IGNITION AND CONTROL OF BURNING OF COAL MINE REFUSE

By James W. Myers, Joseph J. Pfeiffer, Edwin M. Murphy,
and Franklin E. Griffith

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IGNITION AND CONTROL OF BURNING OF COAL MINE REFUSE

by

James W. Myers,[1] Joseph J. Pfeiffer,[2] Edwin M. Murphy,[3]
and Franklin E. Griffith[4]

ABSTRACT

The Bureau of Mines studied factors affecting ignition of coal mine refuse and on methods for control of burning. Laboratory experiments showed that air permeates more readily through segregated than through nonsegregated refuse and that air permeability is greater through coarse than through fine particle refuse. Minus 3½-inch refuse ignites spontaneously more readily than minus ¼-inch refuse. The burning of a 1,000-pound conical coal pile was controlled by capping with an 18-inch-thick layer of minus ¼-inch refuse containing 37 percent combustible.

In field trials, the burning of refuse at operating mines was controlled by capping with a layer of fine refuse. Water, applied as a spray or by injection, quenched surface flames and cooled the burning waste. Inspection of refuse piles at operating mines showed that the spontaneous ignition tendency is affected by the exposed surface relative to the total volume and the segregation of particles during dumping.

INTRODUCTION

The Bureau of Mines conducted research to assist the coal-mining industry in safe and economical disposal of mine refuse. Modern coal-mining practices and coal-cleaning facilities increase the proportion of waste handled. Refuse, ordinarily dumped in piles near mine portals, contains coal, rock, carbonaceous

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shales and pyrites, wood, machine parts, wire and electrical cables, paper, cloth, grease, and oil. The combustible portions of the waste often burn, liberating smoke and toxic gases. These pollute the air and are a nuisance to nearby communities. According to a recent Bureau survey, more than 495 refuse piles are on fire in the United States (4).[5]

Some refuse piles are ignited purposely to obtain red dog, but most fires start by spontaneous combustion, careless burning of trash, and scrub fires. Active burning is generally most evident on sides and bottoms of slopes where larger lumps accumulate during dumping. Air, penetrating through crevices between the lumps, is heated and rises as in a chimney. Appreciable air flows into and out of a pile because of barometric pressure changes.

Many methods, such as flooding, blanketing, slurry injection, compacting, loading out, and sealing, have been tried to control fires. However, unless the temperature within the bank is reduced below the kindling point, a potential fire hazard continues to exist. This report summarizes laboratory and field investigations conducted during the past 10 years by the Bureau of Mines. The Bureau has studied the permeability of coal piles to airflow, factors affecting spontaneous ignition of coal, the smothering of fires by capping with fine refuse, and the control of burning of a mine refuse pile by water application (surface sprinkling and injection). Applications of dry materials as a cover and water as a cooling agent have been made by others. Successful trials on capping were reported by Carr (1) and Harrington (2). Water was applied to a refuse pile in Ohio, and control of burning was achieved (3). However, in Europe attempts to control burning by water were unsuccessful (1).

LABORATORY STUDIES

Laboratory tests were made to study airflow through refuse, the effect of particle-size distribution on ignition, and the quenching of fire in a 1,000-pound conical pile of coal by capping with minus ¼-inch refuse. For these studies, freshly processed washery refuse was used. The original material, finer than 3½ inches, was separated into 3½- by ¼-inch and minus ¼-inch fractions. Table 1 shows that the combustible portion of the fractions ranged from 37 to 54 percent, and the pyritic content from 1 to 16 percent.

TABLE 1. - Combustible and pyritic contents of refuse used in laboratory studies

Particle size, inches	Composition, percent	
	Combustibles	Pyrites
Minus 3½	40	5
3½ by ¼	54	1
Minus ¼	37	16

[5] Underlined numbers in parentheses refer to references at the end of this report.

Permeability of Refuse

Laboratory trials showed that about six times more air passed through the $3\frac{1}{2}$- by $\frac{1}{4}$-inch than through the minus $3\frac{1}{2}$-inch refuse for a given pressure differential. About four times more air passed through the minus $3\frac{1}{2}$-inch than through the minus $\frac{1}{4}$-inch refuse. The fine refuse appreciably reduced the flow of air. These data are shown in figure 1.

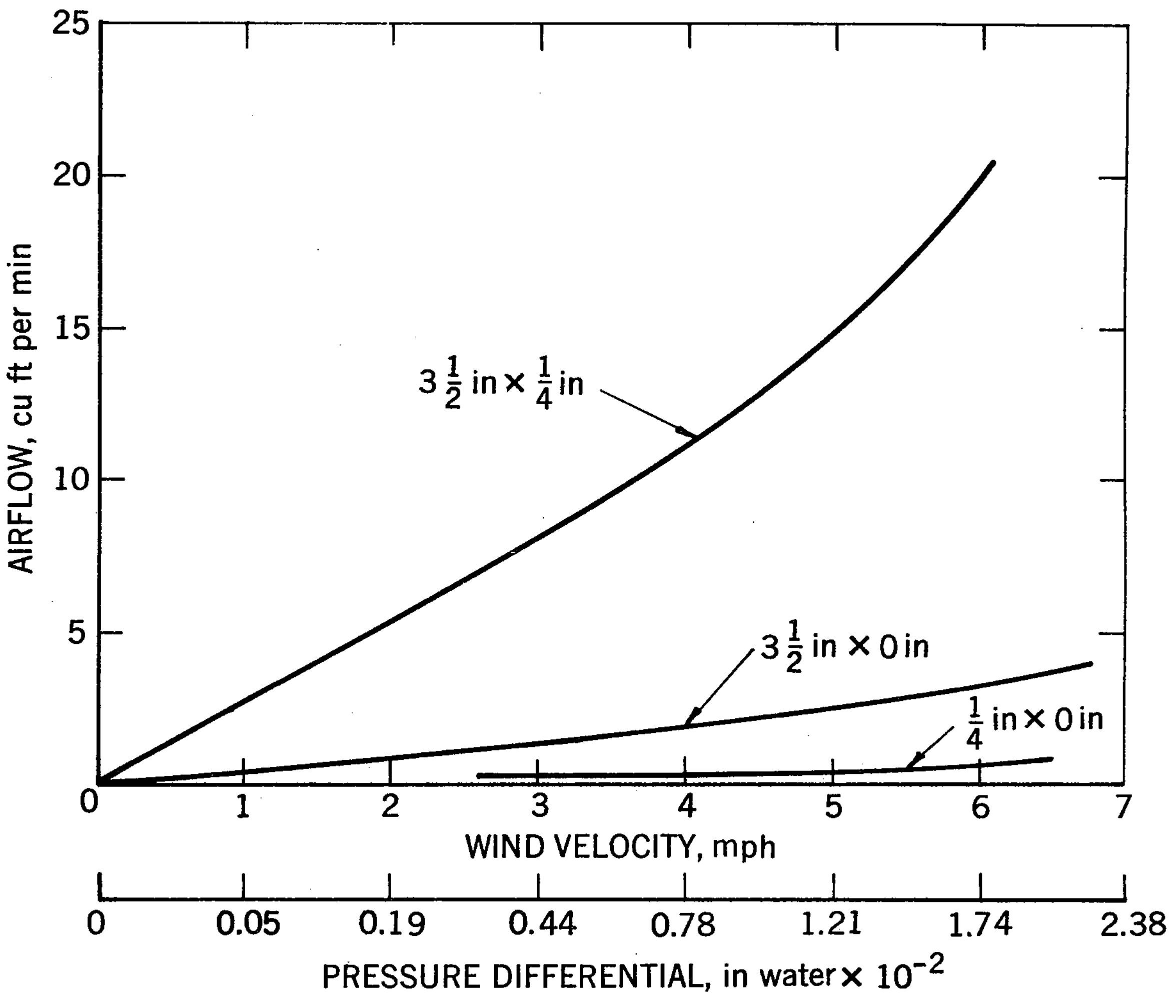


FIGURE 1. - Effect of Pressure Differential or Equivalent Wind Velocity on Quantity of Air Passing Through 9-Inch Layer of Refuse.

The quantity of air passing through a 9-inch layer of refuse was measured with the equipment illustrated in figure 2. The refuse was placed on a screen in a steel drum, and air was forced through the bed by a blower at the bottom. The pressure drop across the refuse for various rates of airflow was measured by a draft gage.

An estimate of the quantity of air passing through a layer of refuse may be obtained by assuming that the impact pressure of the wind is given by

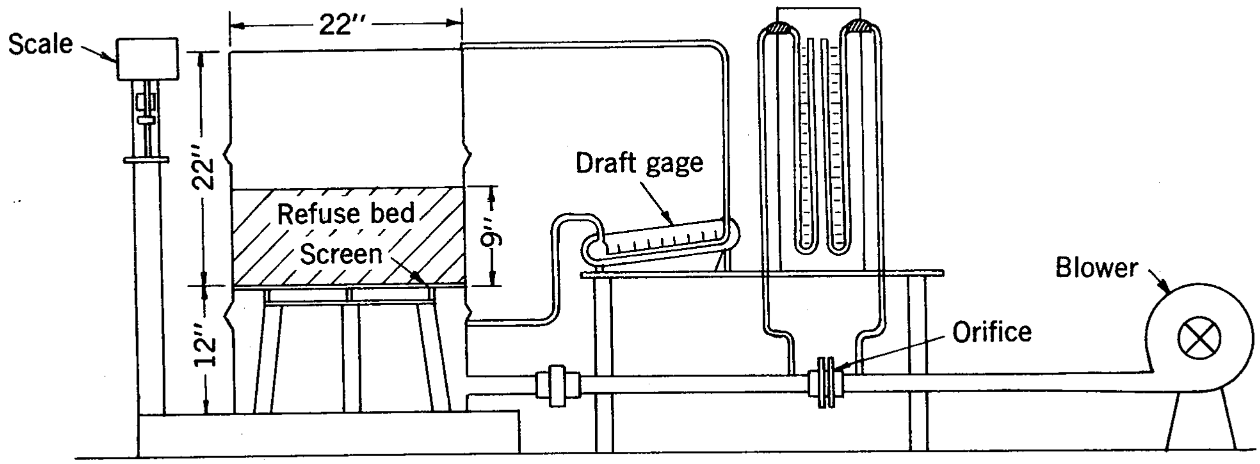


FIGURE 2. - Apparatus for Measuring Airflow Through Refuse.

$$P = \frac{\rho v^2}{2g}, \tag{1}$$

where

P = impact pressure,

ρ = density of air,

v = wind velocity, and

g = acceleration of gravity.

The correlation between calculated wind velocity, air-pressure differential, and quantity of airflow is given in figure 1. The data show that an appreciable amount of air would flow through a 9-inch layer when the wind velocity was 5 miles per hour or more.

Spontaneous Ignition Studies

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, summarized in figure 3, show 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 (fig. 4). 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 (fig. 5).

Trials were made by heating the bottom of refuse in a 27-cubic-foot steel chamber (fig. 6). The heat was supplied by two 1-kilowatt electrical strip heaters located below a 1-foot-wide steel channel extending across the rear wall 5 inches above the floor. An opening, cut in the channel in the front

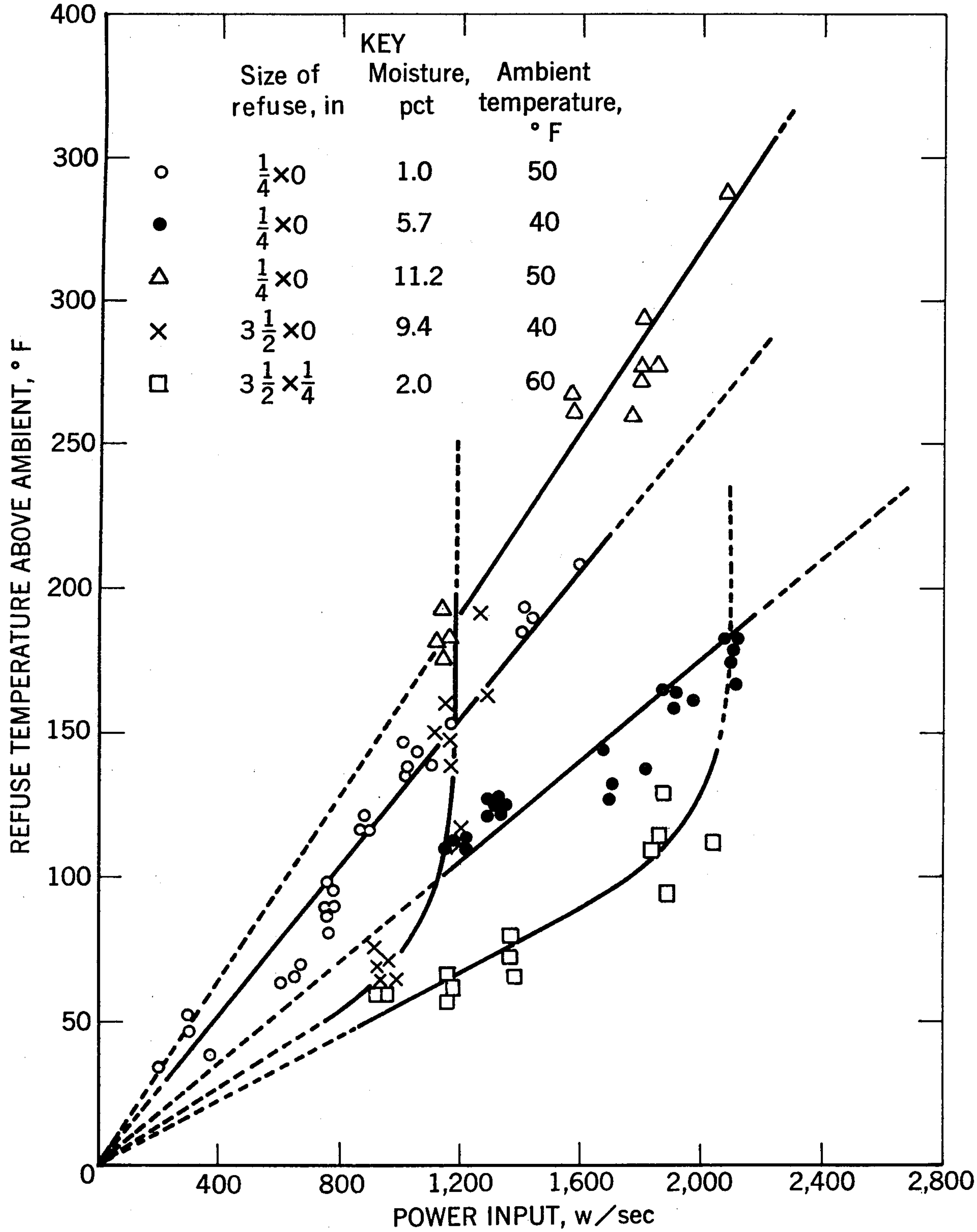


FIGURE 3. - Average Temperature in Refuse Relative to Heat Input.

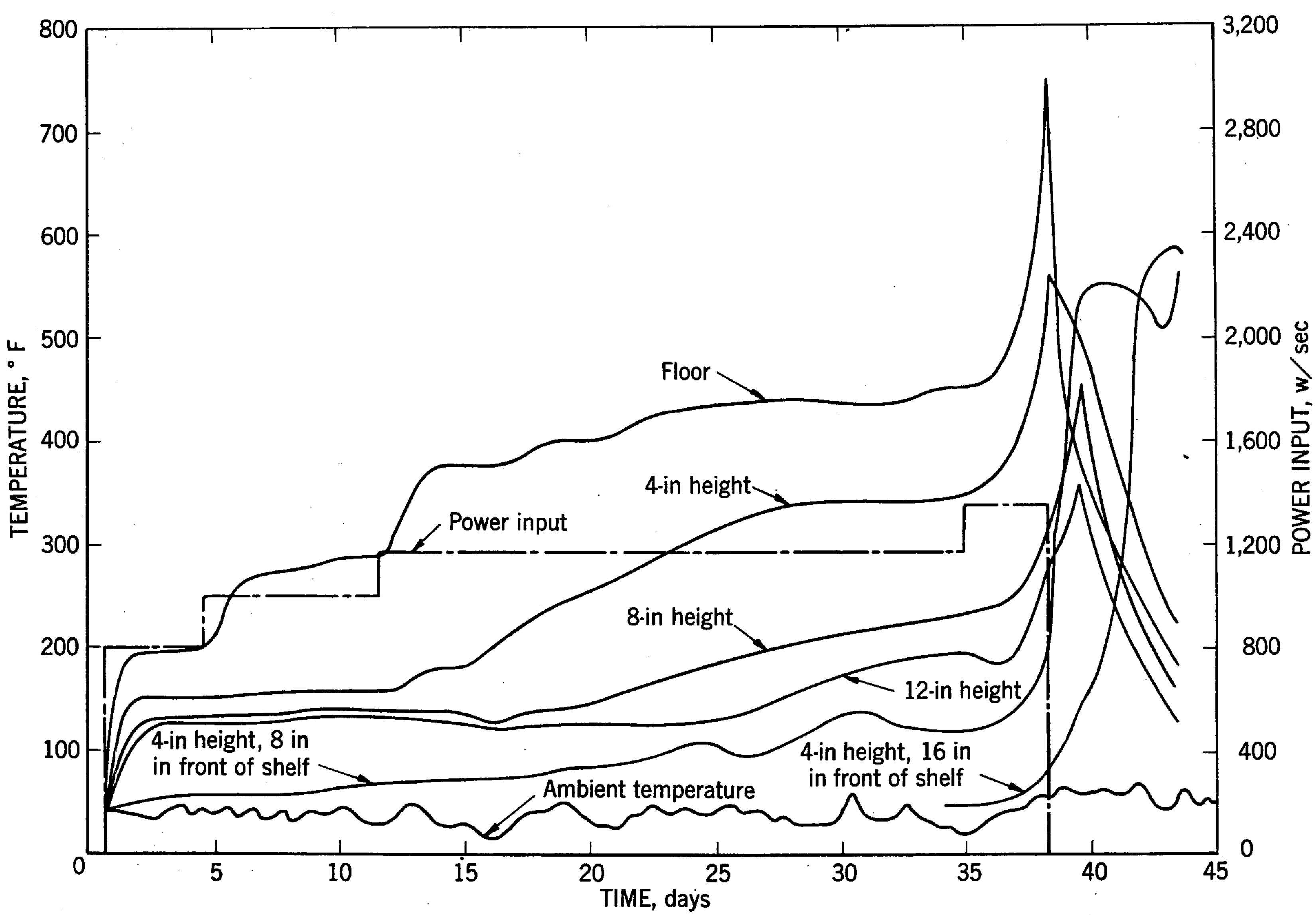


FIGURE 4. - Heat Input and Temperatures in Minus 3½-Inch Refuse (9.4 Percent Moisture).

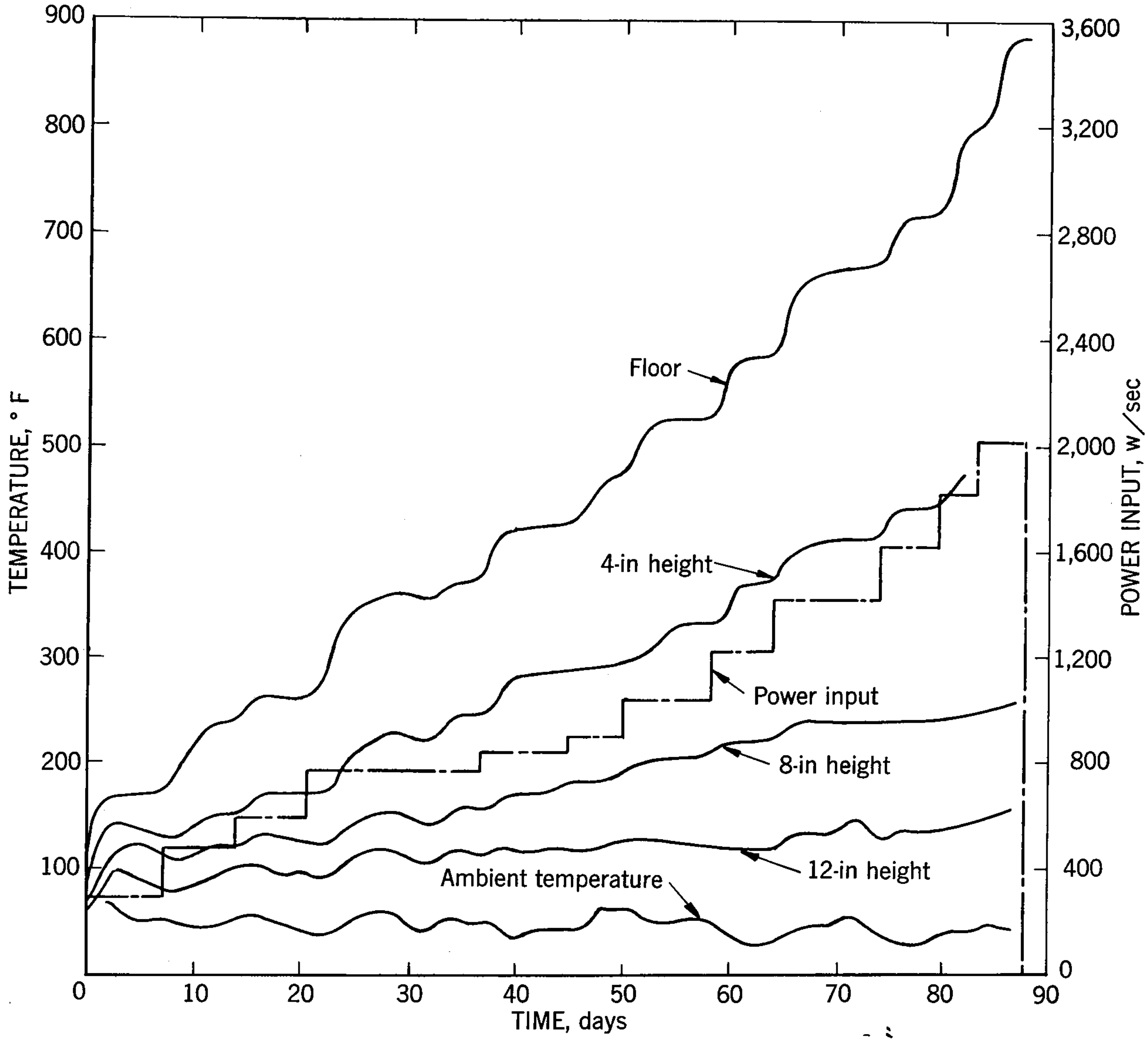


FIGURE 5. - Heat Input and Temperatures in Minus ¼-Inch Refuse (5.7 Percent Moisture).

section, was covered by a screen; air flowed by natural draft into the heated chamber and through the refuse bed. Temperatures were measured at the base and at 4-, 8-, and 12-inch heights in the refuse bed. The heat input was increased periodically; however, it was maintained at a given value until equilibrium was reached. If, for a given heat input, the temperatures within the bed did not reach equilibrium but continued to increase, the refuse was considered to exhibit a tendency toward spontaneous ignition.

Extinguishing a Burning Pile of Coal

Minus ¼-inch refuse was used as a blanketing cover to smother fire in an 11-cubic-foot coal pile. This pile, 3 feet high and 5½ feet in diameter, was

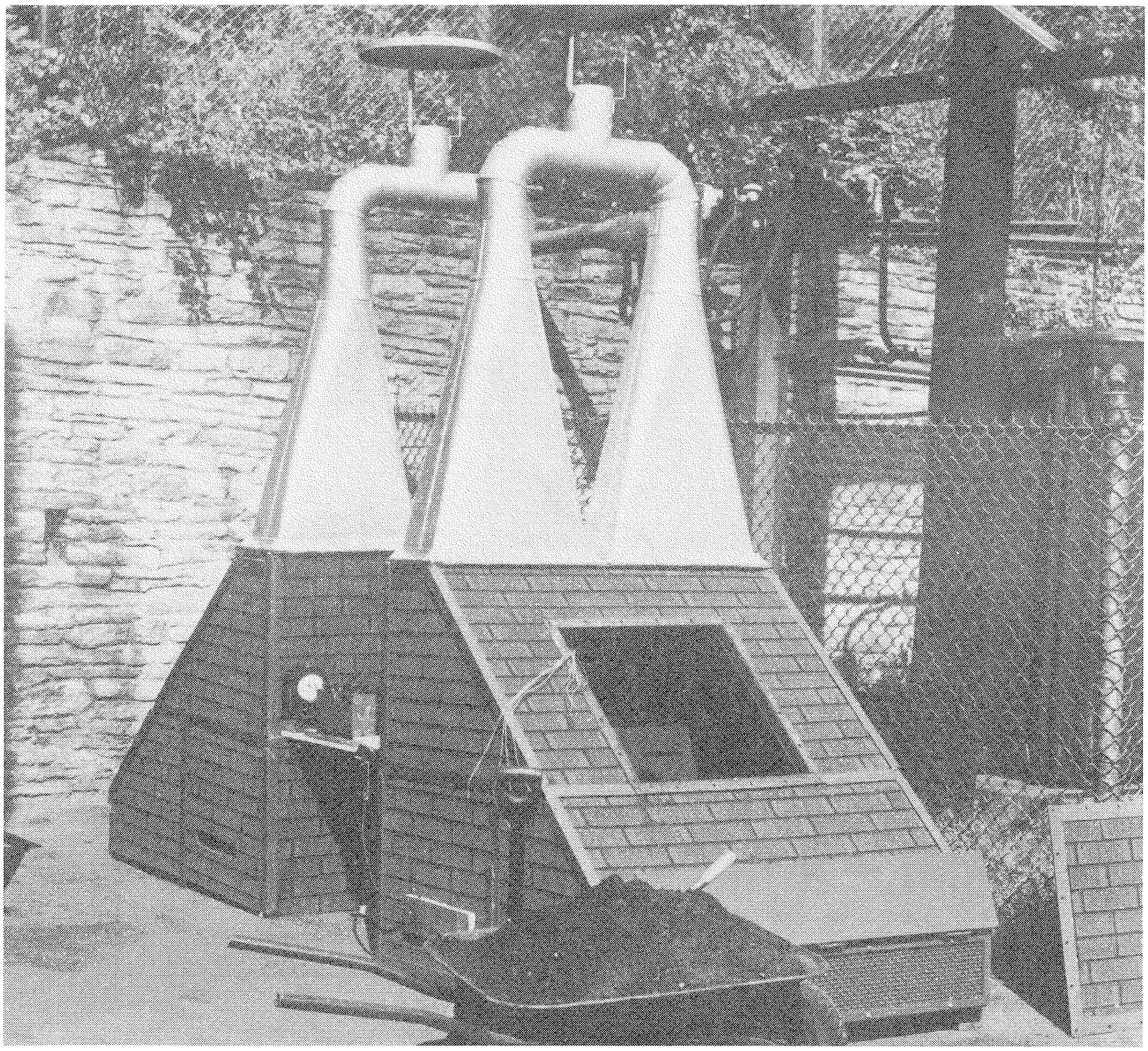


FIGURE 6. - Test Chambers for Studying Spontaneous Ignition.

ignited by a wood fire. The burning coal was covered by an 18-inch layer of the minus ¼-inch refuse. Flames were immediately quenched, and after 2 weeks the fire was essentially extinguished. After 3 weeks, the coal was at ambient temperature. Despite the high combustible and pyritic contents of the minus ¼-inch refuse, this material was effective in extinguishing the fire.

FIELD STUDIES ON CONTROL OF BURNING

Capping With Minus ¼-Inch Refuse

Following the trials in extinguishing fire in the conical pile of coal with minus ¼-inch refuse, a successful experiment was made on a 5-acre refuse pile at a coal mine (fig. 7). The slope of the 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. Seven weeks after the sealing operation began, rain water formed a gulley 3 feet deep in the flank (fig. 8) and exposed the original surface. This gulley was refilled with minus ¼-inch refuse, and a dike was constructed around the top perimeter of the flank to prevent further erosion (fig. 9). The fire was extinguished in 15 months (fig. 10). The temperature in the pile, measured by thermocouples 3 feet below the surface, was below 100° F.

In another field trial, a new refuse pile was constructed of 7- to 10-foot-thick layers of segregated 3½- by ¼-inch refuse. Except in one location, the flank of each layer was sealed with minus ¼-inch refuse before the next layer was placed (fig. 11). A portion of one flank was purposely left unsealed (fig. 12). Spontaneous ignition occurred in the unsealed flank, as well as in sections of the sealed flank where the minus ¼-inch refuse was eroded by rain water. The temperature did not rise in any of the other sealed sections. When the unsealed and eroded areas were covered with fine refuse, the temperature decreased rapidly. Three additional sealed layers of segregated refuse were subsequently added to the pile during 14 months; the ultimate height was approximately 50 feet (fig. 13). Ignition did not occur.

Water Applications

Water was applied to a 50-year-old refuse pile in Pennsylvania. The 20-acre pile is approximately 1,200 feet long, 700 feet wide, and 100 feet high. Figure 14 shows the refuse pile and the portions of the pile burning at the start of the project. Active fire was evident in 50 percent of 1,800 linear feet of perimeter of the main refuse pile. Flames were visible on and at the bottom of the slopes. Smoke and fumes issued from cracks in the top surface within 50 feet of the rim of the bank. The surface affected by fire was estimated to be 145,000 square feet on the top and 300,000 square feet on the slopes. The volume of material from the surface to the 10-foot depth, where the temperature was 100° F or higher, was estimated to be 5 million cubic feet. Analysis of samples from drill holes showed 25 percent of this material was combustible.

Figure 15 shows smoke and steam prior to water treatment. Flames, not clearly shown in the photograph, were most prevalent at the bottom of the slopes. The center portion of the main refuse pile was not burning; the average temperature was 105° F at the beginning of the investigation and 100° F at the end.

Fire Control Procedures

Prior to the water application, forty-four 4-inch-diameter boreholes were drilled 20 feet deep in a lattice pattern across the pile to accommodate thermocouples. One year later, 101 additional 10-foot-deep holes were drilled. The locations are shown in figure 16; the original holes are identified by number. While drilling some of the boreholes near the rim of the bank, red-hot and flaming material was encountered.

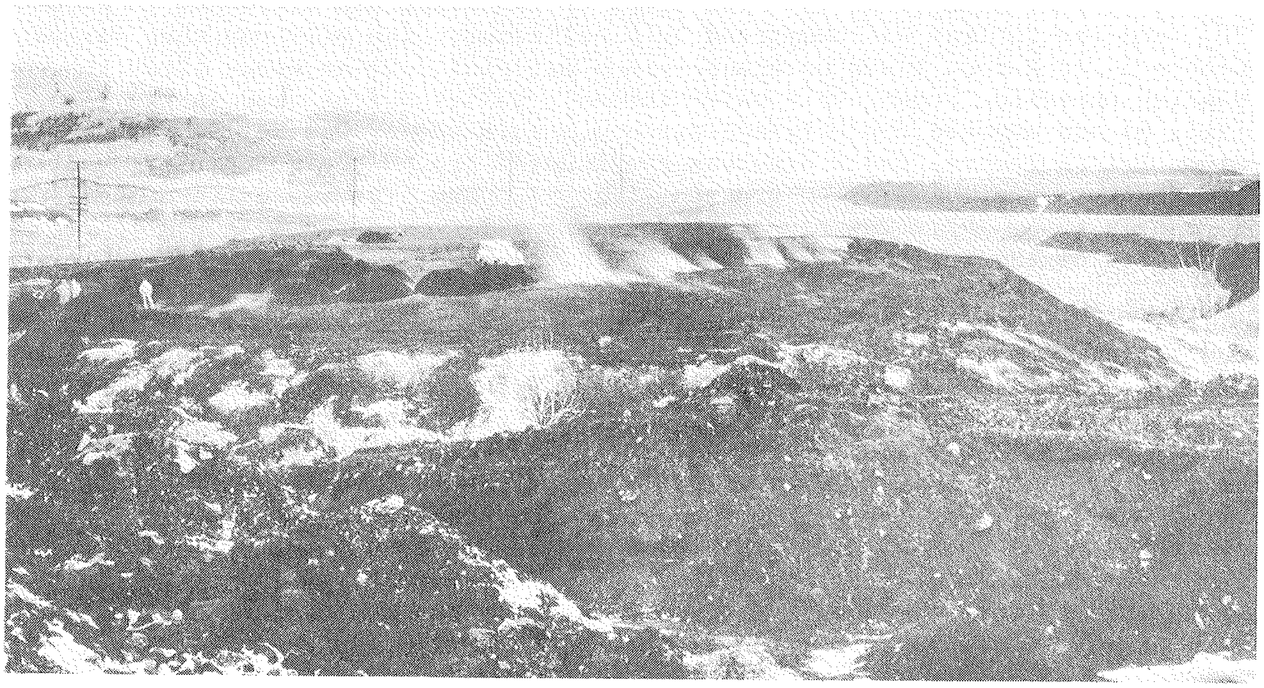


FIGURE 7. - Burning Refuse Pile 1 Prior to Control Operations.

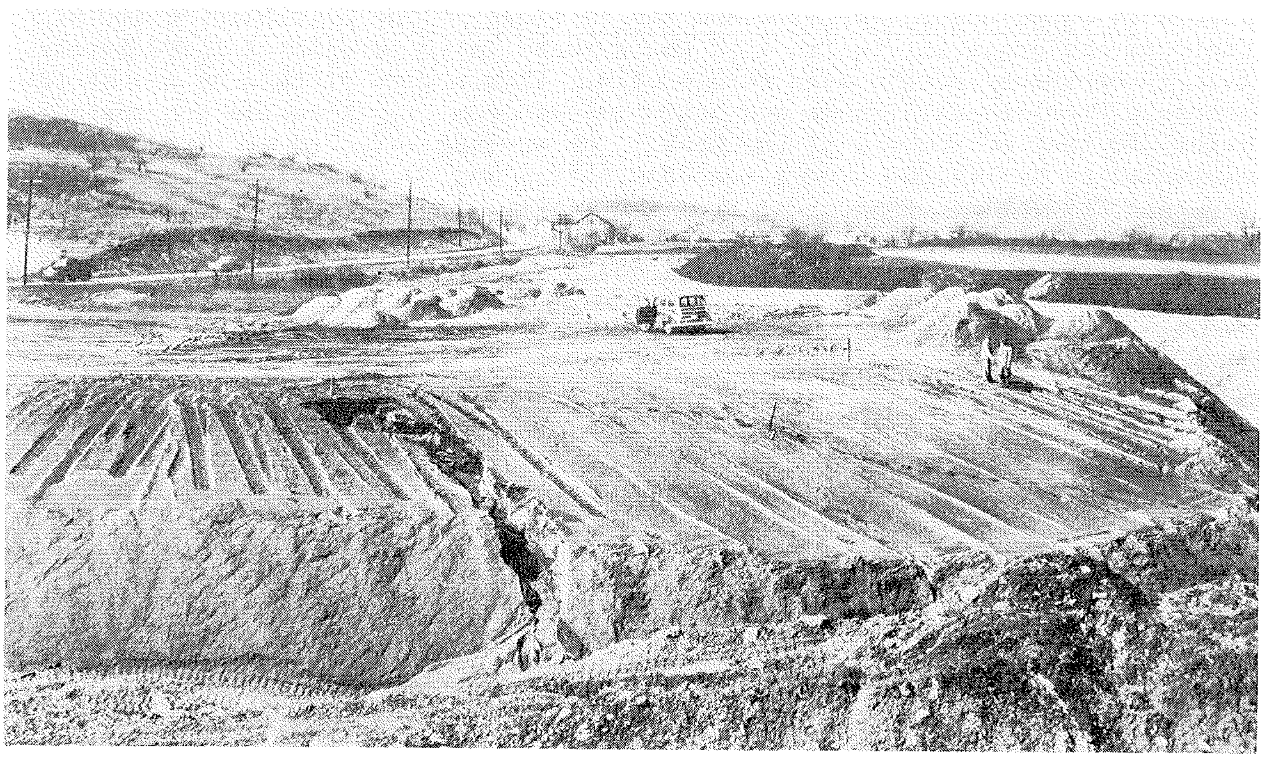


FIGURE 8. - Refuse Pile 1, 7 Weeks After Control Operations Began.

FIGURE 9. - Dike on Top of Pile 1, 15 Weeks After Start of Sealing Operations.

FIGURE 10. - Extinguished Pile 1, 15 Months After Start of Operations.

FIGURE 11. - Flank of 15-Foot-High, Layered, 3½- by ¼-Inch Refuse Sealed With Minus ¼-Inch Material.

FIGURE 12. - North End of 15-Foot Layer of Unsealed Refuse Where Temperature Measurements Were Made.

FIGURE 13. - Flank of 5-Layer Pile of 3½- by ¼-Inch Refuse Sealed With Minus ¼-Inch Material.

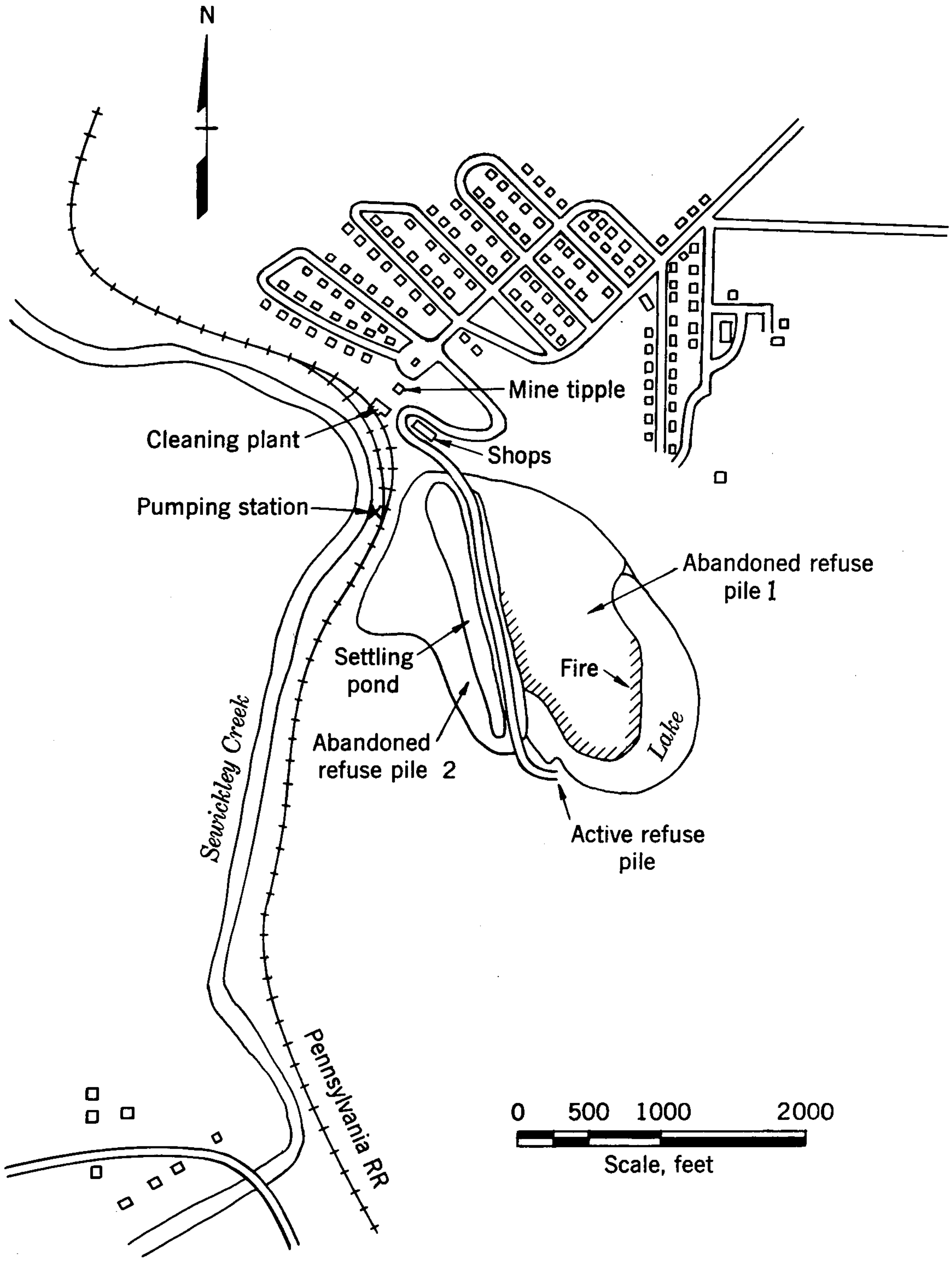


FIGURE 14. - Mine Refuse Pile and Surrounding Area.

FIGURE 15. - Section of Refuse Pile Prior to Water Treatment.

Water was pumped 2,200 feet from a creek through plastic pipe to a 10,000-gallon reservoir on top of the refuse pile. Two pumps forced the water from the reservoir to 20 sprinklers and to 70 injection pipes. Meters, used initially to measure the quantity of water, soon corroded; estimates of the quantity were made from pressure measurements and pump capacities. A gas sample collected on the western slope before water application showed 6.83 percent carbon dioxide and 0.15 percent carbon monoxide. A sample collected in

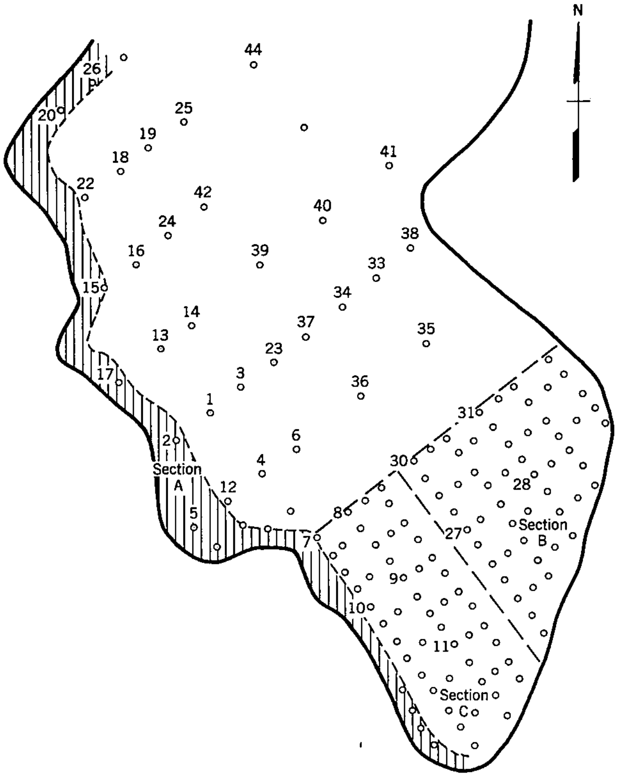


FIGURE 16. - Thermocouple Locations in Refuse Pile. Numbered points indicate initial thermocouples.

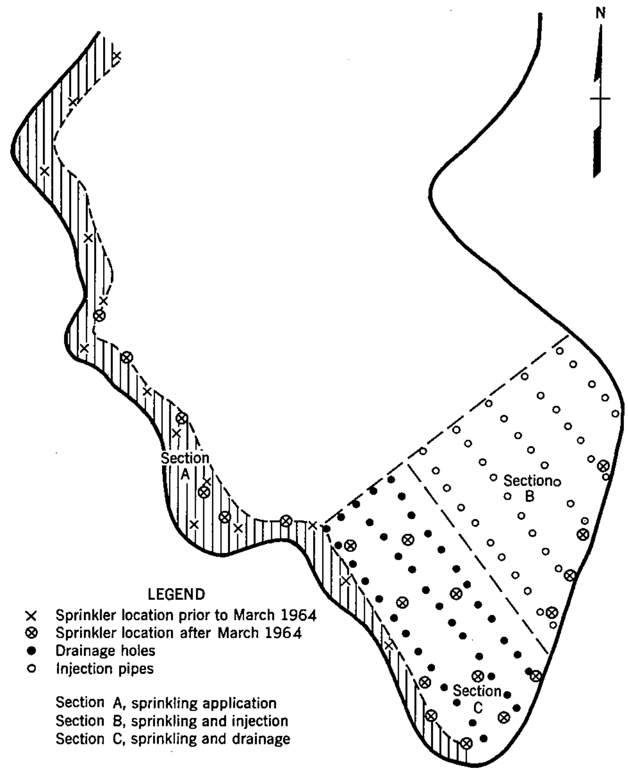


FIGURE 17. - Water Applications and Spray Locations on Refuse Pile.

the same vicinity 2 weeks after water application began showed only traces of these gases. Water was applied by three methods on the sections shown in figure 17.

Saturation Sprinkling

Water was applied by sprinkler to 45,000 square feet of top surface and 200,000 square feet of slope in section A. Each sprinkler sprayed an area 100 feet in diameter. The sprinklers were repositioned when active burning at a location was controlled or if the runoff and channeling became excessive. The rate of water application per sprinkler, 12 gallons per minute, was equivalent to 0.2 inch of rainfall per hour. On the average, water was applied 20 days during a month and 20 hours per day. During the three trial periods, which lasted 5, 2½, and 3 months, 20.0, 6.0, and 5.1 million gallons respectively were sprayed in section A.

Sprinkling and Water Injection Into Cased Boreholes 10 Feet Deep

In section B water was applied to 50,000 square feet of top surface by injection into 70 steel pipes and to 75,000 square feet of slope by 4 sprinklers. The 2-inch injection pipes were 11 feet long; these were placed on 25-foot centers. The rates of application were 12 gallons per minute per sprinkler and 1.5 gallons per minute per borehole. The water applied during two trial periods of 2½ and 3 month's duration was 14.0 and 10.3 million gallons, respectively.

Sprinkling With Surface Drainage Into Boreholes 10 Feet Deep

In section C, comprising 50,000 square feet of top surface and 30,000 square feet of slope, surface water was applied by 10 sprinklers with drainage into 50 uncased boreholes 10 feet deep. The boreholes were on 25-foot centers. Water was applied at the rate of 12 gallons per minute per sprinkler. The water applied during the 2½- and 3-month periods was 10.0 and 8.5 million gallons, respectively.

This method of water application was tried because earlier work in section A indicated that runoff occurred where the surface was compacted. Some of this runoff, when directed into crevices, produced marked reduction in the liberation of smoke and gases. In section C, an effort was made to promote drainage into the interior of the pile; in general this was successful even though most of the holes caved in.

Water applications on the burning refuse pile were successful in controlling burning on the surface. Liberation of smoke and vapors was stopped. The west bank was burning most actively at the start; figure 18, a closeup aerial view of the west bank 20 months after the project was started, shows no fire or smoke. Inspection of the refuse pile 20 months after the water application showed hot spots in about 2 percent of the areas that had been treated.

Complete control of the fire was not achieved; most of the temperatures at the 10-foot depth remained above 100° F. The changes in average temperature in each section are shown in figure 19.

The data in figure 19 show that the average temperatures at the 10-foot depth decreased with application of water except for the second trial in section A. For this trial, the temperature remained relatively constant during the spraying operation. The overall decrease in temperature was 55°, 80°, and 55° F for sections A, B, and C, respectively. In each instance, when the water application stopped the temperature increased. This increase in temperature is probably due to heat transfer from deeper portions in the pile as well as to liberation of heat during the continued oxidation.

The reductions in temperature per gallon of water applied per square foot of area are 0.4°, 0.4°, and 0.2° F for sections A, B, and C, respectively. These data indicate surface sprinkling and drainage into boreholes to be slightly more effective than sprinkling or injection alone. On the average, about 1 pound of water was applied to cool 1 pound of refuse 1° F. It is evident that large quantities of water must be applied continuously for a long time to extinguish a coal mine refuse pile.

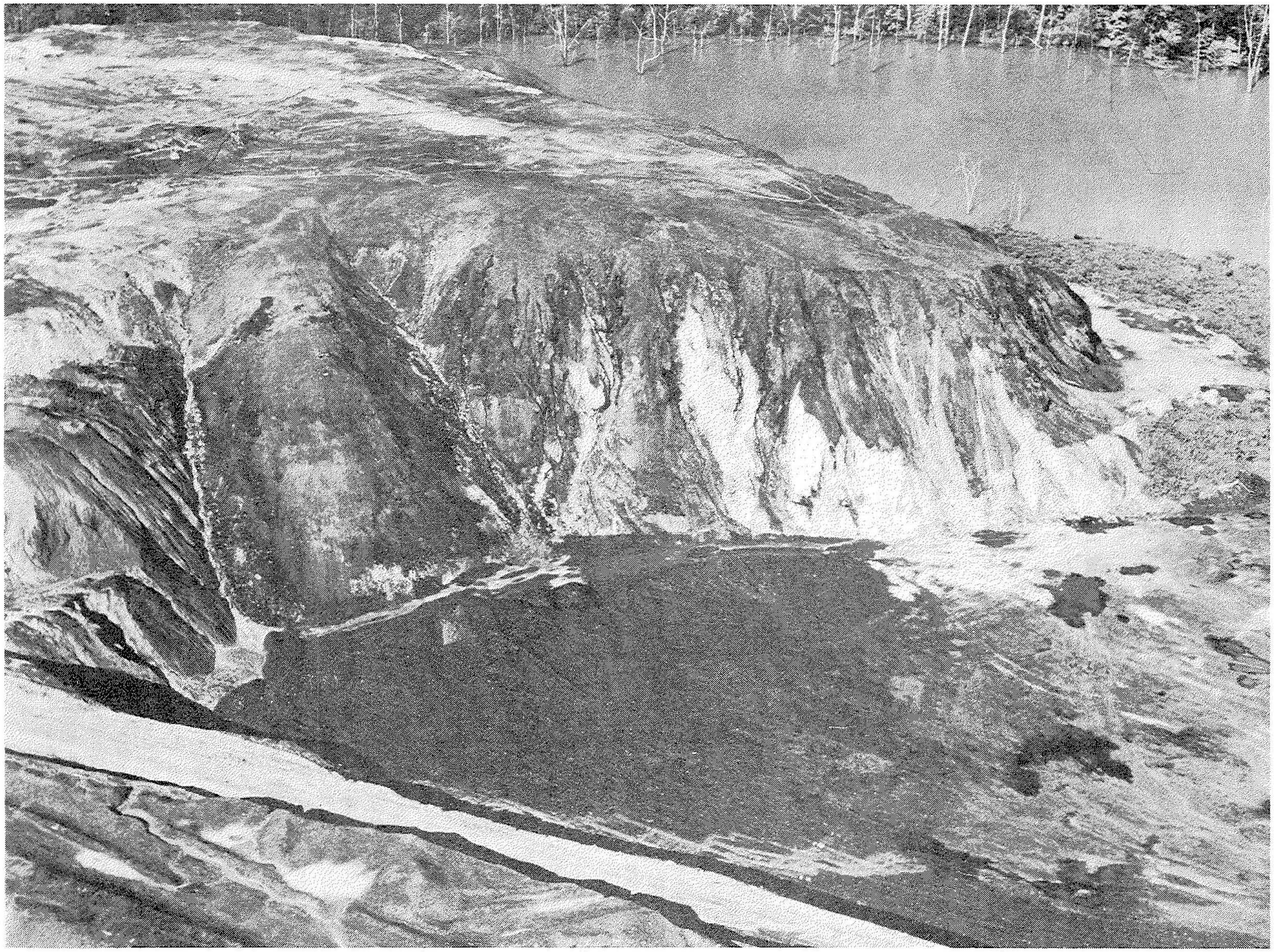


FIGURE 18. - Aerial View of West Bank of Refuse Pile After 20 Months of Water Application.

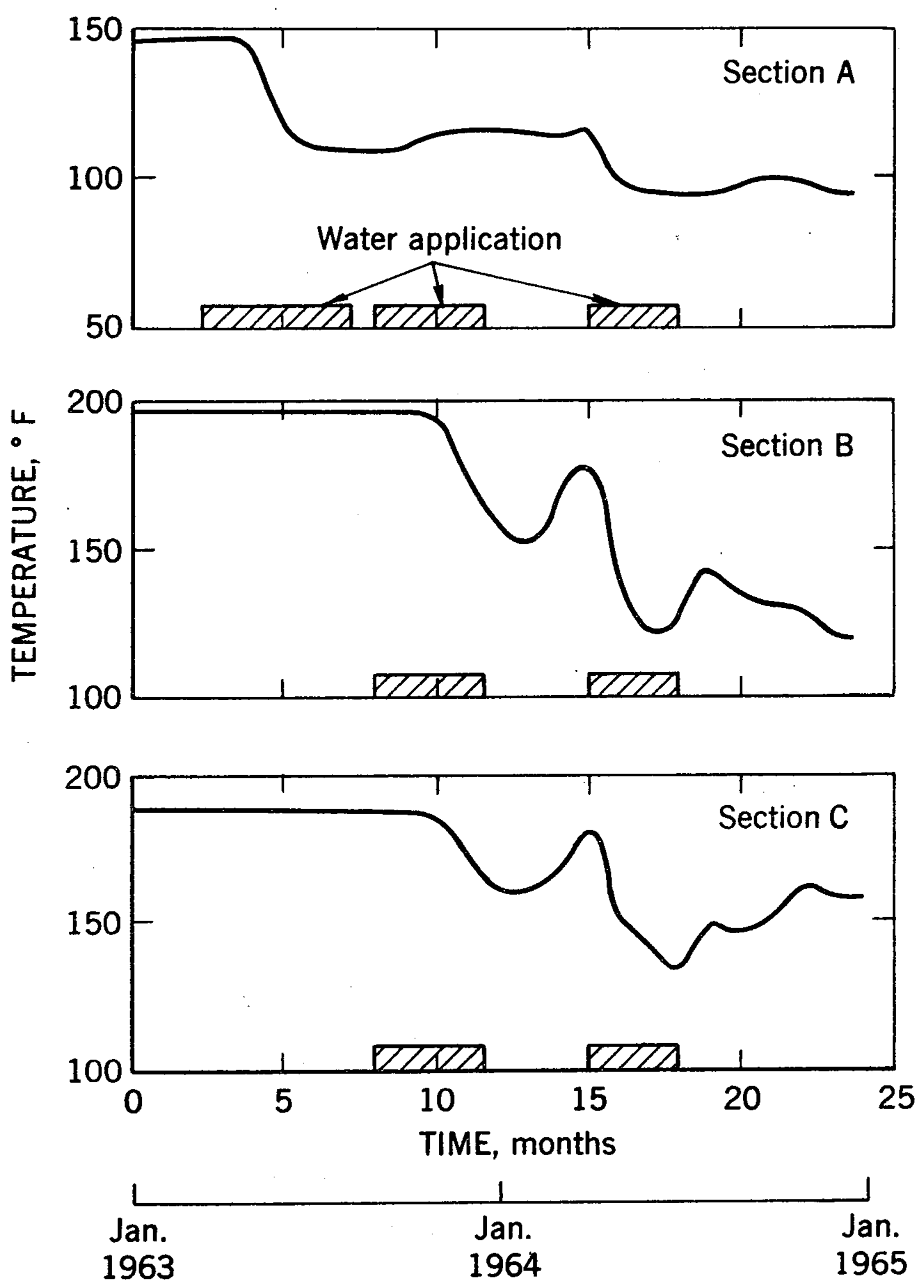
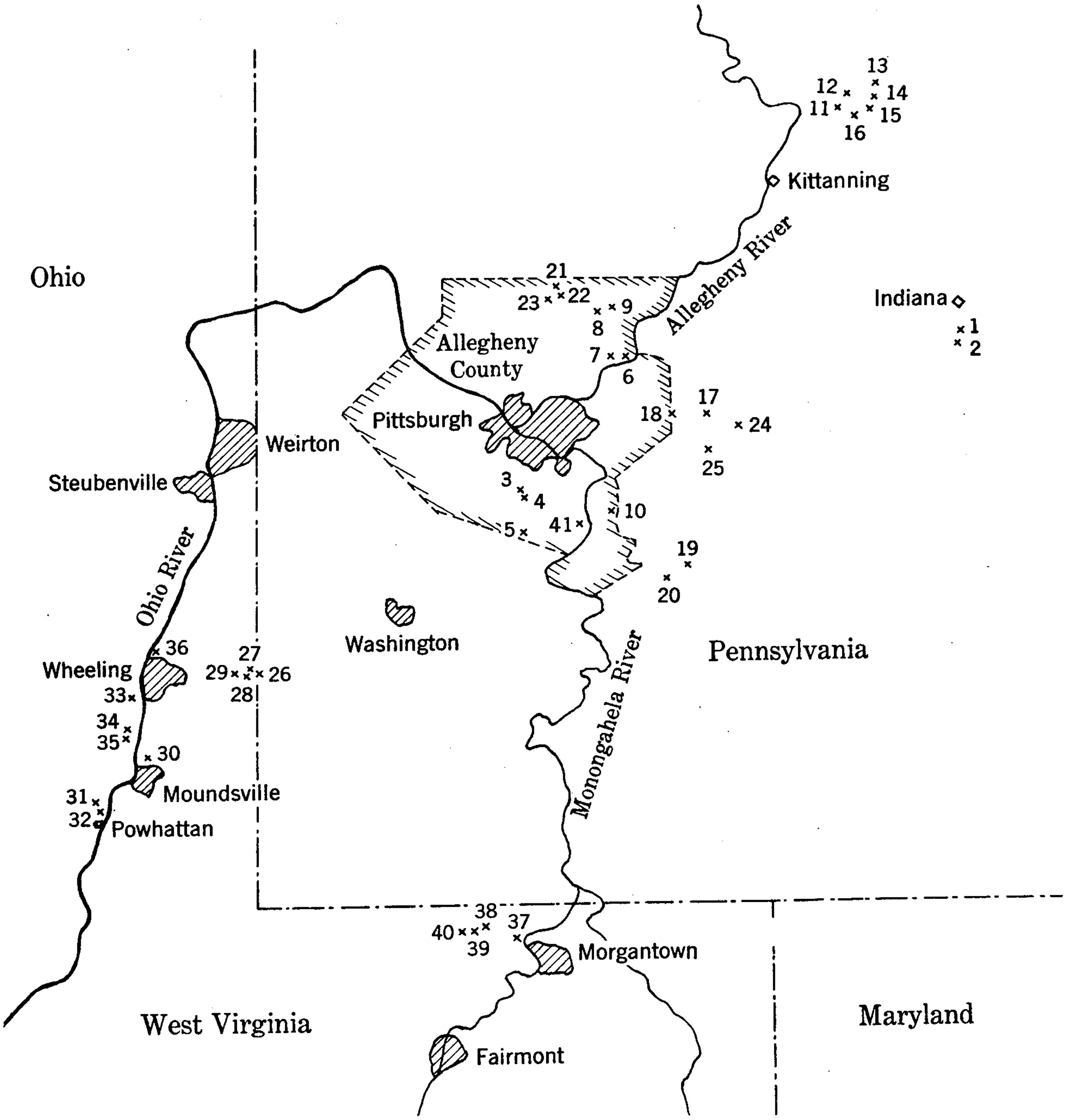


FIGURE 19. - Effect of Water Applications on Temperatures at 10-Foot Level.

SURVEY OF COAL MINE REFUSE PILES

About 40 burning and nonburning refuse piles (fig. 20) were visited to obtain information on pile geometry, particle size, quantity, pyritic content, combustible content, and measures used to prevent spontaneous heating. General features and geometry common to many refuse piles are shown in figure 21. Side-dumped piles are built in layers 10 feet deep. This type of pile has a small flank area relative to the total volume. A tightly packed pile with a continuous surface is formed as the track is moved laterally. End-dumped piles have a large flank area relative to the total volume, and the refuse is not as tightly packed as in the side-dumped piles. Stepwise piling, or benching, is used when the ground is not level. The ratio of flank area to total volume is large in this method, and the refuse is not tightly packed. Refuse is sometimes dumped in small piles to permit weathering for approximately 1 year. It is then leveled by bulldozers. During the weathering period, the refuse is loosely packed, and the ratio of flank area to total volume is large.



Numbers designate mines inspected by Bureau of Mines team

FIGURE 20. - Location of Refuse Piles Investigated in Field Study.

The size of the material in a refuse pile varies with mining and cleaning facilities, as well as dumping procedures. Dumping refuse over a long flank causes the larger pieces to segregate and roll to the bottom of a flank. The size of the refuse is reduced by trucks and bulldozers which crush the larger lumps.

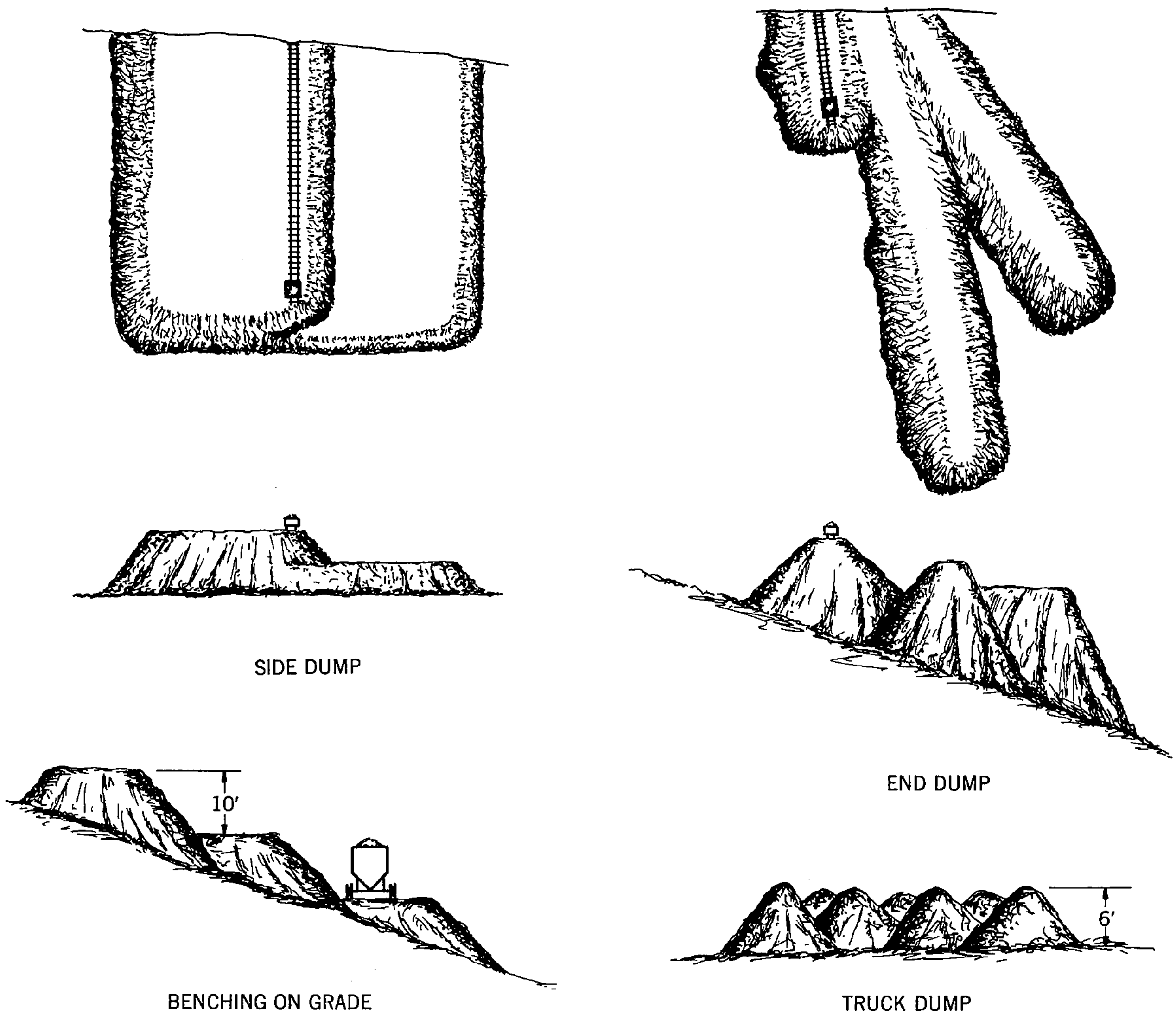


FIGURE 21. - Pile Geometry for Four Methods of Dumping.

At several sites, systematic piling of refuse was attempted to prevent spontaneous ignition. In one plant, the refuse was temporarily placed in small piles for weathering before being placed in a large pile. This procedure causes partial oxidation and reduction in particle size through handling. At other plants, the flanks were sealed with clay or loam. Clay was used to seal individual layers as well as the flank. One of the most successful methods is the use of layer pilings (figs. 22 and 23). The refuse shown in figure 22 was crushed below ¼ inch, and the layers were 1 to 2 feet high.

Field investigations showed that techniques reducing airflow into a pile decreased the tendency toward spontaneous ignition. Since most of the air enters the refuse through the flank, a piling technique that reduces the flank area is desirable. In practice, fewer fires were observed in side-dumped than in end-dumped piles, and no fires were observed in shallow refuse piles

FIGURE 22. - Systematic Layering of Washery Refuse, Mine A. Large pile in background is blast furnace slag.

FIGURE 23. - Systematic Layering of Washery Fines, Mine B.

with clay seals on the flanks and tops. Where clay must be mined and hauled long distances, this method of control may be expensive. Partial oxidation, degradation, and compaction by weathering may reduce airflow into a pile, but ordinarily weathering alone is too slow to prevent ignition.

DISCUSSION

The present studies on mine refuse show that particle size distribution of refuse has a greater effect on spontaneous heating tendency than does the combustible or pyritic content. Less segregation of the refuse occurs on short than on long-flank piles; side dumping is preferable to end dumping or benching. Minus ¼-inch refuse containing as much as 37 percent combustible material has a low permeability to airflow and can be used effectively to seal a mine refuse pile and prevent ignition. Surface seals must be kept intact. Precautions should be taken to prevent erosion by runoff of rain water.

Based on observations and data obtained in the present investigation, it is concluded that water, applied in sufficient quantity and during a sufficient period of time, can control surface burning and liberation of noxious gases from a mine refuse pile.

General recommendations of techniques for future trials follow:

1. Water applications should be made until active burning has ceased and all portions of the pile are cooled below 100° F.

2. The quantity of water applied should be the maximum possible without causing excessive runoff that might contaminate adjacent watersheds.

3. The top of the pile should be made flat and approximately horizontal. The perimeter of the pile should be raised to contain the water to prevent runoff and erosion.

4. Active dumping should not be made in the portion of the pile being controlled with water.

5. The slopes of the pile should be consolidated, made smooth, and covered with fine refuse or other material because the presence of large boulders and rough surface interferes with water percolation.

6. Water penetration could be improved by use of a wetting agent.

7. To increase the rate of cooling, holes might be drilled on 25-foot centers to the bottom of the pile to facilitate water percolation. Uncased holes tend to fill and clog. To increase percolation, the interior of the pile might be broken by blasting.

8. All waterlines should contain filters to prevent clogging of the sprays.

9. Automatic control of waterflow and electric power should be used to prevent excessive runoff should a waterline burst.

10. The water sprays should be moved at intervals to prevent channeling.

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