Harold Owens

H. Owens

STATE-OF-THE-ART IN EXTINGUISHING REFUSE PILE FIRES

Malcolm O. Magnuson and Eugene C. Baker

Bureau of Mines, U.S. Department of the Interior

This Paper Presented Before The

FIRST SYMPOSIUM

On

MINE AND PREPARATION PLANT REFUSE DISPOSAL

Coal and the Environment Technical Conference
October 22-23-24, 1974
Kentucky Fair and
Exposition Center
Louisville, Kentucky

Sponsored by

NATIONAL COAL ASSOCIATION

STATE-OF-THE-ART IN EXTINGUISHING REFUSE PILE FIRES

Malcolm O. Magnuson and Eugene C. Baker

Bureau of Mines, U.S. Department of the Interior

This Paper Presented Before The

FIRST SYMPOSIUM

On

MINE AND PREPARATION PLANT REFUSE DISPOSAL

Coal and the Environment Technical Conference
October 22-23-24, 1974
Kentucky Fair and
Exposition Center
Louisville, Kentucky

Sponsored by

NATIONAL COAL ASSOCIATION

STATE-OF-THE-ART IN EXTINGUISHING REFUSE PILE FIRES[1]

by

Malcolm O. Magnuson and Eugene C. Baker

Bureau of Mines, U.S. Department of the Interior

INTRODUCTION

The art of extinguishing mine refuse pile fires is a relatively new one. Until recently there was not much concern about the burning gob dump. In the mining community it was accepted as a necessary evil. It was usually in an isolated area and the burning of the pile was considered inevitable.

DISCUSSION OF CAUSES OF REFUSE PILE FIRES

When we examine the major cause of their ignition we are struck by the relative simplicity of preventing these fires. The custom which set up the conditions for the mine refuse fire was the almost universal practice of dumping the material over a long slope which segregates and stratifies the refuse. This is illustrated in figure 1 which shows a sectional drawing of a pile of ungraded refuse. Large particles roll to the bottom while the small particles remain at the top. As the pile is built outward the material is stratified. Stratification creates a condition whereby the air enters at the bottom of the pile and circulates up through the stratified material as shown by air paths A, B, and C. Whether or not the pile will fire spontaneously is influenced by many physical, chemical, and atmospheric factors. But the factor of most concern is the relationship between the heat rise and the amount of ventilation along the air path.

Figure 2[2] illustrates this relationship. The horizontal distances represent the amount of ventilation of a portion of a refuse pile and the vertical distances represent the rise in temperature. With no ventilation, there will be no rise in temperature. The zero ventilation point represents the condition of a refuse pile sealed from the air or so densely packed that air cannot circulate through it. If on the other hand, there is ample ventilation, the heat is carried away as fast as it is generated. At the ample ventilation point there is no rise in temperature. Air path A shows an area approximating this condition where the air circulates through coarse refuse at the bottom of the pile. At some point between these two extremes, as indicated at path B,

---

[1] Presented by M. O. Magnuson, Environmental Coordinator, Coal Mine Fire Control Group at Coal and the Environment Technical Conference, Kentucky Fair and Exposition Center, Louisville, Ky., Oct. 24, 1974.

[2] Scott, G. S. Anthracite Mine Fires: Their Behavior and Control. BuMines Bull. 455, 1944, 14 pp.

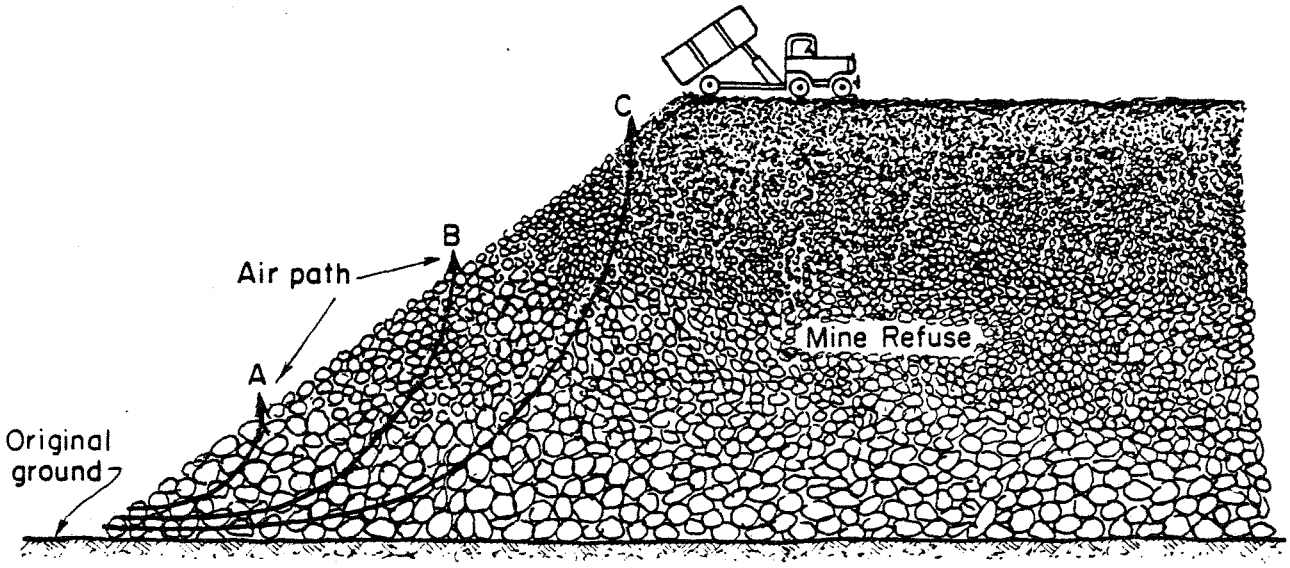

FIGURE 1. - Sketch showing circulation of air through mine refuse material which has been segregated and stratified by dumping over a slope.

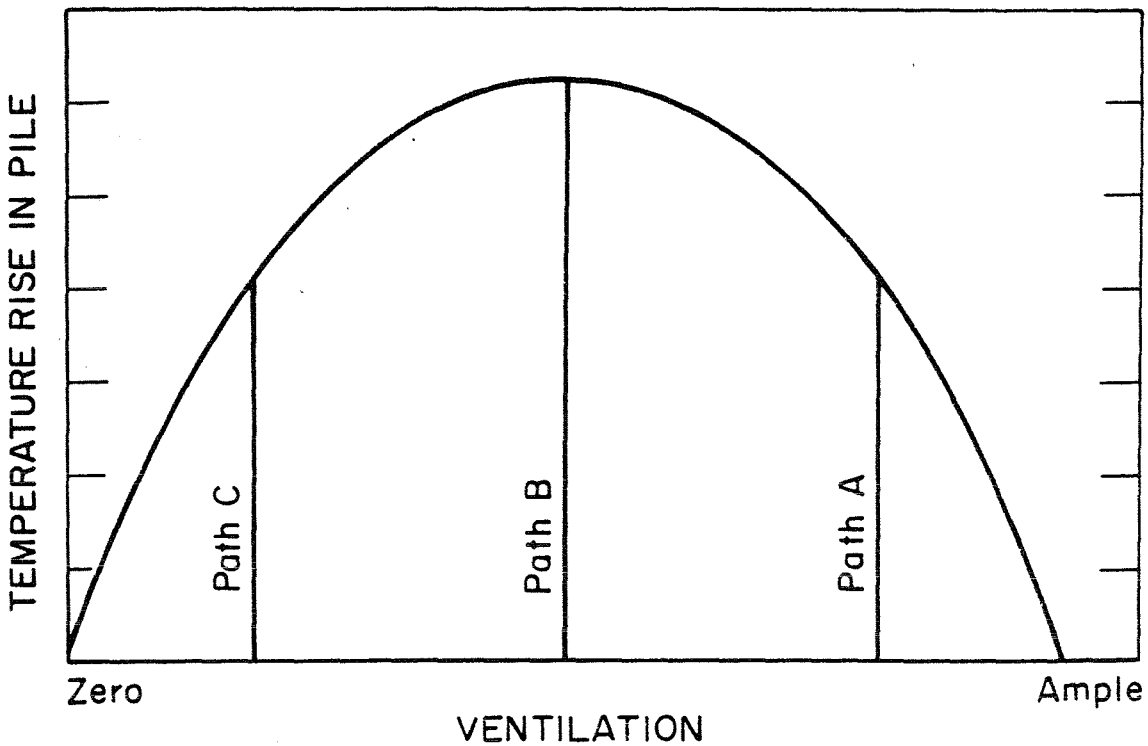

FIGURE 2. - Relation of heating to ventilation in mine refuse pile shown in figure 1.

there is a condition of ventilation which will supply just enough oxygen to provide a maximum rise in temperature but not enough air to cool the path. What sort of a curve represents all of the intermediate conditions between zero ventilation and ample ventilation, we do not know but that the curve must first rise and then fall is evident. This curve shows that if we have a condition of ventilation as at path C an increase in ventilation to path B will produce a more favorable condition for a temperature rise. On the other hand, if the original condition is at path B and we increase the ventilation to path A, we can expect a reduction in temperature. Since there is no way of knowing just what the ventilation is in any given portion of the pile there is great hesitancy in advocating ventilation schemes to prevent fires in refuse piles as we are more likely to make trouble than to prevent it. Returning to figure 1--along path A, the air would move freely through the coarse particles and the area of the coal surface exposed would be a minimum, hence we would have little likelihood of ignition. Along path C, the movement of the air would be at a minimum. The total active surface would be great, but if the fine refuse at the top of the pile was densely packed this would prevent the passage of air and there would be no ignition. Somewhere between the two extremes, as along air path B, there will be an area where the ventilating current is just sufficient to supply oxygen for a maximum rise in temperature and insufficient to remove the heat as generated. This discussion illustrates among other things why the height of the refuse pile is a factor in whether it will fire spontaneously. If this type of dumping is performed, the height of the pile should be kept to less than 10 or 12 feet.

Along the path B flow of air, carbonaceous material in contact with oxygen will oxidize with the liberation of heat. This heat will cause a rise in temperature of both the refuse material and the air. The temperature difference thus creates a chimney effect within the refuse pile causing air circulation through it. This air circulation not only supplies oxygen for further oxidation but carries heat to the material above. As the temperature increases, the oxidation rate also increases. During the initial heating period, the heat liberated is in part carried along the path of air circulation so that there is an accumulative effect, the highest temperature being at a point where the air leaves the refuse pile. As the temperature rises, the oxygen in the emerging air becomes less and less so that oxidation near the point of emergence is slowed. The most active oxidation then takes place in a region below the area of emergence. Continuation of this process causes the hot spot to travel toward the source of air and therefore deeper into the pile. Some observers have stated that, in general, hot spots in large refuse piles are found in the region from 5 to 8 feet below the surface on the slopes of the pile.

Ordinarily, if the refuse is allowed to heat spontaneously to a temperature approximating that of the boiling point of water (212° F) the temperature will rise at an accelerated rate and the pile will ignite.

The factors we have discussed are primarily concerned with the physical condition of the refuse and the construction of the pile. Chemical factors such as the self-heating tendency of freshly exposed coal, decreased action with exposure, and carbonaceous content of the refuse material also have an effect.

A major chemical influence is the distribution of pyrites or iron disulphide (FeS_2) within the refuse pile. Any form of pyrite in a finely divided condition will absorb oxygen gradually from the air with consequent heat production. Sulfur and moisture have an accelerating effect on the heating of a pile. Pyrite in the presence of moist air oxidizes to ferrous sulphide expanding in volume and liberating heat. In expanding, it breaks the carbonaceous material into smaller particles increasing the amount of surface exposed to oxidation. It is suspected that in many cases finely divided disseminated pyrite initiates the heating. The heat produced from the oxidation of pyrites is double that produced by the oxidation of coal for the same amount of oxygen absorbed. In addition, the oxidation rate doubles with each rise of 10° C in temperature.

An understanding of these conditions has led to regulations for the prevention of refuse pile fires.

METHODS OF PILE CONSTRUCTION TO PREVENT FIRES

In 1968, the Bureau of Mines conducted an investigation to locate and examine burning coal waste piles in the 26 coal-producing States.

Two hundred and ninety-two smouldering or burning piles were located in 13 States. Ninety percent of these were found in the Appalachian region.

Of the 292 burning piles, 66 percent were believed to have been ignited by heat of combustion resulting from the flow of air through the refuse.

Bureau of Mines Information Circular 8515 details information on coal refuse fires and their environmental impact.

Coal waste fires may very well be a thing of the past. Most coal-producing States have developed guidelines and enacted regulations that incorporate and insure proper disposal practices, methods of pile construction, and reclamation requirements.

By virtue of Federal Rules and Regulations made effective on June 30, 1971, the States have had the benefit of the Federal Mining Enforcement and Safety Administration's involvement in the construction of refuse piles.

The most important measures stressed by the Federal regulations are: locating refuse piles a safe distance from the active mining operation and facilities, or abandoned openings; clearing disposal site of vegetation; compacting each 2-foot layer of refuse; sealing of open-end(s) and slope(s) with clay or inert material to prevent air circulation, and constructing the refuse surface to facilitate proper water drainage.

New regulations will soon be in effect to require the construction of impoundments for the collection of water and silt.

Following are two methods of coal waste pile construction offered for consideration:

A. The Uncompacted Seal Method (Figure 3)

This pile could be constructed on a flat area which would require uncompacted seals around the pile, or the pile could be butted against a hillside with the exposed slopes sealed.

The sequence of construction steps are:

1. Pile clay in a mound at least 6 feet high.

2. Between the uncompacted clay seal(s) spread refuse 2 feet deep, butted against the seal, and compact.

3. Top this layer with two additional layers 2 feet thick and compact each layer.

4. Steps 1, 2, and 3 are repeated to desired height. Subsequent clay mounds are inset to provide a final slope of about 50 percent.

B. The Compacted Seal Method (Figure 4)

This pile could also be constructed on a flat area or butted against a hill.

The sequence of construction steps are:

1. Pile clay (or other inert material) in a mound at least 6 feet high.

2. Spread two layers of compacted refuse against clay pile then compact clay pile by leveling top of pile and compacting.

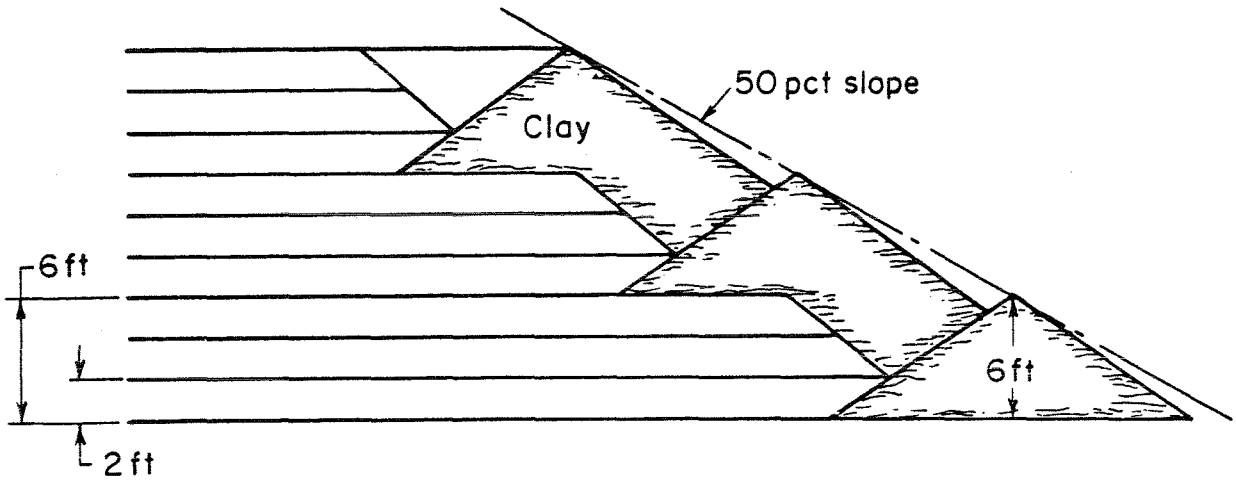

FIGURE 3. - Uncompacted seal method of mine refuse pile construction.

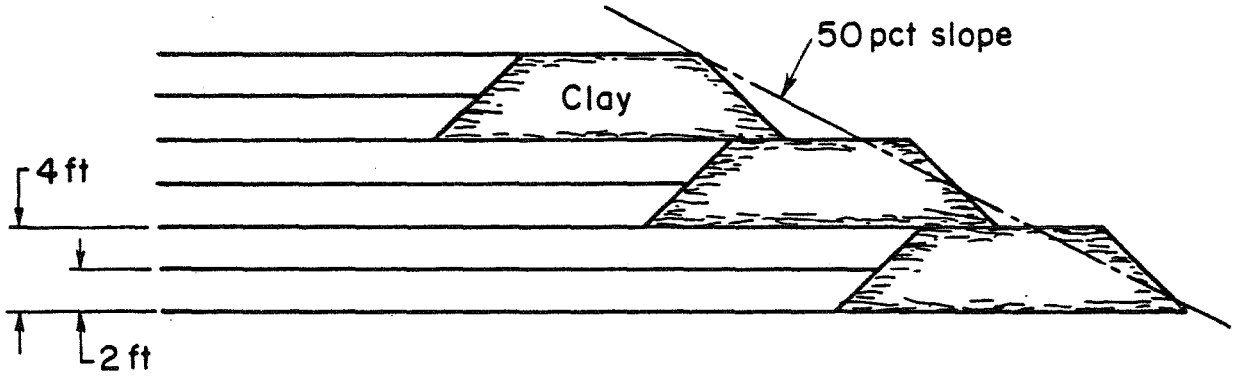

FIGURE 4. - Compacted seal method of mine refuse pile construction.

3. Repeat steps 1 and 2 to desired height but inset subsequent clay piles to obtain final slope of 50 percent.

METHODS OF EXTINGUISHING REFUSE PILE FIRES

Although the new regulations on construction of refuse piles may mean the end of new fires we will still have the smouldering abandoned refuse pile around for some time. There has been some attempt to devise sophisticated, space-age methods of extinguishing them but to my knowledge none has shown any promise. The extinguishment of a mine refuse pile fire is essentially a job of cooling the refuse material to normal ground temperature. The major obstacle is the difficulty in dissipating the heat in the noncarbonaceous as well as the carbonaceous material in the interior of the pile. This heat has usually accumulated over a long period of time because of the insulating effect of the noncarbonaceous materials. Unlike most fire situations the heat of combustion is largely stored in the affected material.

An examination of the methods which have been used to control these fires reveals that the dissipation of heat is the essential problem and success or failure usually depends on how effectively this problem is solved. The control methods can be divided into three categories:

A. Dig out and cool the affected material.

B. Cover to seal the pile against air circulation.

C. Grout to solidify the affected material.

Digging out the affected material, method A, is the most effective in cooling the pile because the material is spread out and cooled either by exposing it to the air or if necessary by the application of water. By covering, method B, the heat is dissipated slowly because of the insulating effect of the sealing cover, in addition to the conditions which are normal to this type of fire. Therefore the seal must be maintained until the pile cools. In the grouting method the hot areas are solidified so that there can be no air circulation. Here again, cooling is a slow process but maintenance of the pile during cooling should not be a problem because the hot material cannot get air.

Method A--Dig Out and Cool the Affected Material

In light of this consideration it is understandable that the most effective method of control is to dig out the heated material, cool and repile it.

The digging out is performed by a combination of earth-moving equipment suited to the size of the pile and the intensity of the fire. Most fires of this type are controlled by using a bulldozer to dig into the hot material and spread it out to cool.

Execution of this type of operation generally varies only in the difficulty involved in handling the hot material. Some operations, where the fire is particularly intense, require large amounts of water. Water cooling may be required both before and during the excavating operations.

Many of the abandoned mine refuse fires in the bituminous region can be controlled by dozing out the material, spreading it out and cooling it by exposure to the air without the use of water. The mine fire control group has controlled several fires by this method, where water was not readily available.

The following figures show some of the operations as they were performed: Figure 5.--Shows an angledozer excavating hot material in a mine refuse dump which had ignited a fire in an underground abandoned coal mine. The refuse material was spread out and cooled by two angledozers working in this manner. Figure 6.--Shows the angledozers working together. One dozer is working in the hot material and the other is compacting the cooled material below. Following the cooling and repiling operations the pile was revegated. Figure 7.--Shows the mine refuse pile being hydroseeded with a mixture of lime, fertilizer, and perennial rye grass seed. Figure 8.--Shows the application of a hay mulch to the reseeded area. Figure 9.--Shows this area 2 years later. The pile is now covered with a thick sod of perennial rye grass and volunteer growth. This ground cover was established in spite of the fact that no top soil or earth material was spread over the compacted refuse pile.

Another digging out and cooling operation was performed on extremely hot material on a fire control project west of Pittsburgh. Figure 10.--Shows an angledozer working on this project. Both this project and the one before were located some distance from residential areas so that the dust and fumes were not a source of complaint. The dozer operators wore respirators and the fan blades on the dozers were turned so that the dust was blown away from the operator. Figure 11.--Shows how the slope of the pile was benched off during the excavating operations.

The following figures show another digging-out and cooling operation which was conducted using another type of equipment. Figure 12.--Shows a highlift digging into material which was hot enough to burst into flame when exposed to air. Figure 13.--Shows the highlift with a bucket full of burning materials as it trammed to the disposal area where the material was spread out to cool. Figure 14.--Shows the highlift dumping the hot material and spreading it out. Figure 15.--Shows the excavated and cooled material being returned to the affected area and repiled. The fire control operation was

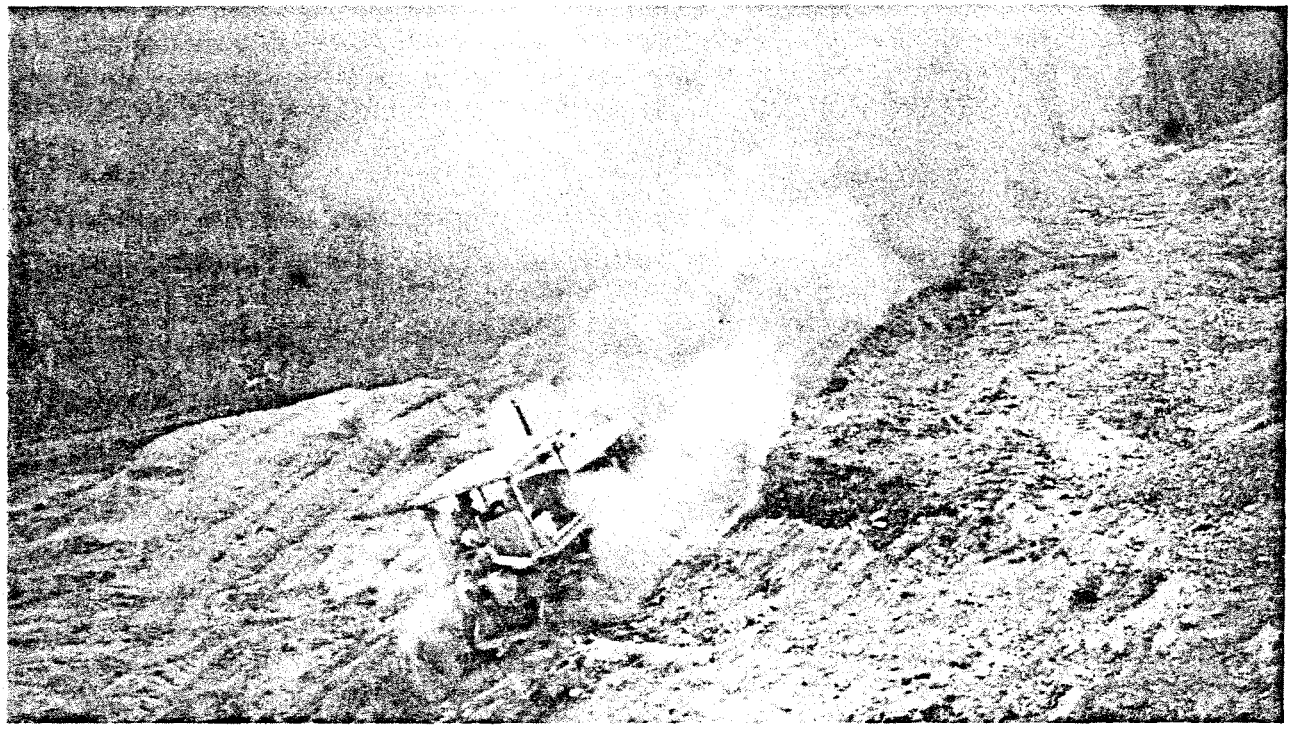

FIGURE 5. - Angledozer excavating hot material and spreading it out to cool.

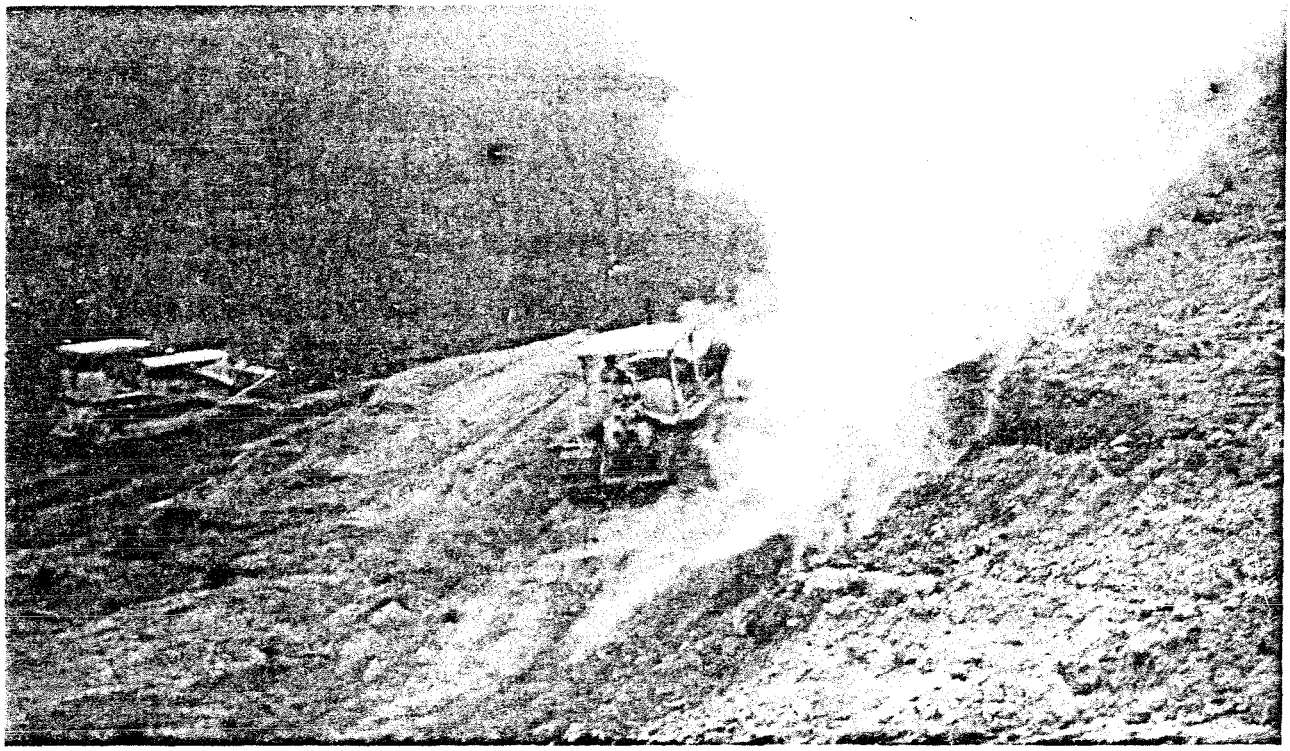

FIGURE 6. - Two angledozers working together on a fire-control operation.

FIGURE 7. - Hydroseeding mine refuse pile with mixture of lime fertilizer, and perennial rye grass seed.

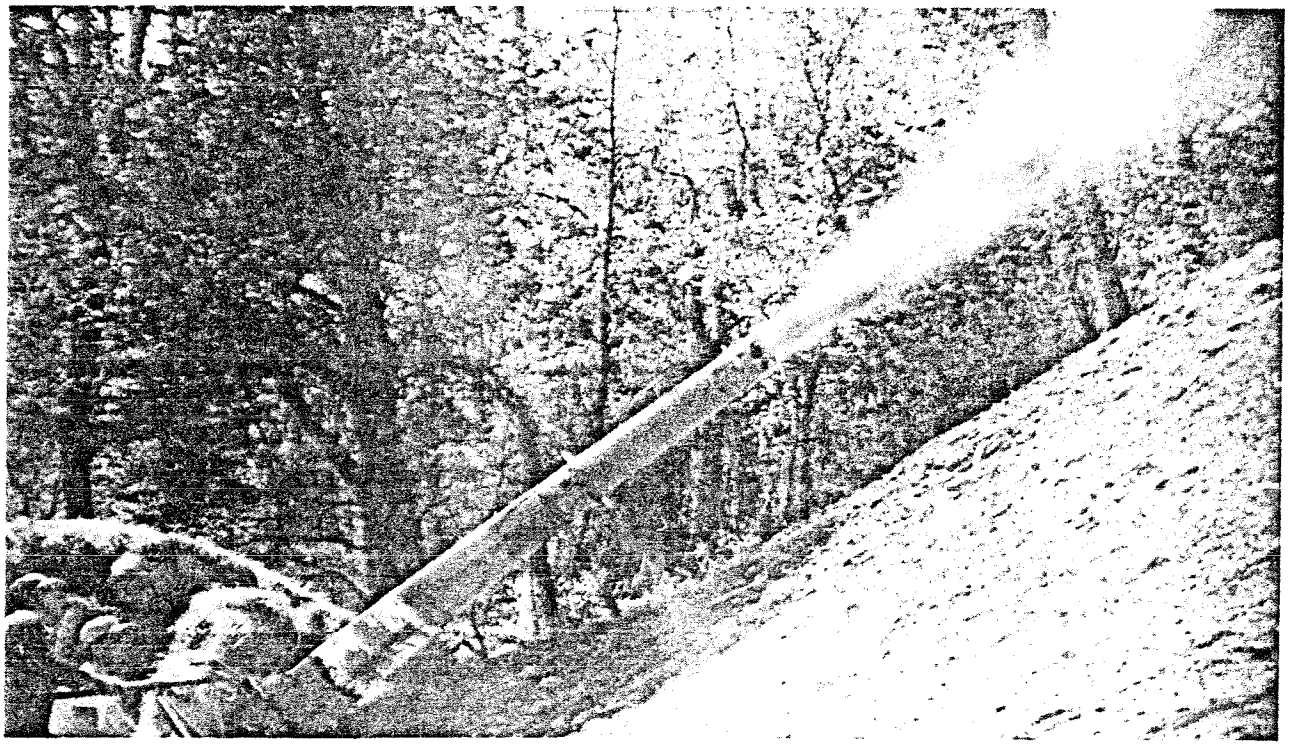

FIGURE 8. - Application of hay mulch to the reseeded area.

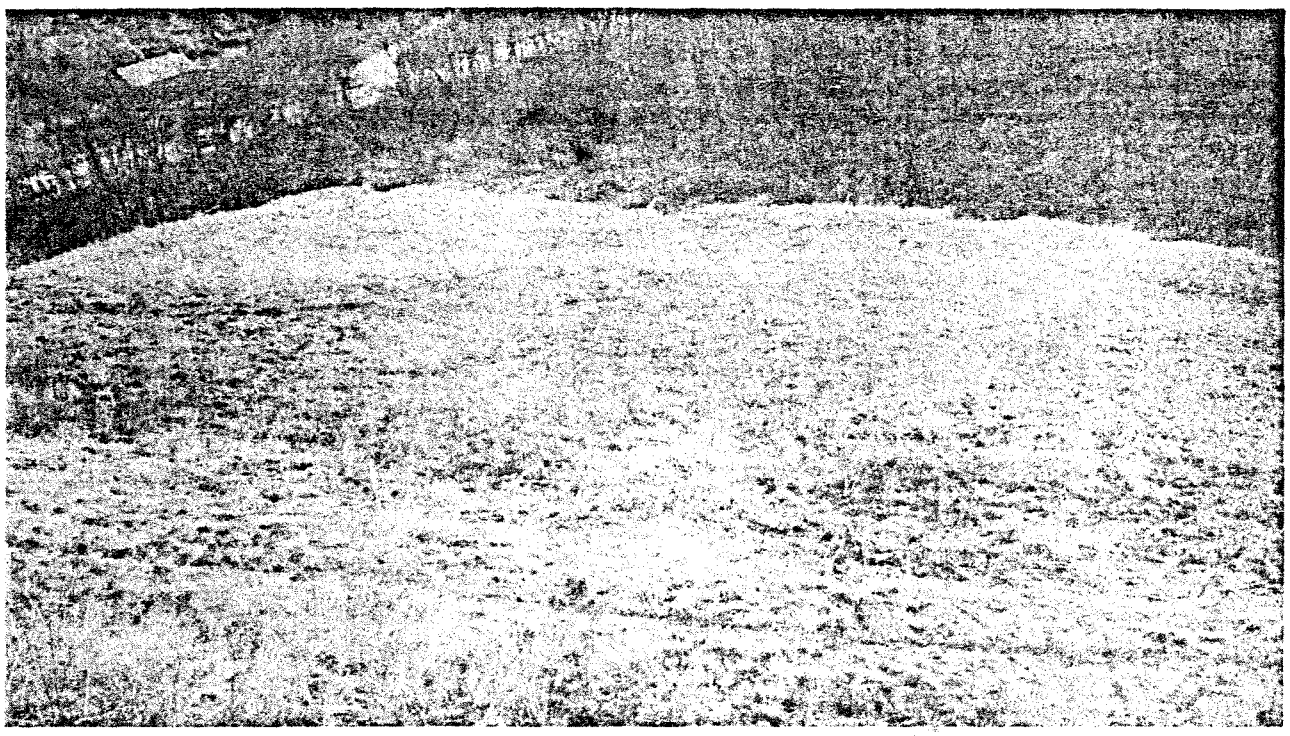

FIGURE 9. - Refuse pile 2 years after control of the fire covered with perennial rye grass and volunteer growth.

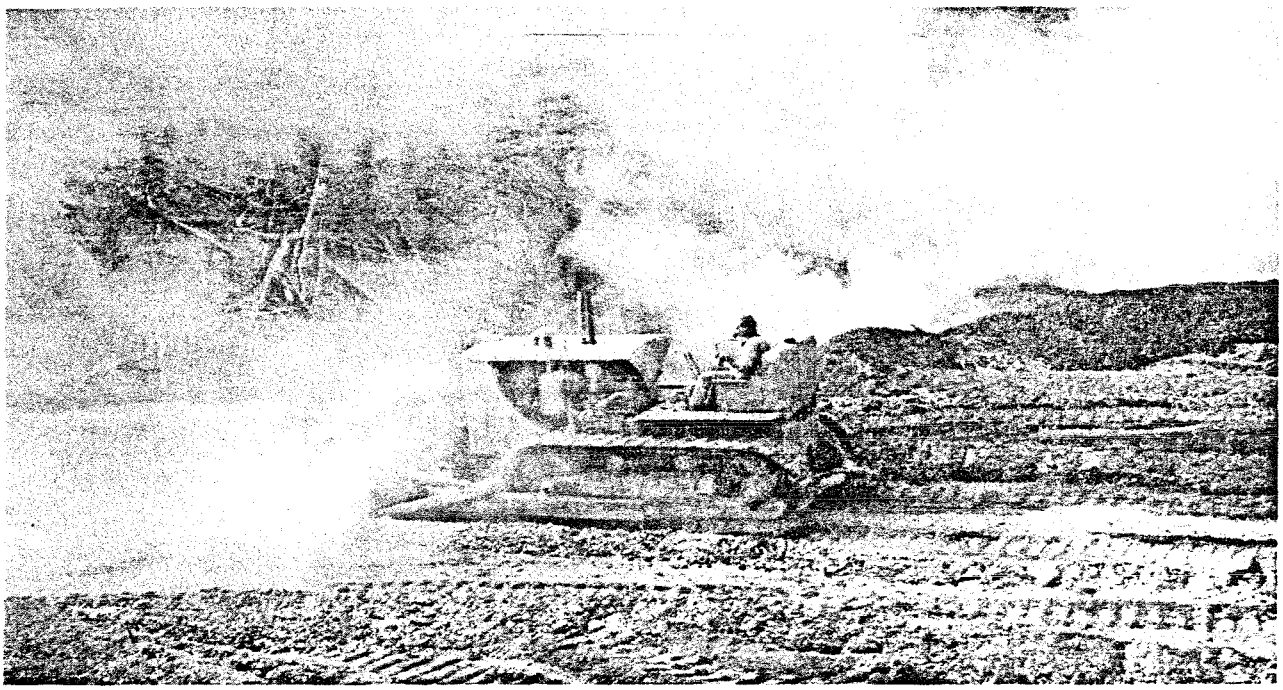

FIGURE 10. - Angledozer working in extremely hot material on a fire-control project west of Pittsburgh.

FIGURE 11. - Angledozer working on the slope of the pile during excavation.

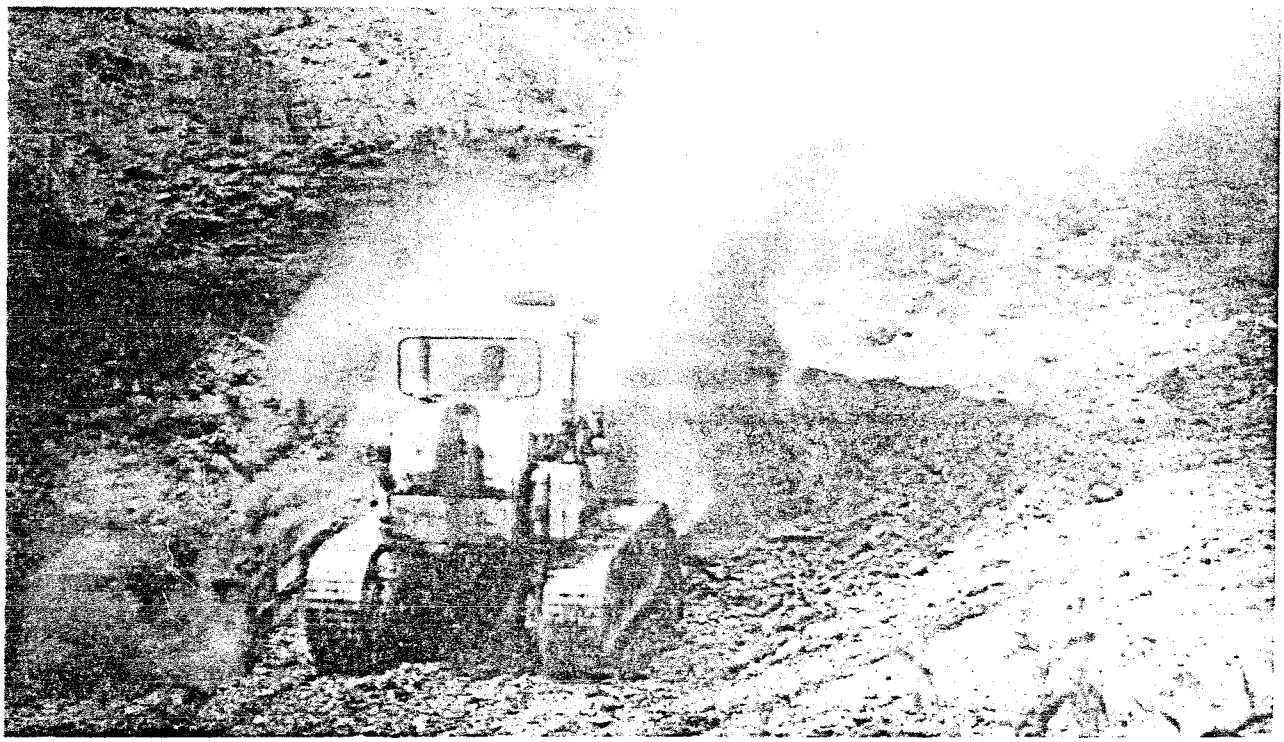

FIGURE 12. - Highlift digging into material which burst into flame when exposed to air.

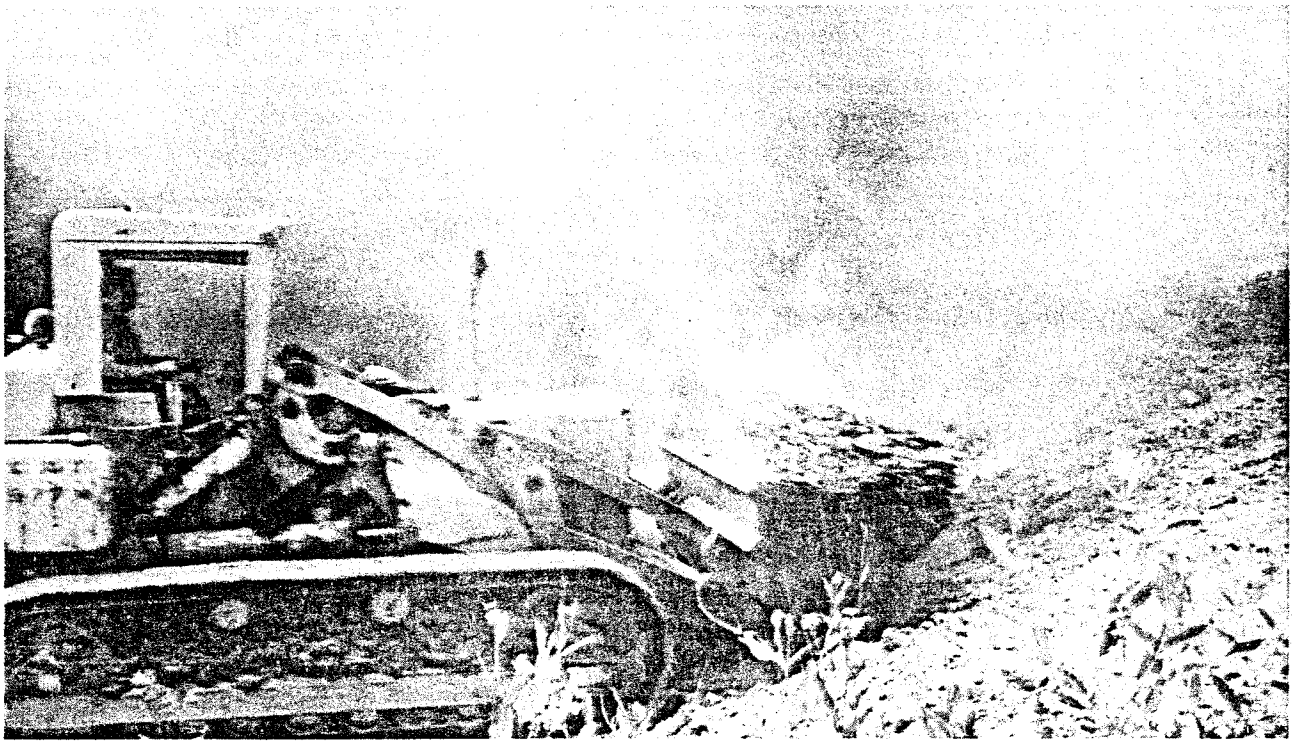

FIGURE 13. - Highlift with a bucket full of burning material as it trammed to the disposal area.

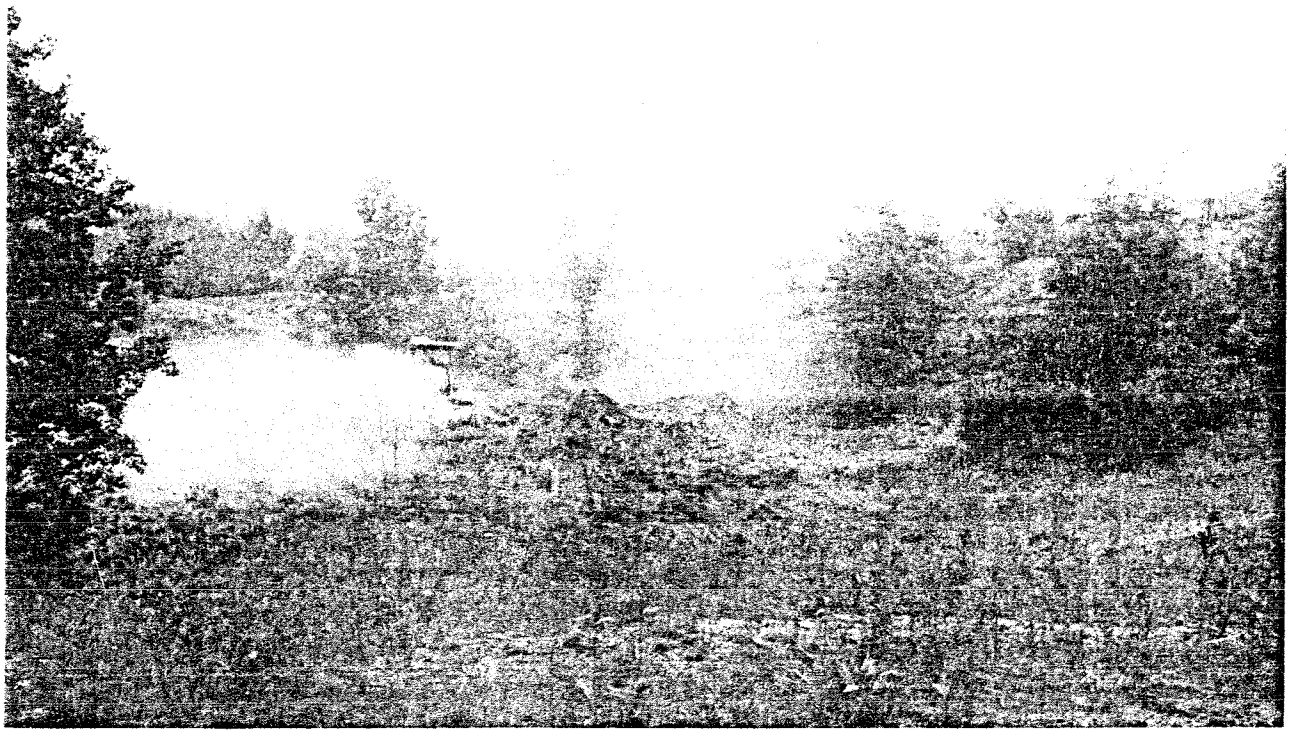

FIGURE 14. - Highlift dumping the hot material and spreading it out to cool.

FIGURE 15. - Excavated and cooled material being returned to the affected area and repiled.

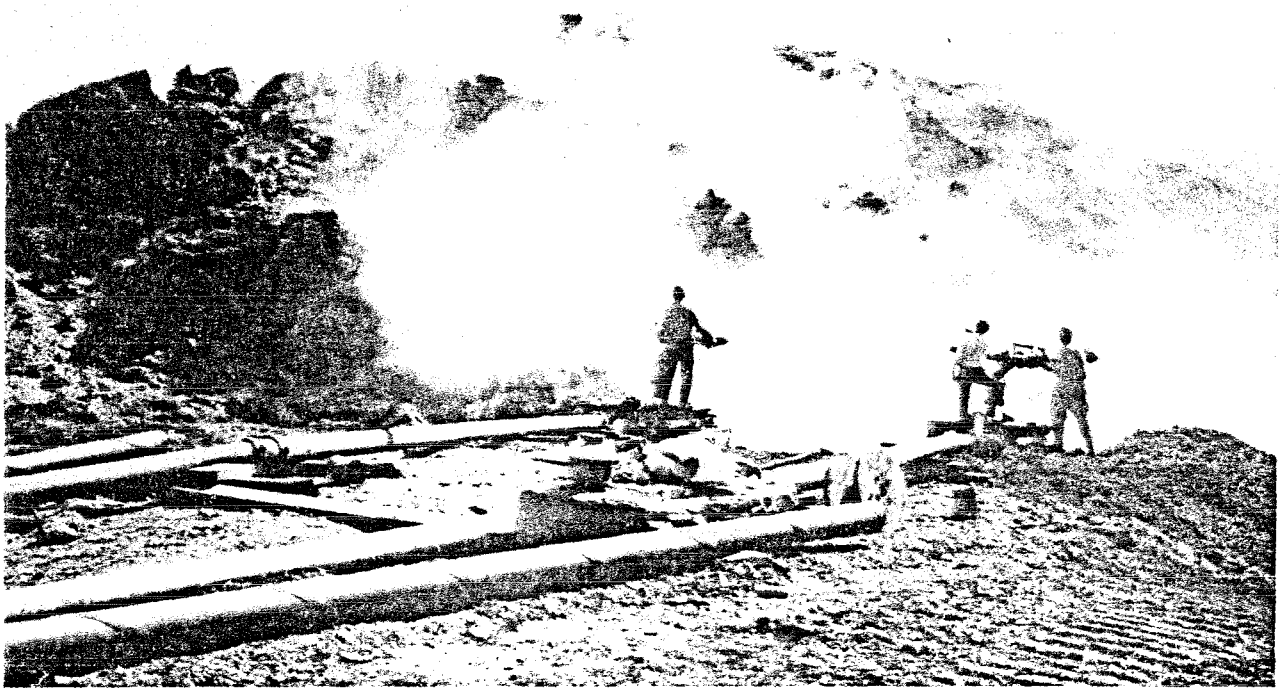

FIGURE 16. - High pressure water cannon used to quench and dislodge the hot refuse material.

performed to prevent a fire in the refuse material from propagating into the coalbed. After the material was dug out and cooled it was returned to the excavation and compacted.

A method of cooling an intense fire in a mine refuse pile is described in Bureau of Mines Information Circular 8485. The method consists of water quenching the surface material to a workable depth, then ripping and removing the material with a bulldozer and a tractor scraper. High-pressure water nozzles and piping are used to reduce the temperature of the refuse material. Following the quenching operation, various types of earth-moving equipment were used to spread and compact the material. Figure 16 shows a high-pressure water cannon used to quench and dislodge the hot refuse material.

Method B--Cover To Seal the Pile

The covering technique involves the creation of an impervious seal over the entire pile to stop the circulation of air through the material. This has been the most often-used method of control because of its apparent simplicity and low cost. The method has been used successfully but there have also been many failures because the seal was not maintained until the pile cooled. The sealing cover actually reduces the rate of cooling because it cuts off the convection currents which carry heat from the pile. An evaluation of the success of a covering operation cannot be made immediately after the seal is installed because of the tendency of the fire to reactivate during the cooling period.

I am not aware of any successful covering operation where there has not been extensive site preparation by reducing the height of the pile and the slope angles on the flanks of the pile.

Extensive site preparation in effect exposes much of the heated material in the interior of the pile and cools it. The success of many covering operations can be attributed in large part to the digging out and cooling performed at this time.

In addition to site preparation, work must be performed after the seal is established to prevent storm water from eroding the seal. Ditches must be established to divert storm water away from the pile. Water falling on the pile should not be allowed to flow over the flanks if it can be prevented.

There are many variations of this method depending upon the type of covering material used. The most common material for this purpose is clay or ordinary surface earth material borrowed in the vicinity of the fire. Clay material used over very hot areas is not ideal because it tends to bake and crack from the heat. But it can be used successfully if the seal is maintained. Covering seals have been made using fly ash, cement dust, and limestone screenings. These materials not only create an impervious seal but seem to maintain a certain amount of fluidity which prevents the crevicing of the mantle. If this type of material is used on slopes, the slope should be reduced to less than 20° and steps should be taken to prevent surface water from flowing over the seal since they have very little resistance to water erosion.

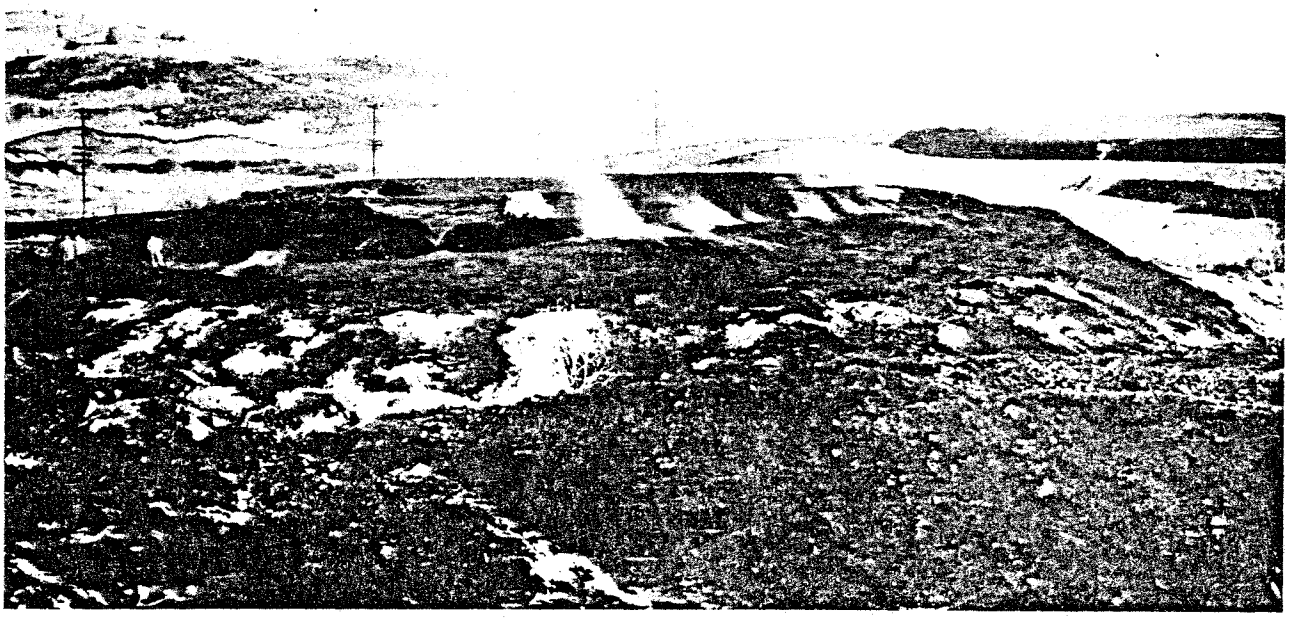

FIGURE 17. - Refuse pile prior to application of cover of 1/4-inch refuse material.

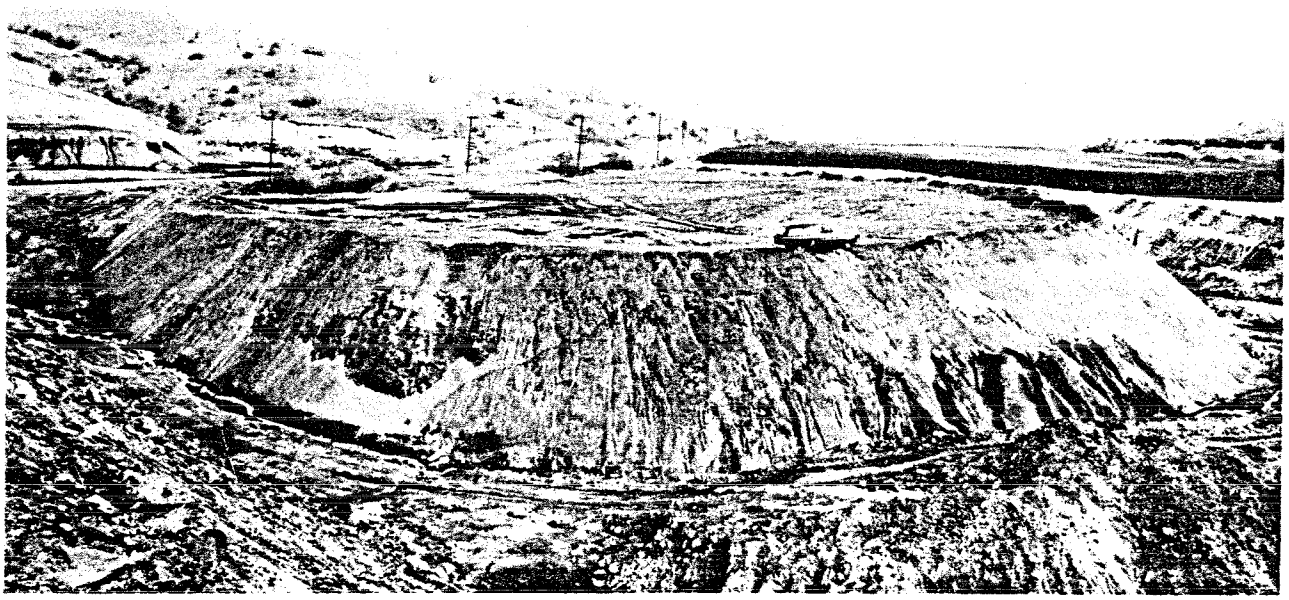

FIGURE 18. - Covered refuse pile 15 months after start of control operations.

The Bureau conducted a successful fire control experiment in which a 5-acre refuse pile was covered with minus-¼-inch refuse. The slope flank was decreased to about 30°, and the surface was compacted by a bulldozer. The pile was then sealed with a 3- to 5-foot layer of minus-¼-inch material. Figure 17.--Shows the burning refuse pile prior to control operation. Figure 18.--Shows the extinguished pile, 15 months after start of control operations. You will note here, as in all successful covering operations the site preparation has a very important effect on the success of the project. The slopes have been reduced and provisions have been made for diverting surface water away from the flanks of the pile.

A covering seal can be made by compacting the surface of the mine refuse pile and covering the slopes with clay or earth material. The top of the pile is leveled off and compacted with heavy equipment or a sheep's foot roller. The slopes should be reduced to less than 30° and then covered with clay or earth material which is relatively cohesive. The surface should be ditched to divert surface water around the pile to prevent erosion of the seals.

Two projects were conducted in Pennsylvania on burning refuse piles in which urethane foam was used as the surface sealing agent. One was successful because the pile was cooled with water and sloped with angledozers to a very low profile prior to installation of the cover. The other failed because of insufficient site preparation. Site preparation had more to do with the successful control of the fire than the urethane foam covering. Figure 19 is a

FIGURE 19. - Photograph of successful urethane covering project 7 years after completion.

photograph of the successful urethane covering project. The urethane foam covering which is about 2 or 3 inches thick is intact and will no doubt remain so indefinitely. Since it does not support traffic or vegetation, its utility is limited.

Method C--Grout To Solidify the Affected Material

The grouting method consists of forcing a slurry of water and finely divided incombustible material into the interstices of the porous refuse material through pipes driven into the pile. Air is excluded from the fire by filling these voids. The slurry is forced into the pile under pressure. This method has been used in the past to grout burning cinder fill areas under industrial plants and equipment. But it was not used for the control of mine refuse fires because the cost of suitable materials like Portland cement, lime, or pulverized limestone made the jobs very costly.

With the development of fly ash slurry injection using a waste material and high-capacity equipment the method may become more common particularly in areas where there is no adjacent ground available for spreading out the pile. The use of this method, however, requires some site preparation in the form of reducing the slopes and leveling the top so that holes can be drilled or injection pipes driven. A grouting operation should be designed to solidify the heated material by filling all the void spaces on or near the slopes. It may be assumed that the refuse material consists of 20 percent void space so that an estimate can be made of the approximate amount of material that should be injected into the material which is to be treated.

A successful grouting operation was conducted by injecting fly ash into a pile near Houston, Pa. Fly ash is an excellent grouting material and is available in many areas as a waste product. The use of fly ash in larger quantities than is ordinarily associated with grouting operations offers an effective tool for combating refuse pile fires. In the Houston project there was extensive site preparation. The pile was cooled with water pumped from a nearby stream and the top was leveled and the sides sloped. Injection pipes were driven in four rows around the crown of the pile to a depth of 10 to 40 feet. The interior of the pile was not treated. It is estimated that about 50,000 cubic yards of refuse was treated with about 10,000 tons of fly ash through 400 injection holes. Figure 20 shows the refuse pile 2 years after control of the fire. A blanket of snow covers the once intensely burning pile.

Grouting projects using sophisticated chemicals have been conducted but to my knowledge none has been successful. These operations apparently have been designed in an attempt to find a material which will inhibit combustion or cool the interior of the pile. Chemicals, such as ammonium sulfamate, ammonium polyphosphate, ammonium bromide, potassium bicarbonate, monoammonium phosphate, cobaltic oxide, methylene bromide, and methyl bromide, have been tried. None has the specific heat or retarding effect desired. In order for

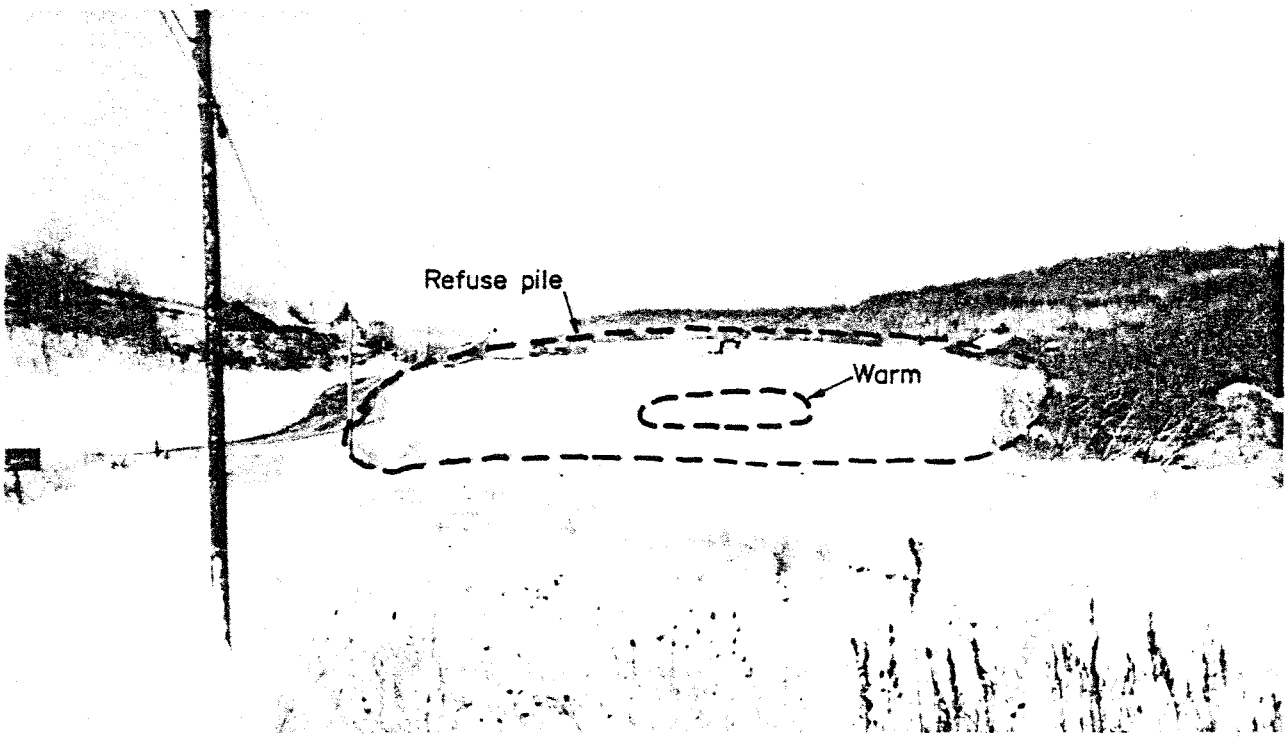

FIGURE 20. - Fly ash grouted refuse pile 2 years after control of the fire.

a grouting operation to succeed large amounts of finely divided solids must be injected into the affected porous material with the intent of solidifying it.

Under certain conditions grouting of a refuse pile may be accomplished by the continuous application of a fine-water spray. Continuous sprinkling was used in Great Britain during World War II for extinguishing the flames on some refuse pile fires which were serving as markers for enemy aircraft. According to a British source most of the sprinkled piles reactivated when sprinkling was discontinued. However, some of them were controlled permanently. It appears that the fires which were extinguished were in piles which contained clays and shales which weathered and disintegrated so that the fines were carried into the interior of the pile by the sprinkled water. The extinguished fires were in effect grouted. Perhaps the technique can be used successfully if an analysis of the refuse material indicates that there are sufficient clays or degradable shales in the pile and where there is a large amount of water available in the vicinity for continuous sprinkling.

SUMMARY

To summarize our analysis of the state-of-the-art in mine refuse pile fire extinguishment we have examined the relative ease of preventing these fires and of course prevention is the best method of extinguishment. It is hoped that new regulations and a concern for the environment will mean the end of the mine refuse pile fire. Many of those now in existence will burn out and cool naturally, others will be controlled due to increased public concern.

For the control of these fires there are several methods available. In spite of our space-age technology the most effective control is the mundane method of digging out the heated material and cooling it. If this is not practical because of space limitations or other conditions, control is possible using covering or grouting techniques.