in drainage ditches and haulageways and causes extra clean up work and possibly hazardous slippery conditions for miners. If spills go unnoticed for too long, solids can build up enough to damage or block mining equipment and delay production. Communication between the sandfillers and the equipment operators at the sand plant is of prime importance. If a leak or some other disruption occurs, instant communication is necessary to shut down the system. Most mines have such communication systems, and they work very well.

Because of the critical nature of the hazards caused by spillage and the high probability of their occurrence, a classification of II. A. is assigned. Spillage is ranked in first position and above the more catastrophic hazards because it is more likely to occur.

b. Toxic or Reactive Compounds

Sandfill crews often come in contact with the sandfill and slurry water in the stope, and if toxic or reactive compounds are present, illness or injuries may result. Hazardous materials brought into the mine with the sandfill may include portland cement and chemicals such as cyanide, which are used in the milling process and may remain in the tailings. Cement can cause dermatitis (skin inflammation) and cyanide as well as other mill chemicals can have toxic effects.

The importance of these hazards depends on what chemicals are used in the milling process, how the tailings are treated, and whether or not cement is used in the backfill. Therefore, if cement is not used and tailings are free from dangerous chemicals such as cyanide, these hazards will not exist.

Cement dermatitis is by far more common than problems with toxic chemicals because metal mines commonly use cemented fill, but most do not have highly toxic chemicals in the mill tailings. This hazard was classified as critical (II.) with a reasonable probability of occurrence (B.). It was ranked higher than falls of fill because it is more likely to occur, even though its consequences are less severe.

TABLE 29. - Ranking of Backfilling Hazards in Metal Mines

Rank	Consequence and Probability Categories	Hazard
1	II. A.	Spillage from pipes and bulkheads
2	II. B.	Toxic or reactive compounds
3	I. C.	Unstable rock and fill
4	I. C.	Oxidation and combustion
5	II. C.	Water pollution from mill tailings
6	III. B.	Construction injuries
7	III. C.	Operation of stowing equipment
8	III. C.	Drilling operations
9	I. D.	Liquefaction of fill
10	II. D	Electrokinetic treatment

c. Unstable Rock and Fill

All personnel in underground mines are exposed to some degree of risk from unstable ground. This risk varies a great deal from place to place because ground conditions are highly variable. Although backfilling can significantly improve ground conditions, some risk of injuries and fatalities always remains.

After sandfill is deposited and dewatered, massive movement of the fill is unlikely except in undercut-and-fill operations and situations where cemented sandfill is exposed as a vertical wall when a pillar is mined. In the undercut-and-fill method, the working stope is located directly beneath the filled area and failure of the retaining structure could allow a massive fall of sandfill into the working area. When

pillars are mined and adjacent cemented sandfill is exposed, failure of the fill to stand in a vertical face could have catastrophic effects on miners' safety.

In situations other than undercut-and-fill and pillar extraction, bulkhead failure would probably not result in massive inflows of sandfill into working areas because material would have to flow horizontally for some distance before it could invade haulageways or vertical workings. However, in some situations such as where stopes with large vertical dimensions are filled, it is possible.

This hazard is judged to have catastrophic consequences (I.), but only a remote chance or occurrence (C.). It is ranked above spontaneous oxidation and combustion because relatively few mines have enough sulfide minerals in tailings used as sandfill to cause oxidation problems.

d. Oxidation and Combustion

Under certain conditions of temperature, moisture and ventilation, finely divided sulfides can undergo rapid oxidation and combustion and cause extensive and persistent fires in underground mines.

Hydraulic sandfill has, at different times and places, been the cause and the cure of this difficult problem. In some mines, sulfide minerals in gob areas, ore pillars, and wall rock spontaneously oxidize and combust and the only effective method known to extinguish these fires is to inundate the affected area with non-sulfide hydraulic sandfill (16). In other cases of spontaneous oxidation and combustion in underground mines, sulfide minerals in mill tailings used as backfill were the cause of the fire (15, 44). In general hydraulic backfilling increases fire safety, assuming the fill does not tend to oxidize rapidly.

The occurrence of a sulfide mine fire would probably be catastrophic (I.) because of the heat, gases and acids generated, but the chances of this happening are remote (C.) for most mines, depending on site specific conditions. It was arbitrarily ranked below falls of fill, but the relative rankings may change depending upon site specific conditions.

e. Water Pollution from Mill Tailings

Chemical pollution from hydraulic backfill in metal mines comes from two sources; chemicals remaining from the milling process, and metals and acids formed when sulfides in backfill are oxidized. Except for cyanide, used in some concentrator mills, these chemicals are more of a general pollution hazard than a direct hazard to miners. Mill tailings used as sandfill have the potential to contribute dissolved solids and acidity to ground water which in time may degrade surface water through mine discharges. This hazard is judged to be critical (II) because of the potential degradation of ground and surface waters, and the chance of occurrence is called remote (C.) because inundation of backfilled areas by ground water will severely limit the opportunity for further oxidation.

f. Construction Injuries

Bulkheads and other retaining structures associated with underground hydraulic backfilling require a great deal of hand labor for construction. Injuries from hand tools and timber or concrete block bulkheads and timber-wire mesh retaining floors may include cuts, bruises and back injuries and so appropriate tools and safe techniques should be utilized by sandfill crews.

Construction of the sandfill system involves a similar risk of minor injuries when setting up pumps, motors, storage tanks and fitting pipes. After the main system is installed, only minor changes and maintenance of pipes and equipment are necessary, so the majority of the system is permanent.

Minor injuries resulting from construction activities constitute a marginal hazard (III.), but they probably will occur (B.). It is ranked fairly low on the list because most of the associated hazards are mitigated by general safety training.

g. Operation of Stowing Equipment

The main hazard encountered during the operation of hydraulic backfilling equipment is spillage from pipes and bulkheads. This problem is treated separately above because of its importance. Other concerns are electrical hazards associated with pump motors and mechanical agitators used in some storage tanks. Injury hazards near storage tank agitators

are negligible if the tank is set up so that people cannot touch moving parts. Backfilling experience indicates very little hazard associated with the operation of backfilling equipment, aside from spillage, and that is why it is ranked very low here (III. C.).

h. Drilling Operations

Sandfill is sometimes delivered into the mine through boreholes from the surface. The associated injury hazard to drillers is essentially the same in other types of drilling. Boreholes often last many years in hard rock, so very few holes are usually needed for this purpose. The experience of backfillers indicates that it is a very minor safety consideration when experienced drillers are hired for the job.

Injuries from drilling activities constitute a marginal hazard (III.), and remote probability (C.) is assigned here because borehole filling is not commonly used in underground metal mines.

i. Liquefaction of Fill

Hydraulic sandfill is deposited in the mine in a liquefied condition, but no occurrence of liquefaction after deposition and draining in metal mines has been discovered in this investigation. An occurrence of liquefaction could be very catastrophic (I.), trapping miners and blocking equipment, but the likelihood of occurrence is minimal (D.) according to the literature and mining experience.

j. Electrokinetic Treatment

Hazards associated with this method include toxic and volatile gas emissions, electrical shock, accidental detonation of explosives, electrochemical corrosion of explosives, electrochemical corrosion of metal appurtenances, and possibly others. These hazards are certainly critical (II.), but since the method is not in widespread use, the likelihood of such accidents is remote (D.). It is ranked very low on the list because this method is not commonly used.

5. Matrix of Hazards - Metal Mines

The purpose of this matrix is to refine the classification of backfilling hazards presented in the preceeding section according to filling methods, mining methods, purposes of filling, and types of fill material. Mill tailings and development wastes are the only kinds of fill materials considered here, and they are labeled in the matrix according to the metals extracted. Hydraulic and mechanical are the only filling methods included because they are the only ones employed with mine waste in metal mines in the United States.

Blind filling can be effectively used with sublevel open-stope and fill as well as room and pillar, but other mining methods require the accuracy of controlled underground filling. Cut-and-fill, undercut-and-fill, and post pillar and fill require that filling be done in consecutive layers and carefully controlled to fill all parts of the stope evenly. In blind filling, sandfill is delivered through boreholes from the surface and can not provide the accessibility and control necessary for the latter mining methods.

Controlled hydraulic filling is the most common filling method used with all the mining methods listed here, and so it is applied to all the mining methods included in the matrix.

Mechanical filling is used to a very small extent with most of these mining methods, but not at all with undercut-and-fill. Therefore, undercut-and-fill is not included with mechanical backfilling. Mechanical filling is used only with development waste rock, while undercut-and-fill requires a solid layer of strongly cemented sandfill at the bottom of each pour and tight filling all the way to the back. Development waste would interfere with that. With other mining methods, development waste can be dumped into mined-out stopes and hydraulic sandfill poured over it, filling voids in the broken development waste.

With any of the mining methods and hydraulic filling, ground support, fire retardation, and waste disposal apply as purposes of filling. Working platforms made of sandfill are not used in undercut-and-fill or sublevel open stope and fill. Sandfill working platforms are rarely used with room-and-pillar mining, but are necessary with cut-and-fill and post pillar and fill mining methods.

Because development waste can not be made into a smooth, hard working floor, and has too much void space to retard fire, these are not included as purposes for mechanical backfilling.

Blind filling is done from the surface, and may require less slurry pipe than controlled filling. There also may be less congestion with a surface operation, and so spillage is classified a IV. C. hazard with blind filling because spills are less likely to happen and would be less likely to cause major damage.

Spillage is classified a II. B. hazard with controlled backfilling for reasons discussed in the section on hazard ranking. Spillage is a hydraulic backfilling hazard, and so it is not included with mechanical backfilling.

The main concern with respect to toxic or reactive compounds is cement dermatitis, therefore it does not apply to blind filling or mechanical filling. Cement is rarely used with these methods and workers are less likely to come in contact with the fill material. When filling for purposes of waste disposal or fire retardance with cut-and-fill, sublevel open stope and fill, or room and pillar, cement is not likely to be used. Therefore, in these cases, toxic or reactive materials are classified II. C.; less probability of occurrence than other situations where cement is nearly always used.

Falls of rock and fill do not apply to blind filling because operations are performed from the surface. This hazard is classified I.C. for all underground situations because any differences would be primarily due to site specific conditions, rather than to mining methods, purposes of filling, or fill types.

Spontaneous oxidation and combustion is classified a I.C. hazard in situations where cement might not be used. In other situations where cement probably would be used, it is classified I.D. because cement tends to block air circulation through the fill and stifle oxidation.

Water pollution from mill tailings is classified II. C. for all situations listed here because differences in risk or consequence would be site-specific, and not greatly affected by the mining or the filling method.

Less construction is required for blind filling operations than for controlled filling operations, so construction injuries are less likely to occur with blind filling operations. With sublevel open stope and fill and with room and pillar methods, less construction of bulkheads and other retaining structures is required than with other mining methods in relation to the volume to be filled. Retaining structures are rarely built specifically for mechanical backfilling. Therefore, construction injuries are classified with a lower probability of occurrence in these situations.

Filling Method		Mining Method	Purpose of Fill	Fill Type	Spillage	Toxic or Reactive Materials	Falls of Rock & Fill	Spont. Oxidation & Combust.	Water Pollution from Mill Tailings	Constr. Injuries	Operation of Stowing Equipment	Drilling Operations	Liquefaction of Fill	Electro-kinetic Treatment	
H Y D R A U L I C	B L I N D F I L L I N G	SUBLEVEL OPEN STOPE AND FILL	GROUND SUPPORT	*	IV. B.	N/A	N/A	I. C.	II. C.	III. C	III. C.	III. C	N/A	N/A	
			FIRE RETARDENT	*	IV. B.	N/A	N/A	do	do	do	do	do	N/A	N/A	
			WASTE DISPOSAL	*	IV. B.	N/A	N/A	do	do	do	do	do	N/A	N/A	
		ROOM AND PILLAR	GROUND SUPPORT	*	IV. B.	N/A	N/A	do	do	do	do	do	N/A	N/A	
			FIRE RETARDENT	*	IV. B.	N/A	N/A	do	do	do	do	do	N/A	N/A	
			WASTE DISPOSAL	*	IV. B.	N/A	N/A	do	do	do	do	do	N/A	N/A	
	C U F O N I N D L T E L R R I O C N L O E U D N D	CUT AND FILL	GROUND SUPPORT	*	II. A.	II. B.	I. C.	I. D.	do	III. B	do	N/A	I. D.	II. D.	
			WORKING PLATFORMS	*	II. A.	do	do	do	do	do	do	N/A	do	do	
			FIRE RETARDENT	*	II. A.	II. C.	do	I. C.	do	do	do	N/A	do	do	
		UNDERCUT AND FILL	WASTE DISPOSAL	*	II. A.	II. C.	do	do	do	do	do	do	N/A	do	do
			GROUND SUPPORT	*	II. A.	II. B.	do	I. D.	do	do	do	do	N/A	N/A	do
			FIRE RETARDENT	*	II. A.	do	do	do	do	do	do	do	N/A	N/A	do
			WASTE DISPOSAL	*	II. A.	do	do	do	do	do	do	do	N/A	N/A	do
		SUBLEVEL OPEN STOPE AND FILL	GROUND SUPPORT	*	do	do	do	do	do	do	III. C	do	N/A	I. D.	do
			FIRE RETARDENT	*	do	II. C.	do	I. C.	do	do	do	do	N/A	do	do
			WASTE DISPOSAL	*	do	II. C.	do	do	do	do	do	do	N/A	do	do

FIGURE 21. Matrix of backfilling hazards in metal mines

* Gold, Silver, Lead, Copper, Zinc tailings

Filling Method		Mining Method	Purpose of Fill	Fill Type	Spillage	Toxic or Reactive Materials	Falls of Rock & Fill	Spont. Oxidation & Combust.	Water Pollution from Mill Tailings	Constr. Injuries	Operation of Stowing Equipment	Drilling Operations	Liquefaction of Fill	Electro-kinetic Treatment
HYDRAULIC	UNDERGROUND	POST PILLAR AND FILL	GROUND SUPPORT	*	II. A.	II. B.	do	I. D.	do	III. B.	do	N/A	N/A	do
			WORKING PLATFORM	*	do	do	do	do	do	do	do	N/A	N/A	do
			FIRE RETARDENT	*	do	do	do	do	do	do	do	N/A	N/A	do
			WASTE DISPOSAL	*	do	do	do	do	do	do	do	N/A	N/A	do
		ROOM AND PILLAR	GROUND SUPPORT	*	do	II. B.	do	I. C.	do	III. C	do	N/A	I. D.	do
			WORKING PLATFORM	*	do	do	do	do	do	do	do	N/A	do	do
			FIRE RETARDENT	*	do	II. C.	do	I. C.	do	do	do	N/A	do	do
			WASTE DISPOSAL	#	do	do	do	do	do	do	do	N/A	do	do
		MECHANICAL	CUT AND FILL	GROUND SUPPORT	#	N/A	do	do	do	do	do	N/A	N/A	N/A
				WASTE DISPOSAL	#	N/A	do	do	do	do	do	N/A	N/A	N/A
				WASTE DISPOSAL	#	N/A	do	do	do	do	do	N/A	N/A	N/A
			SUBLEVEL OPEN STOPE AND FILL	GROUND SUPPORT	#	N/A	do	do	do	do	do	N/A	N/A	N/A
				WASTE DISPOSAL	#	N/A	do	do	do	do	do	N/A	N/A	N/A
			POST PILLAR AND FILL	GROUND SUPPORT	#	N/A	do	do	N/A	do	do	N/A	N/A	N/A
				WASTE DISPOSAL	#	N/A	do	do	N/A	do	do	N/A	N/A	N/A
			ROOM AND PILLAR	GROUND SUPPORT	#	N/A	do	do	N/A	do	do	N/A	N/A	N/A
				WASTE DISPOSAL	#	N/A	do	do	N/A	do	do	N/A	N/A	N/A

FIGURE 21. (Continued) Matrix of backfilling hazards in metal mines

* Gold, Silver, Lead, Copper, Zinc tailings

Gold, Silver, Lead, Copper, Zinc Development Waste

The operation of stowing equipment presents the same hazards for all hydraulic backfilling operations, and since mechanical backfilling utilizes the same equipment used for ore transport, no differences in hazard consequence or probability are expected. Therefore, the operation of stowing equipment is classified III. C. for all situations listed here.

Drilling operations are only being used in blind filling operations where material is injected through a borehole from the surface. Using boreholes for backfilling purposes does not affect the magnitude or probability of hazards normally associated with drilling, and drilling operations are classified III. C.

Liquefaction of fill is not included with blind filling because this method of filling is employed with no personnel underground. It is also not applied to undercut-and-fill and post pillar and fill because cement is used with these methods. Once emplaced and set-up, cemented fill should be incapable of liquefaction.

Hazards of electrokinetic treatment are classified with a low probability of occurrence because it is not in widespread use and because the associated hazards have been studied and the results published (53). Therefore when this method is used, the potential hazards may be anticipated and controlled.

6. Case Study - Fall of Fill

The following is a description of a triple fatal accident involving a fall of cemented sandfill in a metal mine in the western United States. The mining method, sequence of events, contributing causes and preventive measures will be discussed. Supervisory decisions which might have averted these fatalities are suggested and it is hoped that this case study will be helpful to supervisors who must make such decisions in the future. The information provided below was adapted from a Mine Safety and Health Administration (MSHA) Accident Investigation Report.

a. Mining Method

The mining method in the part of the mine where the accident occurred is undercut-and-fill stoping. Conventional drilling and blasting is used, and mucking is done with pneumatically powered, rubber-tired LHD machines. Ore is

transported out of the mine by rail haulage and vertical hoist. Conventional timbering in conjunction with cemented hydraulic sandfill is used for ground support in mined-out stopes. Sandfill is obtained from mill tailings.

The mining cycle consists of drilling, blasting, mucking and timbering. After a stope is completed, it is hydraulically filled with cemented tailings. The normal stope height is two square-sets measuring 22 feet altogether. Square-sets are placed on 5-foot centers and are tied to existing sandfill stope timbers. Timbering is usually done immediately after mucking for support of adjacent sandfill and wall rock.

In this mine, a mined-out stope is prepared for backfilling by building a timber floor and bulkhead at the open end. Then several feet of sandfill are poured with a sand to cement ratio of about 12 to 1. Then the rest of the stope is filled with a 50-75 to 1 sand to cement mixture. The richer cement mixture at the bottom is intended to help hold the sandfill in place while mining proceeds directly below the filled stope. The weaker mixture in the rest of the stope is intended to help improve the cohesion of the sandfill.

b. Description of Events

The stope where the accident occurred had sandfill in the back and on the right side. A wedge of ore about 8 feet thick on the left side was being mined, and beyond the ore was more sandfill. The panel was 6 feet higher than normal with a 6 foot pony set atop of two regular size sets for a total of 28 feet.

The first blast in that area was made and mucking and timbering were completed within two days. After the next blast was made adjacent to the first, a sandfill pipeline became loose at a connection and spilled sand and water into the muck tramway, preventing the rubber-tired mucker from moving the broken ore to the ore pass.

A decision was made to pump the water and install muck floors over the spill. This delayed stope crews from extracting the broken ore after the second blast and completing the timbers in the stope area. A total of six days passed from the time the ore was blasted to the time timbering was resumed in the stope.

As one of the miners was about to bar down some loose ground, the first fall occurred with no warning from the sandfill or timber. One man was trapped up to his waist with timbers and sandfill. During rescue efforts, a second fall

occurred and one man was removed with injuries that later proved fatal. Then a third fall occurred, completely covering the man who was first trapped and the man who was trying to dig him out. Their bodies were recovered later that night.

c. Contributing Causes

The actual cause of the fall of sandfill and timber was the failure of the temporary ground support. This temporary support was left for a much longer time (6 days) than usual because of the previously mentioned spill from a sandfill pipeline between the stope and the ore pass, preventing the LHD machine from traveling between the stope and the ore pass. Work in the stope was delayed while crews corrected the spill problem. The fall was probably not triggered by workers in the stope because they had not started to bar down loose ground. It seems probable that the fall would not have occurred if timbering had been completed shortly after the second blast.

Another possible contributing cause was the extra height of the stope. It is thought that this type of stope would be more stable if it was limited to the height of two standard sets.

d. Preventive Measures

These fatalities might have been averted if the decision had been made to move the broken ore into a timbered area and complete the timber sets in the stope before cleaning up the spill problem. Once pumping was started on the spilled water, the spilled sandfill presented no immediate hazard and crews could have concentrated on completing mucking and timbering in the stope.

Limiting the height of the stope to that of two standard size sets, which is the usual procedure, might contribute to stability in such a situation. A richer mixture of cement in the sandfill above would have improved its cohesion and it would not have flowed into the stope below in such great quantity.

A number of supervisory decisions may have contributed to causing this disaster. This is not to say that they were made in a careless manner, but careful consideration of the contributing causes and options available in this case may help increase the safety of such operations in the future.

C. Positive Health and Safety Effects of Underground Disposal of Mine and Mill Wastes in Metal Mines

Hydraulic backfilling systems, once installed, provide a less labor intensive way of transporting and placing ground support medium than do other ground support methods (56). Square-sets, waste rock filling and rock bolting all require more manual labor and may therefore involve more underground man-hours and risk to miners. Sometimes square-sets or other support methods are used in conjunction with hydraulic backfill for extra support for very heavy ground, but hydraulic backfill provides the most support for the least amount of labor and risk.

In addition to ground support benefits, hydraulic backfilling can improve fire safety, ease ventilation problems, and reduce environmental problems associated with metal mine waste. Waste bank erosion and degradation of surface waters, for instance, are reduced in direct proportion to the amount of waste material placed underground. These positive health and safety effects are listed and evaluated in the following section. A generalized ranking of these effects, in order of their importance is also included.

1. Ground Control

In underground metal mines, hydraulic backfill is one of the most important materials used for limiting caving and subsidence and for supporting pillars and walls. Falls of ground and associated air blasts are prevented in filled areas, and the use of fill facilitates recovery of ore pillars.

In order to provide effective support, especially in deep metal mines, backfill material must take a significant amount of the stress from the surrounding rock. Some fills must be compressed by 20 percent or more of their initial in-place volume before they become effective as support for pillars and walls (52). Also, rock stresses increase with increasing depth of mining, and support needs increase accordingly.

Well-graded material tends to achieve the greatest density and cohesion because the smaller particles fill the voids between the larger particles and lend their cohesive properties. The main problem with using mill tailings for backfill is the large amount of slimes present in most mill tailings. This material settles slowly and decreases the permeability of the fill thereby inhibiting drainage. To remedy this problem,

tailings are usually classified to remove a portion of the slimes resulting in backfill material which more closely resembles a well-graded material and will drain and consolidate fairly rapidly.

Another problem with using mill tailings as backfill is inadequate density. Well-graded soils used in surface construction are often compacted to 130 to 140 lb/ft³ (dry weight basis) by rollers or other equipment, while backfill placed in mine stopes is often less than 100 lb/ft³. A well-graded fill with moisture content of 10 to 20 percent; and compacted to approximately 135 lb/ft³ would have very good support capabilities. However, tailings used as backfill are usually relatively uniform and fine in size, slurries usually contain 30 to 50 percent; water, and there is no room for heavy compacting equipment in underground mines.

One technique to characterize sandfill is to determine the coefficient of uniformity, C_u , using the formula $C_u = D_{60}/D_{10}$. Referring to Figure 22, D_{60} is the particle diameter at 60 percent on the grain size distribution curve, and D_{10} is the particle diameter at 90 percent on the grain size distribution curve. A uniformity coefficient of approximately 5 has optimum physical properties for a mine fill (41). Higher values tend to indicate a more cohesive material with reduced permeability, while lower values indicate a more uniform material.

Vibratory compaction is one method that has been field tested to improve sandfill strength by increasing its density. Sandfill treated with vibration exuded excess water, reduced vein-wall closure and produced a smoother, harder working surface for miners. According to U.S. Bureau of Mines research, vein-wall closure of 11.4 inches with sandfill density of 92 lb/ft³ can be reduced to 3.4 inches of closure by improving sandfill density to 120 lb/ft³ (41).

The addition of cement to sandfill is a commonly used method to improve the working floor and support capabilities. The use of portland cement and/or pozzolanic materials has improved working safety in cut-and-fill mines (41).

The main advantage of backfilling in metal mines is that it reduces vein-wall or stope-wall closure, thereby facilitating mining on all sides of a filled stope. It does this by reducing stress concentrations in unmined pillars and controlling slabbing, which prevents accelerated growth in the size of the weakened area (1).

High-modulus fills can greatly reduce stope wall closure, and this fact has been demonstrated by research performed at the U.S. Bureau of Mines Spokane Mining Research Center (46).

The amount of support supplied by the backfill primarily depends on the compressibility of the backfill since that is the most important factor in determining confined strength. As Figure 22 shows, dense material takes on a much greater confined load for the amount of slope-wall closure than loose material, and so it will begin to resist that closure much sooner than loose material.

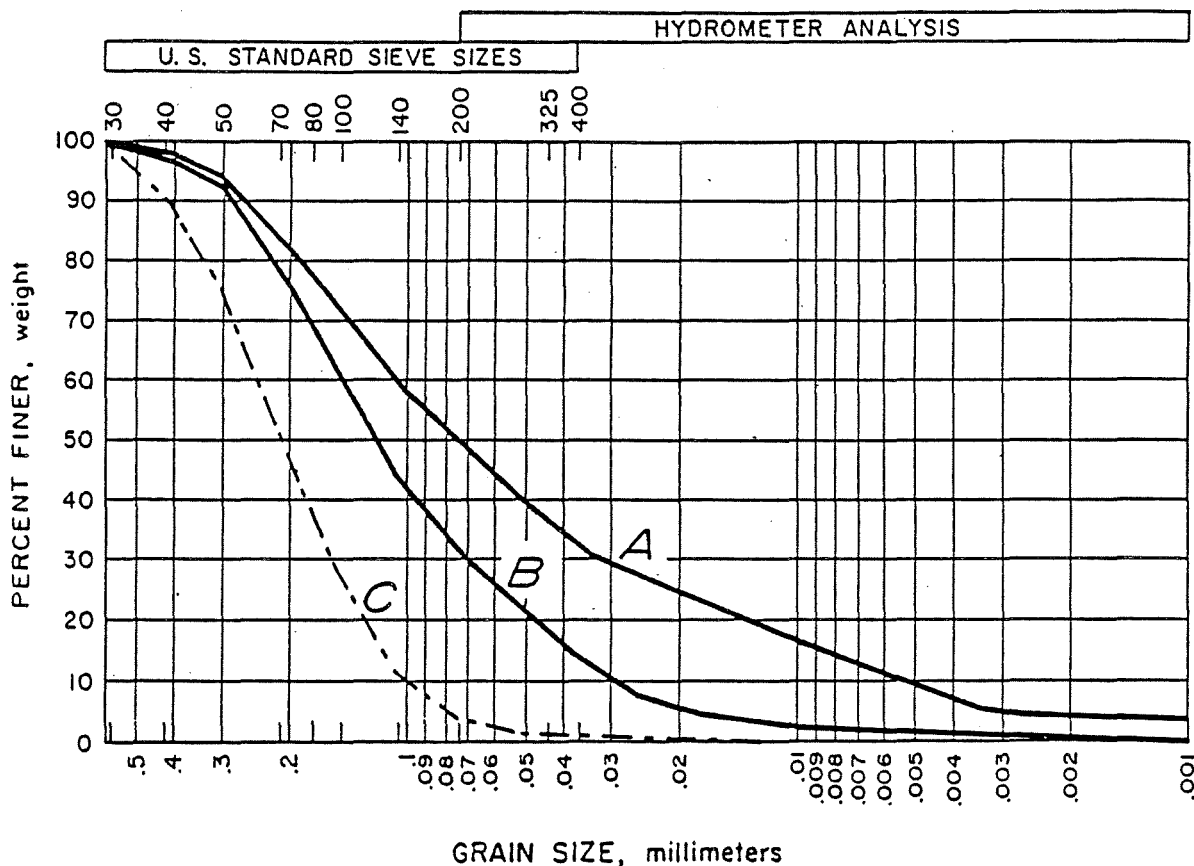


FIGURE 22. Grain-size distribution curves. Curve A shows grain-size distribution of a typical unclassified mill tailing; B, grain-size distribution of the actual fill material obtained from these tailings. Curve C represents a more uniform distribution obtained by removal of additional fines from the original tailings material. Hydraulic backfill on Curve B has a coefficient of uniformity of about five and can be termed reasonably well-graded. (57)

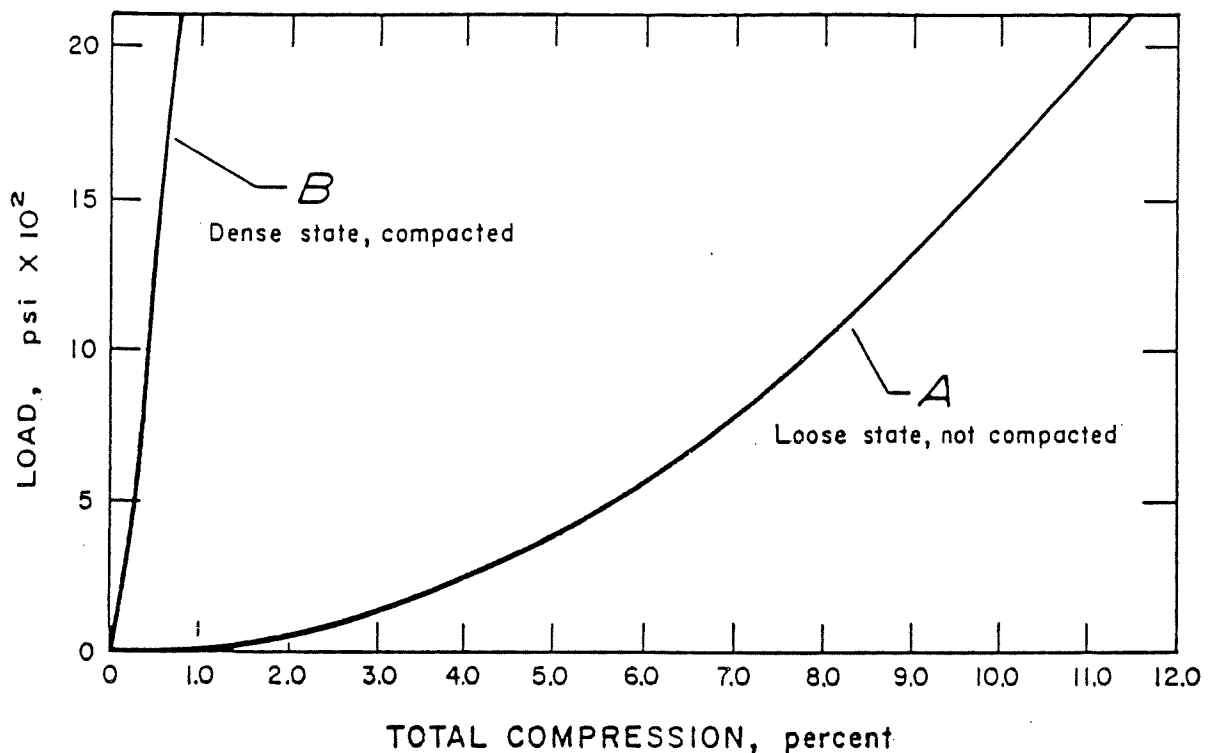


FIGURE 23. Confined compression tests with typical hydraulic backfill. Curve A represents the load compression relationship of a fill in its normal loose state of deposition; Curve B, after compaction to a high mass-unit weight. The results were obtained in laboratory compression tests. (57)

A moderate addition of cement has very little effect on the ultimate strength of backfill unless it is densely compacted and the cement is uniformly dispersed. In deep mines where the ultimate strength of cemented fill has been exceeded, the fill may lose its cohesion and behave like loose sand. In relatively loose packed fills, cement can help form hard working surfaces and add cohesion so that backfill will stand when exposed on a vertical face.

At the Ontario Division of Inco Metals Company, a shrink-fill method has been used and cemented sandfill faces from 80 to 140 feet high have been exposed with no major failures of fill and with minimal ore dilution. Sections are mined by a shrinkage method, then they are backfilled and sections directly adjacent are mined, exposing backfill in the previously mined stope. Then these sections are also back-filled. All mining operations are carried on from outside the stope. This improves safety, minimizes physical work, and eliminates the problem of maintaining an acceptable environment at the working face. Pillars are also removed in this manner, increasing ore recovery (7).

a. Protection Against Falls of Ground

Ore bodies which are judged to be too weak to form a competent back are sometimes mined by the undercut-and-fill method. With this method, mining progresses downward and cemented sandfill reinforced with timber and wire mesh form the back of the stope instead of natural material. This sandfill and timber remain above from the backfilling of the last pass of ore removal. Thus, in such cases, cemented sandfill makes mining possible in ore bodies which would be considered extremely unsafe by any other mining method because of heavy ground.

With other mining methods, the ground support provided by cemented or uncemented sandfill in mined-out stopes also tends to improve the stability of the mine and reduce fall of ground incidents. The degree to which sandfill can do this is not established to a high degree of certainty, but a considerable amount of research has been done in this area (46).

b. Protection from Overlying Bodies of Water

In some cases, an important positive effect of underground backfilling is the limitation of fracturing above the mine workings and thus the protection of overlying aquifers and surface water. If fracturing and subsidence connect such waters with the mine workings, the inundation of the mine would be catastrophic and there may be far-reaching damage to the natural hydrologic regime. In several iron mines in Michigan, backfill support was cited by the Safety Supervisor as being absolutely necessary to keep overlying bodies of water from flooding the mines (16). This effect may be more important in coal mining than metal mining, because metal mines tend to be located in high-relief areas where there are fewer sizable bodies of surface and ground water.

c. Minimization of Surface Subsidence

Backfilling underground mine voids is the most effective means to limit surface subsidence over underground mines. Because of the compressibility of backfill and gaps at the top of the fill target, subsidence often cannot be totally eliminated. Backfill is, however, especially effective in preventing 'chimney failures', where unconsolidated surface materials drop into shallow mine voids and leave large sinkhole depressions at the surface. By filling the available voids, backfilling eliminates most of the vertical movement of surface

materials. In some cases, mining companies have instituted backfilling programs largely to protect their own surface developments, and/or urban developments overlying the mine from subsidence damage.

d. Rockburst Control

Rockbursts often occur in cut-and-fill mining operations when a stope is advanced toward a previously mined (and filled) area. Stress becomes concentrated in the rock between the stope and the mined area and violent failure sometimes occurs. The energy released during the process is called a rockburst.

Two options are available for controlling rockbursts in cut-and-fill stopes. One is increasing the fill modulus and the other is destressing the pillar when a 'critical' geometry is reached. Using higher density fill should lessen the load on the pillar and reduce the possibility of a rockburst. Destressing the pillar at a pre-determined stage of mining is an attempt to release energy from the rock mass so that a violent rockburst does not occur later.

In order for fill to be effective in controlling rockbursts, it must carry enough load to substantially reduce the stresses in the pillar. In his paper, Crouch (13) concludes that high modulus fill is ineffective as a means of increasing the mine stiffness to the extent necessary to control rockbursts. He recommends that more attention be paid to optimizing destressing procedures than to producing very high modulus fill.

According to Coates (12), cemented sandfill support against wall closure is not likely much different from that of uncemented hydraulic fill. He further says that if rockbursts occurred before backfilling, they will probably still occur with cemented fill, but a small amount of firm support increases pillar strength significantly.

Obert and Duvall (45) say that backfill offers resistance when the opening starts to close and compress it. This causes a stress redistribution which reduces the stress concentration at the face and so reduces rockbursts.

2. Fire Hazard Suppression

In many underground metal mines, ore and wall rock contain sulfide minerals which are prone to rapid oxidation. This oxidation reaction produces large amounts of heat and gases and

can cause chronic fire problems. Not only can heat generated in this way start open flames on combustible materials such as timbers, but the sulfides also can burn. An ordinary fire with open flames is really a type of rapid oxidation reaction. Sulfide fires are hot masses of rapidly oxidizing sulfides, releasing large amounts of heat and unbreathable smoke, but with no flames being present.

Sulfide fires are extremely difficult to extinguish. Inundation with water alone has been ineffective in fighting these fires, and the only method known to extinguish sulfide fires is to fill the affected area with hydraulic sandfill, effectively stopping the oxygen supply. The backfill continues to retard fire after dewatering and resumption of mining.

One iron mining company in Michigan backfilled underground workings in large part to control the oxidation of pyritic-carbonaceous slates which were causing fire problems that interrupted production (16).

Another way backfilling can help increase fire safety is when it is used in conjunction with timber support. When timbers are surrounded by sandfill, oxygen supply is cut off and the timber cannot burn. However, it must be remembered that if the sandfill is capable of self heating, the buried timbers might give off large amounts of carbon monoxide, which would seep out of the filled stope and contaminate the mine atmosphere.

3. Improvement of Mine Atmosphere

Ventilation of mined-out stopes is necessary because dangerous levels of gases and heat can evolve and so create hazards to miners in other parts of the mine. Backfilling of these stopes decreases the ventilation demand, improves ventilation control and helps lower air temperatures (56). In addition to reducing the total volume of underground space to be ventilated, backfilling simplifies and shortens ventilation circuits and lessens energy loss due to friction. In hot mines or at deep levels where the surrounding rock is hot, backfilling a stope greatly reduces the amount of exposed wall rock, thereby reducing the amount of heat absorbed by air from wall rock. Backfilling basically reduces the volume of open space in mines, and therefore reduces the amount of ventilation required to maintain air quality.

4. Waste Disposal

Underground metal mining is often conducted in mountainous areas where many metallic ore deposits are found. The high-relief topography in these areas can be a difficult obstacle for safe, environmentally sound surface disposal of mine and mill wastes. The main reason for backfilling in these areas, however, is that cut-and-fill stoping methods are often the only suitable mining methods for these orebodies.

Underground mine waste disposal in metal mines works to improve pollution control and minimize erosion that occurs on surface waste banks. Surface waste banks are subject to weathering which releases metal ions, sulfate, and increased acidity. Also, erosion at these waste piles decreases stability of the piles and degrades streams with increased sediment.

a. Pollution Control

The degree of water pollution control resulting from underground mine backfilling has not been demonstrated. With underground disposal, oxidation of mine waste should be reduced, especially if filled portions of the mine are flooded after completion of mining. Once the mine is abandoned, sand-fill should help raise water levels and reduce the amount of oxygen diffusion through underground mine voids. This technique should be particularly effective in semiarid and arid regions in underground mines producing no discharge.

5. Ranking of Positive Effects

For the ranking of hazards associated with underground mine waste disposal, the consequences of each hazard and its probability of occurrence were considered in order to rank them in order of importance. This type of approach is much more difficult to use for the ranking of positive effects because the positive effects are much more dependent upon site-specific conditions. For example, protection of an overlying body of water is a positive effect only if backfilling is done beneath a body of water. Likewise, suppression of sulfide fires is a positive effect only in mines which have the conditions that lead to such fires. The degree of hazard abatement provided by backfilling in these cases would be high, but would be nonexistent in other situations.

Some of the positive effects of backfilling do tend to occur no matter what the site-specific conditions are. Minimization of surface subsidence and improvement of mine atmosphere are examples.

A system of classification similar to that used to classify hazards is used here to classify positive effects. The hazard consequence categories (see Table 27) are used to classify the potential consequences of hazards which are abated by backfilling, and they are the same as those used to classify hazards. Then, instead of the hazard probability category, a hazard abatement category is chosen from Table 30. This category identifies the degree to which a hazard is diminished by a positive effect of backfilling.

TABLE 30. - Hazard Abatement Category (qualitative estimate)

Abatement Category	Explanation
A	Highest possible. Positive effect will likely eliminate or greatly reduce the hazard it works against.
B	Positive effect will reduce a hazard significantly.
C	Positive effect will reduce a hazard to a small degree.
D	May not have any positive effect at all.

The classifications obtained by this process are then used to help rank the positive effects of backfilling in order of importance with the most important effect at the top of the list. Table 31 depicts a ranking of positive health and safety effects of underground mine waste disposal and a discussion of each follows. This ranking is generalized for the whole industry, and it is suggested that mine operators refine this version to fit their own operation.

TABLE 31. - Ranking of Positive Health and Safety Effects
of Backfilling in Metal Mines

Rank	Consequence and Abatement Categories	Positive Effect
1	I.A.	Safe working platform
2	I.B.	Protection against falls of ground
3	I.B.	Fire hazard suppression
4	I.B.	Improvement of mine atmosphere
5	I.B.	Protection of overlying bodies of water
6	II.A.	Minimization of surface subsidence
7	II.C.	Pollution control
8	I.D.	Rockburst control

a. Safe Working Platform

In most overhand cut-and-fill operations, cemented sand-fill provides a smooth, hard surface on which men and machines perform drilling, blasting, and mucking procedures. Alternative working platforms include broken ore, possibly covered with sheets of steel or plywood. These alternative working platforms are labor-intensive to install and remove and can cause accidents because of difficulty in walking and controlling machines on these unstable surfaces. Cemented sandfill will greatly reduce such potentially fatal accidents, and so this effect is classified I.A. and ranked number one.

b. Protection Against Falls of Ground

This is an important reason for backfilling in most metal mines. Some orebodies cannot be mined with an acceptable margin of safety without the use of filling methods because of the support requirements of unstable ground. Other orebodies can be mined with more complete extraction because of support

provided by sandfill. Even in cases where ground support is not the main purpose of backfilling there is probably some support advantage gained from backfilling.

This effect of backfilling significantly reduces a potentially catastrophic hazard, and so it is classified I.B. and ranks as the second most important positive effect of backfilling.

c. Fire Hazard Suppression

Hydraulic backfilling in metal mines can reduce the risk of fire by restricting air circulation near support timbers and oxidizing sulfides. It cannot completely eliminate such fires because there are many parts of mines which must remain open and ventilated so that mining can proceed. The risk of oxidizing sulfides and timber fires remains in these open areas, but these areas are easier to monitor for fire than mined-out stopes. Fire hazard suppression is classified I.B. because mine fires are potentially catastrophic and backfilling reduces these hazards very significantly. It is ranked below protection against falls of ground because some mines do not have problems with sulfide oxidation and some do not have support timbers and consequently no fire hazards from these sources.

d. Improvement of Mine Atmosphere

The elimination of dead air spaces and reduction of ventilation requirements is an important benefit of backfilling, especially in hot mines or mines where gases like carbon dioxide might build up in mined-out stopes. Problems from heat can be critical and gas accumulations in dead air spaces can be fatal. Backfilling can significantly reduce these problems, so this effect is classified I.B. and ranked in fourth position.

e. Protection From Overlying Bodies of Water

Underground mine backfilling is effective in maintaining rock integrity over mines and therefore helping to prevent mine inundation from overlying surface and ground waters. This effect is classified I.B. because mine inundation is catastrophic and backfilling provides significant protection from this hazard. It is ranked fairly high on the list, number five, but it only applies when overlying bodies of water threaten to flood a mine.

f. Minimization of Surface Subsidence

Surface subsidence caused by underground mines can be minimized to a large degree by backfilling. Mine subsidence is not usually a life-threatening hazard unless it affects roads or buildings or other developments. Backfilling can very effectively minimize this hazard in most cases so this effect is classified II.A. and ranked sixth.

g. Pollution Control

As stated elsewhere in this report, the degree of pollution control resulting from underground mine waste disposal has not been clearly demonstrated. However, there are good reasons to believe that it can reduce pollution from metal mining, especially when the water table rises above the deposited mine waste after mining ceases (49). This effect is therefore classified II.C. and ranked in seventh position.

h. Rockburst Control

The opinions of rock mechanics experts on the effectiveness of backfilling to control rockbursts varies somewhat. Some say it is ineffective (12, 13) and others say it has some effect (45). Because of this uncertainty, it is classified I.D., meaning that it may have no positive effect at all against potentially fatal rockbursts.

D. Management's Role in Minimizing Health and Safety Hazards in Underground Metal Mine Waste Disposal

Accidents are costly in any industry because they reduce the efficiency and effectiveness of an operation and therefore raise production costs. Injury, materials waste, equipment damage, and other property losses increase operational and hidden costs. Much of the following information is taken from Accident Prevention Manual for Industrial Operations - Administration and Programs, published by the National Safety Council (39).

A successful program of hazard control in mine waste disposal requires a team effort from various departments. Engineering departments must design facilities which are free of uncontrolled hazards and provide technical services to other

departments for hazard identification and analysis. Purchasing departments must acquire materials and equipment which meet established health and safety standards and disseminate related health and safety information to supervisors and workers. Maintenance departments must perform the proper preventive maintenance on electrical systems, backfilling machinery, etc. Management must coordinate these departmental efforts. Mining and backfilling crews must also be well coordinated to avoid congestion and other unsafe situations.

An effective hazard control program has six essential processes:

1. Hazard identification and evaluation
2. Ranking hazards by risk
3. Management decision making
4. Establishing preventive and corrective measures
5. Monitoring, and
6. Evaluating program effectiveness.

A good way to identify and evaluate hazards associated with underground mine waste disposal, or any industrial operation, is to select a few individuals who perform the work and interview them about existing hazards and unsafe conditions that have come to their attention. This procedure should be repeated periodically to reveal new problem areas and measure the effectiveness of the accident prevention program.

Ranking hazards according to consequence and probability as was done in this report allows management to address hazards on a 'worst first' basis. This will help improve the efficiency of the accident control effort.

Management must get full, accurate information including all alternatives so that it can make intelligent, informed decisions. It is important to define the underlying problem and avoid treating only the symptoms. For example, rescheduling mining and backfilling crews may alleviate congestion problems, but layout and equipment design and selection might also reduce congestion and allow more flexible scheduling. Alternatives may include training and education of workers, better methods and procedures, equipment repair or replacement, environmental controls, or, in rare cases where modification cannot suffice, redesign.

Preventive and corrective measures are put into effect through administrative controls and engineering controls. Administrative controls include personnel, management, monitoring, limiting worker exposure, measuring performance, training and education, housekeeping and maintenance, and purchasing. Engineering controls include isolation of source,

lockout procedures, design, process or procedural changes, monitoring and warning equipment, and chemical or material substitution. The initiation of a backfilling operation involves major changes which might be met with resistance on the part of the workers. When implementing new preventive and corrective measures, management must include ways to minimize the resistance to change. The greater the departure from the accepted ways of the past, the greater the potential is for resistance on the part of the people involved.

Monitoring includes inspection, industrial hygiene testing, and medical surveillance. Monitoring is necessary: (a) to confirm that hazard controls are working properly; (b) to make sure that modifications have not so altered the workplace that hazard controls cannot function; and (c) to discover hazards that are new or previously undetected. Important items to be monitored include slurry pipes, temperature and moisture content of in-place fill, harmful chemicals, dust levels, and health problems among workers.

Evaluation of the safety and health program involves answering pertinent questions. How much is being spent to locate and control hazards? What benefits are being received (e.g., reduction of injuries, workers' compensation cases and damage losses)? What impact are the benefits having on improving efficiency and effectiveness? The answers to questions like these should show that well-planned accident control programs are cost-effective, and that the best way to do the job is also the safest way.

IV. CONCLUSIONS AND RECOMMENDATIONS

A. Conclusions on Health and Safety in Underground Coal Mine Waste Disposal

While the use of backfilling is a century old, its desirability and techniques of placement have changed considerably. Its use has been most popular in Europe, being used primarily as a subsidence control measure. Due to the limited coal resources in Europe, backfilling was practiced to achieve maximum resource recovery while limiting the subsidence effects. Backfilling benefits these objectives well even though it is a costly activity. However, in the United States, backfilling has been used only on rare occasions and only in a remedial role. The United States' coal resources are much more vast, often being located in regions of moderate to minimal development. As a consequence, coal mining in the United States has been practiced to achieve high production with low costs. Backfilling did not benefit these objectives, but hindered them, and consequently has not been accepted to a large degree in the United States. This study was conducted to investigate the health and safety hazards and benefits that may be encountered through backfilling.

The hazards that will be encountered through the use of backfilling fall into two categories. One, hazards that are encountered during backfilling activities which are unaffected by the activity or which are not significantly new to the mining environment. Two, hazards whose potentials are increased by the use of backfilling activities or which are new to the mining environment because they are particular to backfilling. On the following page is a list of these hazards by category and in order of importance from top to bottom.

Those hazards which are not unique to backfilling and are unaffected by its activities can have significant impact upon personnel who must participate in backfilling activities. The primary hazard, being ranked the number one overall hazard in this group was roof falls when stowing adjacent to the active face. Haulage related accidents also ranked as having a significant hazard impact on backfilling personnel depending on where the haulage routes are located.

While some of these hazards are variable depending on design or operation of equipment, other hazards are inherent to mine conditions. In these cases, the choice of mining method, backfilling method, and location of stowing dictate the risk.

Hazards unaffected by
backfilling

Roof falls when stowing
at the face

Haulage accidents -
working level

Haulage accidents -
surface to level

Haulage accidents -
surface

Hazards affected by
backfilling

Spontaneous oxidation of fill

Dust Generation with pneumatic
stowing

Dust explosions with pneumatic
stowing

Congestion accidents when stowing
at face

Slurry spillage when using
pipeline

Fall of material through the
lining at the face

Quick conditions during hydraulic
stowing

Roof falls when backfilling away
from the face

Pillar Punching

Inplace fill quick conditions

The greatest risk to backfilling crews occurs when backfilling adjacent to an active face as compared to backfilling in mined out panels. Of the mining methods employed with backfilling, longwall mining exhibits the greatest accident frequency. However, this accident frequency does not appear to be much different from longwall mining with caving. Shortwall mining with caving has a much lower accident frequency than longwall mining. However, the use of backfilling in conjunction with shortwall mining does adversely impact the accident frequency.

Regardless of whether particular hazards are more related to one stowing method or another, the overall accident potential for pneumatic stowing appears to be the same as for hydraulic stowing.

The risks involved with stowing in mined out panels are considerably less. Provided careful evaluation and design is employed, backfilling in these areas should be relatively safe.

The health and safety benefits gained through the use of backfilling range from well documented, effective applications, to benefits of minimal impact identified through deductive reasoning. The health and safety benefits derived through backfilling are listed below in their order of importance from top to bottom.

- Control of subsidence damage
- Improvement of mine structural stability
- Mine seepage and flood control
- Hydrologic protection
- Reduction of mine collapse
- Improved sealing
- Arrest of mine fires
- Control of gas emission at the face
- Control of bumps

The top three benefits have been proven in actual applications. Control of subsidence damage has been the most widely accepted purpose for backfilling in both Europe and the United States. While backfilling does not prevent subsidence effects, it does limit its impact.

Excluding subsidence control, the health and safety benefits from backfilling have not warranted its use except under extreme conditions. The application of backfilling has ranged from blanket acceptance (Poland) to complete rejection (Great Britain). In most cases the use of backfilling has had to stand on its own merits.

The successful application of backfilling to minimize health and safety risks will require the following considerations.

Evaluation of backfill material

- Design of backfilling method, stowing location, and equipment to be compatible with the production operations and to minimize risk.
- Specifications of operational procedures to minimize risk.

- Management's acceptance of the application and willingness to see that it is performed correctly and safely.

As with any activity associated with underground mining, planning, training, observation, and cooperation between management and the workers are the requirements to minimize the hazard to personnel and the environment.

B. Conclusions on Health and Safety in Underground Metal Mine Waste Disposal

The main purpose for the return of metal mine waste to underground mines is to support the mine workings. It requires relatively little labor and provides the best means of support in deep metal mines, especially when used in conjunction with portland cement and/or square sets. While the importance of this support may vary from mine to mine, there probably is some benefit in all cases.

Other safety and health benefits attained through backfilling may be extremely important in some mines, and nonexistent in others. Therefore, it is important for mine operators to consider which benefits may be important to their operation when weighing the safety and health effects of backfilling.

The following is a list of known and potential safety and health benefits attributable to underground mine waste disposal. They are arranged in order of relative importance from top to bottom. This ranking order is generalized and must be revised when applied to a specific operation.

- Safe working platform
- Protection against falls of ground
- Fire hazard suppression
- Improvement of mine atmosphere
- Protection from overlying bodies of water
- Minimization of surface subsidence
- Pollution control
- Rockburst control

Almost any of these benefits could be the most important one, depending on the situation. Control of pollution and rockbursts are potential benefits which have not been well documented and professional opinion on these effects are varied.

Hazards associated with underground mine waste disposal are somewhat less dependent upon site specific conditions with the exceptions of toxic or reactive compounds, oxidation and combustion, and water pollution. These hazards are dependent upon the mineralogy of the fill material and mill chemicals and additives in the fill.

The list of underground metal mine waste disposal hazards which follows is a generalized ranking, from most to least hazardous. It can be refined to fit specific situations.

- Spillage from pipes and bulkheads
- Toxic or reactive compounds
- Unstable rock and fill
- Oxidation and combustion
- Water pollution from mill tailings
- Construction injuries
- Operation of stowing equipment
- Drilling operations
- Liquefaction of fill
- Electrokinetic treatment

The following conclusions are presented for the purpose of making mining personnel aware of all known and potential health and safety hazards directly or indirectly related to underground metal mine waste disposal and ways in which these hazards might be abated.

Spillage hazards are much the same for all hydraulic backfilling operations. Spills can cause congestion, deviation from scheduled safe procedures, more man-hours of underground work, and muddy, slippery conditions for miners. It is probably the most common hazard in hydraulic backfilling. Slurry pipes should be located so that they are less likely to be struck by mobile equipment. Horizontal and inclined pipes can be rotated a fraction of a turn for even wear and fewer leaks. Couplers should be properly fastened and checked for faults. Plastic burlap filters on timber bulkheads will not rot and are less likely to allow spillage of solids through bulkheads.

Toxic or reactive compounds of concern here include portland cement and chemicals remaining in mill tailings such as cyanide. Cement dermatitis is common where cement is used and cyanide and possibly other chemicals reagents can have toxic effects on personnel. Cement dermatitis can be averted by using waders and by applying a protective cream to the skin when contact with cement slurry is anticipated. Chemical reagents should be monitored at the sand plant and if present in dangerous quantities, they should be removed or neutralized. Cyanide salts can be broken down by potassium permanganate and bleaching powder, thus eliminating the toxic effects. Acid might be generated by spontaneous oxidation, and can be neutralized with lime or other alkaline material, but heat and dangerous gases are the important hazards of oxidation.

Unstable rock is a hazard incurred by all underground personnel and unstable fill is a concern in undercut-and-fill operations and situations in which there is a substantial fill height. One way to limit these hazards is to limit underground man-hours through the use of less labor-intensive techniques.

Temporary ground supports should be installed as soon as possible after ore is moved. In undercut-and-fill operations concrete and timber retaining structures should be strong enough to provide a safe back in the working stope.

Spontaneous oxidation and combustion can be a difficult problem in hydraulic backfill which contains reactive sulfide minerals. The use of cement may be an effective abatement measure because it tends to limit permeability and oxygen supply to the sulfides. The addition of lime to adjust pH might retard the oxidation reaction. Reduction of ventilation in the filled area when there is either very slow or very fast oxidation might retard the reaction. Fill material should be tested for its tendency to rapidly oxidize so that such problems can be anticipated.

Water pollution from mill tailings can come from chemical reagents used in the milling process and chemical reactions with minerals in the fill. It may be necessary to use elaborate treatment techniques on mine drainage discharged on the surface.

Construction injuries can be minimized by providing well-maintained tools which are appropriate for the given task. Safe work techniques such as proper lifting and timbering methods should be taught and encouraged by supervisors.

Of prime concern in the operation of hydraulic stowing equipment is the communication between the man at the stope and operators at the sand tank and the sand plant. Constant communication by phone has been shown to be effective to quickly shut down the equipment in case of spillage, congestion, or other problems. Pumps can be designed to shut down automatically in case of an overload to prevent equipment damage. Water and sand storage tanks should be inspected for structural flaws that might make them unstable. Mechanical hazards can be reduced with an efficient, uncrowded layout of equipment with the proper guards and warning signs. Electrical equipment must meet safety regulations and receive regular inspections. When mobile equipment is used to dump development waste, firm control must be maintained and hazards such as obstructions along newly-traveled routes should be anticipated.

Drilling operations are rarely used for active mines because boreholes are not practical for delivering fill to small stopes at great depth. Experience has shown that when boreholes are drilled into mine voids there are no special health and safety hazards except for an extremely remote chance of catastrophic mine subsidence. The only way to avoid that is to follow a prudent mining plan using sound rock mechanics principles when workings are designed.

Liquefaction of fill is a potential hazard that can be mitigated by the installation of adequate drainage devices in the fill in order to keep water saturation from occurring after emplacement. Well-graded fills tend to have less void space after emplacement and can not soak up as much water and so are less prone to liquefaction. Properly cemented fills should be incapable of liquefaction.

Hazards associated with electrokinetic treatment of mine waste have been studied in depth and the conclusions of that study are reproduced in the section on electrokinetic treatment.

The overall health and safety effects of underground mine waste disposal are thought to be very positive, provided an effective hazard control program is implemented and well managed. It is hoped that this report will improve the health and safety effects of these operations.

C. Recommendations on Health and Safety in Underground Mine Waste Disposal

The literature research that was conducted for this report made it apparent that very little work had been done to compile statistics and other information on this subject. Although mine accident reporting is probably more thorough and comprehensive in the United States than in most foreign countries, some of the best accident statistics obtained for this report come from foreign countries such as Poland. This is probably because underground mine waste disposal has been more extensively practiced in the coal mines of Poland and other foreign countries. As underground disposal becomes more prevalent in the coal mines of the United States, more accident and health statistics should be generated which will aid hazard control efforts.

Probably the most important shortcoming of the accident research performed for this report is the lack of backfilling-related accident reports for both coal and metal mines. Computer searches of accident report files were performed repeatedly, producing very few reports of backfilling accidents. The few accident reports which were discovered are probably not representative of the hazards encountered in backfilling operations. In fact, the accident case study involving a fall of fill which is presented in this report was not discovered in a computer search of accident reports of that time period. Clearly, accident reporting procedures will have to be refined if statistics on backfilling-related accidents and health hazards are ever to be compiled.

When designing an underground backfilling operation it is important to identify and prioritize potential hazards according to local conditions and requirements. A health and safety program should then be devised to address these hazards. This process should result in preventive measures for such hazards as toxic compounds, oxidation potential, water pollution, dust generation, and potential liquefaction of fill. Monitoring is another important part of a health and safety program. Important items to be monitored include slurry pipes, temperature and moisture content of in-place fill, harmful chemicals, dust levels, and health problems among workers.

A health and safety program covering a backfilling operation should also include emergency procedures which are brought to the attention of the appropriate personnel. These procedures should address such situations as large spills, major liquefaction events, excessive oxidation, and falls of rock and fill. Remedial procedures may also be included to define cleanup priorities after large spills or liquefaction events and to serve as a guide to check oxidation.

Another finding of this investigation is that some of the hazards of underground mine waste disposal have not had adequate experimental study. Experimentation on the oxidation potential of coal and metal mine wastes in the mine environment would be a great aid to hazard control. It may be possible to devise an index of combustibility for coal mine waste and a guide to critical hazardous temperatures for oxidizing coal and metal mine wastes. Likewise, the potential for liquefaction or quick conditions in actual mine waste in the mine environment apparently has not been experimentally evaluated.

Pipe wear experiments with mine wastes used as backfill might lead to the design of safer slurry systems. Modern plastics may prove to be the best and safest materials for slurry transport pipelines.

The reduction of mining related pollution through underground disposal is not well documented. Comprehensive pollution monitoring programs applied to mining operations with surface disposal and other operations with underground disposal would provide comparative evidence on this issue.

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