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Coal Refuse Fires, An Environmental Hazard

By Lewis M. McNay

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CONTENTS

	Page
Abstract	1
Introduction	1
Acknowledgments	3
Nature and origin of coal refuse	3
Cause of coal refuse fires	5
Nature and extent of fires	6
Environmental impact of burning refuse banks	8
Fire control efforts and techniques	15
Guidelines for the prevention of refuse bank fires	22
Summary	25
References	27
Appendix.--Location and size of burning coal refuse banks	29

Alabama, Colorado, Illinois, Kentucky, Maryland, Montana, Ohio, Oklahoma, Pennsylvania, Utah, Virginia, Washington, West Virginia.

ILLUSTRATIONS

1.	Working and living conditions are impaired by fumes and gases emitted by coal refuse fires	2
2.	Typical coal refuse pile	4
3.	Pattern of land use adjacent to burning coal refuse banks	7
4.	Volume of waste contained in burning refuse banks	8
5.	Scene illustrating damage to mature trees growing adjacent to a burning refuse bank	14
6.	Concentric fissures or cracks, subsided areas, and acrid fumes and smoke are evidence that a fire continues to burn beneath an earthen seal	16
7.	Bureau of Mines fire extinguishment project, Scranton, Pa	18
8.	Quenching of refuse bank fire with water cannon	19
9.	Refuse bank fire extinguishment using "rice paddy" technique. (Taylor refuse bank.)	20
10.	Taylor refuse bank project site following recasting and grading of quenched material	22

TABLES

1.	Analyses of two air samples taken from boreholes in a burning coal refuse bank	9
2.	Gases emitted into atmosphere from burning coal refuse banks in 1968	9
3.	Partial list of deaths and accidents attributed to coal waste fires	13

COAL REFUSE FIRES, AN ENVIRONMENTAL HAZARD

by

Lewis M. McNay[1]

ABSTRACT

The Bureau of Mines located and examined 292 burning coal refuse banks throughout the Nation's coal-producing regions in 1968. These coal waste fires, extending over 3,200 acres, produce poisonous, acrid gases and particulate matter that pose a threat to health and safety in the surrounding areas, damage vegetation, and cause the deterioration of nearby structures and buildings. Methods of extinguishing coal refuse fires are discussed, and an approach to eliminating future occurrences of these fires is presented.

INTRODUCTION

Burning refuse banks were once considered inevitable consequences of coal mining. Although smoke and fumes emitted by these banks often caused serious health problems and resulted in extensive property damage, public apathy was widespread because local economies depended on coal mining. However, by the early 1950's coal mines across the country were closing or reducing production. The declining demand for coal was attributed to conversion from coal to gas for heating following World War II and switchover by the railroad industry from steam to diesel engines. Many of the coal mining areas, particularly in the Appalachian Mountain region, were therefore confronted with the problem of economic redevelopment and rehabilitation. New industries were encouraged to build plants, but many businesses hesitated to establish operations in culturally bleak areas. Consequently, citizens and community groups in some mining areas began to seek ways and means of improving the environment by alleviating the land, air, and water pollution caused by mining.

The desire to replace a faltering industrial base was, however, not the only factor to influence or stimulate public concern for the environmental problems associated with refuse bank fires. In the past decade the public has also become increasingly conscious of the fact that waste of our natural resources and continual degradation of our environment can no longer be tolerated. Burning refuse banks and their emitted pollutants were readily visible and malodorous (fig. 1). These unsightly smoldering waste banks became a prime concern of nearby residents and environmental quality advocates.

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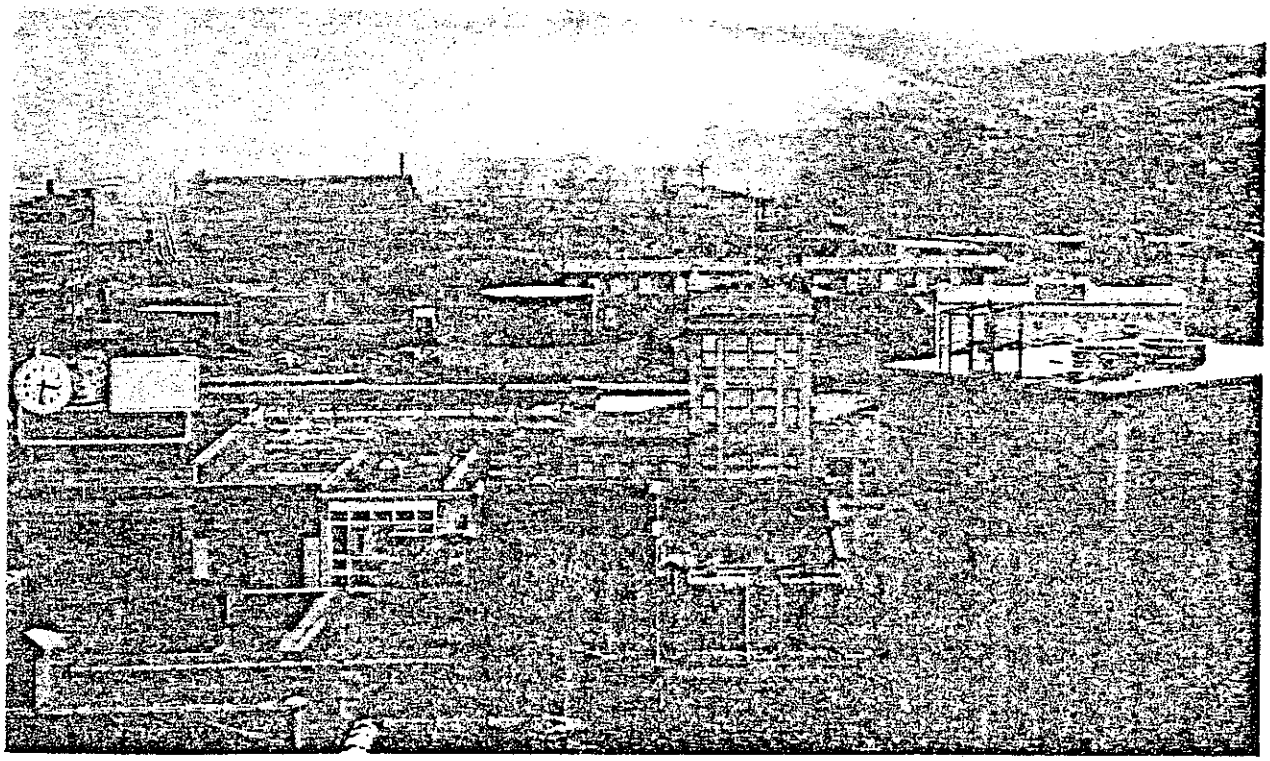

FIGURE 1. - Working and Living Conditions Are Impaired by Fumes and Gases Emitted by Coal Refuse Fires.

In response to public demands for a more suitable environment, Federal and State governments began surveys and studies to identify the nature and extent of the air pollution problems resulting from burning refuse banks and to determine what preventive and remedial measures were necessary. In 1963 the Bureau of Mines, through a cooperative agreement with the Public Health Service, U.S. Department of Health, Education, and Welfare, conducted the first nationwide reconnaissance survey of burning coal refuse banks (28).[2] With the greater interest and concern over the degradation of the environment resulting from burning coal refuse, the Bureau of Mines, under authority of Public Law 89-272, "Solid Waste Disposal Act," again undertook a national study in 1968 to determine the nature and magnitude of such wastes and to develop data necessary for implementing a nationwide abatement program. As a part of this study, a comprehensive field investigation was made of each of the burning banks identified in the earlier survey, along with other burning banks that were subsequently discovered.

[2]Underlined numbers in parentheses refer to items in the list of references preceding the appendix.

ACKNOWLEDGMENTS

This report represents the efforts of many members of the Bureau of Mines staff and the excellent cooperation of State and local government officials. Special acknowledgment is made to the following Bureau of Mines personnel: Herman W. Sheffer, Eugene G. Baker, and Lawrence Y. Marks of the Pittsburgh, Pa., office; John T. Schimmel of the Wilkes-Barre, Pa., office; James L. Vallely, Samuel A. Friedman, and Vernal A. Danielson of the Knoxville, Tenn., office; Robert W. Holliday and Thomas O. Glover of the Twin Cities, Minn., office; Harry F. Robertson of the Bartlesville, Okla., office; and William N. Hale of the Albany, Oreg., office.

NATURE AND ORIGIN OF COAL REFUSE

Before coal mines were mechanized, only the thicker and better seams of coal were developed on a large scale. The coal was mined, picked, and loaded by hand. Consequently, with few exceptions only marketable coal was transported to the surface. With new and improved mining equipment, coal seams with an increasing percentage of impurities could be mined, and the coal could be economically transported to the surface and cleaned of impurities before marketing. These impurities, referred to as coal refuse, culm, or reject material, are a mixture of coal, rock, carbonaceous and pyritic shales or slates, etc. Because this material has no immediate use, it is disposed of as economically as possible and in such a manner that the disposal does not interfere with the operation. A typical refuse pile is shown in figure 2. Very often these disposal sites also become the dump for other discarded items, such as grease-soaked rags, grease and oil containers, paper and cardboard, electrical wire and cable, wornout equipment, timber and lumber, and other junk.

Most coal refuse comes from two sources: (1) waste rock and other impurities generated during mine development and operation and (2) impurities separated from the "run-of-mine," or raw, coal at the preparation plant. Mine waste accumulation begins with the development of a mine. Large quantities of rock material are extracted in the sinking of shafts and driving of rock tunnels and haulageways before the first ton of coal is mined. The removal of waste rock is a continuing operation throughout the life of many coal mines. The largest volume of solid waste is produced at the preparation plant. Here the coal is crushed, sized, washed, and separated from rock and other impurities to achieve a grade of coal meeting the market demand.

A detailed discussion of the types of coal preparation plants that have been used in the past or are presently in operation is beyond the scope of this report. Basically, however, coal is separated from refuse into two classes: coarse (greater than 1 millimeter) and fine (less than 1 millimeter).

Coarse coal is recovered in a dense-medium process. The coal is separated from its associated impurities by floating off the lighter coal in a suspension of finely divided solids in water, aqueous solutions of inorganic salts, or organic liquids. Magnetite, pulverized coal refuse, loess, sand, and barites are frequently used as suspended solids in the process. Calcium

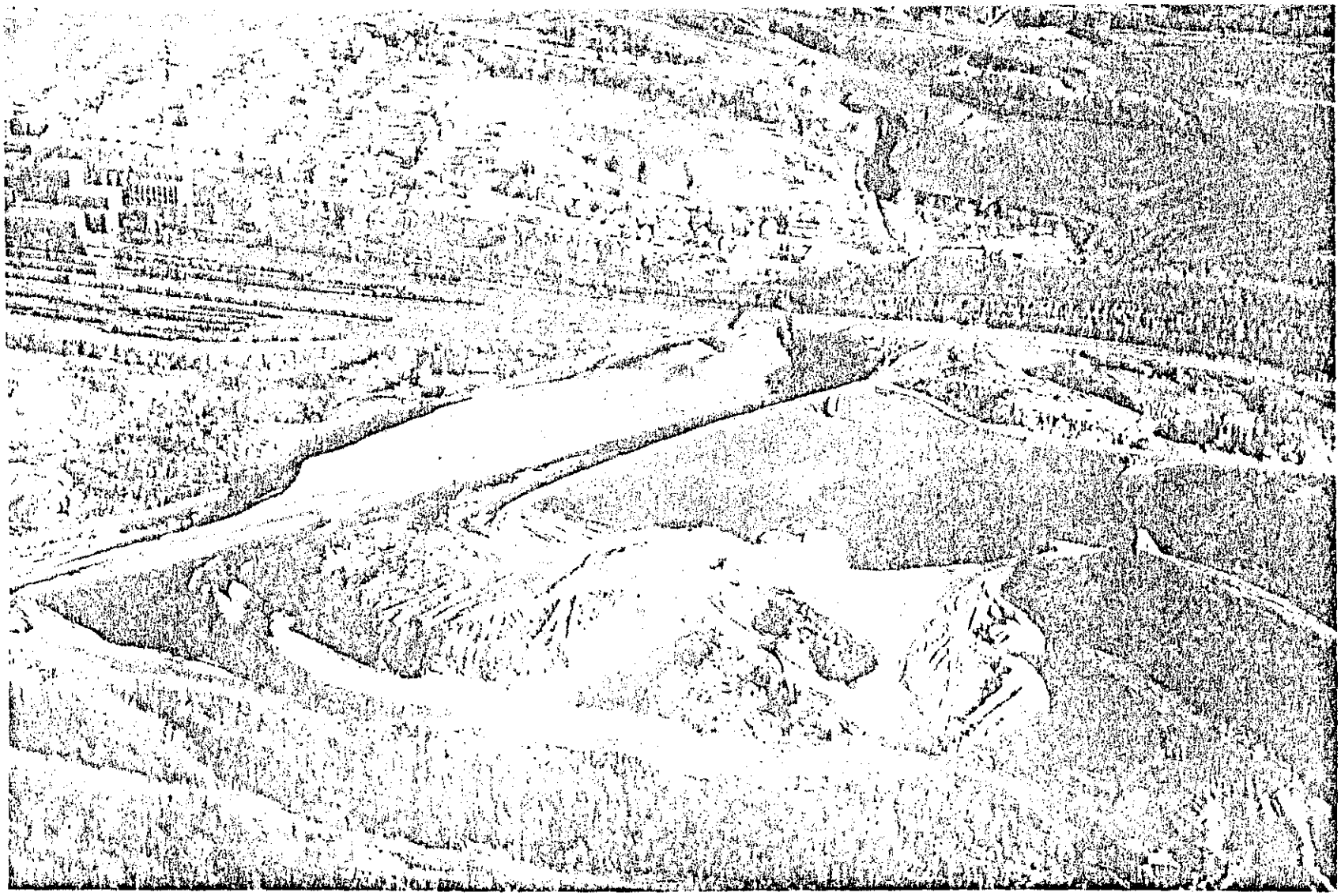

FIGURE 2. - Typical Coal Refuse Pile. Millions of tons of coal refuse cover large acreages of land and deter future land development. When ignited, such piles can burn for many years.

chloride solutions are the predominant means of cleaning coal with inorganic salts. In this process the separating medium is adjusted to achieve a predetermined specific gravity of separation, permitting the clean coal to float and the heavier refuse materials to sink into the bath. Preparation of coarse coal is also accomplished by other methods, such as Bradford breakers and jig washers.

To clean very fine sizes of coal, flotation procedures must be employed. In these the mixture of coal and impurities is fed into a water bath, flotation reagents are added, and the bath is aerated. The flotation agent (such as kerosene plus pine oil) adheres to and coats only the coal particles. The coated particles become attached to air bubbles, which lift the particles to the surface of the water, where they are skimmed off mechanically.

Coarse refuse is carried from the preparation plants by conveyor belts, tramways, or trucks and is deposited on conical or ridge-shaped banks that may range up to 700 feet in height and over a mile in length. Some coarse refuse is transported hydraulically. Fine refuse usually is pumped to a settling pond as slurry.

CAUSE OF COAL REFUSE FIRES

Coal refuse banks can be ignited by spontaneous combustion, freak accidents of nature, or by humans, either intentionally or through carelessness (28). Spontaneous combustion is a common cause of coal refuse fires. Sixty-six percent of the 292 refuse banks found burning in 1968 are believed to have started by heat generated within the pile. This phenomenon results from the flow of air through combustible refuse material and consequent oxidation. When sufficient oxidation occurs, heat is generated, and the combustible components in the pile ignite (16, p. 3).

> When anthracite is oxidized at temperatures up to 350° C, the gaseous oxidation products consist of water vapor, carbon dioxide, carbon monoxide, and nitrogen, together with any unused or excess air. The ratio of carbon monoxide to carbon dioxide varies with the oxidation temperature. Initially the water vapor is greatest in amount, but it decreases steadily during the progress of the oxidation. Part of the oxygen consumed by the coal does not appear in any of these gaseous products but remains "fixed" to the coal. The net heat liberated per unit of oxygen consumed during oxidation within this temperature range equals the sum of
>
> 1. The heat of formation of carbon dioxide,
> 2. The heat of formation of carbon monoxide,
> 3. The heat of formation of water vapor,
> 4. The heat of "fixation" of oxygen by anthracite.
>
> The respective contributions of each of the foregoing thermal processes will depend on both the relative magnitudes of each thermal effect and the relative proportion of each reaction.

Laboratory studies have also been made to determine the ignition of bituminous refuse as a function of airflow through the refuse and particle-size variation (21, pp. 3-4).

> Laboratory trials showed that about six times more air passed through the 3½- by ¼-inch than through the minus 3½-inch refuse for a given pressure differential. About four times more air passed through the minus 3½-inch than through the minus ¼-inch refuse. The fine refuse appreciably reduced the flow of air.
>
> * * * * * *
>
> The spontaneous ignition tendency of mine refuse was determined by heating the bottom layer of material contained in a chamber and observing the temperature rise at various levels. The data . . . show [ed] decreasing ignition tendency for minus 3½-inch, 3½- by ¼-inch, and minus ¼-inch material. The minus 3½-inch refuse, showing signs of activity when the material at the base was heated to 250° F, ignited at 450° F. . . . The results of three trials with minus ¼-inch refuse containing 1, 5, and 11 percent moisture indicated that this material, under the test conditions, had little tendency toward spontaneous ignition. . . .

Other coal refuse fires, especially in populated areas, result from the burning of trash and garbage on refuse dumps. After a mine is abandoned, the disposal area is often a bleak, unsightly "blot" on the surrounding landscape and local residents use these readily accessible sites for the unwarranted disposal of household wastes. Thirteen of the refuse bank fires surveyed are believed to have been ignited by the burning of wastes, while an additional 121 burning banks had waste material that may have contributed to continued burning.

Several fires are known to have started accidentally by human or natural causes. Forest fires and lightning have been identified as the source of some refuse bank fires. Campers, hikers, or picnickers, unaware of the combustibl nature of the refuse material, have built fires on the banks and failed to completely extinguish them.

In the past, coal waste piles were ignited intentionally to obtain the resultant ash product, "red dog." This material is used extensively throughout the coal regions for surfacing residential, industrial, and commercial streets, secondary roads, and parking areas and for landfill in low-lying areas.

NATURE AND EXTENT OF FIRES

Location

Field investigations during the latter part of 1968 and early 1969 revealed that there were 292 burning coal refuse banks in 13 of the

26 coal-producing States, as follows: Alabama, Colorado, Illinois, Kentucky, Maryland, Montana, Ohio, Oklahoma, Pennsylvania, Utah, Virginia, Washington, and West Virginia. The total includes only refuse banks that were determined to be smoldering or burning through visual indications such as flames or "fire glow," thermal waves above the refuse bank, smoke, fumes, or a combination of these conditions. Additional refuse piles undoubtedly would have been found burning if the internal temperatures had been measured with thermocouples or if infrared aerial surveys of the banks had been made. Seven States in the Appalachian region accounted for 264 burning banks, or 90 percent, of the total. States that reported burning refuse banks in the past, but in which none were known to be burning in 1969, include Alaska, Indiana, Iowa, New Mexico, Tennessee, and Wyoming. Detailed information about the location and size of each burning bank found in the present survey is given by State in the appendix.

Texture and Status

Refuse produced during the cleaning of coal varies in diameter from greater than 4 inches in the primary crushing and cleaning stages to less than one-quarter inch in the fine coal cleaning process. The subsurface materials of approximately 230 banks examined consisted primarily of preparation plant rejects with a texture (refuse particle size) between one-quarter inch and 2 inches in diameter. The material on the surface, however, was predominately less than one-quarter inch as a result of the disintegration of shale during weathering processes.

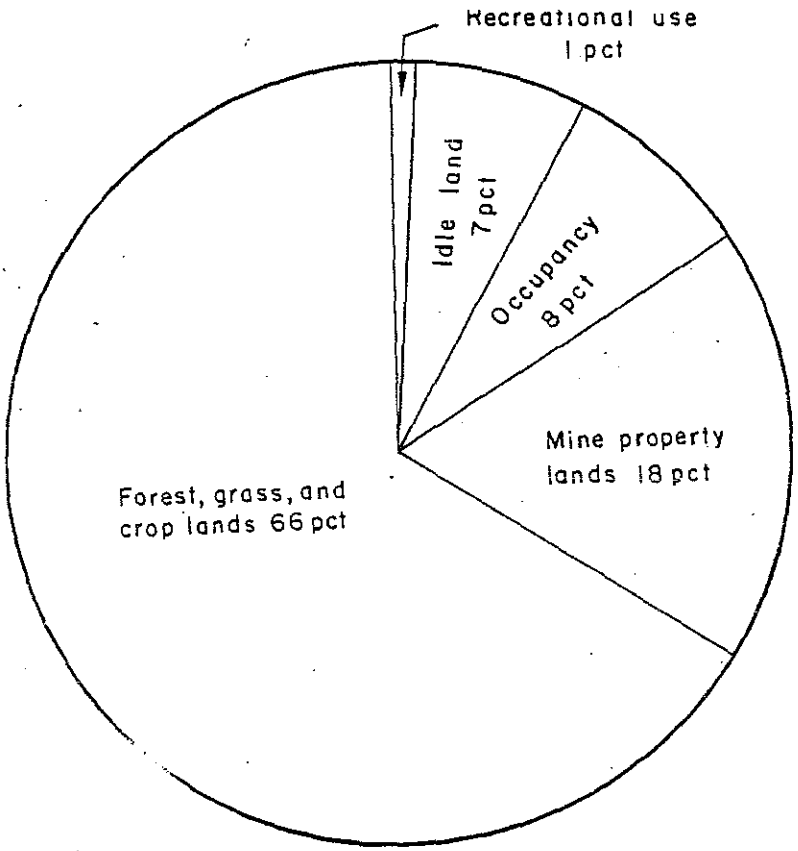

FIGURE 3. - Pattern of Land Use Adjacent to Burning Coal Refuse Banks.

About 42 percent of the banks appeared to be less than half burned, while only 36 percent of the banks had surface indications that three-quarters or more of the pile had completely burned. It should be noted, however, that even though many large banks are burned out surficially, they have been known to burn internally for several years more. Of the banks, 270 were actively burning or smoldering over less than 50 percent of the surface area.

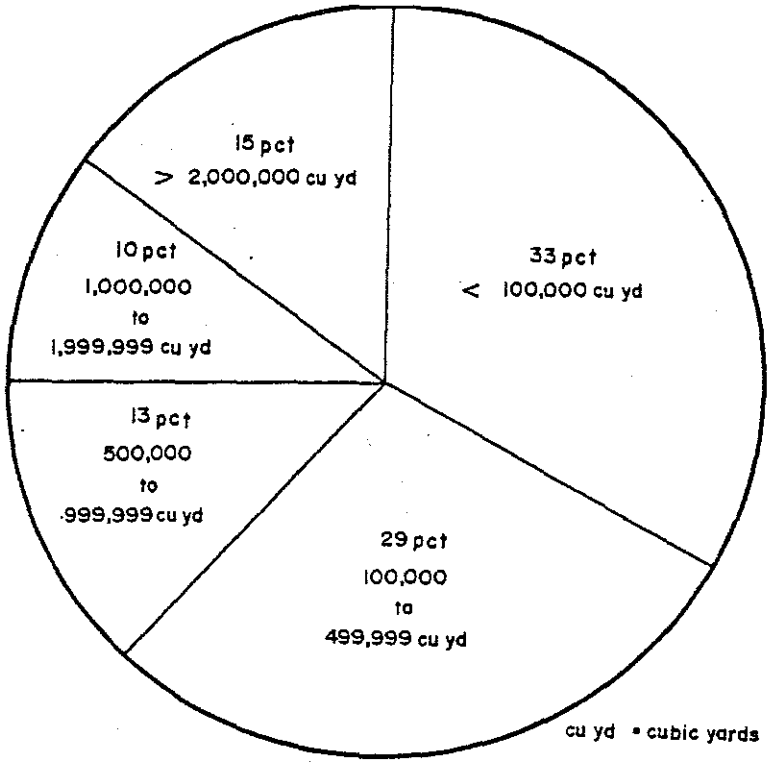

FIGURE 4. - Volume of Waste Contained in Burning Refuse Banks.

Ownership and Adjacent Land Use

Approximately 99 percent of the burning heaps were situated on private lands, most of which were owned by mining companies. Only three fires were believed to be on publicly owned lands. The banks were found adjacent to a variety of land-use patterns (fig. 3). Sixty-six percent of the sites adjoined forest, grass, or crop lands. Twenty-two sites were immediately adjacent to municipal, residential, or commercial lands.

Volume

The survey showed that about 270 million tons of refuse material was contained in the banks (fig. Forty-three, or 15 percent, of the banks were estimated to have volumes greater than 2 million cubic yards; 62 percent contained less than 500,000 cubic yards. Twenty-eight percent of the burning banks were actively receiving new refuse at the time of the survey. One site was receiving more than 2,500 tons per day; nine banks, between 1,110 and 2,500 tons per day; 27 banks between 501 and 1,000 tons per day; and 45 banks, less than 500 tons per day

ENVIRONMENTAL IMPACT OF BURNING REFUSE BANKS

Burning coal refuse banks have existed since the early days of coal mining. The products of these smoldering waste accumulations have contributed significantly to the degradation of surrounding atmospheric conditions, and more recently, have deterred land development and economic growth throughout the coal regions. The total adverse physiological effect that the burning piles have on animal and vegetable life has been discussed for many years; however, it has been only in the last few years that efforts have been made to define and analyze this pollution problem.

Degradation of ambient atmospheric conditions is recognized as a distinctive adverse characteristic resulting from a burning coal bank (8, 29). Once a refuse bank ignites, chemical and physical alteration begins with the heating of the material in the pile. Resulting products are smoke, minute dust particles, and poisonous and noxious gases that in many instances have proven fatal to vegetative life. The most toxic gases are carbon monoxide,

carbon dioxide, hydrogen sulfide, sulfur dioxide, and ammonia. Other undesirable products resulting from a burning refuse bank are sulfur trioxide, sulfuric acid, and oxides of nitrogen.

Only limited efforts have been made to analyze, quantitatively and qualitatively, these gaseous emissions and to research the mechanisms responsible for the spontaneous ignition of refuse bank fires. In 1940, air samples were gathered by the Bureau of Mines from boreholes in a burning coal refuse bank (19). Methods of collection and analysis were quite rudimentary, and only the gases that were present in significant amounts were identified and measured (table 1).

TABLE 1. - Analyses of two air samples taken from boreholes in a burning coal refuse bank[1]

Gases identified	Percent of gas present	
	Sample 1	Sample 2
Oxygen	7.6	1.0
Carbon dioxide	10.55	20.3
Carbon monoxide	2.15	1.05
Methane	.23	1.01
Nitrogen[2]	79.47	76.64

[1]Source: (19).
[2]Determined by subtracting total percentage of other gases from 100.

The gases released into the atmosphere by burning coal refuse banks in 1968 (14) are listed in table 2. These emissions represent a small percentage of pollutants released into the atmosphere that year. For an accurate understanding of the potential public health hazard and the unsightliness of a burning coal refuse bank, consideration must be given to local physiographic and atmospheric conditions. Unfortunately, this type of detailed data has not been assembled.

TABLE 2. - Gases emitted into atmosphere from burning coal refuse banks in 1968[1]

Gas	Emissions (million tons)	Percent of total
Carbon monoxide	1.2	1.2
Sulfur oxides	.6	1.8
Hydrocarbons	.2	.6
Nitrogen oxides	.2	1.0
Particulate	.4	1.4

[1]Source: (14).

Between 1940 and 1960 a growing concern over the effect of air pollutants in the Nation's urban areas was manifest, but problems in the coal regions drew little attention and concern until recently. The first new research and fact-gathering studies on the problems of mine waste accumulations were initiated in the Pennsylvania anthracite and bituminous coal regions, where

highly developed industrial centers are located. Sulfur dioxide and hydroge sulfide measurements were made in communities having burning coal waste pile The sulfur dioxide concentrations averaged more than 1.0 ppm (parts per million) with maximum peak concentrations exceeding 4.5 ppm. In several tests (29) hydrogen sulfide was measured at more than 0.4 ppm.

A better understanding of the magnitude and effects of atmospheric pollutants resulted from the enactment of Public Law 89-206, "Clean Air Act, as strengthened by Public Law 89-272, "Amendments to Clean Air Act." This legislation directed the Secretary of Health, Education, and Welfare (HEW) to establish research and training programs and conduct investigations concerning air pollution problems. Public Law 90-148, "Air Quality Act of 1967 directed the Secretary of HEW to establish air quality regions and criteria by which State governments could establish permissible emission standards.

Air quality criteria for sulfur oxides and particulate matter were released by HEW's Public Health Service in January 1969 (22-23). The following data are excerpts from these HEW reports which "represent the Administration's best judgment of the effects that may occur when various levels of pollution are reached in the atmosphere."

Effects on Health

At concentrations of about [3]715 $\mu g/m^3$ (0.25 ppm)[4] of sulfur dioxide and higher (24-hour mean), accompanied by smoke at a concentration of 750 $\mu g/m^3$, increased daily death rate may occur.

At concentrations ranging from 300 $\mu g/m^3$ to 500 $\mu g/m^3$ (0.11 to 0.19 ppm) of sulfur dioxide (24-hour mean), with low particulate levels, increased hospital admissions of older persons for respiratory disease may occur: Absenteeism from work, particularly with older persons, may also occur (23, p. 10/20).

At concentrations of about 715 $\mu g/m^3$ (0.25 ppm) of sulfur dioxide (24-hour mean), accompanied by particulate matter, a sharp rise in illness rates for patients over age 54 with severe bronchitis may occur.

At concentrations of about 600 $\mu g/m^3$ (about 0.21 ppm) of sulfur dioxide (24-hour mean), with smoke concentrations of about 300 $\mu g/m^3$, patients with chronic lung diseases may experience accentuation of symptoms (23, p. 10/21).

Effects on Direct Sunlight

At concentrations ranging from 100 $\mu g/m^3$ to 150 $\mu g/m^3$ for particulates, where large smoke turbidity factors persist, in middle and high latitudes direct sunlight is reduced up to one-third in summer and two-thirds in winter (22, p. 12/19).

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[3] $\mu g/m^3$ = micrograms per cubic meter.
[4] ppm = parts per million.

Effects on Visibility

At concentrations of 285 $\mu g/m^3$ (0.10 ppm) of sulfur dioxide, with comparable concentration of particulate matter and relative humidity of 50 percent, visibility may be reduced to about 5 miles (23, p. 10/21).

At concentrations of about 150 $\mu g/m^3$ for particulates, where the predominate particle size range from 0.2 μ[5] to 1.0 μ and relative humidity is less than 70 percent, visibility is reduced to as low as 5 miles (22, p. 12/19).

Effects on Materials

At a mean sulfur dioxide level of 345 $\mu g/m^3$ (0.12 ppm) accompanied by high particulate levels, the corrosion rate for steel panels may be increased by 50 percent (23, p. 10/21).

At concentrations ranging from 60 $\mu g/m^3$ to 180 $\mu g/m^3$ (annual geometric mean), for particulates in the presence to sulfur dioxide and moisture, corrosion of steel and zinc panels occurs at an accelerated rate (22, p. 12/19).

Effects on Public Concern

At concentrations of approximately 70 $\mu g/m^3$ for particulates (annual geometric mean), in the presence of other pollutants, [the public may experience the effects of air pollution, and awareness may] increase proportionately up to and above concentrations of 200 $\mu g/m^3$ for particulates (22, p. 12/19).

Effects on Vegetation

At a concentration of about 85 $\mu g/m^3$ (0.03 ppm) of sulfur dioxide (annual mean), chronic plant injury and excessive leaf drop may occur.

After exposure to about 145 $\mu g/m^3$ to 715 $\mu g/m^3$ (0.05 ppm to 0.25 ppm), sulfur dioxide may react synergistically with either ozone or nitrogen oxide in short-term exposures (e.g. 4 hours) to produce a moderate to severe injury to sensitive plants (23, p. 10/22).

With the limited air pollution information presently available, specific problems, such as damage to structures and vegetation, cannot be adequately evaluated. Based on weather data and known emissions it is reasonable to assume at this time, however, that critical concentrations, as outlined above, are reached when a region experiences a temperature inversion. Under such conditions vertical movement of acrid gases and particulate matter is restricted. The result is the formation of a blanket of these gases that often settles over an area for many days.

[5] μ = micron.

The location of the refuse site magnifies the serious effects that can result from an excessive concentration of these gases. Flames, thermal waves, smoke, and fumes were observed at all 292 burning coal waste piles surveyed in this study. Approximately 94 piles, 32 percent of the total, in the survey were located in valley bottoms, while 60 percent, or 173 piles, were situated on the side of a hill or mountain where the prevailing wind movement determined the direction and rate at which the gases dispersed. Residents in communities as far as 5 miles away could be adversely affected. This survey revealed that 260 banks, or 89 percent, were located within 5 miles of a community of more than 200 people; 131 of the sites, or 45 percent, were less than 1 mile from the nearest community. A further delineation of community population relative to burning coal waste piles follows:

Number of banks	Surrounding population at each bank
138	Less than 1,000.
123	1,000 to 10,000.
25	10,000 to 100,000.
6	More than 100,000.

Deaths and serious accidents that have been attributed to burning coal refuse piles are given in table 3. In addition to these accidents, 22 other deaths, for which details were not available, have been reported: eight in West Virginia, six in western Pennsylvania, six in the anthracite region of Pennsylvania, and two in Virginia.[6] Seven burning refuse bank explosions and 11 waste bank slides were also identified, but the extent of resultant damages was not described. Still another casualty occurred on July 1, 1969, near Scranton, Pa., when a young man working for a private enterprise stepped through the crust of the bank into a burning cavity about 4 feet deep. The victim received burns over 95 percent of his body, and had he not been wearing an oxygen mask at the time, he would never have been able to crawl out of the hole. Approximately 10 percent of the coal refuse accumulations surveyed in the study are believed to pose a potential hazard to mining or public facilities in the event that bank stability should deteriorate. The majority of these banks contained a minimum of 500,000 cubic yards of material.

Lead-base paints and certain metal surfaces are subject to discoloration and corrosion when exposed to hydrogen sulfide fumes. Many structures in the vicinity of burning refuse banks (including those recently painted) exhibit a darkening, which is a black lead sulfide film precipitated by the chemical reaction of hydrogen sulfide and lead-base paints. Preliminary investigations have shown that steel corrosion panels can lose 5 to 6 percent of their original weight when subjected to sulfur dioxide.

Gases emitted from burning banks can severely damage or destroy surrounding vegetation (fig. 5). Seventy-three percent of the burning banks were adjacent to forest, grasslands, croplands, or idle lands. The extent of damage and the critical levels causing damage to vegetation by these gases

[6] Written communication to Director, U.S. Bureau of Mines, from Director, U.S. Geological Survey, July 10, 1970.

have not been adequately studied. In one case, however, the gases emitted by a burning bank seriously affected a planting of trees 3 miles away (10).

TABLE 3. - Partial list of deaths and accidents attributed to coal waste fires

Location	Remarks
Iowa.....	An explosion during excavation of a coal waste bank burned 6 men, 3 fatally.
Do.....	An explosion during excavation of a coal waste bank burned 11 men, 3 fatally.
Sagamore, W. Va.....	Thirteen killed by an explosion of a burning coal refuse pile.
Lochgelly, W. Va.....	One killed by slide while digging red dog.
Oakwood, Va.....	Seven killed by an explosion and resultant slide of a bank.
Virginia.....	Burning refuse bank ignited coal seam. Two killed by an explosion in the mine while investigating the extent of the fire.
Alabama.....	Two killed while excavating burning refuse material.
Mayberry, W. Va.....	One child killed by falling through surface crust on a burning coal refuse pile.
Oakwood, W. Va.....	Two killed by explosion while digging red dog.
Sharples, W. Va.....	Burning coal slide covered mine opening; all men were rescued 48 hours later.
Hemp Hill, Ky.....	Two killed by asphyxiation after falling into burning bank.
Rhoda, Va.....	Two killed by bank slide.
Amherstdale, W. Va.....	Explosion and resultant bank slide injured one child and destroyed several homes.

Some banks occupy prime sites that could be used for industrial, residential, or commercial development. There were 74 burning coal refuse banks, covering approximately 1,000 acres, that could have some higher land use. In addition, 121 of the inspected sites were considered to have only poor to fair appearance because of the presence of one or more abandoned structures or vehicles and junk, garbage, trash, or construction materials. Not only do refuse banks prohibit the economic redevelopment of particular sites, but they

FIGURE 5. - Scene Illustrating Damage to Mature Trees Growing Adjacent to a Burning Refuse Bank.

also adversely affect the aesthetic environment and discourage the developme of other available and suitable lands in the surrounding area.

Infiltration of water into coal refuse banks occurs either from direct precipitation, storm runoff, or normal stream flow. Regardless of its sourc water penetrating and flowing from a refuse bank carries pollutants in the form of dissolved gases, salts, and fine particulate matter, which contamina adjacent watercourses. Physical and chemical pollution or a combination of them was observed at 118 burning refuse banks. Ninety-seven of the banks were polluting streams that flow adjacent to or less than 2 miles from commu nities with populations between 200 and 10,000.

During periods of precipitation, smog forms from a combination of gase and minute materials emitted from burning banks. The smog hampers traffic along nearby highways and creates a serious safety hazard to motorists. Fifty-seven percent of the smoke-generating banks were within 500 feet of Federal and State highways or other areas frequented by the general public.

FIRE CONTROL EFFORTS AND TECHNIQUES

Present Efforts

Efforts to control fires were evident at only 63 of the 292 burning banks. Forty-two of these control attempts were made by mining companies and private individuals. Only partial success was achieved in 40 of these control efforts, and indication of a completely successful extinguishment was limited to nine locations.

Although the number of fires located was substantially less than the 495 fires located in the 1963 survey (28), the decrease in number was due more to the fact that many of the older fires had burned themselves out than to interim efforts to control them.

Fire Control Techniques

The first serious effort to control and extinguish coal refuse bank fires was made in Great Britian (4, 7, 24 - 25) during World War II because the fires served as beacons to guide enemy bombers to targets. The British installed water sprinklers over burning piles. Water was permitted to percolate into the bank. This method required a large and continuous supply of water and was considered successful, even though the fires generally rekindled after sprinkling was stopped.

The most commonly practiced control technique used by the mining industry in the United States has been blanketing refuse banks with noncombustible material (3, 9, 11-12, 19, 27). The technique has been widely used because of its relative inexpensiveness; however, it is generally considered unsuccessful. It involves covering the burning bank with a mantle of clay, dirt, or other readily available noncombustible material, which restricts the flow of air through the burning pile. The effectiveness is short term unless continual maintenance and repair of the seal is provided. Experience has shown that the seal is rendered ineffective by several forces if left unattended:

1. The normal weathering of the wind may erode the seal; air is then readmitted to rekindle the hot, but dormant, carbonaceous material.

2. The seal may be washed away by water falling upon, flowing across, or flowing adjacent to the bank.

3. The internal temperatures of the bank may bake the underlying portion of the earthen seal and cause the seal to crack and fissure (fig. 6).

4. Smoldering beneath the seal causes coal refuse to be converted to an ash product that occupies less space, and a pocket is created beneath the seal. The seal may then slump or subside into the void by gravity, or it may cave in as a result of an animal or person walking across the supposedly solid surface.

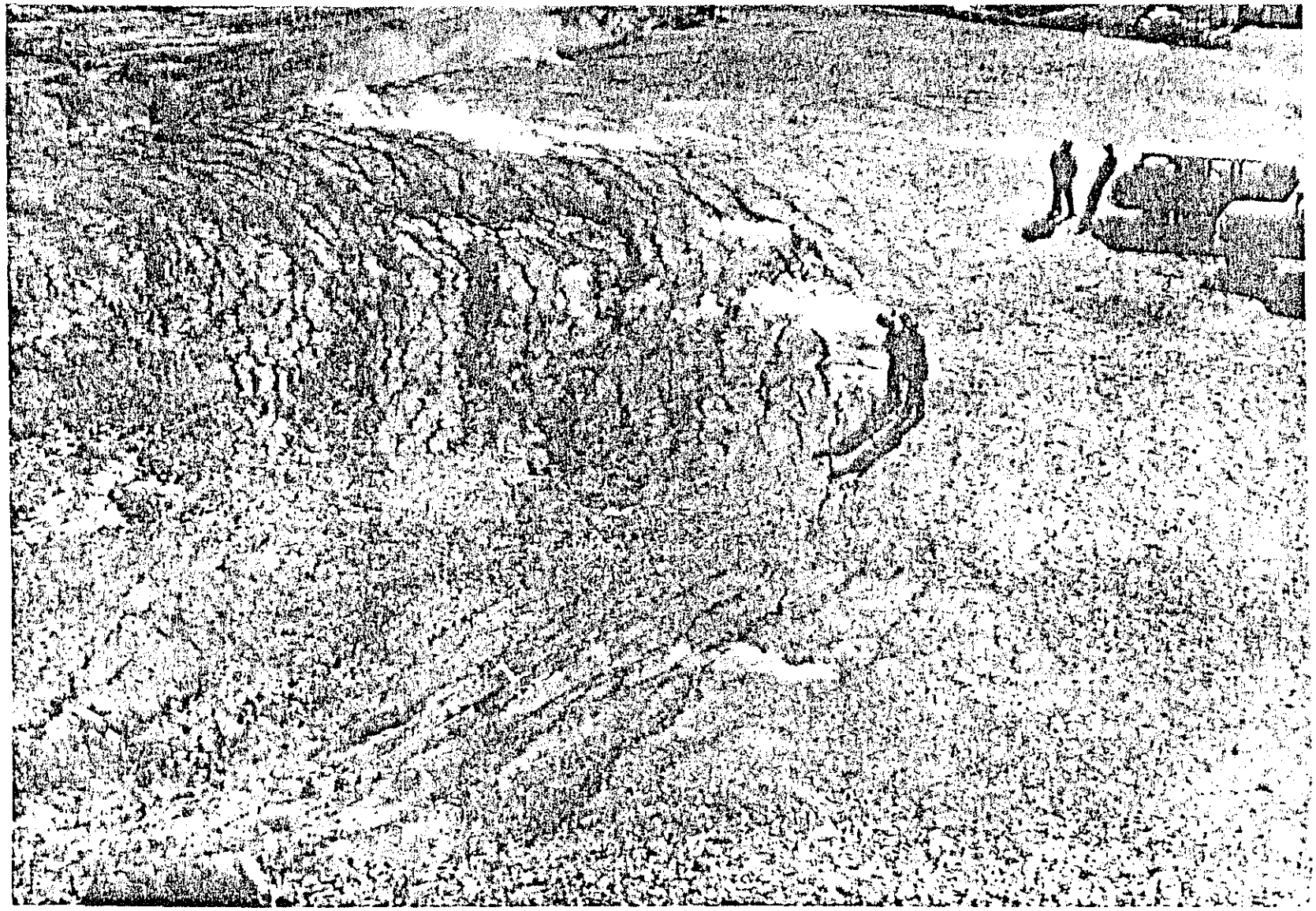

FIGURE 6. - Concentric Fissures or Cracks, Subsided Areas, and Acrid Fumes and Smoke Are Evidence That a Fire Continues to Burn Beneath an Earthen Seal.

In 1963-64 the Bureau of Mines completed an experimental demonstration project to control and extinguish a burning coal refuse bank. Three procedures were tested: (1) saturation sprinkling onto the natural surface of the bank (similar to the aforementioned British technique); (2) saturation sprinkling with surface drainage into 125 uncased 10-foot-deep boreholes to achieve deeper water penetration; and (3) water injection through pipes extending 10 feet into the pile. The quantity of water sprinkled on the bank was delivered at a rate equivalent to 0.22 inches of rainfall per hour. All three techniques achieved approximately the same reduction in temperature at the 10-foot depth. No reduction was evident at the 20-foot level during the operation. Three months after the project was halted, little or no evidence of fire was observed on or near the surface of the refuse pile. However, temperatures at the 10-foot level were as high or higher than the temperatures originally observed before water application.

In 1968 the Bureau of Mines completed a demonstration project in Scranton, Pa., which was considered a step toward developing a successful, low-cost procedure for quenching and removing burning coal refuse (1). The project site is shown in figure 7. Various combinations of water cannons and earthmoving equipment were tested and evaluated for effectiveness and cost.

1. The first set of procedures included a series of high-pressure water cannons[7] to quench and dislodge the hot refuse material (fig. 8). The loose material was then hydraulically transported away from the quenching site. The placer mining sluicing approach to moving the cooled refuse proved ineffective because of the angularity of the material, loss of hydraulic force away from the cannons, and infiltration of water into the bank.

2. The use of a battery of water cannons to cool and dislodge the refuse was greatly facilitated by the use of a bulldozer to push the cooled refuse to an adjacent disposal site. Using a bulldozer increased the rate of material movement from the 40 cubic yards per hour with hydraulic transport to 120 cubic yards per hour. The estimated cost for water quenching plus bulldozer haulage was $0.66 per cubic yard.

3. The final procedure tested and evaluated also used water cannons to cool the refuse material. In addition, a water sprinkling system was placed over the test area. Water was played on the site overnight to reduce surface temperatures to permit the movement of rubber-tired vehicles over the project site. A bulldozer equipped with a ripper was used to loosen the coal refuse to facilitate loading, movement, and disposal of the cooled refuse by a tractor-scraper. The quenched refuse was moved to an adjacent strip mine area for disposal. The material was compacted by the tractor-scraper's movement across the site and was covered with available noncombustible material. The use of a water cooling system and heavy earthmoving equipment resulted in a production rate of 300 cubic yards per hour. The cost was estimated at $0.44 per cubic yard.

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[7]All water cannons operated at a rate of 100 pounds per square inch, gage. The commercial nozzles used ranged from 1,000 to 4,000 gallons per minute.

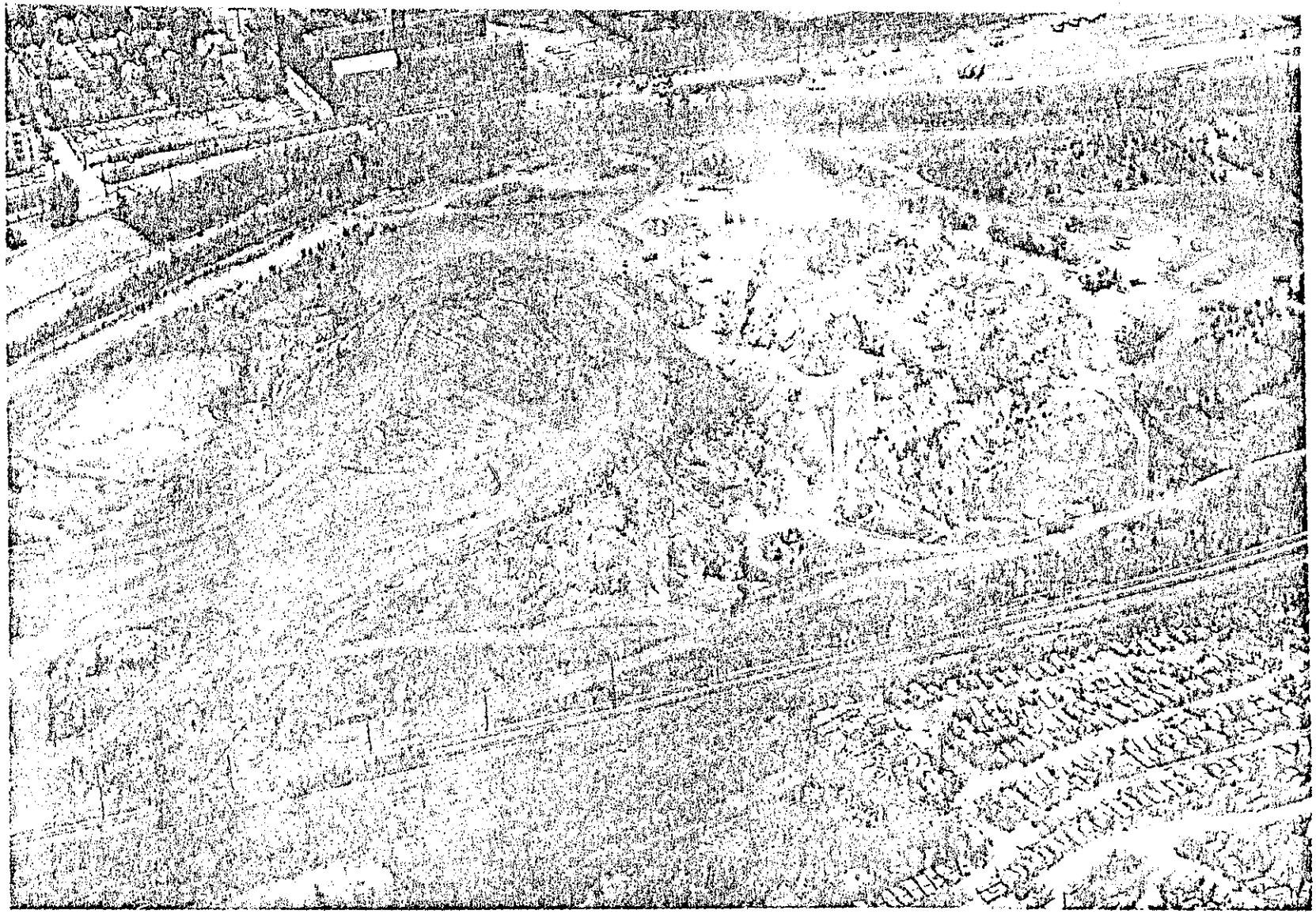


FIGURE 7. - Bureau of Mines Fire Extinguishment Project, Scranton, Pa. Water quenching and excavation on left temporarily suppressed the emission of smoke and gases, while right section of bank

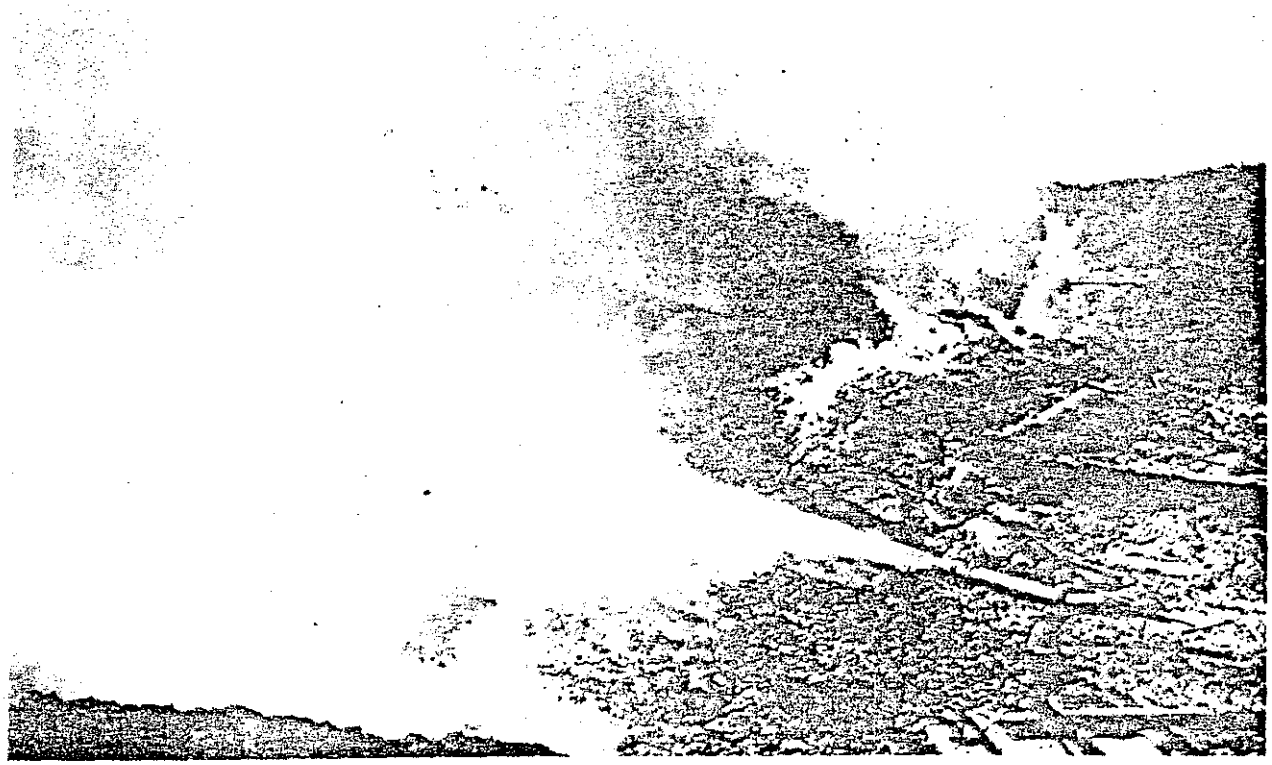
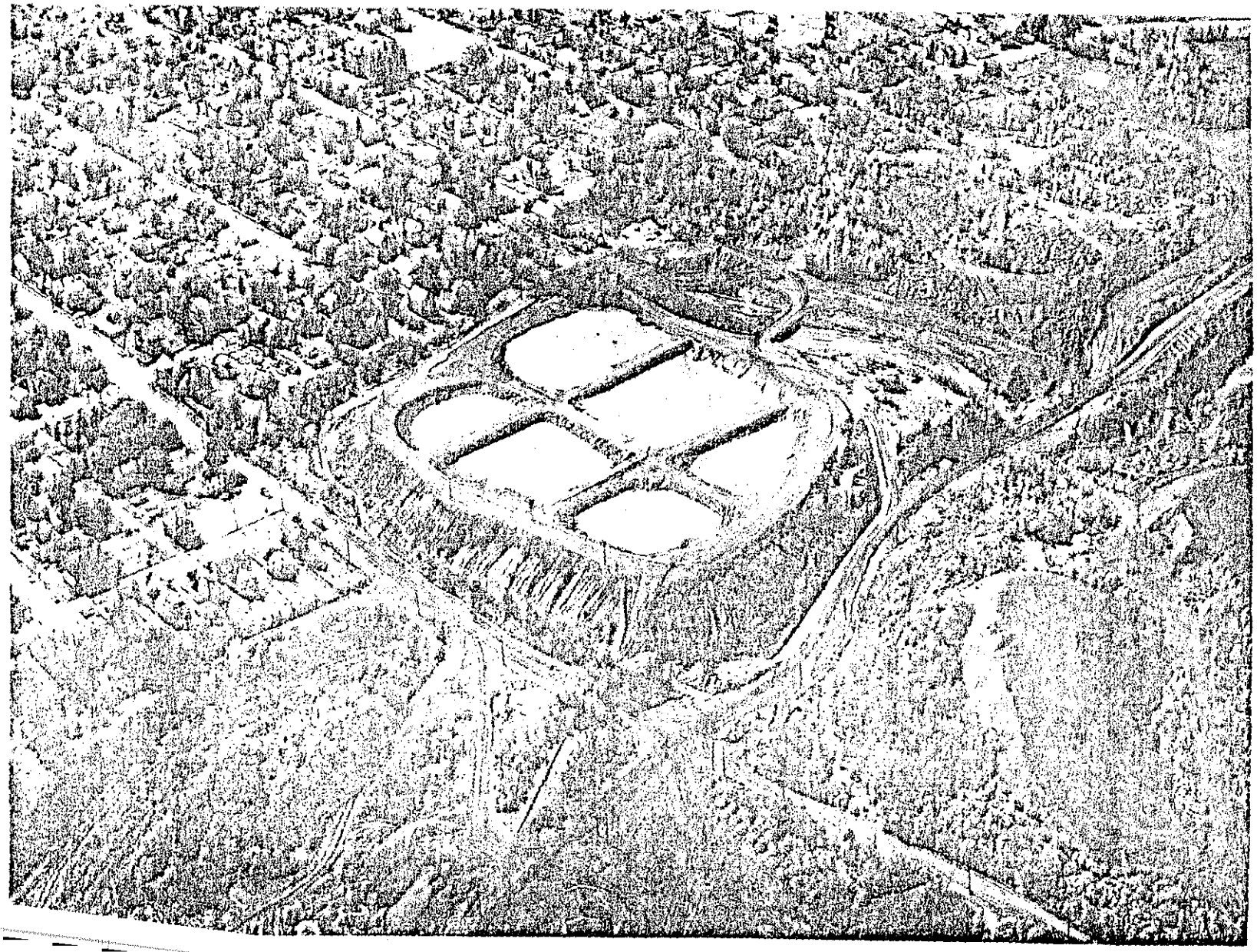


FIGURE 8. - Quenching of Refuse Bank Fire With Water Cannon. The large quantities of generated steam can create "water gas" explosions.

Following the physical work phase of the demonstration, a series of boreholes was drilled across the cooled refuse disposal site. The recorded temperatures from the holes verified that complete extinguishment had been accomplished at a comparatively low cost per cubic yard.

In 1970, at the Taylor bank near Scranton, Pa., a cooperative demonstration project between the U.S. Bureau of Mines and the Pennsylvania Department of Mines and Mineral Industries was completed. The project was designed to test and evaluate a unique method referred to as the "rice paddy" technique (fig. 9) to extinguish a refuse bank fire located adjacent to many occupied residences and shops. The method was selected because it would minimize gases, dust, and possible explosions during the extinguishment process.

The selected demonstration site was readily adaptable to the "rice paddy" technique because the bank had been graded and covered with a clay seal in an earlier attempt to extinguish the fire. The sides of the bank were graded to a smoothly contoured, steep-sloped configuration, and the top of the bank was level. At the time the project was initiated, the sides were scarred with small erosion gullies, and the top of the bank had subsided several feet as a result of the continued burning and consequent slumping beneath the clay seal.



"Rice Paddy" Technique. (Taylor refuse bank.)

The following procedures were followed during the demonstration work:

1. An earthen dike was constructed around the perimeter of the bank, and three transverse dikes were built to subdivide the bank into six individual ponds or "rice paddies."

2. A water manifold was laid to the individual ponds, and water was pumped into the ponds from the underlying inundated mines. The water levels were maintained around the clock for 30 days. During this period, water from the ponds percolated down through the burning refuse bank to reduce the internal temperatures. Temperatures inside the bank exceeded 1,800° F at the outset of the project.

3. Following the waterflooding phase, an electric dragline was used to systematically excavate and transfer the cooled refuse material pond by pond. Water was applied to the excavation site throughout the material-handling phase. The turnover operation was continued until all known burning areas were controlled.

4. The final phase of the project required that the quenched material be returned to the excavation site, compacted, and leveled (fig. 10).

A detailed report describing the total operation, its effectiveness, and cost was being prepared at the time of this writing. The quantity of material transferred per cubic hour was not yet available. The estimated costs for this project were much higher than the costs previously discussed, but because the project location was adjacent to occupied homes and shops, the safety of the occupants demanded high-priority consideration. The preliminary costs of the demonstration are roughly estimated around $5 per cubic yard.

Under Public Law 90-128, the "Air Quality Act," the Secretary of Health, Education, and Welfare (HEW) was directed to establish air quality standards. An important facet of this effort is to identify pollution sources and to provide technical advice on how to control or eliminate them. As a part of this program, 15 demonstration projects have been or are being conducted by HEW in cooperation with the States of Kentucky, Pennsylvania, and West Virginia to determine the extent to which burning banks contaminate the air and to evaluate various extinguishment techniques.

A few techniques that were tested during the HEW demonstration projects include--

1. Sealing or capping to prevent air circulation through burning refuse banks by using various chemicals and compounds such as polyurethane foam, several types of plastic material, and fine waste dust from cement plants.

2. Injection into the bank through drill holes of a mixture of sludge, "yellow boy," which is produced during the neutralization of acid mine water with limestone.

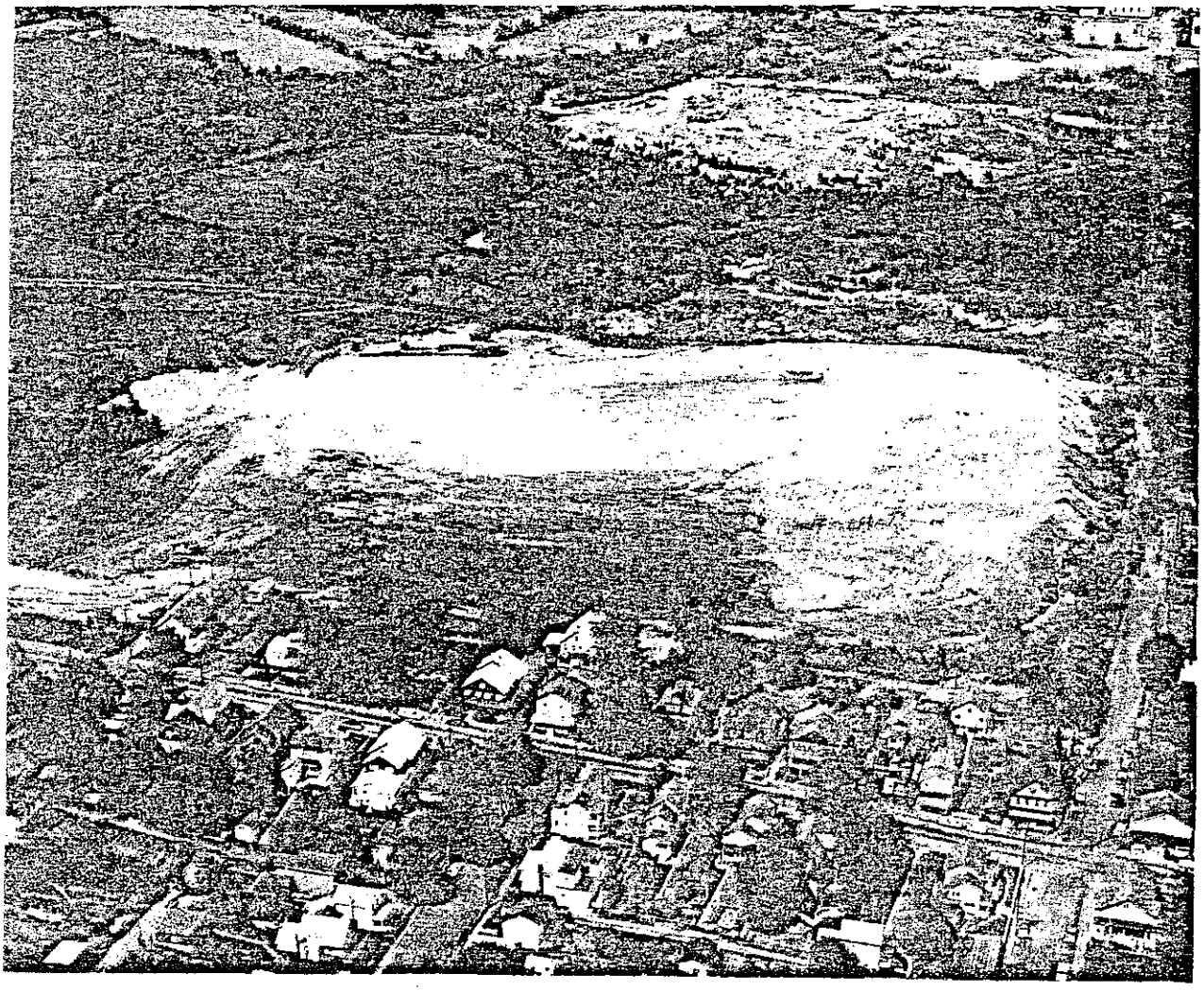


FIGURE 10. - Taylor Refuse Bank Project Site Following Recasting and Grading of Quenched material.

3. Drill hole injection of a mixture of vermiculite, limestone, and sodium bicarbonate into the refuse pile.

4. The use of explosives to fracture fused refuse material to facilitate the infiltration and percolation of water through the hot cores of banks.

When these extinguishment methods have been evaluated by the National Air Pollution Control Administration, a report will be released.

GUIDELINES FOR THE PREVENTION OF REFUSE BANK FIRES

The complete elimination of refuse bank fires may not be achieved soon, but the possibility of such fires starting up in the future can be reduced through effective design, storage, and maintenance of coal refuse accumulations. Industry and Government agencies have investigated and proposed more effective waste disposal methods (2, 5-6, 13, 15, 20, 26, 31-32).

Site Selection and Preparation

More attention must be directed to the handling and disposal of coal refuse in the design of coal mining operations. In the past, the primary concerns were a site large enough to handle the waste and a system of waste disposal that would not hinder production. It is necessary, however, to consider several other important criteria in site selection and preparation.

The best location for coal refuse disposal is relatively flat terrain, which facilitates the movement of equipment. In addition, the disposal site should be designed and constructed with proper engineering principals of soil mechanics and dam construction (where needed). In hilly or mountainous regions coal waste disposal should be conducted in valley bottoms or ravines. These areas are generally more accessible, and waste disposal can be properly engineered and managed. Coal waste should never be deposited atop ridges or dumped across hill or mountain slopes. Sites and waste disposal designs should harmonize with surrounding landscape and land use.

The geologic environment of a disposal site, including rock types and soil classification, must be considered, particularly in hilly and mountainous regions. Prior to final site selection all data concerning soil compaction, permeability, composition, and rock strength competence must be identified and evaluated. For example, it would be illogical to construct a refuse disposal retaining dam on shale or clay zones, which become water saturated or plastic following periods of normal rainfall. Knowledge of soil and rock characteristics is essential for the construction of proper retaining structures.

Site selection should include consideration of waterflow. Waterflow through a refuse bank can create several problems: (1) Water will dissolve minerals and salts, carry them to the watercourse, and cause water pollution; (2) saturated refuse banks become less stable and possibility of a failure either in the bank slope or the underlying support material increases; and (3) the water may encourage heat generation inside the refuse bank from the formation of water vapor. If possible, an area where no perennial or intermittent flow of water occurs should be selected. Most often, however, this is impossible. Consequently, measures should be taken to divert streams around the disposal site through construction of water channels. In the rugged regions where it may be impossible to divert the water source, a reinforced concrete pipe should be laid beneath the refuse bank. This pipe should be designed to handle maximum runoff.

The disposal site should be close to an adequate source of noncombustible materials, to be sandwiched between layers of coal refuse. The sides of the disposal site should also be covered with a noncombustible material and compacted to eliminate the inflow of air. Materials that may be considered include clay, shale, coal sludge fines, fly ash, and fines or wastes from plants, such as cement, gypsum, and ceramic and glacial loess.

After the most suitable site has been selected, several steps should be taken to properly prepare the site prior to any waste disposal. All brush, trees, and other combustible materials should be grubbed and removed from the

site. In areas where coal seams or other highly carbonaceous zones are known to crop out, precautions must be taken to place an adequate inert seal between the waste and the outcropping resources. The site should be graded to assure proper drainage away from the site, and watercourses should be diverted around or placed beneath the disposal site. Definite guidelines for slope angles cannot be established accurately without investigating onsite geological conditions.

Refuse Bank Design

Refuse bank design and subsequent disposal of the reject material are probably the most important phases in handling coal waste. Most safety hazards and environmental degradation are caused by improper disposal techniques or the lack of proper engineering. Proper engineering practices have been implemented at a few mining operations, but the problems resulting from poor waste disposal practices continue to grow.

After the disposal site has been selected and other variables such as amount of waste, disposal methods, and possible use of site following abandonment are established, the design of the disposal operation may be considered. The engineering principles applied to rockfill or earth embankments should be considered in the design of coal refuse disposal operations. Consideration must be given not only to the initial structure but also to future raises (layers) of the refuse bank. In hilly mountainous regions the slope of the terrain must be carefully evaluated to insure that waste will not slump and slide. Such movements may be generated by the weight of the material itself or result from the accumulation or seepage of water into the waste. The permissible slope angles of the supporting ground and of the refuse bank are als dependent upon such physical characteristics of the refuse as size and shape.

Many refuse disposal problems may be controlled by spreading the waste material in horizontal layers and compacting the material to increase its strength. Many slides and slumps of coal waste deposits have occurred in mountainous or hilly regions where compaction of refuse has often been impossible.

Segregation of the material by size should be avoided because the flow air through refuse is increased when the size and shape of waste is uniform Compaction of refuse reduces the size of openings and voids. The optimum c paction of coal refuse is achieved if refuse is wet. The water serves as a lubricant to soften the material and make it more workable. After a preest lished thickness of coal refuse is deposited and compacted, a layer of nonc bustible material should be added and sandwiched between each succeeding refuse layer. All outside slopes of refuse banks should be compacted and sealed to exclude air movement through the waste.

Aerial tramway disposal creates conditions favorable to spontaneous c bustion because refuse material becomes graded and sized. This condition facilitates the movement of air through a refuse bank. Operations using t disposal should include provisions for leveling waste piles and mixing fir and coarse refuse material.

New methods and techniques of discarding refuse are needed to lessen the ever-existing potential of refuse bank fires. Refuse material deposited in abandoned surface mines and properly insulated from the outcropping coal could result in the reclamation of strip-mined lands for more useful purposes (21). The backfilling of abandoned underground mines with reject material is, if the mines are properly sealed, another method of disposal that would alleviate potential mine subsidence and cave-ins.

Site Reclamation and Abandonment

Prior to closing the disposal site, precautions should be taken to reduce the possibility of a future refuse bank fire. The bank should be properly graded, compacted, and sealed; a final layer of the best available noncombustible material should be placed over the bank. A vegetative cover should be established over the covered refuse bank to prevent or reduce erosion. Fencing and posting the site will minimize the chance of ignition of the bank by trespassers. The site should be inspected at regular intervals, and all necessary maintenance should be carried out promptly.

Improvement in coal preparation techniques to reduce the percentage of carbonaceous material presently being classified as waste would solve part of the fire problem. As much as 20 percent of the refuse, depending on the type of preparation plant, is combustible. This percentage is governed by the grade of coal that is mined.

An alternative that offers a partial solution to the problem of refuse bank fires is the development of uses for the waste. Research has been conducted to utilize refuse waste to manufacture light-weight aggregate for concrete and block (18). Additional research may discover new marketable products.

SUMMARY

Burning coal refuse was formerly part of the way of life for the residents of mining communities. Today, however, a changing socioeconomic pattern is emerging throughout the Nation's coalfields. People are becoming increasingly opposed to the objectionable and detrimental effects of coal refuse bank fires, and measures must be taken to eliminate them.

Coal refuse fires have proven to be extremely hazardous to the environment and its inhabitants. At least 55 unsuspecting persons are known to have fallen victim to these infernos. The health and safety of nearby residents, particularly children and elderly persons, is threatened as a result of the impairment of the surrounding air quality by the generation of poisonous and noxious gases. Vegetation and building materials are severely damaged or destroyed when the gases reach critical concentrations.

Federal and State governments, aware of these problems, have undertaken research projects on the extinguishment of burning coal waste. Various techniques tested have included quenching with water, sealing with layers of incombustible materials, and grouting the piles by injecting a mixture of

different materials, such as limestone dust, cement waste dust, mine water sludge, and vermiculite.

Each refuse bank fire has unique physical characteristics that will determine the most economic method of controlling it. Specific factors that demand special consideration are the shape of the burning refuse bank; its accessibility to roads and highways; space to maneuver the necessary equipment; adequate supply of water; a suitable disposal site for quenched materials; source of a noncombustible cover material; and the value of the land for other purposes.

The sensible approach to controlling and eliminating environmental problems associated with coal refuse accumulations is adequate advance refuse disposal planning. Although there is no Federal legislation to control refuse disposal, several States have enacted regulations to prevent and control air pollution from coal refuse disposal areas (17, 24, 30).

The results of this study indicate that coal waste and, in particular, burning or smoldering coal waste piles contribute to the degradation of our air, land, and water resources. They are public health and safety hazards. An intensified research and correction program is needed to meet the challenge.

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UNITED STATES
DEPARTMENT OF LABOR
MINE SAFETY AND HEALTH ADMINISTRATION
COAL MINE SAFETY AND HEALTH DISTRICT 4

GROUND CONTROL PLAN
(SECTION 77.1000, 30 CFR)

Ground control plan for reclaiming, removing or relocating material from refuse piles. This plan shall not apply to the surface mining of coal from its natural deposit.

MSHA ID NO._____ MINE_____

COMPANY_____

LOCATION_____
(Town) (County) (State)

OPERATOR'S NAME_____ TITLE_____

ADDRESS_____

_____

LIST OF EQUIPMENT TO BE USED:_____

_____

_____

_____

PROPOSED METHODS OF EXCAVATION. (INCLUDE DRAWINGS OR SKETCHES FOR ILLUSTRATION)_____

_____

_____

_____

AVERAGE HIGHWALL HEIGHT (FEET)_____

WIDTH OF BENCHES_____

MAXIMUM SLOPE OF GROUND (NOT TO EXCEED 27°)_____

SITE LOCATION MAP ATTACHED? YES_____ NO_____

In addition to the aforementioned information, the following must be submitted:

1. Maps or drawings showing location of sites, including roads, structures, residences, streams, mine openings, and other pertinent features that could be affected.
2. The following safety precautions shall be adopted and posted:

   (a) Any persons on the terrace to which the material is being pushed shall be at least 50 feet to either side of the slide area.

   (b) If any slides develop while the material is being loaded, all persons shall immediately withdraw fifty feet to either side of the slide area.

   (c) After any rain or freeze or thaw or other weather condition that might cause a hazard, the area shall be examined for hazards before work is done in that area.

   (d) If any hazardous conditions develop, the condition shall immediately be corrected in the safest manner possible. If this is impossible, the area shall be posted.

   (e) If it becomes necessary for men to work between equipment and highwall, adequate precautions must be taken to see that they will not be covered by a slide.

   (f) No material shall be removed at night (unless adequate illumination is provided).

   (g) Burning refuse is never to be excavated by hand.

   (h) The final slope is obtained by starting on top and removing the layers in lifts of 6 inches to 2 feet across the area which is to be sloped. If the area is not to be sloped (on a flat surface), small lifts are still to be taken. After the removal of each lift in burning areas, the equipment is to be indexed over to permit the area to cool between lift removals.

(i) Warning signs shall be posted to alert personnel of hazardous areas.

(j) First-aid materials shall be kept at the site as required by Section 77.1707.

(k) No material shall be removed when it contains visible flames.

(l) Dozer operations on any burning refuse pile are to be suspended in the areas subjected to harmful amounts of gases. Extreme caution is to be practiced during periods of atmospheric conditions such as rain, overcast skies, and still air.

(m) Loading and material handling operations are to be conducted in a manner as to utilize the wind to keep smoke, particulate matter, and gas away from personnel.

(n) Precautions shall be taken when operating equipment under power-lines, as specified in Section 77.807-2.

(o) Communications shall be provided as required by Sections 77.1700 and 77.1701.

(p) All personnel are to removed immediately in the event of movement and rumbling of the ground and/or pulsating emitted smoke and/or change of color of the smoke.

(q) All authorized persons are informed of the hazards associated with work being performed on the refuse pile.

Signature_____
(To be signed by a responsible official)

GUIDELINES FOR APPROVAL OF EXCAVATION METHODS

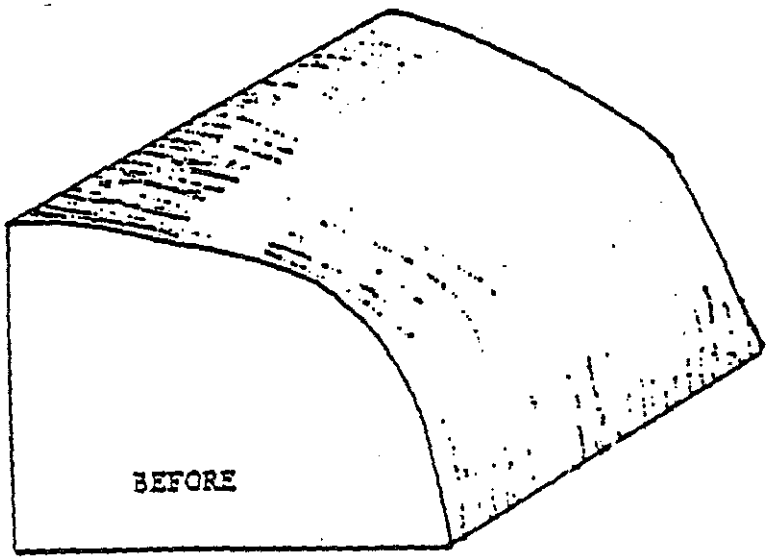
Loading out of an unburned or completely burned refuse pile which is not steeper than the natural angle of repose. If the material is removed from the bottom, the highwall face cannot be higher than the heavy equipment can reach. However, unless such equipment is used as power shovels, clams or other equipment having the bucket well away from the operator and suspended from a lever arm, the highwall face is not to be more than 12 feet. All personnel are to be cautioned against being adjacent to the highwall. Signs should be used to assist in personnel awareness. The necessary surface examination will be made as required.

Loading out of a smoking and/or burning refuse pile. The likelihood of slides and other safety hazards increases with the height and the steepness of the pile. Consequently, the height of the highwall face is limited to 12 feet and no one is permitted next to this highwall. Signs and other measures should be employed to assist in personnel awareness. The slope should be less than 27 degrees unless the material is removed to the original terrain and the slope gradient should be determined before starting any removal. The attached sketches illustrate one way to prevent steep highwalls.

The material is to be removed in sequence starting from the top and working the layer progressively down to the toe.

After removing material from the toe, the process of removing material is to be continued by redetermining the slope and start loading operations again at the top.

Extreme caution has to be practiced when heavy equipment is operating near or on burning refuse piles. It is not unusual to encounter burned-out areas in the pile that are covered with a crust of sturdy appearance which will not support the weight of the equipment or personnel. A weighted bucket such as a shovel, endloader or heavy material like a weight attached to a crane rope or a dozer blade can be dropped over the entire area of the refuse area being traveled to assist in determining regions where only a crust covers a voided space beneath the surface.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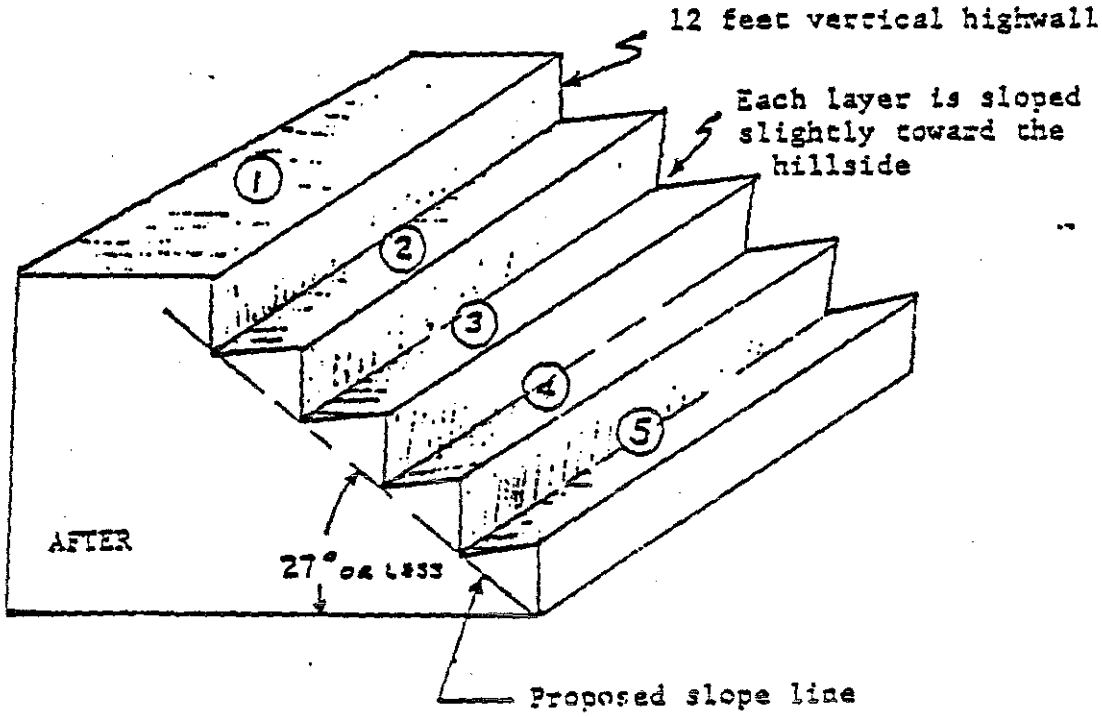
12 feet vertical highwall
Each layer is sloped slightly toward the hillside
1
2
3
4
5
AFTER
27° or less
Proposed slope line