Bulletin 590
BUREAU OF MINES

CONTROL OF FIRES IN INACTIVE COAL FORMATIONS IN THE UNITED STATES

By F. E. Griffith, M. O. Magnuson,
and G. J. R. Toothman

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1960

UNITED STATES DEPARTMENT OF THE INTERIOR
Fred A. Seaton, Secretary

BUREAU OF MINES
Marling J. Ankeny, Director

This publication has been cataloged as follows:

Griffith, Franklin E.

Control of fires in inactive coal formations in the United States, by F. E. Griffith, M. O. Magnuson, and G. J. R. Toothman. Washington, U.S. Govt. Print. Off., 1960.

vii, 106 p. illus., tables. 26 cm. (U.S. Bureau of Mines. Bulletin 590)

1. Coal mines and mining—Fires and fire prevention. 2. Coal mines and mining—Safety measures. I. Title. (Series)

TN23.U4 no. 590 622.06173

U.S. Dept. of the Int. Library

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington 25, D.C. - Price 60 cents

Preface

The activities of the Bureau of Mines in controlling fires in inactive coal formations in the United States are discussed in this Bulletin. The fire-control methods are described and evaluated from experience gained in these activities.

A summary of salient data (in tabular form) on 70 fire-control projects—planned, executed, and partly or totally financed by the Federal Government—is included.

Research to develop new methods, and investigative work on extinguishment of carbonaceous-fill and refuse-dump fires also are discussed.

CONTENTS

ILLUSTRATIONS

TABLES

CONTROL OF FIRES IN INACTIVE COAL FORMATIONS IN THE UNITED STATES[1]

By

F. E. Griffith,[2] M. O. Magnuson,[3] and G. J. R. Toothman[3]

Introduction

ABANDONED-MINE fires have a destructive and demoralizing effect upon a community. They constitute a menace to the health and safety of the public, destroy surface lands and property, and involve serious wastage of the fuel resources of the Nation. The interest of the Federal Government in the control of coal-mine fires dates from the very inception of the Bureau of Mines, and much time has been devoted to investigating these occurrences and to consulting and advising on their control. It was not until July 1, 1948, through enabling legislation followed by the act of 1954, that money was appropriated by Congress to control or assist in the control of these fires. For administrative purposes, the coal-mine fire-control activities were under the Safety Division of the Bureau of Mines until June 30, 1959, after which the Health and Safety Research and Testing Center of the Bureau was made responsible.

It is now the policy of the Federal Government, as set forth by Congress, to provide funds for the control of these fires on Federal lands and to give financial and technical assistance in the planning and execution of projects for the control of these fires on nonfederal lands. To effectuate this policy the Secretary of the Interior has been authorized to conduct surveys, investigations, and research relating to the causes and extent of outcrop and underground fires in coal formations and the methods for control or extinguishment of such fires; to publish the results of any such surveys, investigations, and researches; to disseminate information concerning such methods; and to plan and execute projects for control or extinguishment of fires in inactive coal formations.

Between July 1, 1948, and the writing of this Bulletin, 40 fires occurring on Federal lands and 30 fires occurring on non-federal lands were controlled or in the process of being controlled.

The following benefits have resulted from the work completed:

1. Public health has been protected by the elimination of harmful fumes and gases.
2. Public safety has been improved by minimizing subsidence and fire hazards.
3. Coal resources have been conserved.
4. Ignitions of coal reserves have been appreciably reduced by backfilling and surface-sealing work.
5. Surface lands and structures have been protected from threatened damage.
6. Devastated areas have been restored to beneficial use.
7. The threat of forest and brush-fire ignitions by mine fires in these areas has been eliminated.

[1] Work on manuscript completed August 1959.
[2] Supervising mining engineer, Coal-Mine Fire-Control Group, Health and Safety Research and Testing Center, Bureau of Mines, Pittsburgh, Pa.
[3] Mining engineer, Coal-Mine Fire-Control Group, Health and Safety Research and Testing Center, Bureau of Mines, Pittsburgh, Pa.

The prevention and control of fires in inactive coal deposits presents an entirely different problem from the prevention and control of fires in active coal mines. In an active mine the operator takes immediate steps to control the fire; however, confuson and indecision often prevail as to the responsibility for taking the necessary action to control a fire in an inactive mine. Private-property owners usually are unwilling or financially unable to perform the work, and laws ordinarily do not require them or local governing agencies to do such work. Legislation has been passed by the Federal Government and some coal-producing State governments defining what assistance they can give in these situations. Local government officials in coal-producing areas should be responsible for doing such work, or they should bring the matter to the attention of others who may assist in controlling and extinguishing these fires.

The purpose of this Bulletin, in addition to presenting a history and description of Bureau activities in controlling these fires, is to provide the mining industry and the public with information concerning methods of controlling fires in inactive coal formations. The Bulletin is intended to serve as a guide to the public and more specifically to mining supervisory personnel and engineers who may be called upon to extinguish such fires.

HISTORY

EARLY FIRES

The problem of coal-mine fires has existed in the United States for many centuries. The extensive areas of scoriaceous materials throughout the coalfields of western United States are evidence that outcrop fires consumed inestimable quantities of carbonaceous materials during prehistoric times. At one mine in eastern United States, mining operations disclosed that fire had consumed a strip of coal 0–100 feet wide along the outcrop for a distance of about 4 miles. The fact that heat or fire was not encountered at any place where the workings intersected the burned material is evidence that this fire had existed in prehistoric times and had been extinguished by natural causes.

As early as 1766, the Reverend Charles Beatty referred to a coal-mine fire in his diary.[4] This fire apparently was burning near the top of Mount Washington, Allegheny County, Pa.:

In the afternoon we crossed the Mocconghehela River accompanied by two gentlemen, and went up the hill opposite the fort, by a very difficult ascent, in order to take a view of that part of it more particularly from which the garrison is supplied with coals, which is not far from the top. A fire being made by the workmen not far from the place where they dug the coal, and left burning when they went away, by the small dust communicated itself to the body of the coals and set it on fire, and has now been burning almost a twelve month entirely under ground, for the space of twenty yards or more along the face of the hill or rock, the way the vein of coal extends, the smoke ascending up through the chinks of the rocks. The earth in some places is so warm, that we could hardly bear to stand upon it; at one place where the smoke came up we opened a hole in the earth till it was so hot as to burn paper thrown into it; the steam that came out was so strong of sulphur that we could scarce bear it. We found pieces of matter there, some of which appeared to be sulphur, others nitre, and some a mixture of both. If these strata be large in this mountain it may become a volcano. The smoke arising out of this mountain appears to be much greater in rainy weather than at any other times. The fire has already undermined some part of the mountain, so that great fragments of it, and trees with their roots are fallen down its face. On the top of the mountain is a very rich soil covered with a fine verdure, and has a very easy slope on the other side, so that it may be easily cultivated.

There is another reference to the same fire in the diary of David McClure:[4]

1772 Oct. 14th—We crossed the Monongahela, and ascended the top of the hill, opposite Pittsburgh, to take a view of the effects of the fire on its top, which has been burning more than 12 months. The fire among the coal has formed a basin or crated, 60 or 70 yards in circumference, and killed the trees and herbage some distance around. As I sat near the edge, I perceived the ground warm, and forcing a staff through the surface, there appeared to be a cavity, and the staff came out black and smoking. Should the fire continue a volcano may be formed of the sulphurious coal. Some uneffectual efforts have been made to extinguish it.

This fire was reported to be active as late as 1846; however, there have been no reports of fire activity in the area during this century.

Two fires, one in the vicinity of New Straitsville, Perry County, Ohio, and the other at Summit Hill, Carbon County, Pa., started in active deep mines but eventually extended to the surface and persisted as abandoned-mine fires. These fires and the methods employed to control them attracted widespread attention. The fire at New Straitsville was ignited in 1884 and continues to burn in the isolated area under relatively thin cover (0–100 feet). Work to stop the extension of this fire was begun in 1936 with funds made available by the Works Progress Administration. Incombustible barriers were installed at three selected locations at a cost of about $1 million. The fire at Summit Hill was ignited in February 1859, and several costly attempts were made by private parties for its control before it was successfully isolated.

A fire that ignited in the Astor mine, Allegany County, Md., about 1862, has continued to burn out of control. In the early part of this century private interests expended several thousand dollars in unsuccessful attempts to control or extinguish it. This fire has consumed an immense tonnage of minable coal, and, because of the fire hazards such as heat, flame, and injurious gases, it has been unsafe to mine contiguous areas of high-quality coal.

BUREAU ACTIVITIES—1933–48

Between 1933 and 1948 work was done by such agencies of the Federal Government as the Civil Works Administration and the Works Progress Administration; Bureau engineers acted in a consulting capacity in controlling and extinguishing fires in abandoned mines at

---

[4] Eavenson, Howard N., The Pittsburgh Coal Bed—Its Early History and Development: Trans. AIME, Coal Division, vol. 130, 1938, pp. 9–10.

Bruceton (Lick Run mine), Crafton (Herschel Street), Pittsburgh (Pitt Stadium), and Connellsville, Pa., and at New Straitsville, Ohio. The work done in controlling or extinguishing these fires was successful at the Crafton and Pittsburgh fires; however, the Lick Run mine and Connellsville fires were reactivated.

Public Law 49, 77th Congress, approved May 7, 1941, and known as the Federal Coal Mine Safety Act, empowered authorized Bureau personnel to make inspections for hazards in coal mines and to make recommendations for correcting the hazards observed. An amendment to Public Law 49, designated "Title II," approved July 16, 1952, provided penalties for noncompliance with those recommendations made to prevent major disasters (accidents in which five or more lives are lost). The hazards named as subject to the penalty provisions were the danger that a mine explosion, mine fire, mine inundation, or man-trip or man-hoist accident will occur.

BUREAU FINANCIAL PARTICIPATION

The Interior Department Appropriations Acts for fiscal years 1949–55 contained a proviso authorizing the Bureau of Mines to expend appropriated moneys in conducting a program for controlling and extinguishing fires in inactive coal deposits as follows:

> Provided that the Secretary is hereby authorized and directed to make suitable arrangements with owners of private property or with a state or its subdivisions for payment of a sum equal to not less than one-half the amount of expenditure to be made for control or extinguishment of fires in inactive coal deposits from funds provided under the authorization of this act except that the expenditure of Federal funds for this purpose in any privately owned operating coal mine shall be limited to investigation and supervision.

In a decision dated October 6, 1948, the administrative interpretation of the foregoing proviso was that the cooperating party or parties on a project to control or extinguish an underground fire should contribute one-third of the total funds spent.

Acting under this interpretation of the law, the Bureau created the Fire-Control Group, with headquarters at Pittsburgh, Pa., to administer and direct the various activities having to do with the control and extinguishment of underground fires in inactive coal deposits. From 1949 to 1954 the Bureau, in its administration of this congressional act, did work to control and extinguish 24 fires on public lands and cooperated with contributing parties (State or local governmental agencies, corporations, or individuals) to control or extinguish fires at 18 projects on private lands.

On August 31, 1954, Public Law 738, 83d Congress, was enacted, which provided funds for the control and extinguishment of outcrop and underground fires in coal formations, and for conducting research and other work in connection with underground fires. Under sections 3 (*a*) and (*b*) of this act the Bureau was authorized to conduct surveys, investigations, and research relating to the causes and extent of outcrop and underground fires in coal formations and the methods for control or extinguishment of such fires; to publish the results of any such surveys, investigations, or research; to disseminate information concerning such method; and to plan and execute projects for control or extinguishment of fires in coal formations.

Under terms and conditions set forth in section 4 of the act, the Bureau is authorized to expend funds to plan and execute projects for the control of outcrop fires on public or private lands as follows:

> (*a*) On public lands the Bureau can pay all costs of any work done to control or extinguish fires in coal formations.
>
> (*b*) In any privately owned coal mines the expenditure of funds by the Bureau is limited to surveys, investigations, and research relating to the causes and extent of outcrop and underground fires in coal formations and to publish the findings.
>
> (*c*) In inactive coal mines on private lands the Bureau, acting under properly executed and approved agreements with State or local governments, corporations, or individuals, can contribute one-half the total cost of work done to plan and execute projects for the control or extinguishment of fires in coal formations.

From the enactment of Public Law 738, 83d Congress, to June 30, 1959, the Bureau has expended funds to control or extinguish 16 fires on public lands and has cooperated with contributors in the control or extinguishment of 12 underground fires on private lands. Funds have been expended also for doing research work on three experiments.

DEVELOPMENT OF SURFACE-SEALING METHOD

The surface-sealing method described in this Bulletin is largely an outgrowth of the cooperative fire-control program of the Bureau. Prior to this program the scheme of sealing all surface openings met with virtually no success. It was observed that openings to the fire reappeared a few months after they had been sealed, and no followup work was done to reseal the new crevices and openings. As a result the fire reactivated and continued to extend into unburned areas. These unsuccessful and discouraging experiences led to the belief by experienced mining men that a coal-mine fire could not be controlled and extinguished by a surface-sealing method.

Engineers of the Federal Government assigned to supervise and administer the act of Congress were confronted with a problem; for, if some of the Nation's most insidious underground fires extending over wide areas were to be brought under control at a reasonable cost, new methods had to be found. In reviewing various methods that had been used successfully or unsuccessfully in the past, a "long look" was given to the unsuccessful surface-sealing methods. The reason for failure in most instances appeared to be lack of maintenance of the surface fire seal over an extended period. After several conferences regarding the cost and effectiveness of various suggested fire-control methods, the Director of the Bureau of Mines approved plans to experiment with a proposed maintained surface-sealing method. This would be done alone or with other methods that in themselves would not control and ultimately extinguish the fire.

The development and perfection of the surface-sealing method was extremely important, especially to the success of the Bureau cooperative fire-control program, because it provided a control method that could be employed on a great many of these fires with a high degree of success and yet was economical enough for local governments and individuals to participate in the program on a matching-fund basis. Other methods such as loading out, inundating, and trenching are more positive approaches, but in many instances they are either not applicable to a particular fire or the cost of a project employing one of them would be virtually prohibitive to Federal and local governments as well as to corporations and individuals.

The features transforming an unsuccessful method into an effective one at reasonable cost are methodical and complete coverage of the affected area. All openings in the vicinity suspected of admitting air to the fire are closed, and the surface is plowed or material borrowed to make an effective covering mantle. A long-term, inexpensive, maintenance program, arbitrarily set at 2 years, and in some instances a longer period, may be required.

In contrast to unsuccessful surface sealing (filling obvious crevices and openings), the method now involves complete blanketing of the affected surface and adjacent ground. This procedure closes small crevices, which are especially difficult to detect in ground covered with vegetation. The area covered must be extensive enough to get ahead of a fire and behind it. In this way new crevices created as a fire progresses can be silted-in or easily detected and filled. Maps, if available, are studied to find outcrop openings and abandoned shafts. An attempt is made to close all openings into contiguous workings extending from the burning area. Strip pits in the vicinity are filled to cover such openings; this filling also covers solid exposures of coal and prevents the ignition of new fires in the strip pits.

The surface seal is established either by spreading borrowed fill material on the surface or by plowing the surface to a depth of several feet with an angledozer to create a blanket of pulverized earth. The borrowed-fill method can be used where suitable fill material is available nearby at nominal or no cost, but this method would be expensive if the material had to be purchased and transported a great distance. The development of the surface-plowing system, employed extensively in the eastern coal regions, has been an important factor in reducing the expense involved in controlling outcrop and abandoned-mine fires.

The most important new concept in connection with surface sealing is emphasis on maintaining the seal after it has been installed. Crevices and sinkholes in the seal are expected, owing to the conditions created as the fire area cools. After the seal is set, heat loss from the fire is reduced, because convection currents exhausting through the overburden are blocked. A temporary rise in fire-area temperatures may occur. Then, if the smothering seal is effective, the fire will begin to cool as heat is conducted through the strata and dissipated. The expansion and contraction of the strata, caused by these temperature changes, will cause crevices and sinkholes. These must be filled promptly or the fire will reactivate. The maintenance program therefore provides for periodic inspection of the seal and prompt filling of any new openings either by hand or machine work. Certain areas may be disk harrowed to fill small crevices. Access is provided by inspection roads to facilitate inspection and movement of equipment. The maintenance contractor maintains drainage facilities installed during the sealing work; such maintenance is important to retain the effectiveness of the seal. Temperature readings are obtained from inspection boreholes, and a record is kept of these readings to ascertain whether the fire area is cooling.

The surface-sealing method has had wide and highly successful application. It is described under the section on "Surface-Sealing," and examples of control projects employing this method are given.

PROCEDURE FOR INITIATING COOPERATIVE FIRE-CONTROL PROJECTS ON NON-FEDERAL LANDS

INVESTIGATION OF FIRES

Requests for investigations of fires on private property and for financial aid from the Federal Government are received from numerous sources. They include U.S. and State senators and Congressmen acting on behalf of their constituents; State, county, city, township, and borough governments; companies and private individuals. If the request is from an individual, he is referred to his local government. On official request, the Bureau investigates and reports on the fire.

An effort is made to have representatives of the State and municipal governments benefiting from control of the fire accompany the Bureau engineers during the investigation; information is then collected on the origin and history of the fire, and the area is photographed. A report of the investigation is prepared from the facts available; a proposed method of control and the estimated cost are included, along with the photographs and maps of the fire area. Copies of this report are sent to persons who have indicated an interest in controlling the fire.

JOINT-CONTRIBUTIONS AGREEMENT

If some indication is given that at least the required 50 percent of the cost to match Federal funds can be raised, and if Federal funds are available, the Bureau will prepare a formal cooperative agreement covering the responsibilities and contributions of each of the cooperating parties, after it is generally understood how and to what extent the parties can contribute or participate in the program.

A joint-contributions agreement may include several parties in addition to the Federal Government, such as State, county, borough, or township governments, companies, or individuals. Before final execution of any agreement, its legal correctness and form is approved by the Solicitor's Office of the Department of the Interior. The format of an agreement entered into between the Federal Government and a State, county, and township government follows:

Contract No. _____

THIS AGREEMENT, MADE AND ENTERED INTO this ___ day of __________, between the (1) Commonwealth of ___________, hereinafter called "Commonwealth," (2) the County of ___________, hereinafter called "County," (3) the Township of ____________, hereinafter called "Township," and (4) the United States of America, by and through the Department of the Interior, Bureau of Mines, hereinafter called "Bureau," witnesseth:

WHEREAS, there exists a subsurface mine fire in the worked-out and abandoned workings of the ___________ coalbed underlying a certain area of surface land in __________ Township under a portion of ___________, __________ County, ___________; and

WHEREAS, the fire has already damaged a County road, is spreading toward homes and County property, is a nuisance, and presents a hazard to the health and lives of persons living or traveling in or near the fire area; and

WHEREAS, all of the parties will benefit from and desire to participate in a project (hereinafter referred to as the "project") to control and extinguish said subsurface fire.

NOW, THEREFORE, it is agreed as follows:

ARTICLE 1. The project shall consist of work as described in the Operations Contract (hereinafter referred to) and the specification attached thereto, to control and extinguish the said subsurface fire in the area shown on the plat attached hereto, by means of (*a*) flushing incombustible material into the abandoned workings to stabilize the road, (*b*) surface sealing, and (*c*) maintaining the surface seal for a period of at least 2 years. The work under items (*a*) and (*b*) of this Article is referred to herein as the "initial phase," and the work under item (*c*) of this Article is referred to herein as the "final phase." The final phase consists of work designed to maintain the surface seal resulting from the performance of the initial phase.

ARTICLE 2. It is estimated that the total cost of the project, including both initial and final phases, will be the sum of $__________, exclusive of the contribution of the Township to the project but including an allowance to the Bureau of 12 percent of money expended to cover the cost to the Bureau of supervision and administration. Commonwealth and County shall each contribute one-quarter of the cost (i.e., not to exceed the sum of $__________ each) in cash, and the Bureau shall contribute one-half of the cost (i.e., not to exceed the sum of $__________) including said allowance for supervision and administration. The Bureau's contribution is subject to the provisions of the Act of August 31, 1954, 68 Stat. 1009, 30 U.S.C., sec. 551 to 558 (Supp. 11, 1952), and to the availability of appropriated money.

ARTICLE 3. The initial phase shall be performed by an independent contractor under a contract with the Bureau, hereinafter called the "Operations Contract." The final phase (maintenance of the seals made during the initial phase) will be performed by the Bureau, under such contracts as it may see fit to enter into for this purpose, for a period of at least 2 years from the completion of the initial phase.

ARTICLE 4. The contributions of the Commonwealth and County shall be paid in advance to the Bureau for deposit in the Treasury of the United States in a trust fund for such withdrawals and expenditures by the Bureau as the Bureau deems necessary for performing the work.

ARTICLE 5. The Township, without allowance or charge to the project, shall (*a*) provide and deliver to a point on or near the project site water-cooled slag or other finely divided incombustible material needed for the flushing operations, and (*b*) shall procure and deliver to the Bureau, in a form satisfactory to the Bureau, releases of all liability from the owners of all property which may be affected by the project work. This agreement shall not become effective until said releases have been provided by the Township and accepted by the Bureau.

ARTICLE 6. The Bureau shall conduct such operations as it deems necessary to control and extinguish the fire, under such contracts as it sees fit to make. Commonwealth, County, and Township shall have representatives at the opening of bids for any such contracts, and shall advise the Bureau concerning the qualifications of such bidders. All operations shall be under the exclusive direction and control of the Bureau. Commonwealth, County, and Township shall consult with, advise, and collaborate with the Bureau's representatives with respect to the performance of the work.

ARTICLE 7. County and Township grant to the Bureau, its officers, agents and contractors, the right to enter upon streets, roads, and other land owned or controlled by the County and Township adjacent to and overlying the fire, and to conduct thereon the operations referred to in this agreement. County agrees to hold the Bureau harmless from any claim for damages arising out of the operation of this contract to property title to which is in County of ______________ and which lies within the lines designated as "Affected Area" as shown on Exhibit A to the Operations Contract. Commonwealth and Township, jointly and severally and as representing the Commonwealth of ______________, shall hold the Bureau harmless from any claim for damages arising by reason of the Township's failure to procure and deliver valid releases to all lands except those lands title to which is vested in the County.

ARTICLE 8. Upon completion of the maintenance period hereunder, Township shall be solely responsible for maintenance of the project.

ARTICLE 9. If any part of the original contributions from Commonwealth and County remain unspent upon completion of the 2-year maintenance period, it shall be repaid to them in equal portions.

ARTICLE 10. No Member of or Delegate to Congress or Resident Commissioner shall be admitted to any share or part of this contract or to any benefit that may arise therefrom; but this provision shall not be construed to extend to this contract if made with a corporation for its general benefit.

IN WITNESS WHEREOF, the parties hereto have hereunto set their hands and seals the day and year above written.

Variations will occur in each agreement, dependent on the degree of participation of the parties involved. Some of the main differences from the one quoted may be as follows:

1. The description of the work will change to fit the particular situation.

2. In the quoted agreement it is stipulated that the Bureau will be given an allowance of 12 percent of the money expended to cover the cost to the Bureau of supervision and administration. This allowance is not made when equalizing services are provided. For example, if services of a foreman or engineer are provided by those cooperating with the Federal Government, and these services equal in time and value those performed by the Federal agency, the costs are balanced, and no allowance is charged.

3. In the quoted agreement it is stated that the final phase (maintenance of the seals made during the initial phase) will be performed by the Bureau under such contracts as it may see fit to enter into for this purpose. In some instances a local government agrees to maintain the effectiveness of the surface seal under the general supervision of the Bureau.

4. In the quoted agreement it is stated that the township will provide certain materials delivered to the site of the project at its own expense as a contribution to the project. This is not always the arrangement, as local governments often make a financial contribution as well.

AMENDMENT TO JOINT-CONTRIBUTIONS AGREEMENT

As work progresses on a project, an unforeseen condition may develop that is not covered in the original agreement. After discussion with parties to the original agreement, the problem is resolved, the original agreement amended, and the amendment executed by all parties concerned.

OPERATIONS CONTRACT AND SPECIFICATION

The operations contract and specification are prepared in accordance with Government regulations and reviewed and approved by the parties to the contributions agreement. The Bureau lets the contract on a competitive basis to the low bidder. The private contractor works under Bureau supervision, according to the plan of operations specified. The operations contract covers information and instructions on the following matters:

Statement of work.
Default by other parties.
Unit prices of work.
Contractor's claims and vouchers.
Contractor's equipment.
Commencement, prosecution, completion, default, damages.
Direction of work.
Additional laborers, powersaws, angledozers, and trucks.
Crews and supervision.

Accident prevention.
Blasting.
Releases and liability.
Covenant against contingent fees.
Officials not to benefit.
Disputes.
Additional security.
Nondiscrimination in employment.
Definitions.
Davis-Bacon Act.
Minimum wage rates.
Apprentices.
Eight-hour law—overtime compensation.
Payroll records and payrolls.
Nonrebate of wages.
Withholding of funds to assure wage payment.
Subcontracts—termination.
Convict labor.
Approval.
Alterations.

The specification gives details on work to be done, type of equipment to be used, and different units of work or materials required to perform the operations. Services may be bid on a cubic-yard basis or at an hourly rate for actual operation or performance; materials and supplies are bid at unit prices. The contract is awarded to the low bidder. The bid is evaluated by multiplying the bid prices by the estimated requirements given in the specification. It is explained in the operations contract that the actual amount to be paid to a contractor will be determined according to the operations performed at bid prices. The prices fixed for units of time for angledozing, trucking, hi-lift, and drilling include the cost of operators of the equipment and all costs of maintenance, repairs, supplies, fuel, and power for the contractor's equipment.

The Davis-Bacon Act applies to fire-control projects in excess of $2,000, and in compliance therewith wage determinations for the type of services needed are obtained from the U.S. Department of Labor and attached to and made a part of the operations contract. It is explained in the contract that all mechanics and laborers must be paid at wage rates not less than those slated in the wage-determination decision of the Secretary of Labor.

MAINTENANCE PHASE

When the surface-sealing method is employed to control a fire, it has been found that at least a 2-year maintenance program is required to accomplish extinguishment. This program involves periodic inspection of the fire site to find and close any openings that would permit air to reach and rekindle the underground fire. If, in accordance with the joint-contributions agreement, the Bureau is to assume this responsibility, it enters into a contract for the maintenance work to be carried on for a period of 2 years. The same procedure for obtaining bids is used as in contracts for the initial work. In some instances, however, a local government does this task under Bureau supervision without allowance or charge to the project under the agreement.

PROPERTY RELEASES

Generally, the joint-contributions agreement gives to the Federal Government, its officers, agents, and contractors the right to enter upon streets, roads, and other land owned or controlled by the governments that are parties to the contract so that fire-control operations can be accomplished. However, most project work is performed on property owned by companies or private individuals. The responsibility for obtaining releases from private companies or individuals before any work is begun is set forth in the agreement. Usually, this responsibility is assumed by a local government. Quoted below is a standard release form; however, these releases may vary in some minor degree, generally at the request of an attorney representing an individual property owner.

KNOW ALL MEN BY THESE PRESENTS, That whereas a subsurface fire is presently burning in the worked-out and abandoned workings of the ____________ coalbed underlying a certain area of surface land near ____________ in ____________ Township, ____________ County, ____________, as generally shown on a plat thereof hereto attached and made a part hereof, and

WHEREAS, the Government of the United States and the Commonwealth of ____________ are willing to expend money and have certain work performed in attempting to halt the progress of said fire, bring the same under control, and extinguish same by a trenching and surface-sealing process, and

WHEREAS, other persons, firms, or corporations may cooperate and assist the Government of the United States and the Commonwealth of ____________ in their attempt to bring said fire under control, and

WHEREAS, the undersigned are owners of property either overlying or underlying, or both, involving part or parts of the area above mentioned.

NOW KNOW YE THAT WE, the undersigned owners of property near ____________, in ____________ Township, ____________ County, ____________, within the area aforesaid as shown on the plat thereof hereto attached, intending to be legally bound hereby, for and in consideration of the attempts to be made by the Government of the United States, the Commonwealth of ____________, and others cooperating with and assisting them in bringing the fire above described under control and ultimately extinguishing the same, and in consideration of the benefits which may inure to us, do hereby remise, release, and forever quitclaim the said Government of the United States and the Commonwealth of ____________ and their agents, servants, employees, contractors and subcontractors, as well as any individual, firm, corporation, or municipality cooperating with said Government of the United States and the Commonwealth of ____________, of and from any and all damage, actions, or causes of action whatsoever inuring or which could inure to our benefit by reason of the work done by said Government of the United States and the Commonwealth of ____________, their agents, servants, employees, contractors and subcontractors in connection with the attempt to control and extinguish the said fire.

We do further specifically grant unto said Government of the United States and the Commonwealth of ____________ and those working for, with or under them, the right to enter in and upon the land owned by us with such equipment as may be necessary and to do such things as may be required to control and extinguish the fire. We do further grant unto the Government of the United States and the Commonwealth of ____________ and those working for, with, or under them, the right to remove any outbuildings, fences, hedges, or trees which may be upon the premises owned by us, if in the opinion of said Government of the United States and the Commonwealth of ____________, or those working for, with, or under them, the removal of same is necessary; and we waive any right of compensation therefor or damage occasioned thereby; and we waive, further, the right to have such outbuildings, fences, hedges, or trees replaced by the Government of the United States or the Commonwealth of ____________.

We do further covenant and agree to inform immediately the person or persons having charge of the work on behalf of said Government and the Commonwealth of ____________ of any cracks or crevices which may appear on our land or in the foundations, walls, or basement of any dwelling or other building which we may own on the land in question and do agree that said Government and Commonwealth or those working for, with, or under them, may enter into and upon said land and buildings and fill and seal such fissures, cracks, or crevices as appear.

We do hereby intend, by these presents, to remise, release, and forever quitclaim the Government of the United States and the Commonwealth of ____________, their servants, agents, employees, contractors, subcontractors and those cooperating with them from any and all damages which we may sustain by reason of the work to be done, as above set out and do further intend hereby to grant unto said Government of the United States and the Commonwealth of ____________, their agents, servants, employees, contractors, and subcontractors, full and sufficient rights and privileges to enter in and upon our land and to do any and all things therein deemed necessary for the control and extinguishment of said subsurface fire; provided, however, that upon the completion of the work the Government of the United States and the Commonwealth of ____________ shall leave the surface of the land in at least as level and usable condition as it was in before the work was begun.

IN WITNESS WHEREOF, we have hereunto set our respective hands and seals intending to be legally bound hereby, this ____ day of ____________, 19__.

WITNESS

____________________ ____________________ [SEAL]
____________________ ____________________ [SEAL]
____________________ ____________________ [SEAL]

FIRES IN INACTIVE COAL FORMATIONS

The Federal Government program of planning, executing, and assisting financially in projects for the control of coal fires is restricted to inactive coal formations. Most fires in inactive coal formations are in partly mined coal. These present a serious problem because they burn rapidly and spread over extensively mined areas. Most of the fire-control projects have been concerned with this type of fire, and some knowledge has been gained as to their origin and characteristics and the effectiveness of various methods of controlling them.

Fires in unmined coal formations present a somewhat different problem and are treated separately in this publication. These fires are numerous in the Western United States, and consume vast amounts of coal reserve. Fire-control methods similar to those used in mined coal formations are being used successfully, but it is felt that methods particularly suited to this type of fire could be developed, since their rate of propagation along the crop and the depth of penetration underground are affected by the fact that the coal is unmined. One such experiment is suggested in the section on "Unmined Coal Formations."

MINED COAL FORMATIONS

Fires in mined coal formations burn more rapidly than fires in unmined coal formations. The combustion rate of a coal fire depends entirely on the rate oxygen is brought into contact with the coal. Underground mining opens passageways and exposes coal surfaces to oxygen. These passageways also provide openings through which air may flow to the fire, and mining often causes crevices and sinkholes in the overburden through which air may find access to the fire.

If the area has been mined extensively the fire is more difficult to control; there are openings through which the fire may propagate rapidly. Experience in controlling these fires and observation of excavations in burned-out fire areas indicate that propagation is primarily along the ribs and in the roof coal and shales of the abandoned entries. All fire-control work in the East and most in the West has been in mined coal deposits—specifically, fires in abandoned coal mines.

SOURCES OF IGNITION

A coal formation is a vast bed of combustible fuel. Mining makes oxygen available to the fuel. All that is required to initiate combustion is a source of heat to raise the temperature of the fuel. The ignition source need not heat the coal to its ignition temperature (between 800° and 900° F.) to start a fire. If the coal is heated to about 200° F. and oxygen is available, the ignition source could be removed, but the accelerated rate of oxidation at 200° F. is such that the process would continue to ignition—assuming that the heat of oxidation accumulates more rapidly than it dissipates. This condition often prevails because of the insulating effect of the strata surrounding the coalbed; therefore, it is unnecessary to heat coal to its ignition temperature to cause combustion if conditions are such that the heat from the accelerated oxidation will accumulate in the bed.

The sources of ignition listed below are sources of heat that have come in contact with an exposure of the coalbed. They were taken from actual case studies of abandoned-mine fires in Bureau records. A survey of these ignition sources should provide information helpful to those interested in preventing mine fires. Prevention is the least expensive and most effective fire control. Removing known ignition hazards should be considered by local officials and property owners in areas underlain by mined coal. Generally, any surface exposure of a mined coalbed must be regarded as a fire hazard, since under this condition fuel and oxygen have intimate contact; all that is required for combustion is a source of heat to initiate rapid oxidation of the fuel. Filling sinkholes, closing old mine entries, properly backfilling abandoned strip mines, and extinguishing spoil and gob fires will help to eliminate the hazard of future ignitions.

TRASH FIRES

One of the most common sources of ignition in populated areas is caused by burning trash or brush near an exposure of a coalbed. A depression in the surface (commonly called a sinkhole) is a convenient place for disposing of the trash. Inasmuch as sinkholes are often the result of subsidence caused by mining under shallow cover, the coal or carbonaceous shales may be exposed in the holes or be only a short distance below the bottom. When an accumulation of trash is burned in the sinkhole, the heat from the fire contacts the carbonaceous material or is conducted to it through shallow cover. In this way the coal may be ignited. Abandoned mine openings and abandoned strip mines also present conditions under which the careless burning of trash may become the source of ignition in an exposure of the coalbed.

WARMING FIRES

Warming fires, especially those kindled by people digging house coal from an abandoned mine opening or strip highwall, are often responsible for mine-fire ignitions. Mine fires have been started by children building warming fires in old open mine entries in which they have been playing. The same is true of warming fires used by hunters.

BRUSH AND FOREST FIRES

Brush and forest fires have been known to ignite a coalbed at an opening along the outcrop or in an abandoned strip mine. In remote wooded areas it is suspected that many fires have been started in this manner.

MINE REFUSE CONTAINING CARBONACEOUS WASTE

Mine refuse containing carbonaceous waste has been a source of igniting fires in coal mines. Ignition occurs when the burning material is above an exposed coalbed or one that is thinly covered. In the latter instance heat from the fire is transmitted by conduction to the coal. Such fires create a health problem and are unsightly, in addition to creating the hazard of igniting the coal when they are near an exposure. Carbonaceous fill or strip spoil should not be placed directly against the coalbed in backfilling operations, because a fire in the spoil material could ignite the coalbed.

BACTERIAL ACTION

Bacterial action may be an indirect cause of a mine fire; the direct cause is a fire in a garbage or trash dump over or near the coal outcrop. Unless precautions are taken to prevent air circulation in a garbage dump, the dump may be ignited by the accumulation of heat from the decay of organic matter within the pile. Once ignited, such a fire is difficult to extinguish. Dump areas should not be located over or near a surface exposure of a mined coalbed. The use of an abandoned strip mine for dumping purposes is particularly hazardous. Vegetation should not be included in backfilling material because heat generated by bacterial action could come in contact with an exposure of the coalbed.

CHEMICAL ACTION

Chemical action, resulting in spontaneous ignition, may start a fire in a low-rank coalbed. Low-rank coal is susceptible to spontaneous ignition, owing to its tendency to disintegrate upon exposure to the atmosphere, thereby exposing much new surface area to oxidation. Mines in low-rank coal, which are abandoned and not sealed, may be ignited in this way.

Spontaneous ignition is not a likely source of ignition in an abandoned bituminous-coal or anthracite mine, since this coal does not disintegrate appreciably on contact with air. Presumably, if spontaneous ignition were to occur in the coalbeds it would have occurred during the period of active mining. Oxidation of coal faces would have been rapid when the coal was first exposed by mining. After a period of exposure, the surface coal becomes oxidized, resulting heat from this chemical action is dissipated, and further heating from these surfaces is not likely to occur.

A similar situation exists in connection with mixtures of carbonaceous and noncarbonaceous materials such as strip-mine spoil and mine-refuse dumps. Fires in these materials often are thought to be started by chemical action; however, this may not be so. A mine-refuse pile, which begins to burn many years after it was deposited, is most likely to have been ignited by an external source of heat. Strip-mine spoil is seldom ignited by chemical action. Investigation usually reveals that a trash or warming fire has been burned on the material, and the transferred heat ignited the combustibles in the spoil.

PREVIOUS ACTIVE MINING

Ignition in an abandoned mine may date back to active mining in the bed. The fire may have been sealed from the rest of the mine, or the mine may have been abandoned because of fire. This fire may propagate toward shallow cover until it affects the surface. Occasionally, such an underground fire will be uncovered by strip-mining operations along the outcrop.

CHARACTERISTICS OF PROPAGATION

A fire will spread with relative ease through open entries in an abandoned mine. The oxygen supply is most accessible in these entries, so the fire propagates rapidly, consuming coal in the roof and ribs.

The type of mining done has an important bearing on the propagation of the fire. Much of the mining in early days was done near the outcrop, and considerable quantities of coal were left in place. Numerous surface openings were made for drainage, ventilation, and access. Entries were narrow, and much coal was left in solid pillars. Most of these narrow entries remain partly open indefinitely. Top coal was often left for roof support, and bottom coal in many instances was left because of water conditions. In many worked-out areas more carbonaceous material was left in the ground than was extracted by mining. These worked-out areas near the outcrop usually are connected to extensive deep mines, either abandoned or active. This condition creates a vast underground area through which the fire may propagate.

The rate at which the fire propagates depends upon how well it is ventilated; and ventilation in the fire area depends upon many factors, most of which cannot be known readily. In a flat-lying bed convection currents are induced by a low-pressure area over the fire, created by expanding fire gases escaping through crevices to the surface. These convection-current stacks induce airflow into the fire area from lateral openings around the outcrop. Other currents are set up in the creviced overburden—some crevices intaking, others exhausting. A crevice or sinkhole also may intake and exhaust at the same time. In such openings, hot gases will issue from the center, while air flows to the fire around the perimeter of the opening. A crevice extending to the surface may exhaust gases at one point and intake air at another. Underground fires also exist that are known to be very active, but no exhaust gases can be observed escaping from the surface of the overburden. In such instances the ventilating circuit could be entirely within the abandoned mine, or the exhaust gases may diffuse and flow through the porous overburden of a wide area but cannot be detected by concerted visual observation.

The underground fire always propagates when fuel is available toward fresh air. That portion of the fire nearest the source of fresh air gets the most oxygen; therefore, propagation is always most rapid in that direction. In the area farthest from fresh air the atmosphere becomes deficient in oxygen because of the high concentrations of the products of combustion; therefore propagation is minimized in this direction. If the fire burns in a steeply pitching coalbed currents are set up, owing to differences in elevation of the coalbed and increased air temperature. A fire near the outcrop of a mined dipping bed has an "open stack" to the surface; thus a draft will be created, which will draw fresh air from the lower sections of the mine. The fire under these conditions then may propagate more rapidly downgrade.

The compactness of caving or, conversely, the openness of abandoned entries in and surrounding a fire area, is another important factor affecting the ventilation of the fire. Open entries provide passageways for the infiltration of air to the fire. Open drifts, shafts, and strip cuts contribute to the ease with which an underground fire may obtain oxygen for combustion from the surface air.

Much of the heat evolved from an underground fire is retained in the coal and strata in the immediate vicinity of combustion. This not only affects the ignition and propagation of the fire but is an important consideration in its control and extinguishment. The surrounding rock strata and the coal itself are poor conductors of heat, so heat loss by conduction is low. Radiation from the fire is absorbed by the coal and strata, so there is slight loss from this source. The only appreciable heat loss from the fire is by convection currents, which issue through the surface crevices. These convection currents also are responsible for increasing the ventilation of the fire, since they create the drafts drawing fresh air into the fire area. Closing all surface openings and crevices to prevent airflow smothers the fire, but it also prevents heat loss from the fire area by convection. These effects tend to counteract each other. When an abandoned-mine fire is controlled by sealing (smothering), enough time must be allowed for the heat in the strata and coal to be conducted to the surface and dissipated to the atmosphere. Otherwise, if this heat is not dissipated, the fire will be rekindled by the stored heat when oxygen is again admitted.

The heat from the fire causes the overlying strata to expand and fracture. This causes crevices, which will extend from the fire area to the surface. These crevices become stacks over the fire, exhausting fire gases to the atmosphere and furnishing avenues through which air can reach the fire. In this way the fire propagates underground by creating new breaks to the surface for ventilation and thus leaving a subsided area of broken ground in its wake.

However, the limits of a subterranean fire cannot be reliably estimated from surface evidence alone, particularly if the fire is under more than 30 feet of cover. Experience has shown that the active fire front in mined areas is usually in advance of surface indications; however, this may not be true if the fire is in unmined coal. Another reason for not relying solely on surface evidence is that the fire may find an entry or group of entries through which it will travel rapidly but show little or no surface crevicing or subsidence at the time of the inspection.

Geological conditions such as thickness and type of cover, thickness of the coalbed, presence of other beds, and ground-water conditions have an effect on the fire. The thickness and composition of the strata over the fire affect the ease with which surface breaks occur.

Also, the thickness of the overburden determines the height of a stacking crevice. Since a higher stack produces a stronger draft, it is assumed that a break through deep strata provides more ventilation than one through shallow strata. The thickness of the coalbed is probably a factor in the amount of caving and crevicing that will occur over the fire. The presence of adjacent and subjacent coalbeds, if they have been mined, will increase the amount of fracturing and caving of the strata. Where the beds are separated by less than 30 feet of strata, there is also the possibility of heat from the fire communicating to the other bed, either by conduction or convection, and igniting it. Water conditions are also a factor in the ignition and propagation of a mine fire. Water extending to the roof of the mine will provide a fire barrier, thus preventing propagation of the fire into the submerged coal. Surface water percolating through the strata onto an underground fire is known to have a cooling effect on the fire area. Presumably, the same is true of water flowing over parts of the fire and through abandoned entries. Heat will be absorbed and taken from the fire area by the flowing water. In addition, some of this water will be converted to steam in areas where the rocks and coal are above 212° F. This conversion of water to steam will have a smothering as well as cooling effect.

The volatility of burning coal has no significant effect on the propagation of a mine fire, except in anthracite. The volatile products of anthracite contain a high percentage of hydrogen. It has been suggested that the accumulation of hydrogen in an elevated area away from an active fire and its subsequent ignition could cause an extension of the fire into a new area. In this instance no connection of burned coal exists between the two fires, even though the new fire is an extension of the old.

The combustion rate of an underground mine fire may be extremely slow, but such fires seldom are extinguished by natural causes. The characteristics of its propagation and the conditions under which it burns are such that the heat produced is retained in the strata for long periods, and sufficient air infiltrates through the broken strata to sustain oxidation. A fire may seem to be extinguished in one area, only to reappear in another. It is not safe to assume that a fire is extinguished until extensive exploration reveals that no above-normal ground temperatures exist in the vicinity.

HAZARDS AND DESTRUCTION

As stated in the introduction, abandoned-mine fires have a destructive and demoralizing effect upon a community. They are a hazard to the health and safety of the people living and traveling in the vicinity, and they threaten fire and subsidence damage to their property. In addition, the fires consume coal reserves and threaten the destruction of forest lands.

LIFE AND HEALTH HAZARDS

Harmful gases and fumes are evolved from a mine fire. They issue through breaks in the overburden and pollute the atmosphere in the vicinity. Because of the oxygen-deficient conditions under which the fire burns, carbon monoxide is one of the constituent gases. The fumes contain distillates from the coal and carbonaceous shales, which are irritating to the respiratory passages and have an objectionable odor. In addition to polluting the general atmosphere, these gases may seep into buildings through crevices extending to the underground fire. The accumulation of these fire gases in a poorly ventilated space has been fatal to occupants.

The hazard created by these mine-fire gases may prevent the economical exploitation of an adjacent tract of partially mined or unmined coal. In an active mine in coal contiguous to the fire or in a coalbed above or below the fire, gases could be drawn into a ventilating current and endanger the life or health of the mine workers.

The surface over the burning coal in the vicinity of the crop presents a hazard to those traveling or working in the vicinity. Here may be found large crevices and sinkholes, some of which open into the coalbed where the material is burning. In addition to exposed openings, there may be concealed cavities just below the surface of the ground; these are in the shape of inverted cones, terminating in the mine. Such conditions are not apparent on the surface, and the weight of a person or animal walking over the cavity causes the surface to collapse. This has occurred in several instances, resulting in loss of life. These areas create an "attractive" nuisance, because the unusual conditions of smoke and devastation attract the curious, and particularly children, into the hazardous area.

LOSS OF RESOURCES

Outcrop and underground fires have destroyed large quantities of the coal reserves of the Nation. If not controlled they will continue to consume much of these valuable resources. In abandoned mines they destroy vast quantities of coal that would have been available for second mining. In unmined coalbeds, especially those of low rank, an underground fire will burn for great distances along the outcrop and consume vast quantities of coal. A fire will also prevent the mining of contiguous reserves or beds of coal above or below the burning bed.

Underground fires also destroy surface vegetation. If the fire is less than 30 feet below the surface, destruction will be nearly complete. Large trees will be dislodged by the crevices and breaks in the overburden. The heat from the fire and the acid soil conditions created by the fumes and gases make the area devoid of vegetation. In addition, an outcrop fire may ignite and reignite a forest, causing widespread destruction of forest reserves far beyond the limits of the mine fire.

SURFACE SUBSIDENCE

One of the most insidious aspects of an underground fire is the damage it may cause to surface structures over the fire. This damage occurs from localized or uneven subsidence of the overburden as the fire burns beneath it. Many residential, commercial, and industrial areas, particularly in the coal-producing Eastern States, are located over abandoned coal mines. The surface over a mined area is usually safe for building purposes if the coal was removed several years before surface development and the structures are a reasonable distance above the bed. The surface will have subsided, and static equilibrium been reestablished within the overburden. However, when a mine fire is ignited and begins to burn through the abandoned entries this equilibrium is disturbed. Supporting pillars are consumed or weakened by the fire, and the heat of combustion causes expansion of the rock strata. These conditions create new stresses in the overburden, causing crevices and sinkholes. Homes and other surface structures above the fire area may be cracked and broken by shifting and subsiding ground and may collapse. (See fig. 1.) Roads and highways will be damaged, causing traffic hazards. There have been instances where homes built near the coal outcrop have been ignited by a mine fire and burned to the ground. (See fig. 2.) Other homes have been moved intact or razed to remove them from the path of an underground fire. Property values depreciate, and potential building sites are rendered useless under such unfavorable conditions.

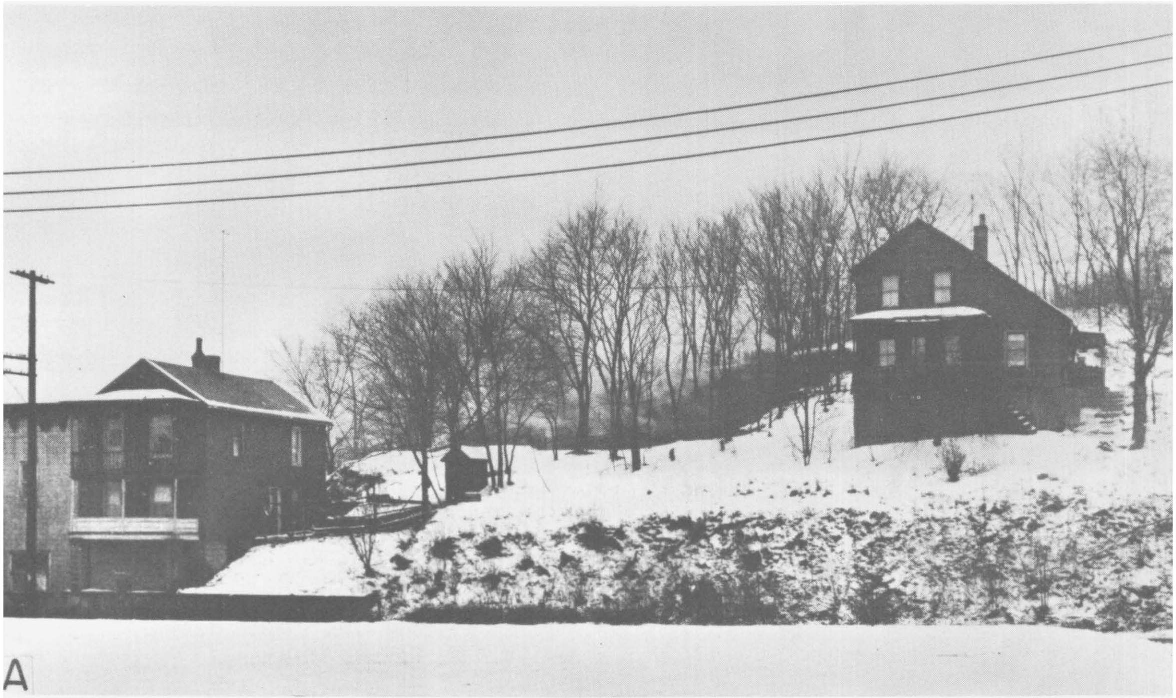
UNMINED COAL FORMATIONS

Unmined coal is known to have burned in prehistoric times, because there is evidence of this preserved in rock formations, particularly in Western United States. Scoriaceous materials are believed to have been caused by prehistoric fires in coal formations, although the origin, nature, and extent of these fires are obscure. There are early historical references to burning coalbeds in areas where it is reasonably certain that no mining had been done. Reference was made to the evidence of a fire around the outcrop of a solid bed, which penetrated as much as 100 feet into the coal. These observations, in addition to recent experience with controlling crop fires in Western United States, leave no doubt that a fire will propagate along the outcrop of solid coal and extend for some distance underground into solid coal.

Little is known about the rate of propagation of a fire along the outcrop of a solid coalbed or of the depth to which it would penetrate into solid coal. A knowledge of these two factors may permit engineers to develop new techniques for controlling this type of fire.

A study conducted by the Bureau to determine the amount of weathering in a solid coalbed concluded that this particular bed was unaffected at distances greater than 50 feet from the outcrop. The cover at this distance was less than 25 feet. These conclusions indicate that under normal conditions there is no oxygen available for combustion very far inby the outcrop. However, under conditions where the outcrop has been ignited and the fire begins to propagate normal to the crop, the heat of the fire would expand the strata and cause crevices in the overburden. This would allow the fire to obtain oxygen and propagate further underground as it creates successive breaks in the overburden. How far this process would continue is not known, but from experience gained in controlling fires in abandoned mines it appears that when the fire reaches an overburden greater than 60 feet it would no longer cause breaks to the surface. When it can no longer break to the surface, lack of oxygen will prevent the fire from penetrating deeper into the solid coal. It is believed that this matter deserves thorough investigation and experimentation with a view to developing new methods of control. It is the hope of Bureau engineers that such work can be done in the near future.

One experiment that is being considered for controlling a fire in solid coal, or in a small coal mine surrounded by a large tract of solid coal, is the construction of two plug barriers, one on either side of the fire. The plug barriers would begin at the coal outcrop and terminate when the overburden reaches a depth of about 60 feet. The two barriers are intended to prevent propagation of the fire along the outcrop on either side of the fire, and it is thought that the solid coal, when its overburden reaches a certain thickness, will prevent continued propagation into the coalbed normal to the crop line. A plan view of this proposed method is shown in figure 3. Plug barriers are discussed under "Fire Barriers."



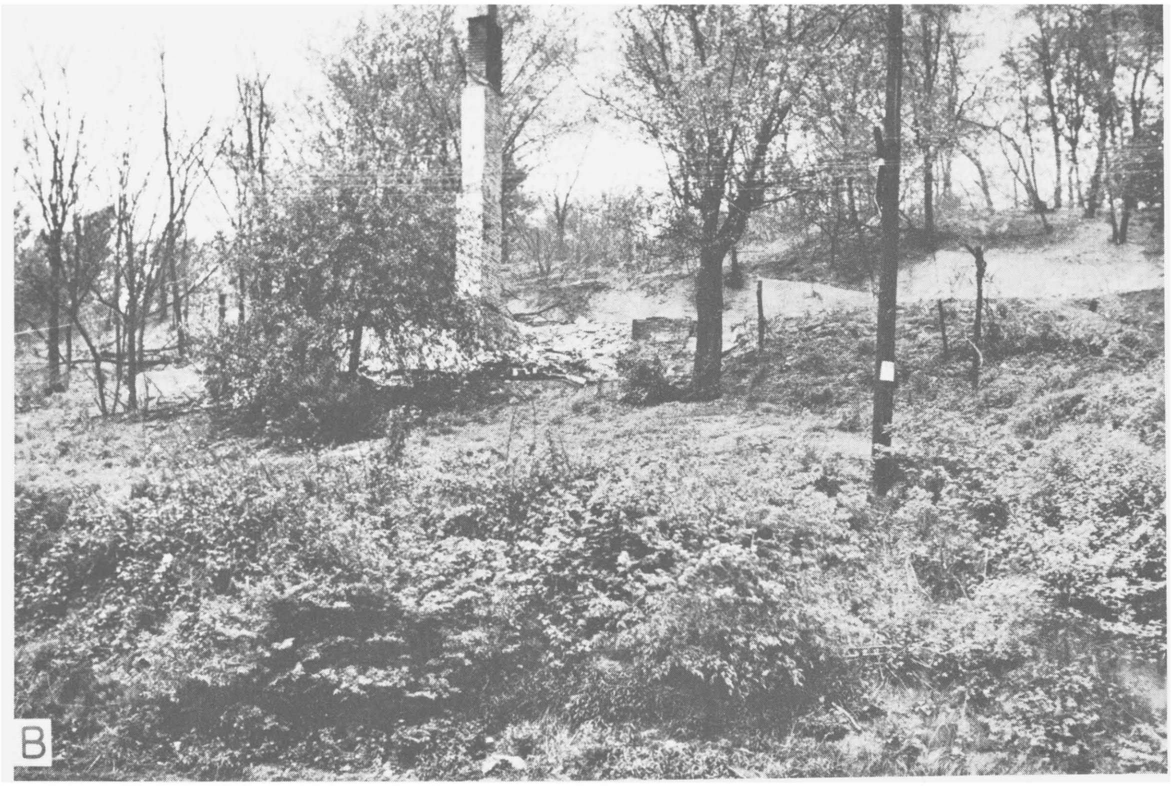


FIGURE 1.—Store Building, Showing Progressive Damage Caused by Subsidence Over Fire Area.

FIGURE 2.—*A*, Mine Fire Burning in Center Background and Approaching Home Built Over Outcrop of Coalbed; *B*, Remains of Home Destroyed by Fire.

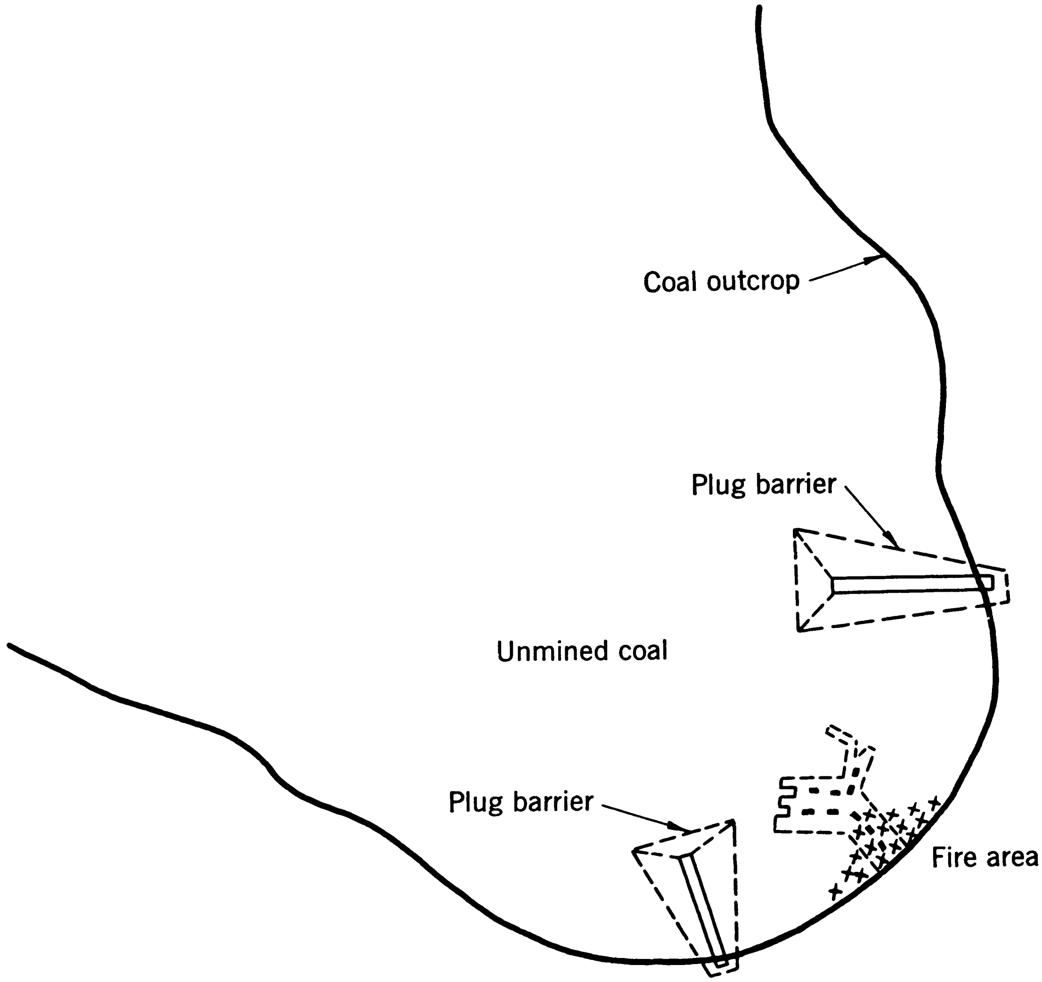


FIGURE 3.—Plan View of Proposed Method of Controlling Fire in Small Isolated Mine. (Plug barriers prevent propagation along outcrop, and unmined coal prevents propagation underground.)

METHODS OF CONTROLLING FIRES IN INACTIVE COAL FORMATIONS

There is no single method that can be used to control or extinguish all underground mine fires. Each fire presents its own unique condition, so a control method suited to each fire should be selected.

Several fire-control methods have been used successfully in the United States, either singly or in combination. They are: Loading-out, inundation, fire barriers, flushing, surface sealing, and underground sealing. These methods and some examples of projects employing them are described in the following text.

ENGINEERING CONSIDERATIONS

Many conditions must be considered when selecting the most practical and effective method of control. The extent of the fire along the outcrop and underground, as well as how long the fire has been burning, are important factors. The availability of water and sealing or flushing materials must be considered, as well as the type and extent of previous mining in the coalbed. Each fire site will present different geological and topographical conditions, which must be considered. These have to do with the character and thickness of the overburden, slope of the surface over the fire, the existence of multiple beds of coal, the thickness and pitch of the coalbed, and the character of the burning material.

A fire may be loaded out when a relatively small amount of material is affected and it is under shallow overburden of such a character that it can be readily excavated. Water should be available for cooling the hot material during excavation. Conditions favorable to loading-out generally prevail when the fire is of recent origin.

Inundating the fire area, usually with water but also at times with mediums such as steam, inert gas, or chemicals, may be done if one of these mediums can be confined so as to exclude oxygen or to contact the fire. The dip of the coalbed, the location of swags and rolls in the mine, the location of barriers, the elevation of the water table, and the number and kind of surface openings will affect the ease with which the inundating agent can be confined.

The flushing method consists of filling the mine cavities with a finely divided incombustible material introduced as a slurry through boreholes drilled from the surface. It is most successful when concurrent work can be done underground to direct and confine the deposition of solids from the slurry. Therefore, accessibility of entries near the fire is important, although flushing is done also without underground direction. Flushing is essentially a method of inundating the fire area with solid materials, so that many of the same conditions will affect these operations as affect the successful use of the inundation method. It is difficult to confine the material to the fire area in steeply pitching beds, especially if multiple coalbeds are involved. The method is not usually employed on widespread fires in extensively mined areas because of the great quantities of water and flushing material required. The depth and composition of the strata affect the ease with which boreholes can be drilled.

Surface sealing is usually employed on fires extending for great distances along the outcrop. One fire controlled by this method in Pennsylvania extended 3 miles; however, this method may not be successful if the slope of the surface over the fire is too steep to permit installation or maintenance of a covering seal. Furthermore, the surface must be of such composition as to create a relatively impervious seal when it is pulverized, or else a suitable covering material must be available in the vicinity for blanketing the surface with a borrowed fill.

A trench barrier may be installed if the fire can be surrounded from outcrop to outcrop without encountering excessive overburden or making the trench too long to be economically practicable. A plug barrier must start at the outcrop and terminate in unmined coal under deep cover, so a knowledge of the mine layout is necessary in order to plan this operation.

SOCIOLOGICAL CONSIDERATIONS

Each fire situation will present certain sociological aspects that must be considered with the engineering problems. Some of these apply only to the cooperative fire-control program of the Federal Government; others apply to all fire-control situations.

Because the Federal program requires a 50-percent contribution on projects for controlling fires on private property, the availability of contributor funds and the general concern of the individuals and local governments involved are important factors in initiating and adopting a control project. Subsequently, during the planning of a cooperative control project, suggestions of the cooperating party or parties are given serious consideration. The amount of contributor matching funds available to a project and the suggestions and preferences of the contributors can and often do affect the selection of a method for controlling the fire.

Releases must be obtained to enter and to do control work on private property. The type of work to be performed during the control operations will affect the ease with which these releases may be obtained. If drastic alterations must be made or homes and/or outbuildings removed, the release may not be obtained voluntarily. In such instances condemnation proceedings would be necessary, and this requires the cooperation of local authorities. Releases to perform surface-sealing work usually are not difficult to obtain, although there have been instances where condemnation proceedings were required. Trenching projects, feasible from an engineering viewpoint, have been abandoned because the necessary releases for such work could not be obtained.

Some operations may require the interruption of traffic or working in positions where a hazard is created to transportation facilities. Such a situation occurred during the excavation of a fire on a steep hillside above a four-lane boulevard in Pittsburgh, Pa., and also at the Carroll Township surface-sealing project, a portion of which was performed on a steep slope above a railroad right-of-way. These situations require additional precautions and add to the cost of the project.

Heavy blasting in the vicinity of homes may precipitate lawsuits for damges. In a trenching operation where blasting is anticipated, this possibility should be foreseen and precautions taken accordingly.

When using a control method such as flushing, which requires large quantities of water, the water should be pumped from a stream or pond if feasible. The use of "city" water for such operations may consume the supply at a rate that water will not be available to other users on the line. This situation occurred at two flushing operations where no other source of water was available, and the flushing operations had to be restricted to offpeak hours or days of operation.

Certain operations, particularly surface sealing, will change the established drainage pattern in the vicinity of a project. Special precautions should be taken to protect all homes below the project area from water runoff damage. Surface runoff will usually be increased by removing vegetation and closing surface crevices and openings. Provision should be made to channel this runoff into established drainage courses that are adequate to take the flow and dispose of it without damage.

LOADING-OUT BURNING MATERIAL

Experienced mining men agree that to do an effective fire-control job by the direct-attack method, the work of loading-out the fire should be started at the earliest possible burning stage. If crop fires are controlled in the incipient stage, excavation, cooling, and removal from the site ordinarily holds the most promise of successful eradication. With the many types of transportable excavating equipment available for immediate delivery to the fire site, it is necessary only to provide a copious supply of water to assure that the fire will be eradicated expeditiously and safely. However, a superficial appraisal of this method for controlling a fire can lead to serious consequences. To execute the work safely and as quickly as possible, water should be available to cool the burning materials to prevent undue damage to equipment, to allay dust, and to cool excavated materials sufficiently to prevent reignition. Operators of equipment in the immediate vicinity of the fire are exposed to the hazard of bursting stones, deadly fumes, extensive airborne dust clouds, and flame outbursts. Precautions must be taken to provide for the safety of the workers.

The location and extent of the fire usually will determine whether an attempt should be made to eradicate the fire by loading it out; however, other factors have to be considered before its success can be assured. Some of the more important of these are: (*a*) Availability of a disposal site for the excavated material, (*b*) the character and thickness of the materials over the coalbed, (*c*) the presence of surface improvements over or near the fire area, and (*d*) the availability of a sufficient quantity of water.

The loading-out work should be done so as to get between the burning and unburned material as rapidly as possible, so that when air is admitted the fire will not extend faster than the burning material can be excavated.

Bureau coal-mine fire-control engineers have advised on the successful loading-out control operations of a number of such fires. In a few instances the Federal Government has shared in the cost. Some of these worthy of mention are the Hope Hollow fire, McGibbeny School fire, the Bedford Dwellings-Bigelow Boulevard fire, and the Monessen City Park fire. Details of these projects are described under "Examples."

EVALUATION OF LOADING-OUT BURNING MATERIAL

The four projects described later as examples of loading-out burning material were selected from many similar fires; they illustrate how it is possible to take prompt action in controlling underground mine fires in the incipient stage and at relatively little expense. The cost of controlling the three smaller fires described ranged from $100 to $2,000 as compared with $50,000 or more needed for controlling those fires that have been burning unabated for longer periods. The Bedford Dwellings-Bigelow Boulevard fire, an example of prompt loading-out, was an exception because of its geographic location and other extenuating conditions. This fire had been active for less than 3 months when the work of extinguishing it was begun; the cost was $35,000. Had this fire been permitted to burn out of control for a longer time, the work necessary for its control would have been much more difficult, more hazardous to perform, and much higher in cost.

Other benefits obtained from taking prompt action to eradicate mine fires in their incipient stages are: (*a*) Children and other persons living near or traveling in the affected area will not suffer from the effects of obnoxious and harmful gases and fumes; (*b*) the sudden collapse of surface land or buildings is prevented; (*c*) forest- and grass-fire ignitions are prevented; (*d*) land values will not depreciate; and (*e*) valuable mineral resources are saved.

To preclude these dangers and wasted resources, local, county, and State governments should enact legislation enabling them to act promptly to control or eradicate fires in outcropping coal and abandoned coal mines. The Commonwealth of Pennsylvania has enacted legislation that permits it to expend funds directly or in cooperation with others to control mine fires. The Commonwealth has cooperated with the Federal Government in many projects. In addition, counties, cities, boroughs, and townships in the Commonwealth have cooperated and contributed to fire-control projects. The State of Maryland has cooperated also and contributed financially in controlling a fire near Frostburg, Md.

EXAMPLES OF LOADING-OUT BURNING MATERIAL

HOPE HOLLOW PROJECT

In June 1949 a fire, believed to have been ignited by burning rubbish adjacent to the coalbed, occurred in the exposed crop of the Pittsburgh bed along Hope Hollow Road, Scott Township, Allegheny County, Pa. Water was pumped on the fire for about 3 days by the township fire department, until it was believed that the fire was extinguished. On August 9, 1949, fire-control engineers were summoned to the site. They found that the fire was burning in an abandoned drift opening. Recommendations were made to the property owner that the fire should be loaded-out immediately. A hi-lift was engaged the same day, and the work of excavating the fire was completed within 2 days. Subsequent inspections of the site determined that the operation had successfully eradicated the fire.

McGIBBENY SCHOOL PROJECT

In response to a telephone request received April 6, 1953, an investigation, made the same day, revealed that flame emanated from two portals of an old abandoned mine, and fire could be observed at least 30 feet underground. This fire was burning along the Pittsburgh coal outcrop south of and near the McGibbeny School in Baldwin Borough, Allegheny County, Pa.

The fire was evidently of recent origin, and it was recommended that it be eradicated by the loading-out method (quenching and excavating). After consummating legal formalities with the Federal Government, which permitted the borough to do the work with Bureau financial cooperation, officials of the borough provided a hi-lift dozer power unit and pumping facilities to supply water to attack the fire on a round-the-clock basis beginning at midnight, April 7, or the day after the Federal Government was notified of the fire. This is a good example of how prompt action by all government officials resulted in the control and extinguishment of a fire that would have resulted in a serious threat to health and property.

Watchmen were employed at the site to inspect the area and check for possible rekindling. An inspection of the site in June 1953 indicated that the fire was extinguished. Figure 4 is a view of the fire location before and during loading-out operations.

MONESSEN CITY PARK PROJECT

An inspection of a fire burning in the Pittsburgh coalbed in Monessen City Park, Westmoreland County, Pa., was made June 14, 1951, in response to a request received from the city engineer on June 13, 1951. Investigation revealed that much flame and smoke was emanating from the portal of the inactive mine, making it impossible to inspect the underground area and determine how far the fire had pene-

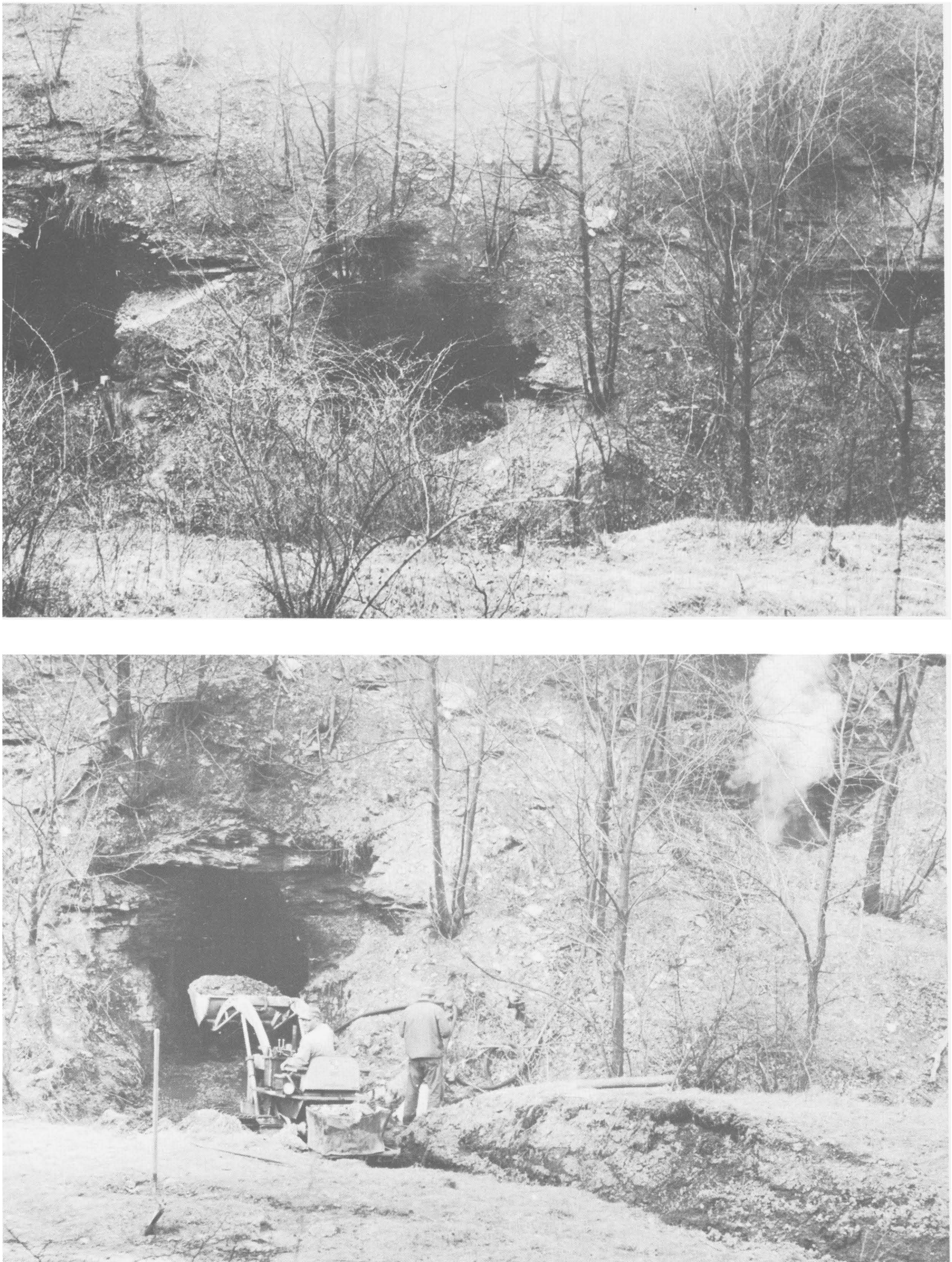


FIGURE 4.—Fire Site Before and During Loading-Out Operations, McGibbeny School Project.

trated. A large quantity of water applied to the fire by city firemen failed to extinguish the fire; therefore, a Bureau engineer recommended that immediate action be taken to load-out the fire by direct attack, and, if this could be accomplished, to close the mine openings to prevent subsequent ignition. On June 14, after receiving assurance that the Federal Government would cooperate financially in controlling the fire, the city council passed a resolution directing the work to be done. Excavating equipment and a supply of water were available at the site of the fire to begin the work within 1 hour after passage of the resolution.

After all work of extinguishing the fire by water cooling, loading-out the hot materials, backfilling the openings, and grading the surface was completed, the Bureau was advised by the city that the owner of the surface land and the owner of the coal had reimbursed them for their expenditures in controlling the fire; therefore the work was accomplished without direct cost to the Government agencies involved. Figure 5 is a view of the site.

FIGURE 5.—Site Where Burning Coal Was Stripped Along Outcrop and Abandoned Portal of Mine, Monessen City Park Project.

BEDFORD DWELLINGS-BIGELOW BOULEVARD PROJECT

It is believed that this fire was ignited by children in the neighborhood who built a wood fire near an exposure of the coalbed a few weeks before its discovery. An investigation of the fire site by Bureau engineers in January 1952 disclosed that it was burning along the coal outcrop on a steep hillside for a distance of about 150 feet. The depth to which it had extended underground could not be determined by visual inspection. An attempt to extinguish the fire by hand-loading efforts and water was made by city workmen, but these efforts were abandoned when it was found that the fire was more extensive than first suspected.

Exploratory boreholes made in the affected area indicated that the fire had not traveled underground to any great depth and that a loading-out program had a good chance of being successful. Work to extinguish the fire by loading-out the burning materials was begun July 7, 1952.

The relation of this fire to multihome dwellings, a four-lane heavily traveled boulevard, and a railway passenger station and depot placed serious limitations on how the operations could be done to prevent injury to the public and to workmen. Figure 6 is a map of the project site, showing location of the fire in relation to Bedford Dwellings and Bigelow Boulevard, and a profile of the affected area.

Figures 7 and 8 show views of the fire area and how several of the loading-out and subsequent backfilling operations were performed.

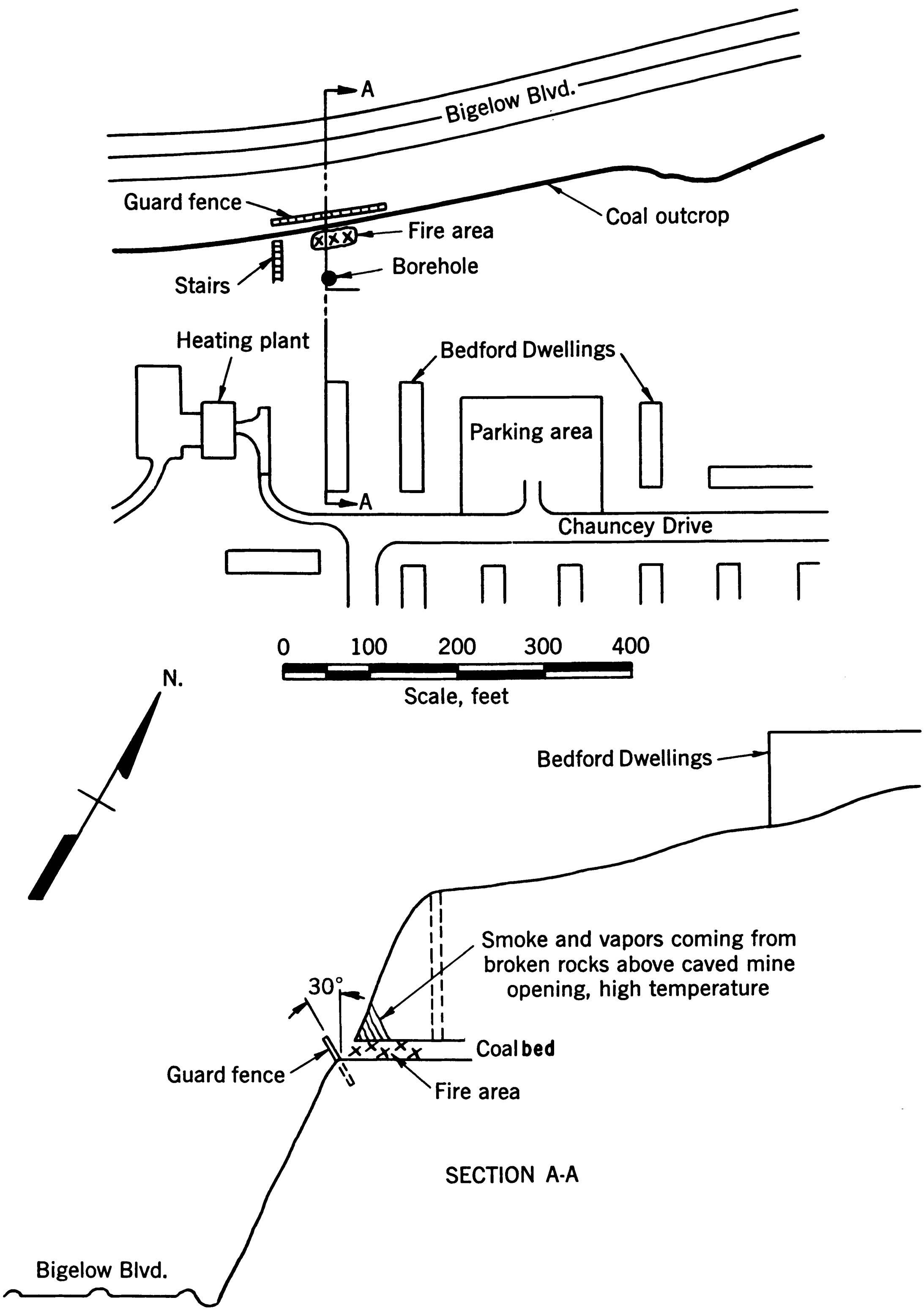


FIGURE 6.—Plan and Section View of Bedford Dwellings-Bigelow Boulevard Fire-Control Project.

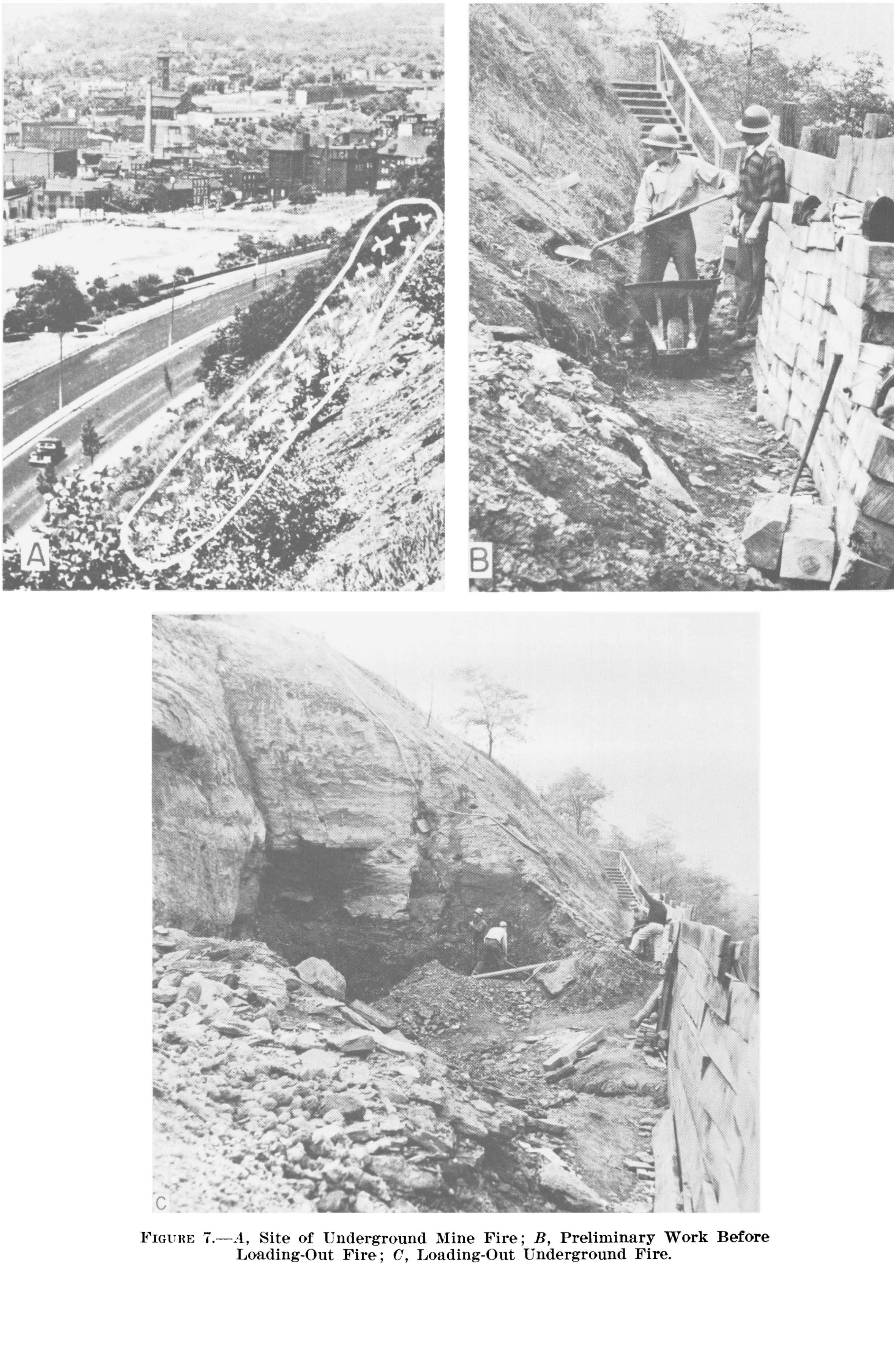


FIGURE 7.—*A*, Site of Underground Mine Fire; *B*, Preliminary Work Before Loading-Out Fire; *C*, Loading-Out Underground Fire.

It is apparent from these photographs that the work was difficult and involved hazards not usually associated with a fire-control project. Except for short intervals during blasting operations, which were accomplished at offpeak traffic periods, traffic was maintained on the boulevard without a serious incident. Every known precaution was taken to protect the public and workmen. Safety equipment such as lifelines, safety belts, gasmasks, and protective clothing were worn by workmen when needed. Work was done for 6 months, involving more than 7,500 man-hours of exposure, without a lost-time injury.

Prompt action by city and Federal officials made possible the loading-out and complete eradication of this fire, which could have caused widespread damage.

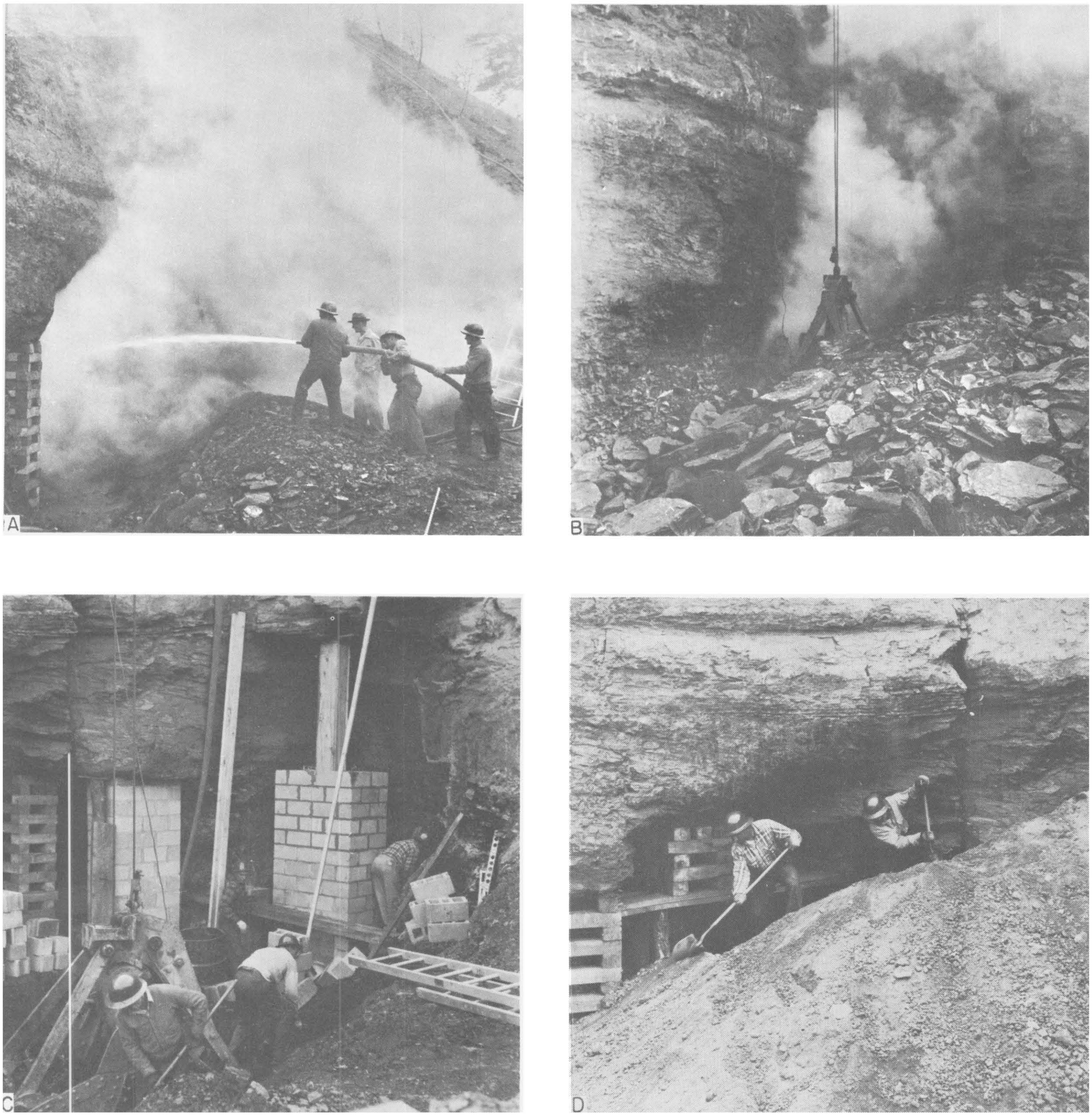


FIGURE 8.—Cooling Materials Before Loading-Out Operation; *B*, Clamshell Loading-Out Blasted and Cooled Material; *C*, Installing Masonry and Wooden Supports Before Backfilling; *D*, Backfilling Excavated Fire Area; *E* (p. 26), Shoring Wall Installed to Retain Earth-Blanket Backfill; *F*, Completed Project, Showing Drainways and Backfilled Area.

546210 O—60——3

FIGURE 8—Continued

INUNDATION

WATER

Inundation, or flooding a mine with water to control and extinguish an inaccessible blaze, is the method mostly advocated by the public and some experienced mining men. The idea has much merit, for there is no better medium than water for extinguishing such a fire and effectively dissipating the heat of the conflagration. However, introducing water into a mine and confining it so as to extinguish the fire may be difficult to accomplish and impossible under certain conditions.

Conditions that favor flooding are: (1) a fire area below the normal surface-water-drainage level, (2) a sufficient quantity of water available to flood the mine areas, and (3) the affected mine isolated from active mine or mines at the same or a lower elevation. Under these conditions, the waterflooding method holds much promise for success. The only factor that might interfere is the trapping of air in high elevations of the mine; in this instance the trapped air is compressed, counteracting the pressure of the water, and prevents the water from reaching hot-burning materials in the compressed-air dome. If the flooded area is dewatered before the heat from the fire has been dissipated, the fire will rekindle.

Where burning coal and carbonaceous shales are above the ground-water level, the problem of confining the water so as to accomplish complete inundation is difficult. The ground strata may be pervious, permitting water to reach the surface; under such circumstances it is difficult to prevent leakage around stoppings or bulkheads closing entries to the mine. Water inundation is excellent in theory but has many shortcomings for safe, practical, and successful application.

INERT GAS

Inert gases and vapors have been suggested also as mediums for inundating underground fires. Carbon dioxide gas and steam have been tried. Carbon dioxide is a good fire-extinguishing agent but has practically no cooling effect, and for this reason is especially recommended for flash fires where there is much flame but relatively little stored-up heat. It accomplishes its objective in these instances by momentarily excluding oxygen from the fire. When used on a mine fire, this gas is difficult to confine to the fire area long enough to permit the cooling of the hot materials. It is difficult and laborious to introduce in effective quantities, and if a great quantity of the material were required it might be prohibitively expensive.

STEAM

Water vapor in the form of steam has essentially the same effect as carbon dioxide gas in that it will exclude oxygen and extinguish the flame. It has the added advantage of penetrating voids and crevices to higher elevations, where the oxidation of combustibles is generally more rapid and intense. By applying water to a fire and converting it to steam, much heat is absorbed (roughly 1,000 B.t.u. per pound of water). Water, when applied to very hot materials (over 1,600° F.) may combine with carbon to form carbon monoxide and hydrogen. Under some conditions this would present a health and explosion hazard. Because it is possible to dissipate great quantities of heat with a minimum of water when it is changed to steam, the Bureau of Mines has and is continuing to conduct experiments utilizing this method to control and extinguish coal-crop fires under relatively shallow cover. This experimental work and some of the data obtained are discussed under the heading of "Research To Develop Fire-Control Methods."

LIQUID CHEMICALS

Liquid-chemical fire-extinguishing agents, such as carbon tetrachloride, soda-acid solutions, and foams, have not been used to control coal-crop fires. The large quantities of material needed would make such an operation very expensive, and it would be difficult if not impossible to apply them directly to the burning material. Work is being done at the Bureau experimental mine to ascertain whether a mine fire can be extinguished by water in the form of bubbles, transported to the fire by an induced current of air. The results of this experiment indicate that the method holds much promise for controlling underground fires in their early stages. The results of the experiment will be published.

EVALUATION OF INUNDATION

Inundation has not been used or suggested by Bureau engineers to control an abandoned-mine fire, because conditions never have been favorable. Inundating with water would be very effective provided the fire was completely covered and dewatering was not done prematurely.

Reports on inundating operations show that the method has one serious drawback, which must be considered. During the flooding, air in the mine may be trapped and compressed into pockets at high places. The hydrostatic head may be several times that necessary to flood the mine, but these pockets of compressed air will prevent covering all the burning materials. The fire in these pockets will be extinguished for lack of oxygen, but the heat in the coal and strata will not be dissipated as rapidly as if it were inundated. Therefore, if the mine is dewatered too soon after the flooding operation the fire will rekindle in these pockets.

Trapped air in high places of a mine may be released by drilling from the surface if the location of the air is known.

FIRE BARRIERS

A fire barrier, as the term is used in connection with abandoned-mine fire control work, is an incombustible dam placed between the fire and the contiguous coal. The barrier is intended to confine and isolate the fire from the main body of coal. The barrier must break the continuity of all coal and carbonaceous shales and also be wide enough to prevent the transfer of heat from the fire area to the opposite side. Unless the barrier is wide enough to prevent heat transfer, active combustion can be initiated in the carbonaceous material on the protected side of the barrier even though the continuity of the bed has been broken. After the burning coal is isolated, the fire will be extinguished for lack of fuel when the combustible material in the isolated area has been consumed. In practice, however, the fire is usually extinguished before all the coal in the isolated area is consumed.

Three fire-control methods utilize the barrier or isolation principle—the trench barrier, the tunnel barrier, and the plug barrier.

TRENCH BARRIERS

The trench barrier is installed by excavating an open trench between the fire area and the threatened area and backfilling it with incombustible material (earth, fly-ash, granulated-slag). The trench extends vertically from the surface to the bottom of the coalbed and horizontally from the outcrop on one side of the fire to the outcrop on the other side. This confines the fire within an area delineated by the coal outcrop and the incombustible barrier. (See fig. 9B.)

PLANNING THE OPERATION

Before attempting to confine a fire by this method, an estimate should be made of the amount of material to be excavated, the amount of carbonaceous material to be disposed of, and the amount of backfilling material required. These are the principal factors affecting the cost of the operation. To make these estimates, certain information concerning the extent of the fire and the character of the overburden should be known. If this information cannot be obtained from surface inspection or maps and records of the mining in the area, it may be necessary to conduct exploratory drilling.

Exploratory boreholes should be drilled on 10-foot centers or less along the centerline of the proposed trench location. The temperatures obtained in these boreholes, and perhaps the cuttings from the hole, will indicate whether the fire has passed beyond the proposed trenching site. There have been instances where exploratory drilling failed to

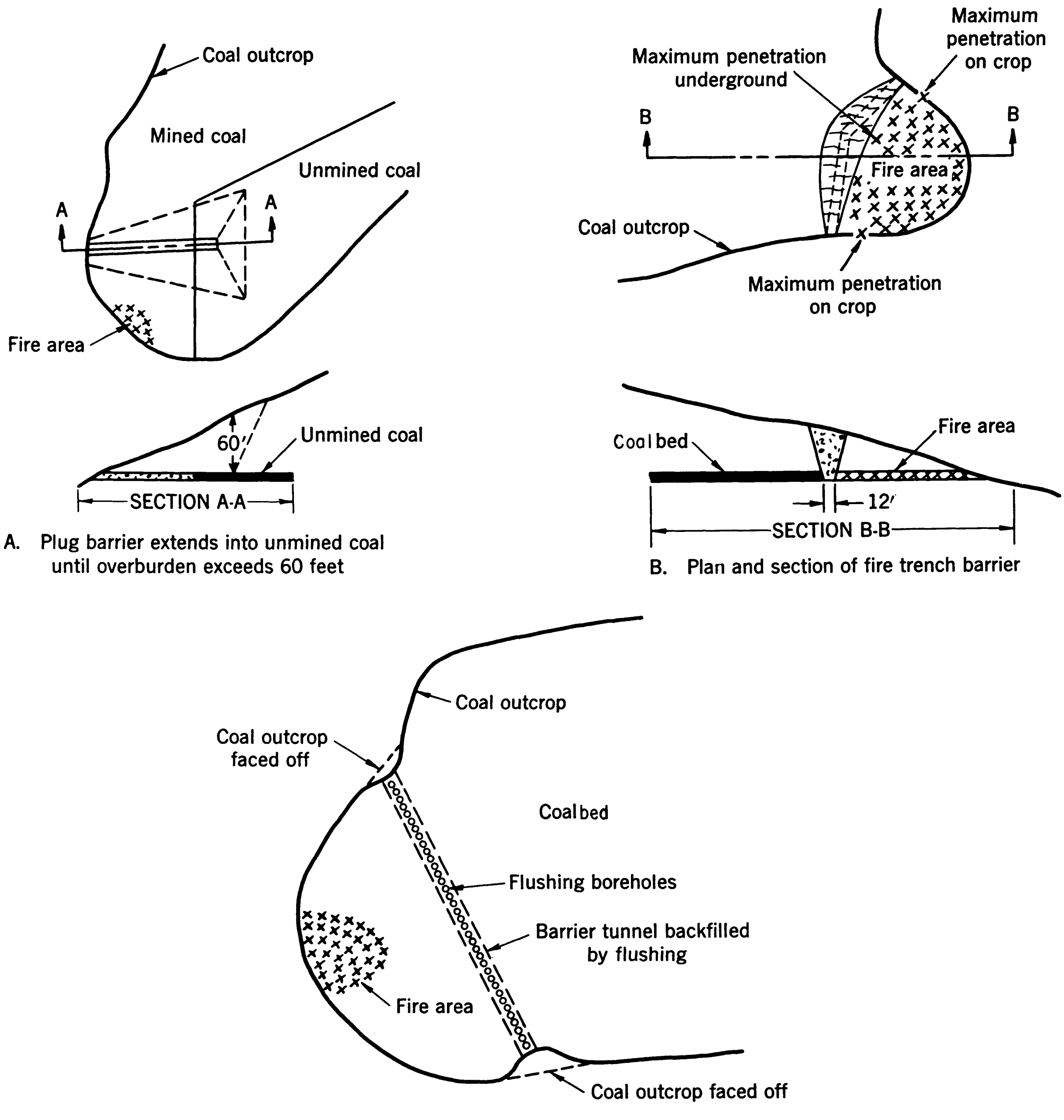


FIGURE 9.—Fire Barrier Methods.

show where a fire had crossed beyond a trenching site even though holes were drilled on 10-foot centers; but in the absence of a more reliable method exploratory drilling is usually a worthwhile precaution.

Extent of the fire underground and along the outcrop will determine the length of the trench. (See fig. 9B.) Extent of the fire along the outcrop usually can be determined by inspecting the surface, but penetration of the fire into the abandoned entries under deeper cover cannot; exploratory drilling is the only practical method of obtaining this information.

Drilling also will give accurate information on depth of the overburden and its composition. The thickness and character of the material encountered is an important factor in determining the cost. Thick, hard strata may require heavy blasting, which would be objectionable in a heavily populated area. The log of the boreholes will furnish information as to the amount of noncarbonaceous material that can be salvaged for backfilling.

EXCAVATING

The volume of material to be excavated from the trench is calculated from the total length and the average cross section. The length of the trench is determined by the size of the fire area to be enclosed. The cross section of the trench will vary as the depth of the trench varies from zero at one outcrop to a maximum, and then to zero at the other outcrop. The minimum width of the trench should be at least 12 feet wide at the bottom of the coalbed. The 12-foot width has become an accepted minimum, because 12-foot barriers proved successful in isolating the New Straitsville fire, and as far as can be determined has been used successfully in subsequent operations. In calculating the area of the cross section, the angle of draw of the trench walls must be considered. The angle of draw is the angle formed by the intersection of a vertical plane and the sidewalls of the trench. An effort is made to keep this angle as small as possible to reduce the amount of excavation. The angle of draw will depend on the composition and condition of the strata but seldom will be less than 15°. The angle of draw accounts for the fact that the volume of material to be handled increases disproportionately as the depth of the trench increases. The maximum depth of the trench is a limiting factor. Experience has shown that it is impracticable to attempt a trenching operation where the maximum overburden is much greater than 50 feet when using the type of equipment that can be transported to the site without dismantling. The cross section of a trench at the point where the depth is 50 feet would be 40 feet at the surface using the minimum angle of draw of 15° and a bottom width of 12 feet. A trench having this cross section involves the excavation of a great volume of material, a portion of which will be carbonaceous, requiring disposal or selective placement in the trench so as not to be a source of reignition. Carbonaceous material may under selective placement be returned to a part of the trench as shown and described in figure 10.

A dragline is the safest and most efficient piece of equipment for making a trench-barrier excavation. Although the dragline is not best suited for digging in hard strata, which is often encountered in this work, it offers advantages in regard to safety and disposal of material. By using a dragline, all digging and loading operations can be conducted above the lower levels of excavation, thus minimizing the exposure of men and equipment to falling material, intense heat, and harmful gases and fumes. With a dragline, the carbonaceous and noncombustible materials can be separated and stored at the surface on either side of the trench.

BACKFILLING

The trench is always backfilled on all fire-control projects supervised by the Bureau. Although an open trench may serve the purpose of cutting off the fire and preventing the transfer of heat to contiguous coal, certain undesirable conditions are created by leaving the trench open. An open trench creates the same hazards and unsightly conditions made by an unfilled strip cut; in addition, the coal on the protected side is exposed to the hazard of future ignition.

Backfilling should proceed immediately behind the excavation. The toe of the backfill slope progresses close behind the toe of the excavation, which minimizes the possibility of losing the trench by caving sidewalls. Furthermore, while the trench is open, increased air flow will reach the fire through the openings created by the trench. Prompt backfilling minimizes this effect.

Any finely divided, incombustible material may be used for backfilling; however, the most economical procedure is to use the incombustible earth material available at or near the trenching site. The fill must not contain any carbonaceous material, including vegetable matter, unless it is returned to the trench as described in figure 10.

The noncarbonaceous material excavated from the trench may be separated from the carbonaceous material and returned to the trench as backfill. In addition to this salvaged material, in most instances some additional backfill will be required. This is usually obtained from a "borrow" area as near the trenching site as possible to hold the cost of backfilling to a minimum. However, if it is not available from the surface adjacent to the trench or from a nearby borrow pit, it must be transported from a more distant place.

Hot carbonaceous material excavated from the trench must be cooled with water or by spreading it on the ground. If removed from the site, a suitable location for disposal may be difficult to find. Transporting the material to the disposal site also may add appreciably to the cost of the project. As an expedient, the carbonaceous materials may be spread on the surface on the fire side of the trench (within the isolated area); however, this would not be desirable in a residential area.

During excavation, noncarbonaceous material is cast on the cold side of the trench, and

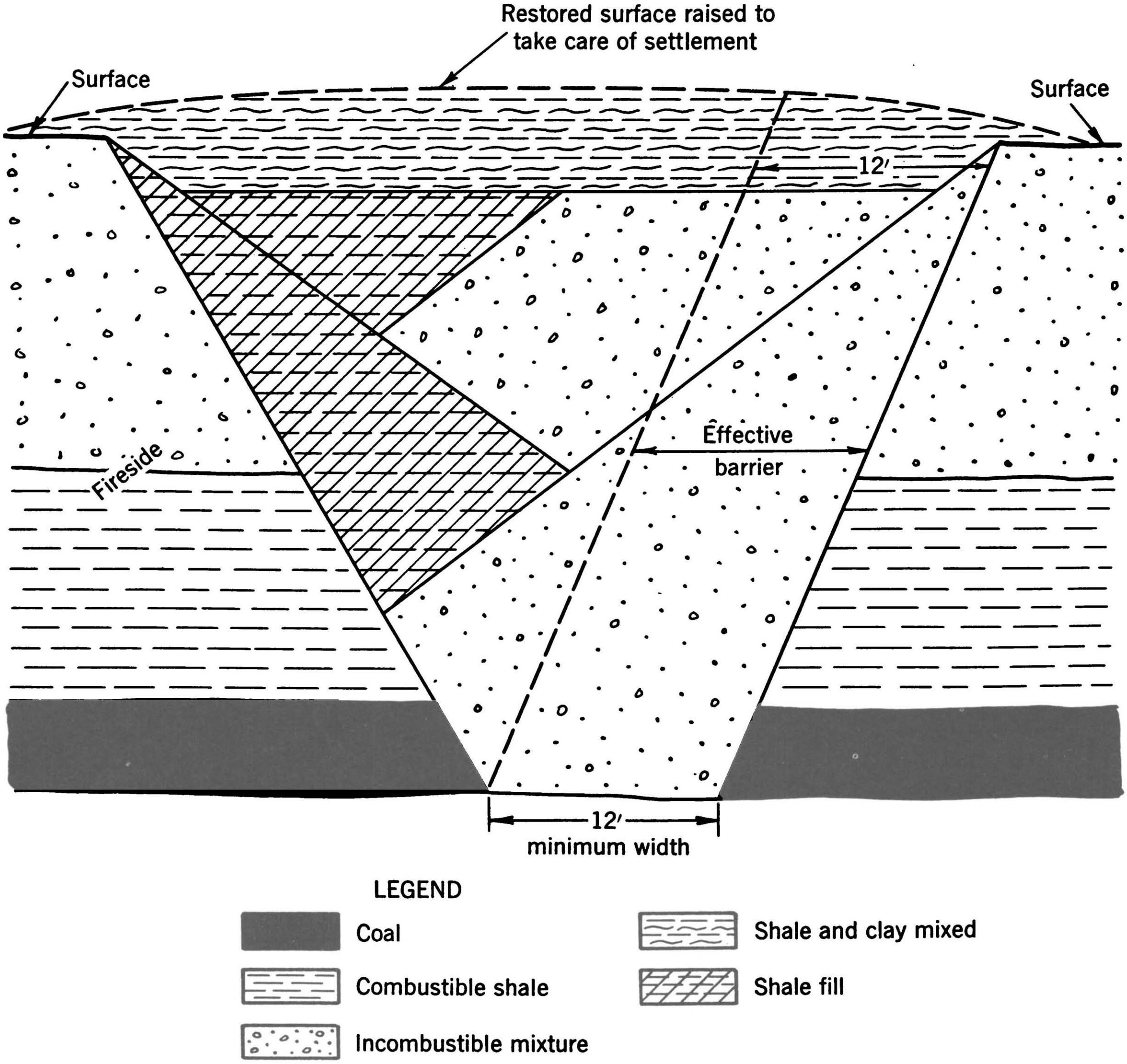


FIGURE 10.—Schematic Drawing Showing How Excavated Materials May Be Returned to Trench To Form an Effective Fire Barrier.

carbonaceous material on the hot side. Figure 11 shows this manner of storing and subsequently returning excavated materials to a trench and the restored surface after completing the trench. The noncarbonaceous material is returned to the trench, usually by bulldozing. The carbonaceous material may be pushed away from the trench and spread out over the fire area, returned to the trench as described in figure 10, or loaded into suitable vehicles and hauled from the site. Additional backfill needed to bring the trench site to a desirable contour may be obtained from the surface adjacent to the trench or from a borrow pit.

EXAMPLE OF TRENCH BARRIER

Cook Plan Project.—An early example of an isolation-trench barrier to control a coal-mine fire was begun in what is known as the Cook Plan, Monessen, Pa., July 6, 1949, and was accomplished under Bureau of Mines supervision and with the financial cooperation of the Federal Government and the city of Monessen.

The area over the fire was a peninsular-shaped tract of land lying west of Third Street in the vicinity of Wilson Street and comprised the Cook Plan subdivision. This fire had been burning for several years. By 1946 it had traveled to within a few hundred feet of homes

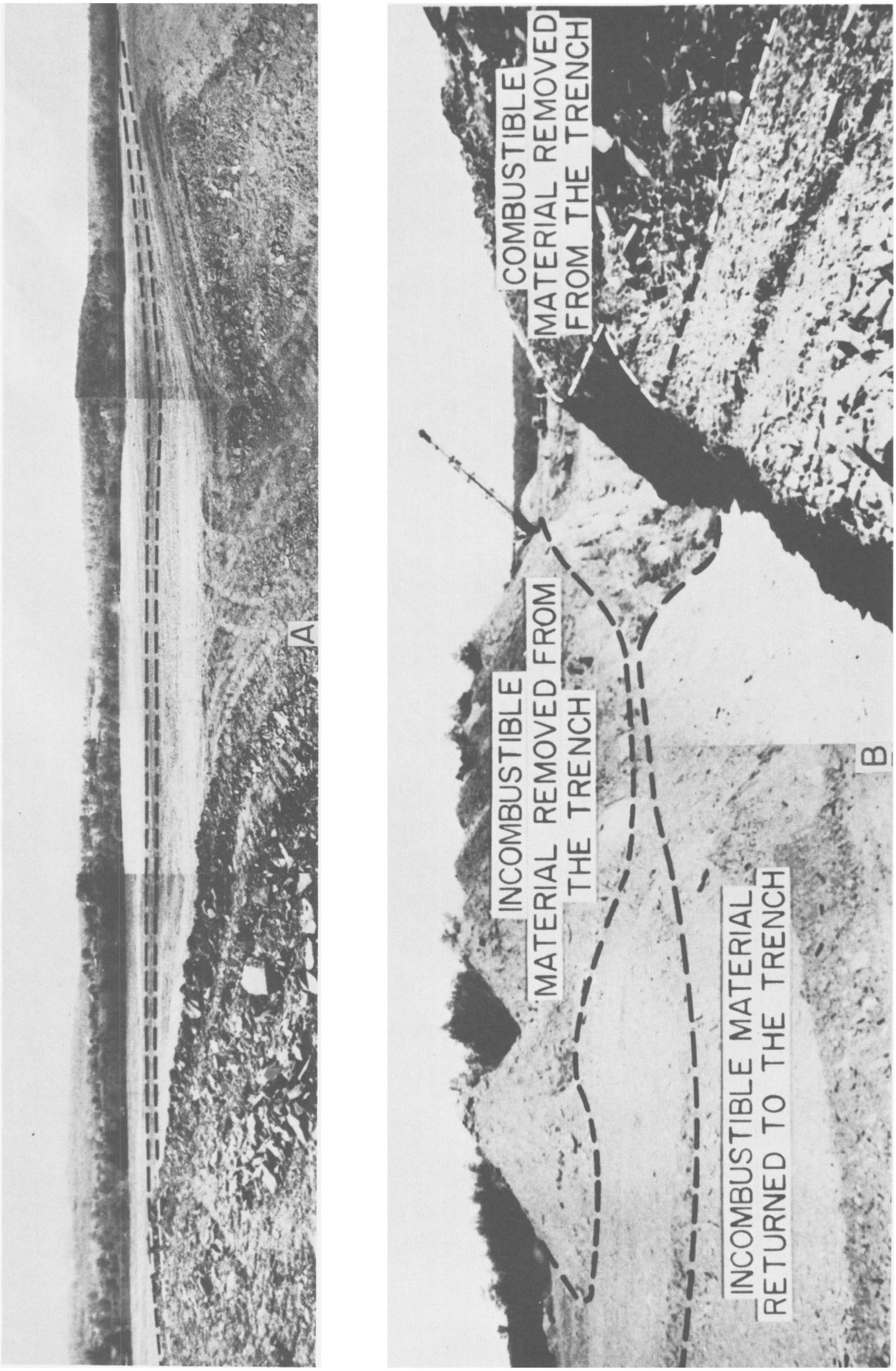


FIGURE 11.—*A*, Looking Over Completed Project. (Dotted line shows approximate location of trench.) *B*, Looking Along Trench. (Shows separation of excavated materials used for backfilling purposes.)

and streets and threatened to spread to schools and other surface improvements in the area. At this time the city spent several thousand dollars in an unsuccessful attempt to control the fire. Part of the work done by the city was to install a plug barrier in the coal outcrop at its southwestern extremity. This plug barrier extended from the outcrop into the coalbed about 125 feet. The purpose of this plug was to keep the fire from traveling in a westerly direction in the outcropping coal. Superficial evidence indicated that the plug was successful in halting the progress of the fire at this location, but it continued to burn and spread at other places to the north and east of the plug barrier.

Early in 1949 officials of the City of Monessen requested that Bureau engineers investigate the fire site and submit a plan for its control. The plan presented to and concurred in by the Monessen City Council recommended among other things that a trench barrier be excavated and backfilled with incombustible material to isolate the fire. The trench was designed to extend from the outcrop at the northwest extremity of the affected area and extend to and join the north extremity of the plug barrier previously described.

Figure 12 is a map showing the location of the trench barrier and its relation to the underground fire, homes, streets, and other surface improvements in the immediate vicinity. Also shown are the exploratory boreholes drilled for measuring underground temperatures to determine the extent of the fire. Figure 13 shows views of the trench location and backfilling the trench with granulated slag.

The trench barrier was 513 feet long, not less than 12 feet wide at the bottom, and varied from 3 to 33 feet in depth. The coal and combustible shales excavated from the trench were removed from the site by trucking. Granulated slag obtained from local steel mills was used with salvaged earth material for backfilling the trench to relatively even contour.

The location of several homes on the unprotected or fire side of the trench barrier made it necessary to supplement the trench-barrier operation with surface-sealing work to extinguish the fire and prevent its damaging these homes. All evidence indicates that the project was successful and that the fire was extinguished. About 3 years after completing the initial surface-sealing work, a large residence was erected on the project site where the fire had been very active. Construction provided for reinforced footers and ventilation of basement areas. The home has been occupied for several years, and no adverse results have been experienced from fire gases or subsidence.

TUNNEL BARRIER

The tunnel barrier, an underground tunnel backfilled with incombustible material, is a means of extending a fire barrier from outcrop to outcrop under an overburden too deep to permit economical trenching or when surface structures would interfere with a surface operation. (See fig. 9C.) It should be at least 12 feet wide and extend from the floor of the coalbed to a height above the rider coals and carbonaceous shales, if present. Exploratory work to decide the location of the tunnel is the same as for the trench barrier. The tunnel must extend around the fire from outcrop to outcrop or begin at the outcrop and terminate in a large tract of unmined coal under at least 60 feet of cover.

During construction of the tunnel precautions must be taken to prevent fire gases and fumes from affecting those engaged in the tunnel work. Stoppings must be erected in the abandoned entries that intersect the tunnel so that the backfill material will be confined, and combustible timbers and other materials must be removed progressively just before backfilling.

Backfilling is begun in the middle and extended toward the ends. If the tunnel terminates in unmined coal, then backfilling is begun at the solid-coal terminal and advanced toward the outcrop.

The tunnel must be tightly backfilled with incombustible material. One method of accomplishing this is to fill the tunnel with coarse rubble hauled from the outside. Then holes are drilled from the surface to intersect the center line of the tunnel, and finely divided material is flushed to fill the interstices of the coarse rubble. The flushing holes are drilled on about 25-foot centers. Sections of the tunnel are flushed as the underground backfilling or packwalling retreats toward the outcrop. In this way progress of the flushing can be observed and, to an extent, directed from underground.

EXAMPLE OF TUNNEL BARRIER

New Straitsville Project.—Bureau engineers have had no occasion to use the tunnel-barrier method since enactment of laws providing Federal funds for fire-control work. However, before enactment, they recommended the method and acted in an advisory and consulting capacity on several tunneling projects. One such project was the installation of three tunnel barriers to isolate an underground mine fire in the vicinity of New Straitsville, Perry County, Ohio. Figure 14 shows this location and some of the work operations performed to construct the tunnel barriers.

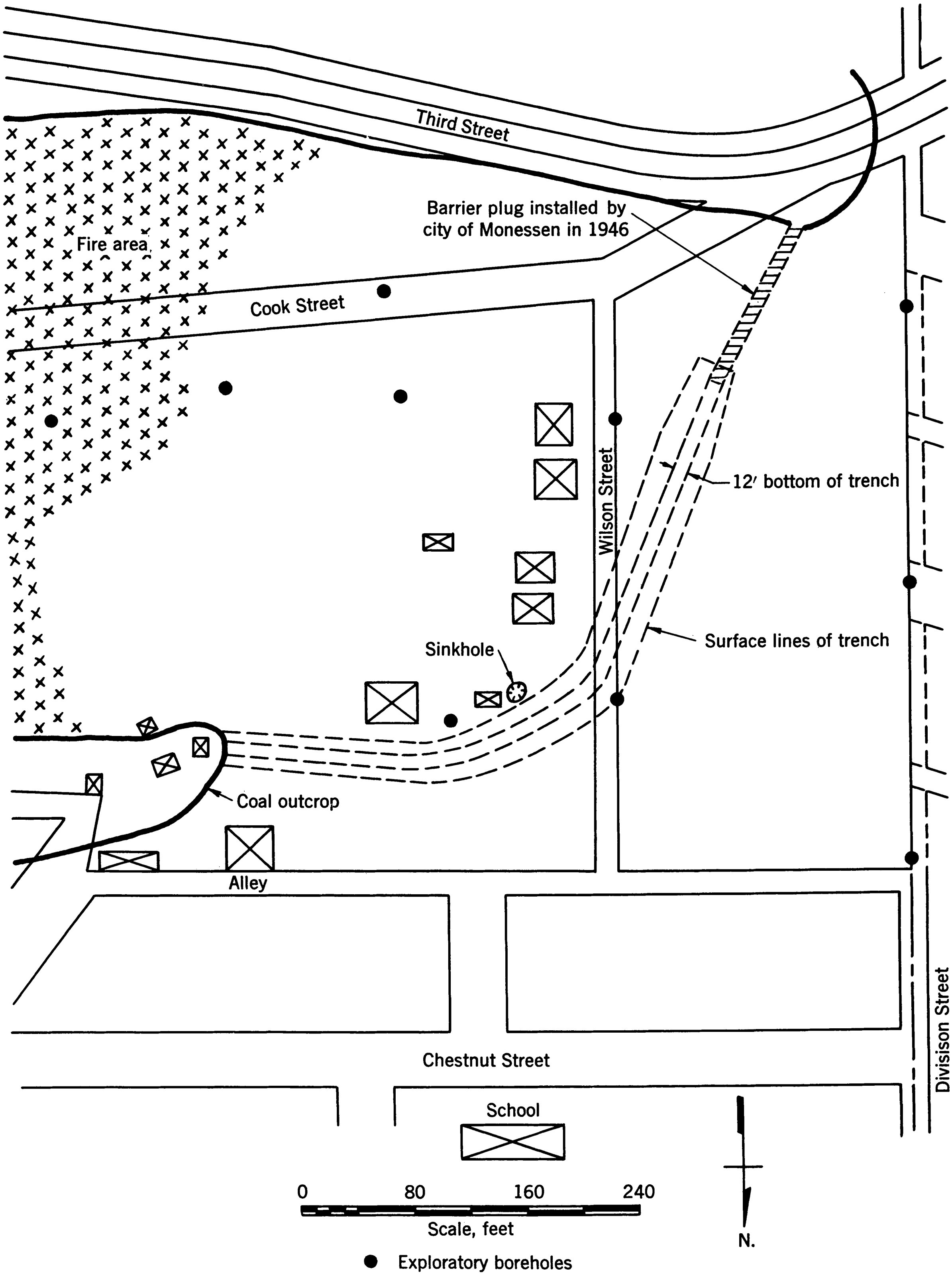


FIGURE 12.—Buildings, Surface Properties, and Location of Trench Made To Isolate Mine Fire Burning in Cook Plan Lots, City of Monessen, Westmoreland County, Pa.

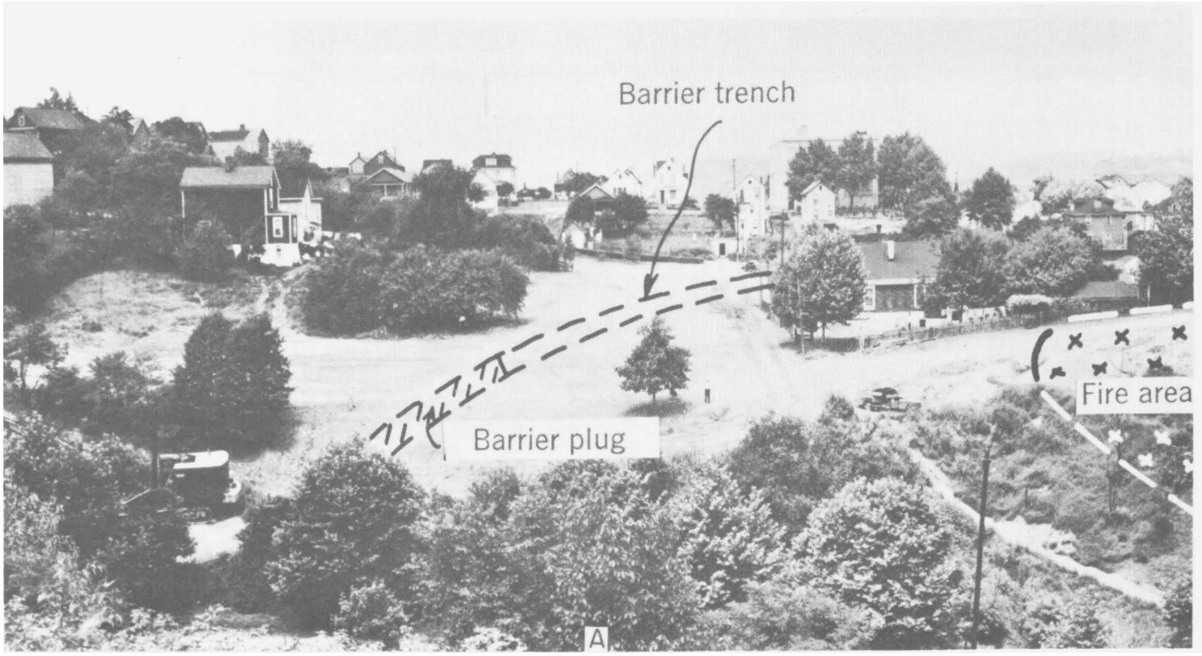


FIGURE 13.—Trenching Operation: *A*, Location of Plug Barrier and Trench Barrier and Their Relation to Mine Fire; *B*, Backfilling Bottom Partof Trench With Granulated Slag. (Incombustible soil will be placed over slag and continued to surface.)

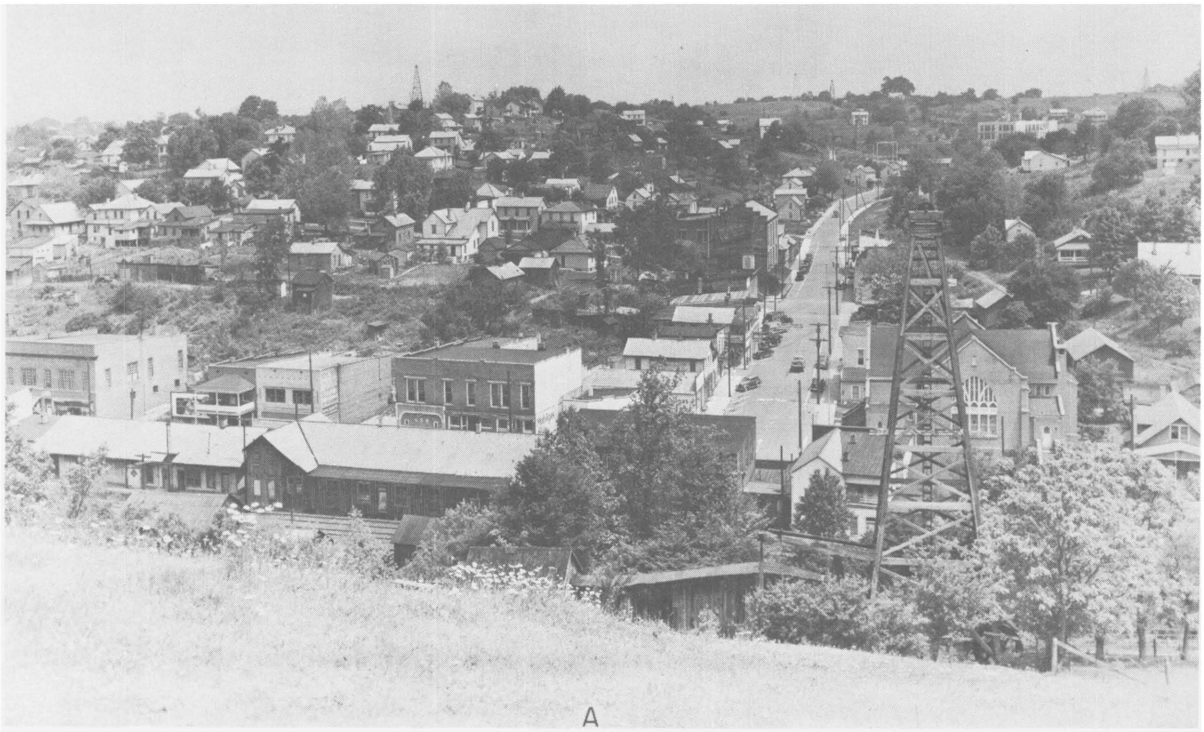


FIGURE 14.—Sites of Installations of Tunnel Barriers To Isolate Mine Fire Burning in Vicinity of New Straitsville, Perry County, Ohio: *A*, Part of New Straitsville Threatened by Underground Mine Fire; *B*, Surface Evidence of Fire; *C* (p. 36), Thickness of Middle Kittanning Coalbed Involved in Fire; *D*, Caved-Roof Characteristics of Conditions Through Which Barrier Tunnels Were Driven; *E*, Typical Example of Heavy Timbering Required for Roof Support Tunneling Operation; *F*, Roof Supports Removed and Tunnel Partly Backfilled With Rubble. (Slurry introduced through boreholes was used to close small voids in barrier.)

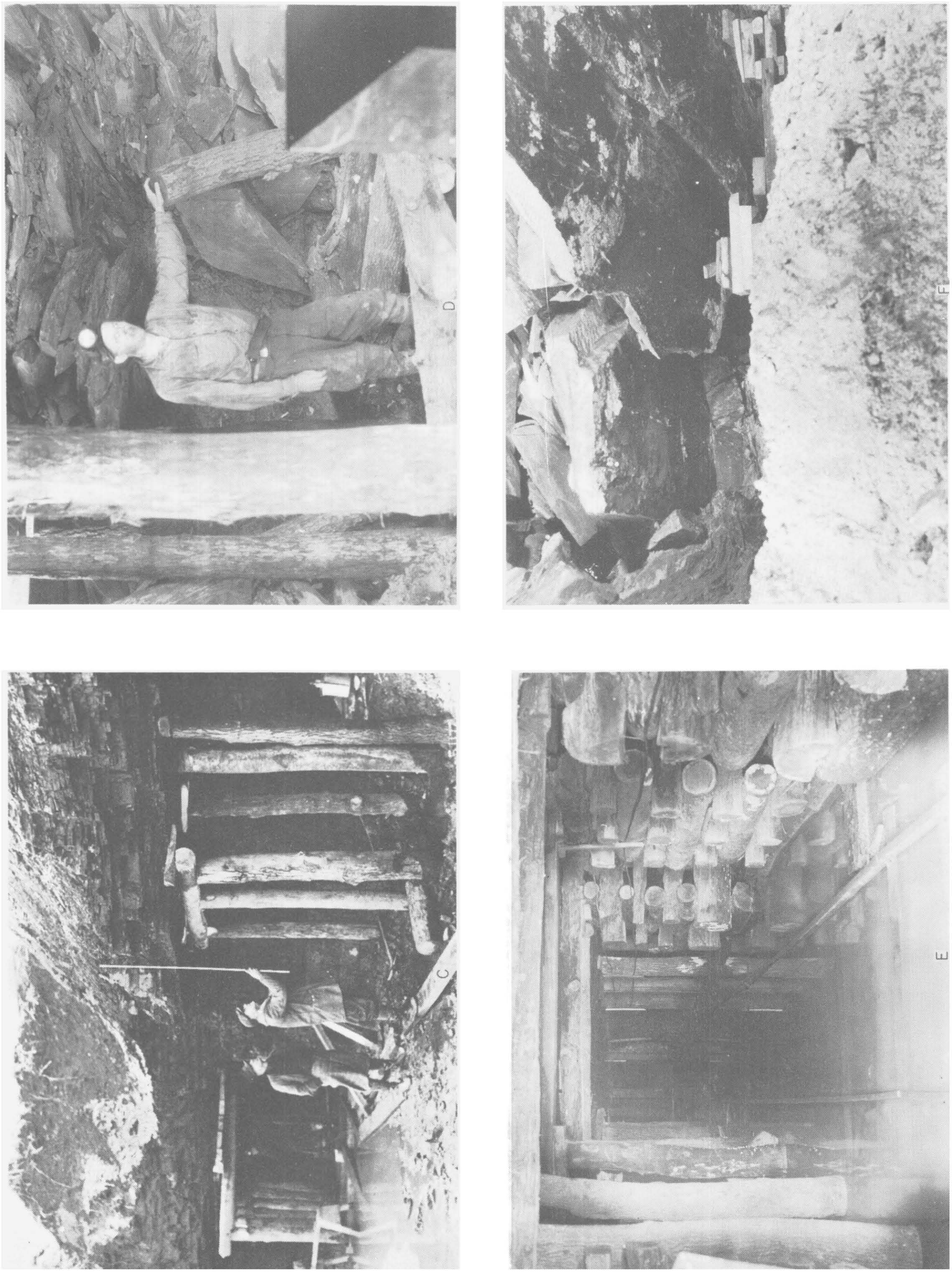


Figure 14—Continued

The tunnel barriers were constructed at three widely separated locations as shown on map in figure 15. These tunnel barriers, designated *A*, *B*, and *C*, were approximately 5,280, 5,280, and 640 feet long, respectively. This confined the fire to an area of about 24 square miles. They were designed to protect large tracts of partly mined as well as virgin coal. A short time after construction of barrier C, the fire reached the northern extremity of this barrier approaching along the outcrop. It burned along the eastern side of the barrier for 3 years and emerged at the outcrop on the southern end but did not cross to the protected side. This was an outstanding example of the effectiveness of a properly designed and well-constructed tunnel barrier. These barriers were effective in confining the fire, but unrelated fires have been ignited since in the protected areas. These have nullified the value of the work to a great extent.

PLUG BARRIER

The plug barrier may be a trench or a tunnel or a combination of both. It is called a plug because it does not extend to the opposite outcrop. (See fig. 9*A*.) The plug, as shown in this figure, is begun at the outcrop and terminated in a large tract of unmined coal under at least 60 feet of cover. It takes advantage of the fact that an underground fire does not penetrate extensively into unmined coal under thick cover. After completing the plug, the fire area is surrounded by a solid coal face, an earth barrier, and the coal outcrop. The exploratory, excavation, and back-

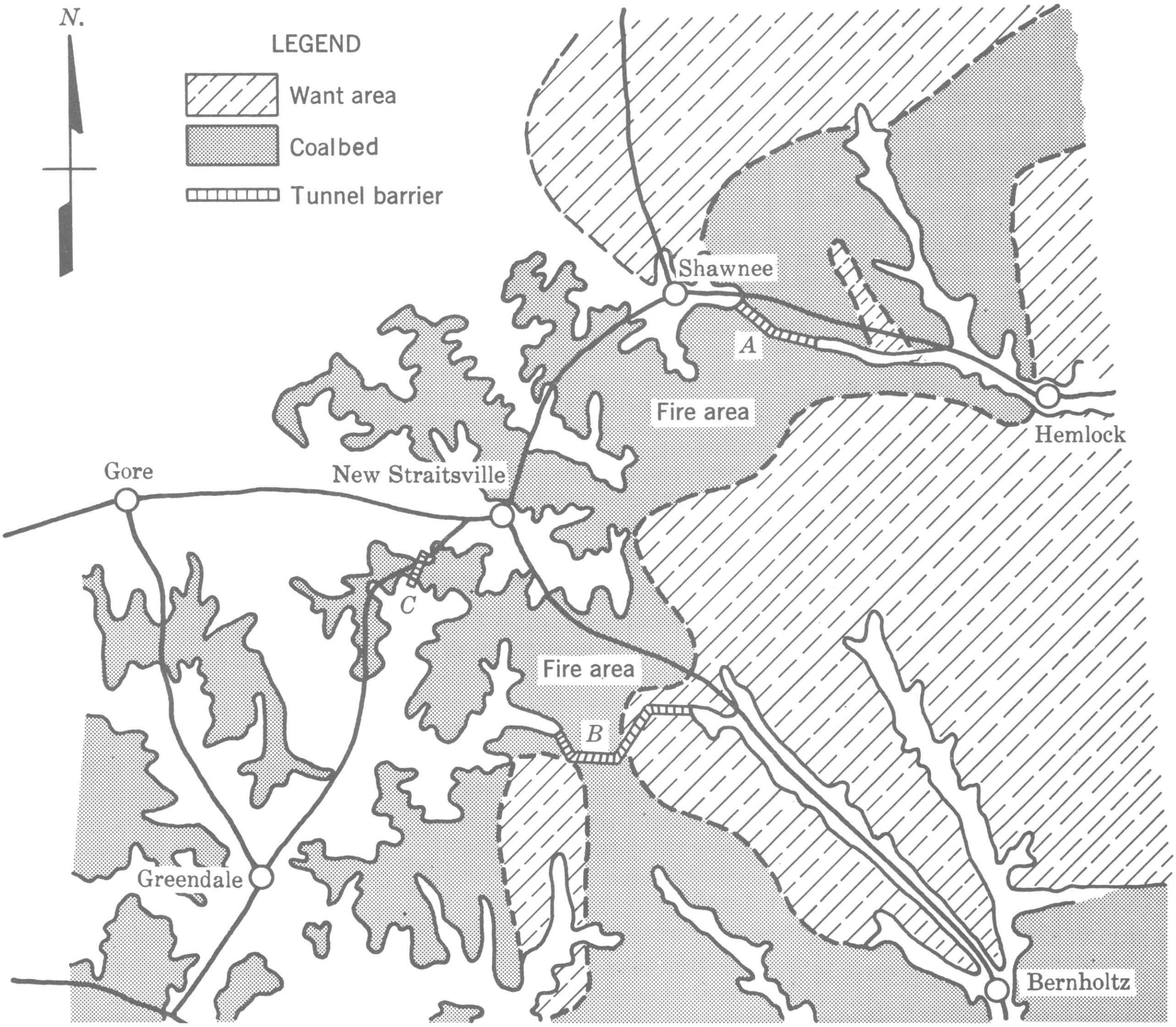


FIGURE 15.—Portion of Hocking Valley Coalfield, Hocking and Perry Counties, Ohio, Showing Location and Relative Position of Tunnel Barriers A, B, and C, Installed To Isolate Mine Fire.

filling work necessary to accomplish this type of fire barrier is similar to that undertaken when installing the trench barrier previously described.

As suggested, the plug barrier should not be terminated until the cover over the solid coal is at least 60 feet. This provides additional assurance that the fire will not burn around the barrier. Experience indicates that the fire will penetrate into solid coal as long as it breaks the overburden to the surface and creates an opening for air circulation. However, this crevicing and breaking of the surface seldom occurs where the overburden is greater than this depth.

Plug barriers terminating in abandoned mine openings have met with varying degrees of success. The uncertainty of success when installing this type of plug requires that all extenuating conditions be evaluated carefully before it is recommended or undertaken. The principal condition against success of the open-end plug is that air may reach the fire through old unsealed abandoned openings of the mine. In one such instance a fire extended a great distance through these openings in a relatively short time.

Bureau engineers have recommended that plug barriers be used to confine or isolate mine fires and also have supervised their installation. A plug barrier was installed in the outcrop of the Pittsburgh bed on Government-owned lands at the Bruceton (Pa.) experiment station. The plug was 330 feet long and extended into a small block of solid coal under about 58 feet of cover. Temperatures measured in boreholes on the protected side of the plug barrier indicated that the progress of the fire along the crop toward valuable surface property was effectively halted. It developed, however, that the fire later burned against and along the side of the plug into open, abandoned entries for nearly 2 miles toward an active mine. When it was discovered fire-seal stoppings were erected to stop its progress.

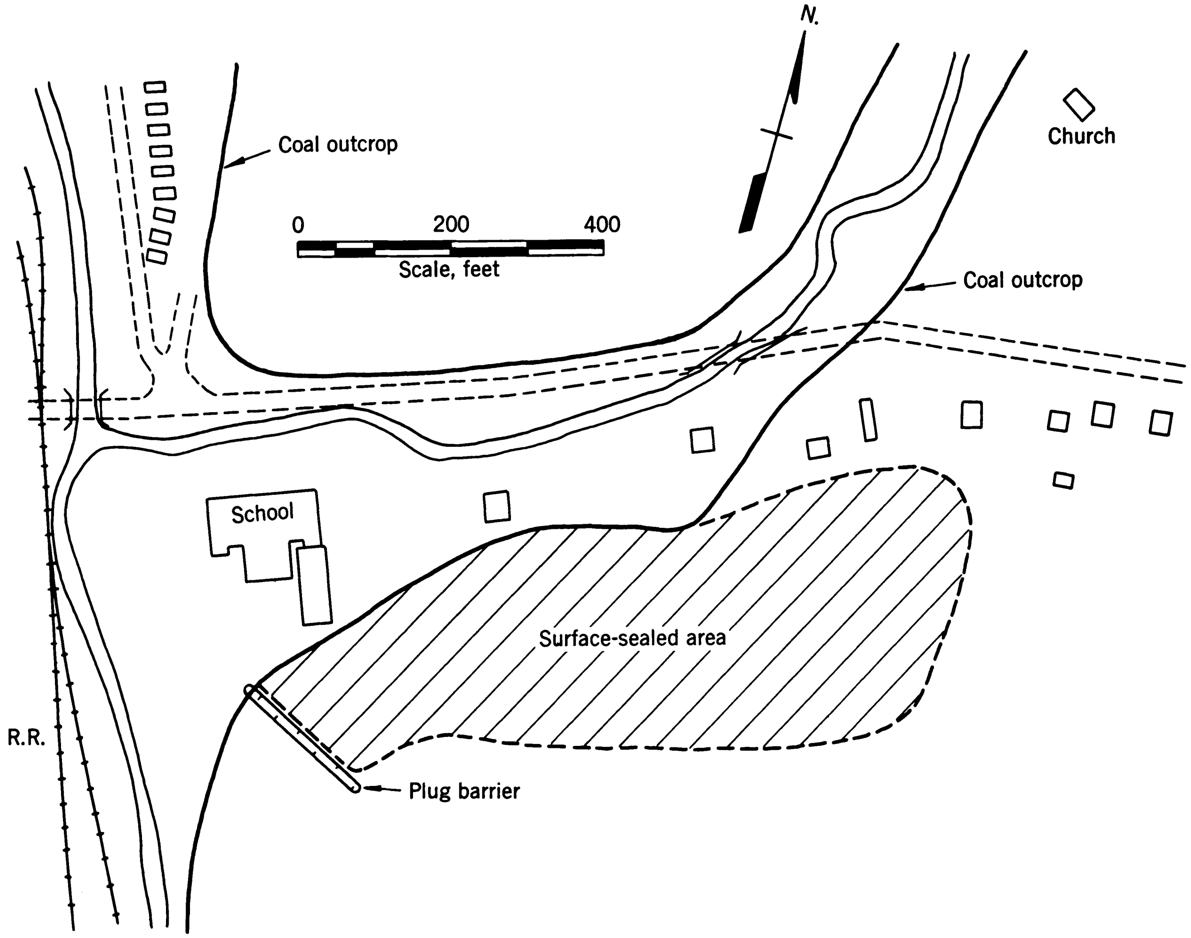


FIGURE 16.—Plan View of Plug Barrier and Area Covered in Surface-Sealing Operations, Pricedale Coal-Mine Fire, Pricedale, Westmoreland County, Pa.

EXAMPLE OF PLUG BARRIER

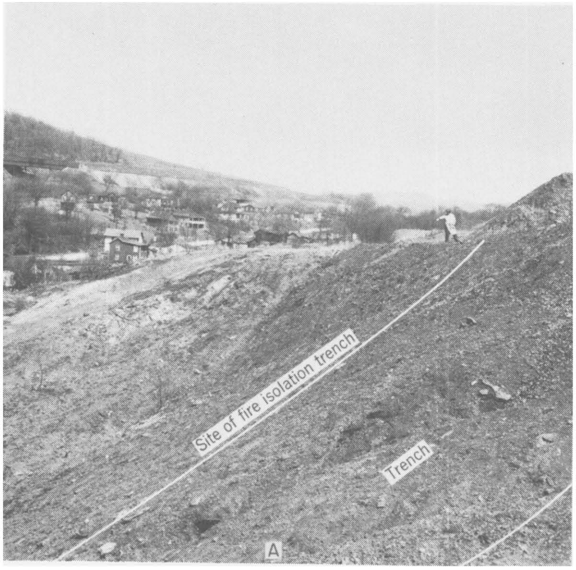
Pricedale Project.—In March 1952 the Bureau initiated work to control a mine fire in an abandoned domestic coal mine located near Pricedale, Westmoreland County, Pa. This fire had spread over several acres of abandoned workings and threatened to travel to the workings of a nearby active mine.

Few fires in extensively mined coalbeds can be controlled by a plug barrier; however, its effectiveness as an auxiliary means of control and extinguishment has been proved in some instances. Its use as an auxiliary means of control will be mentioned in this Bulletin in connection with the Lick Run mine fire at Bruceton, Pa.

The Pricedale underground mine fire was controlled by surface and underground sealing. The plug barrier in this instance was installed from the outcrop into the coalbed for a distance of 275 feet to halt the progress of the fire toward an active coal-mine portal. Figure 16 is a map showing the location of this plug barrier. The map also shows the relation of the fire to mine workings and surface improvements and the surface-sealed area.

The plug barrier proved to be successful in halting travel of the fire where it was in-

FIGURE 17.—Plug Barrier Operation.



← *A*, Cleared Site Preparatory to Excavating Plug-Barrier Trench.

→ *B*, Excavating Plug-Barrier Trench.

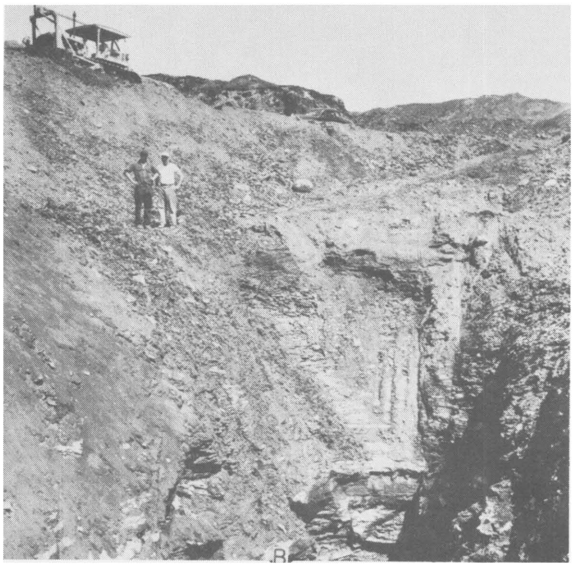
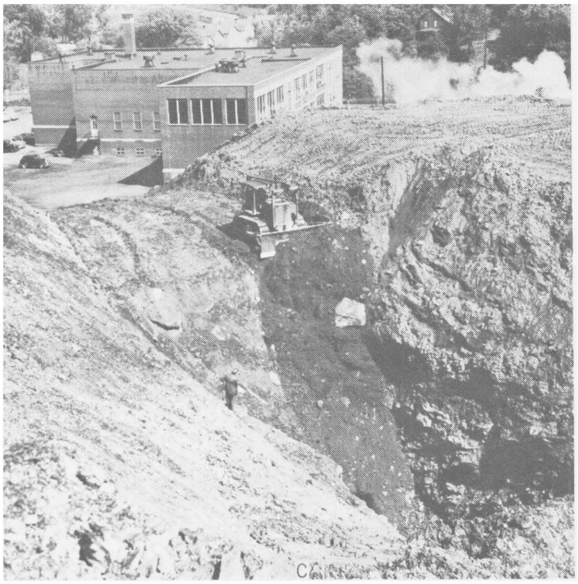


Figure 17—Continued



←

C, Backfilling Trench With Incombustible Material for Plug Barrier.

→

D, Site of Completed Plug Barrier.

stalled, and evidence available at the fire site indicates that the fire is extinguished. Figure 17 is a view of the plug-barrier operation.

EVALUATION OF FIRE BARRIERS

A properly designed and well-constructed fire barrier is an effective means of preventing the propagation of a fire into contiguous coal. In planning a fire-control project consideration is given to (*a*) loading-out, (*b*) inundation, and (*c*) fire barriers. If the fire is too extensive or too deep to load-out, and if it cannot be inundated, a fire barrier is installed where practicable.

This method has several drawbacks in application: It is primarily a means of preventing the spread of a fire and is not intended to extingiush the fire within the isolated area. In this area the fire continues to burn, so the fire hazards and damages are not eliminated in the isolated area.

In addition, the installation of a barrier is a relatively expensive operation. It usually involves the excavation of large quantities of material, the carbonaceous portions of which require disposal or special placement; it also involves extensive backfilling.

In most instances it is a hazardous operation, especially when making a tunnel barrier. Precautions must be taken to protect workers from fire gases and fumes as well as from the usual hazards connected with tunneling and excavating work.

One serious drawback to planning and executing this type of project is that the fire may have advanced beyond the proposed trench line. This possibility arises because of the difficulty of delineating the course and progress of the fire before excavating operations are begun. An extension of the fire may travel through an entry of the mine far in advance of any superficial evidence, and this advance may not be detected by exploratory drilling. Much money and effort may be expended on a fire-barrier project only to find that because of the undetected extension the fire cannot be surrounded nor the project completed with available equipment and funds.

FLUSHING

Flushing is a method designed to fill the voids in an underground fire area with finely divided incombustible solids. This stops circulation of air in the fire area and smothers the fire. The objective is to prevent flow of air to the burning coal and carbonaceous shales by filling the crevices, voids, and interstices in the abandoned mine and, to some extent, openings in the overlying strata.

The method of injecting solids into the entire active fire area to make the mined coalbed and overlying strata relatively impervious or nonporous to the flow of air has been used, particularly in the anthracite region. Flushing may be done to fill an entry or group of entries leading to the fire, or it may be done to stabilize the strata under surface structures that are subsiding or may subside. The latter two applications generally are undertaken in conjunction with other control methods, and it is in this connection that flushing has been used on more recent fire-control projects.

Flushing is accomplished by drilling holes into the burning mine from the surface. Finely divided incombustible material is mixed with water to form a slurry of a consistency that will flow into the underground openings. The slurry usually consists of one-fourth to one-third solids by volume. The solids are intended to be deposited in the mine voids and interstices in the strata, whereas the water is expected to drain off into adjacent openings.

Several kinds of flushing materials have been used, depending upon kind of material available in the particular fire area. The material must be finely divided and be incombustible or contain only a small amount of combustible. Rock dust, fly ash, water-cooled slag, dehydrated lime, portland cement, and earth material such as shale, sandy loam, and silt material consisting mainly of sand have been used. The availability of the flushing material and water at reasonable cost is an important consideration. The amounts required will depend upon the extent of the area to be flushed and the amount of voids and crevices in the area. If the fire is extensive and the entire fire area is to be flushed, the cubical requirements of flushing materials may be prohibitively large.

546210 O—60——4

EVALUATION OF FLUSHING

Flushing is an effective method of filling entries or mine cavities if they can be located by drilling or from mine maps of the area. It is also an effective way to stabilize the strata underlying surface improvements. Small fires in flat beds with a simple mine layout have been controlled successfully by this method, but adverse results can be expected when attempting to extinguish an extensive fire in a pitching bed or where partly mined, interconnected multiple beds are to be flushed. The method was tried under these adverse conditions at Carbondale, Pa., without much success. Flushing has been used in conjunction with other methods, primarily to stabilize strata under highways; namely, in Rostraver Township and Catfish Run. Flushing is more effective where the deposition can be controlled and directed from underground workings by the erection of stoppings and dams, but this is seldom possible when fighting an abandoned-mine fire. Underground control and direction minimize the possibility of the materials draining into adjacent areas and not filling the interstices around the fire. This possibility is one of the greatest drawbacks of the method.

Flushing has been used to advantage in combatting fires in cinder-fill areas where the slurry has been forced into the interstices under pressure or by gravity flow. These applications, called grouting, are described under "Carbonaceous Fill Fires."

EXAMPLES OF FLUSHING IN WESTERN PENNSYLVANIA

Flushing underground voids has been employed on three fire-control projects in the coalfields in western Pennsylvania. On two of the projects flushing was done primarily to provide support under improved highways in an attempt to minimize subsidence. In the third instance flushing was done to supplement the surface seal and also to cool burning materials in the affected area.

In Snowden Township a portion of Pennsylvania Route 88 was stabilized by flushing granulated slag into mine voids under the road.

Introducing a granulated-slag slurry to boreholes is a relatively simple matter. A hose discharging water under pressure is introduced a distance of about 18 inches into the collar of the borehole, and the slag is then dumped onto a ½-inch-mesh screen directly over the borehole. Slight agitation of the slag with the action of the water causes the slag to cave readily into the borehole. Figure 18 shows boreholes being drilled in the fire area for flushing voids under a highway.

Ninety-eight 6-inch boreholes were drilled along both sides of the road in the affected area. The boreholes were on 12-foot centers and 3 feet from the edge of the paving. They averaged 44.5 feet in depth. Approximately 1,100 tons of screened slag was slurried into the underground voids.

Flushing was performed also along Pennsylvania Legislative Route 118 near Pricedale to minimize subsidence of this four-lane limited-access highway. Measured temperatures in the boreholes indicated that the fire had traveled under the highway in a northerly direction to the opposite side and under an adjacent cemetery.

The log of the drilling operation shows that 137 6-inch-diameter holes were drilled having an average depth of 22.8 feet. It was estimated that 292 yards of granulated slag were slurried to the underground openings with water pumped from a nearby creek. Figure 19 shows views of the drilling and flushing operations at this project.

At the third project where flushing was done, primarily to cool the underground fire materials and to supplement the surface seal, it was necessary to use fly ash in place of granulated slag. Fly ash is a much finer material than commercial grade granulated slag and is more difficult to mix with water. Advantages gained by using fly ash are that it does not have to be screened before introduction into the borehole, and, because of its extreme fineness, it remains suspended in a slurry and flows into the underground openings more readily than slag. Figure 20 is a sketch of a method developed by Bureau engineers to facilitate the using of fly-ash slurry in boreholes. Figure 21 is a map showing the location of the boreholes and their relation to streets, homes, and commercial structures in the affected area. The area where ground temperatures ranged from 90° to 865° F. is shown.

Eighty boreholes were drilled in a pattern indicated as most suitable by surface contours and other conditions of terrain. The bore-

FIGURE 18.—Drilling Boreholes Along Highway in Affected Area.

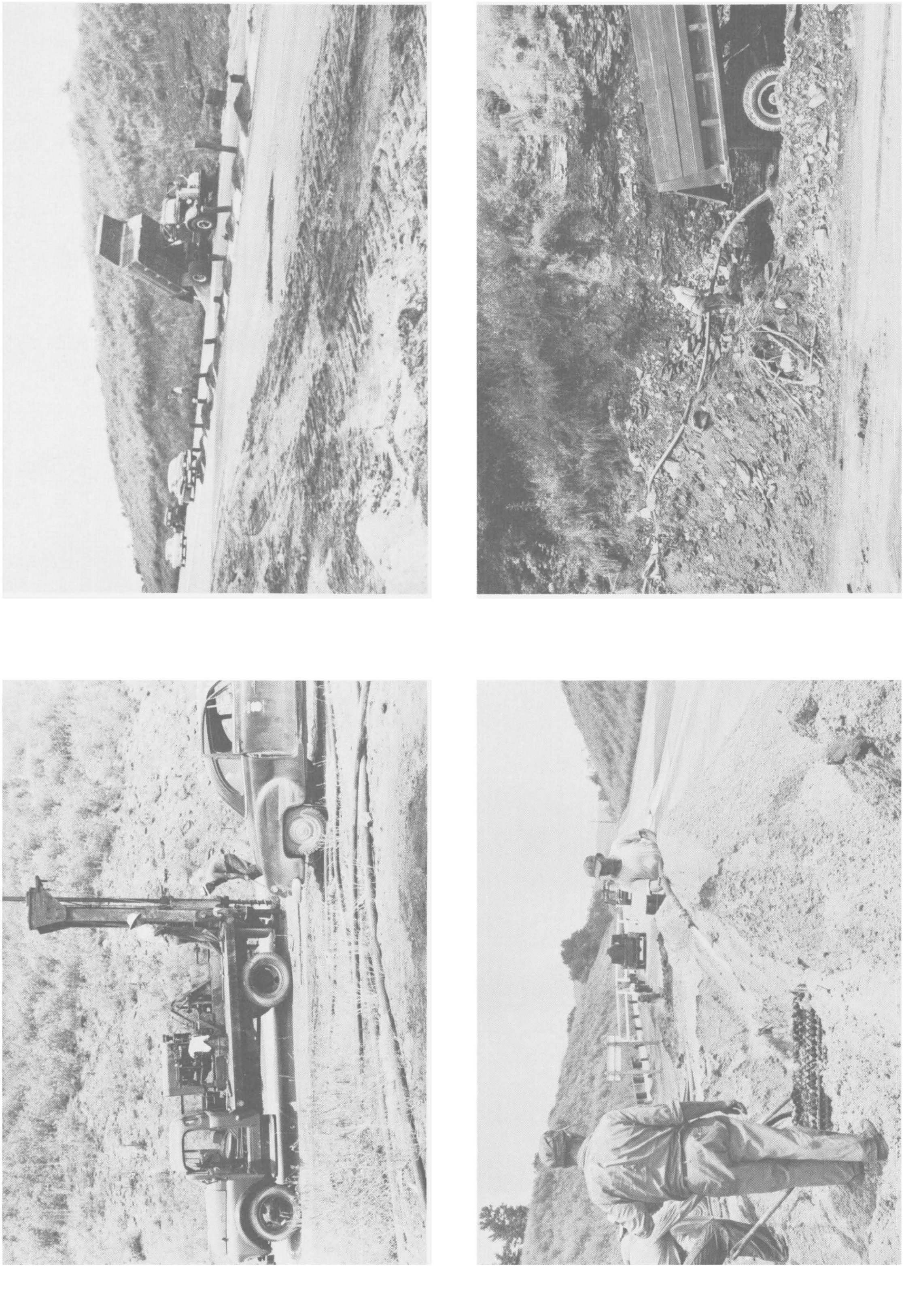


FIGURE 19.—Several Operations Employed in Drilling and Flushing Underground Openings Along Legislative Route 118 Near Pricedale, Pa.

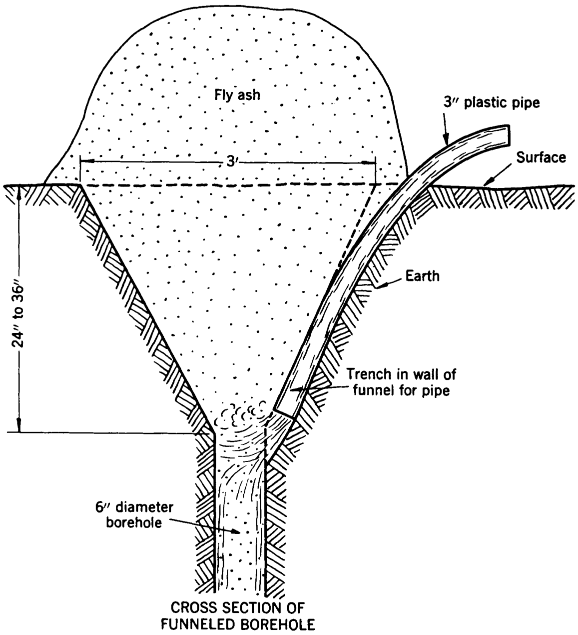


FIGURE 20.—Sketch of Earth Funnel Used to Prepare a Fly-Ash Slurry for Flushing Underground Voids. Water Used for This Purpose Should Be Under Pressure, and Quantity Needed Will Vary With Conditions.

holes ranged from 13 to 56 feet in depth, averaging 37.8 feet. Approximately 1,500 tons of fly ash was used to flush the underground voids. Figure 22 is a view showing steam issuing from some of the uncapped boreholes before flushing.

EXAMPLE OF FLUSHING IN EASTERN PENNSYLVANIA

The Bureau of Mines and the Commonwealth of Pennsylvania, in cooperation with a large anthracite mining company, conducted an extensive fire-control flushing operation in the City of Carbondale, Pa. The fire at this location was burning in three previously mined coalbeds and had extended to a fourth unmined bed, which had been broken and fractured from previous mining below. A finely divided waste product from coal-cleaning plants was transported to the site and mixed with water to form a slurry. This was flushed through boreholes to fill the voids of the burning mines.

Some extremely adverse conditions operated against successful control of the fire; namely, (1) extension of the fire under many acres of land, and (2) pitching, interconnected, partly worked-out beds of coal. This work cost approximately half a million dollars.

Present plans are to raze homes and other buildings in the affected area and excavate the burning material by stripping. Some scenes of the Carbondale mine-fire control project are shown in figure 23.

SURFACE SEALING

The surface-sealing method for controlling and extinguishing underground fires is an outgrowth of the cumulative experience of Bureau engineers in doing fire-control work. This has been discussed at some length under "Development of the Surface-Sealing Method," and it should have some repetition under this heading.

The insidious and unpredictable behavior of fires in abandoned-coal mines, and the fact that they usually involve a comparatively large area of surface, assures that any effective method employed for their control will be very costly. It should be stressed that two fires seldom have the same characteristics or, once ignited, will propagate according to a set pattern. Therefore, each fire should be considered separately, and the most effective and economical method for its control should be determined from facts disclosed after a thorough investigation.

It is known that if air can be prevented from reaching a fire it will be extinguished. Before the Fire-Control Group was formed, Bureau engineers, recognizing this fact when called on for advice in such matters, usually recommended that all surface crevices and openings leading to the fire be closed. This method of control, seeming to be simple, was in most instances dictated by lack of funds to perform work that would assure a more thorough job. No fire has been extingiushed by the initial closing of surface openings. At the time Federal funds were made available for controlling and extinguishing such fires it was more or less the thinking of Bureau personnel familiar with such matters that surface sealing was ineffective.

As the work of the Fire-Control Group progressed it soon became apparent that if any considerable number of fires were to be attacked a method less costly than either the isolation-barrier or the direct-attack methods would have to be adopted. Investigation of some earlier fire-control work revealed a successful surface-sealing operation. The distinctive feature of this operation had been the maintenance of the surface seal after its initial installation. Therefore, it was concluded that in addition to initially sealing the fire, the seal must be maintained until the temperature is reduced sufficiently to prevent reignition.

Much has been learned from the experiences utilizing this method to extinguish a large number of underground fires, and it is reasonable to suppose that other refinements will

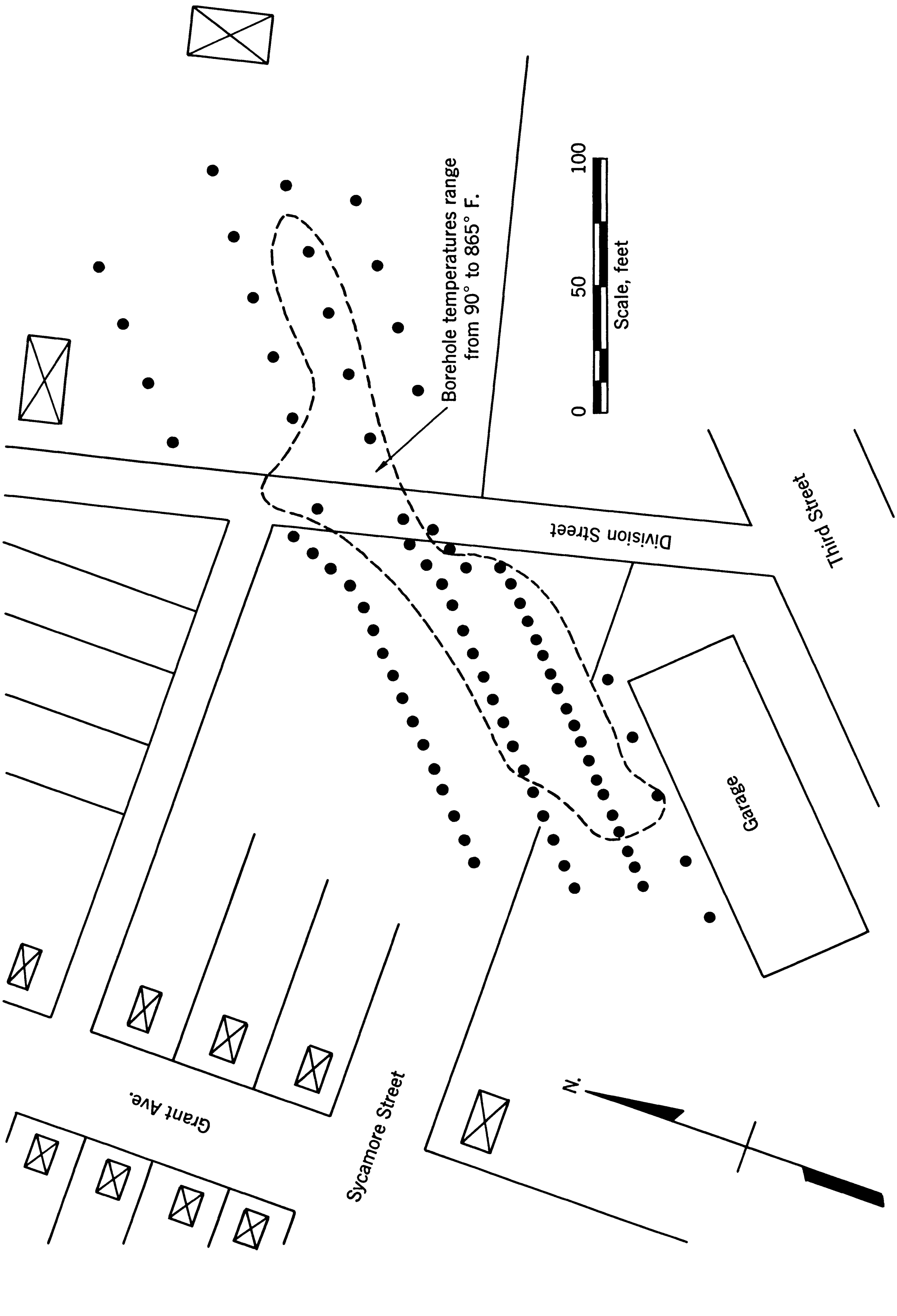


FIGURE 21.—Location Map of Boreholes Drilled on Project to Determine Extent of Fire Area and For Flushing Underground Voids to Exclude Air.

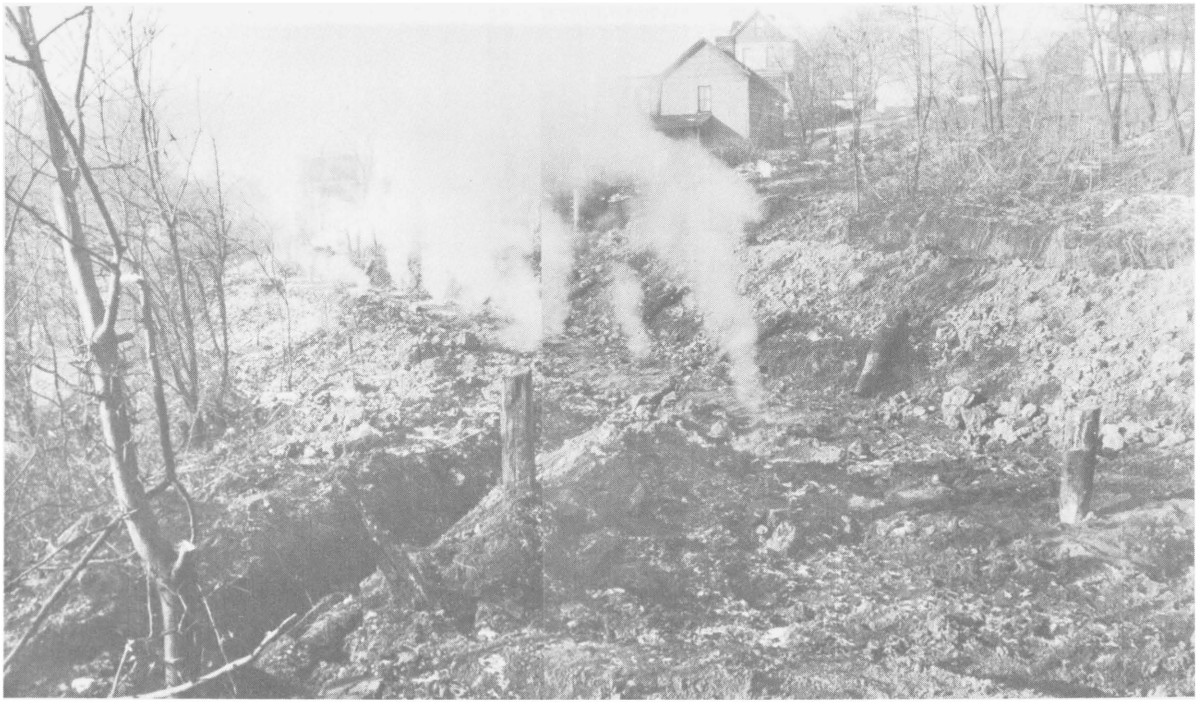


FIGURE 22.—Smoke and Steam Issuing From Boreholes Before Flushing With Incombustible Materials. Drilling Operations in Background.

be introduced as new conditions are encountered. Quite often it is necessary to supplement surface-sealing work with other methods, such as flushing or partial barriers, to assure that the seal will be effective.

Surface sealing is a method of controlling and extinguishing an underground mine fire by closing surface openings leading to the fire. The method generally is applicable to those fires under shallow cover near the outcrop of the coalbed. All openings into the coalbed that are accessible from the surface are closed. This includes both intake and exhaust openings. However, extinguishment is affected primarily by closing the crevices and sinkholes on the surface through which the fire gases exhaust to the atmosphere. As a result, the fire is smothered in an oxygen-deficient atmosphere created by the products of combustion, which accumulate around the fire. Figure 24 is a sketch showing how ventilation is disrupted by a surface seal. These smothering conditions are maintained until the heat of the fire has been conducted through the surrounding rock strata to the surface and dissipated tó the atmosphere. The surface-sealing operation, therefore, consists of two phases: (1) A sealing phase during which a thick mantle of pulverized earth is placed on the surface over the fire area, and (2) a maintenance phase during which the mantle is maintained in an effective condition until the temperature of the affected area is reduced sufficiently to prevent reignition.

Two methods of establishing a surface seal have been used successfully. One method creates a seal by plowing the surface to a pulverized condition, using an angledozer. The other method creates a seal by transporting earth-fill material from a borrow pit and depositing it on the surface over the fire. The latter is used to a greater extent in Western United States, where suitable fill material is usually available at or near the fire site.

SURFACE SEALING BY PULVERIZING SURFACE

CLEARING AREA

The fire area is cleared of all vegetation. Brush and small trees are grubbed with a bulldozer; larger trees are pushed over and uprooted. Trees on steep slopes or on the edge of a stripping highwall usually are pulled out, using the cable and winch equipment on the dozer. It is desirable to remove roots during the clearing operation so that they will not obstruct the plowing operations that follow.

The vegetation is disposed of by whatever means are safe and convenient. If the timber has little or no value, the usual procedure is to burn the vegetation on the site. The brush, small trees, and roots are pushed into piles

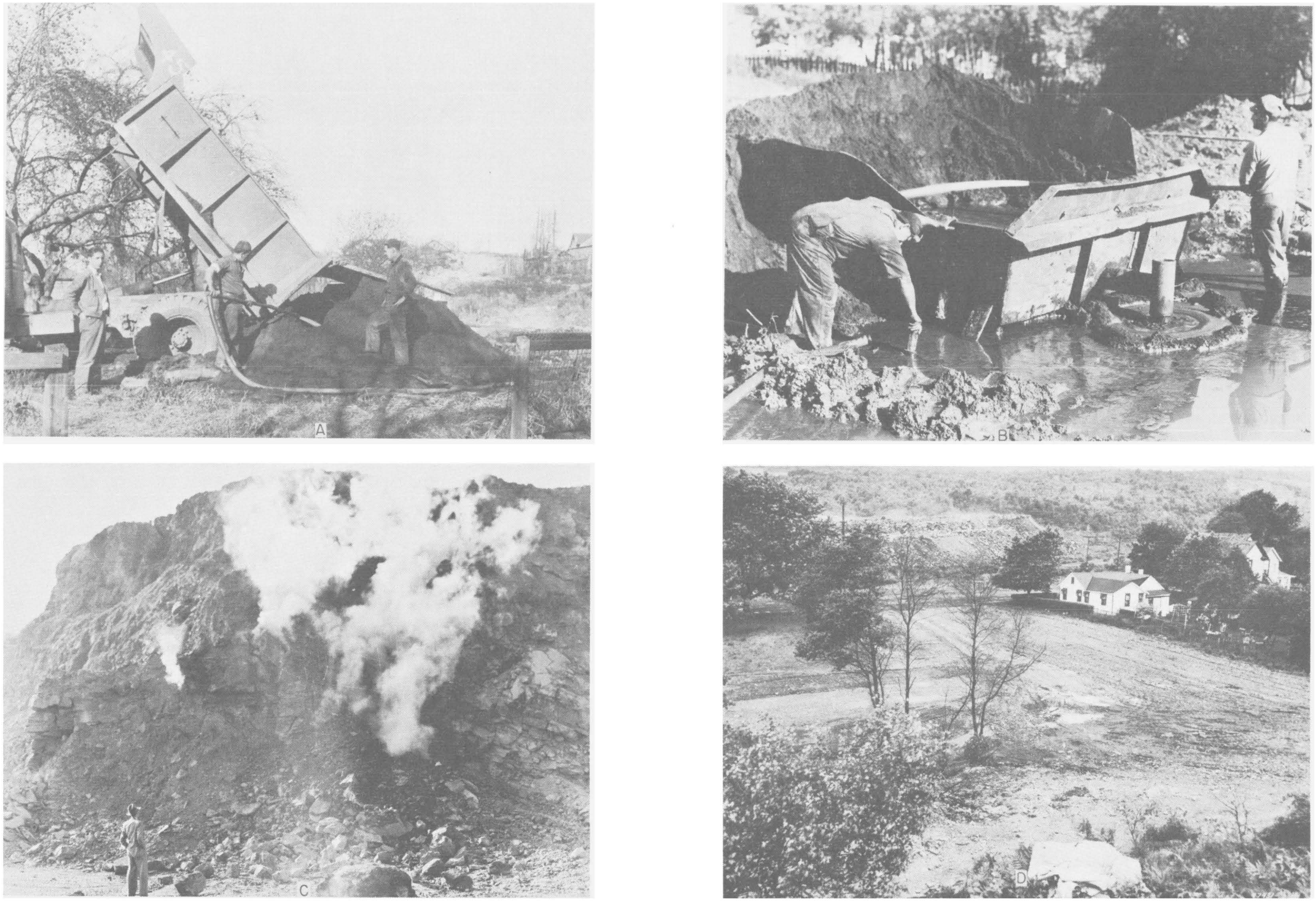


FIGURE 23.—Carbondale (Pa.) Mine-Fire Control Project: *A*, Flushing Materials Through Boreholes Into Mine Openings to Control Spread of Underground Fire; *B*, Equipment Used for Flushing Material Into Boreholes; *C*, Smoke and Steam Issuing From Openings Leading to Underground Fire; *D*, Part of Area on Which Top Soil Has Been Applied and Angledozed to Relatively Even Contour.

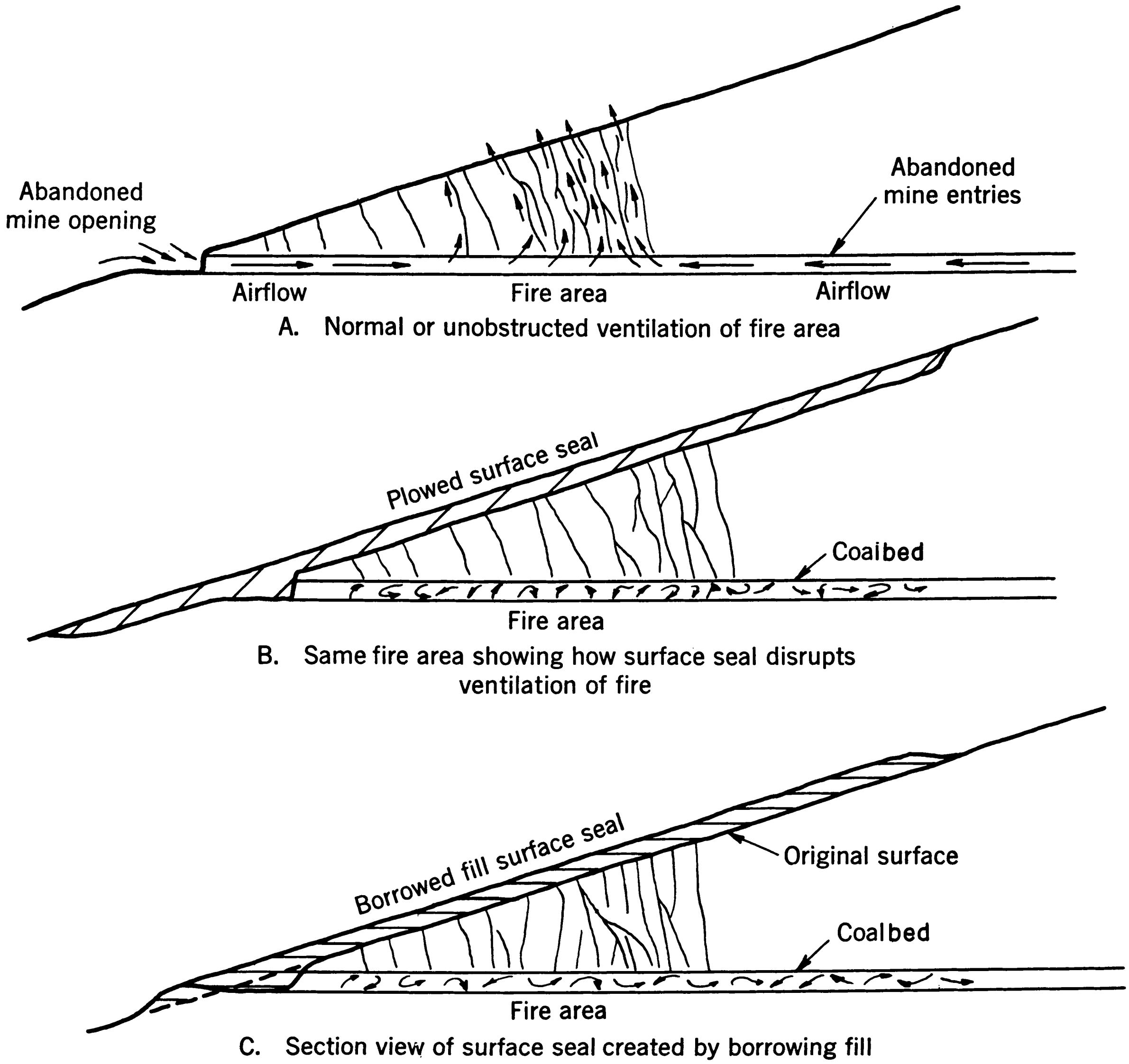


FIGURE 24.—Section Drawings of Abandoned-Mine Fire Areas Near Coal Outcrop.

and burned. Large trees may be cut into lengths suitable for handling and thrown into the fire. When burning this vegetation, precautions are taken to prevent ignition of the unaffected portion of the coalbed. The vegetation should not be burned in a sinkhole where the coal is exposed or where heat may be conducted to the coalbed.

PULVERIZING SURFACE

The seal is made by plowing the surface with an angledozer. An angledozer is designed so that the blade can be angled at 30° to the long axis of the tractor, and the blade can be tilted at a slight angle with the surface. With the blade angled and tilted, the blossom, or outcrop of the coalbed is dozed-out by making a deep cut, 14 to 20 feet wide, or just below the outcrop, thus exposing the entire length of outcrop within the area to be sealed. This excavated material is spilled below the outcrop. As much of the fire and hot material as can be reached is cut away from the coalbed and spread out to cool. The outcrop cut serves three purposes: (1) It provides a definite reference line for delineating the sealed area, (2) usually a portion of the fire can be dug out and cooled, and (3) it removes the portion of the coalbed near the surface and therefore most likely to be ignited later. The outcrop cut is backfilled with material spilled from subsequent contour cuts.

The pulverizing operation consists of making overlapping cuts on the surface over the fire.

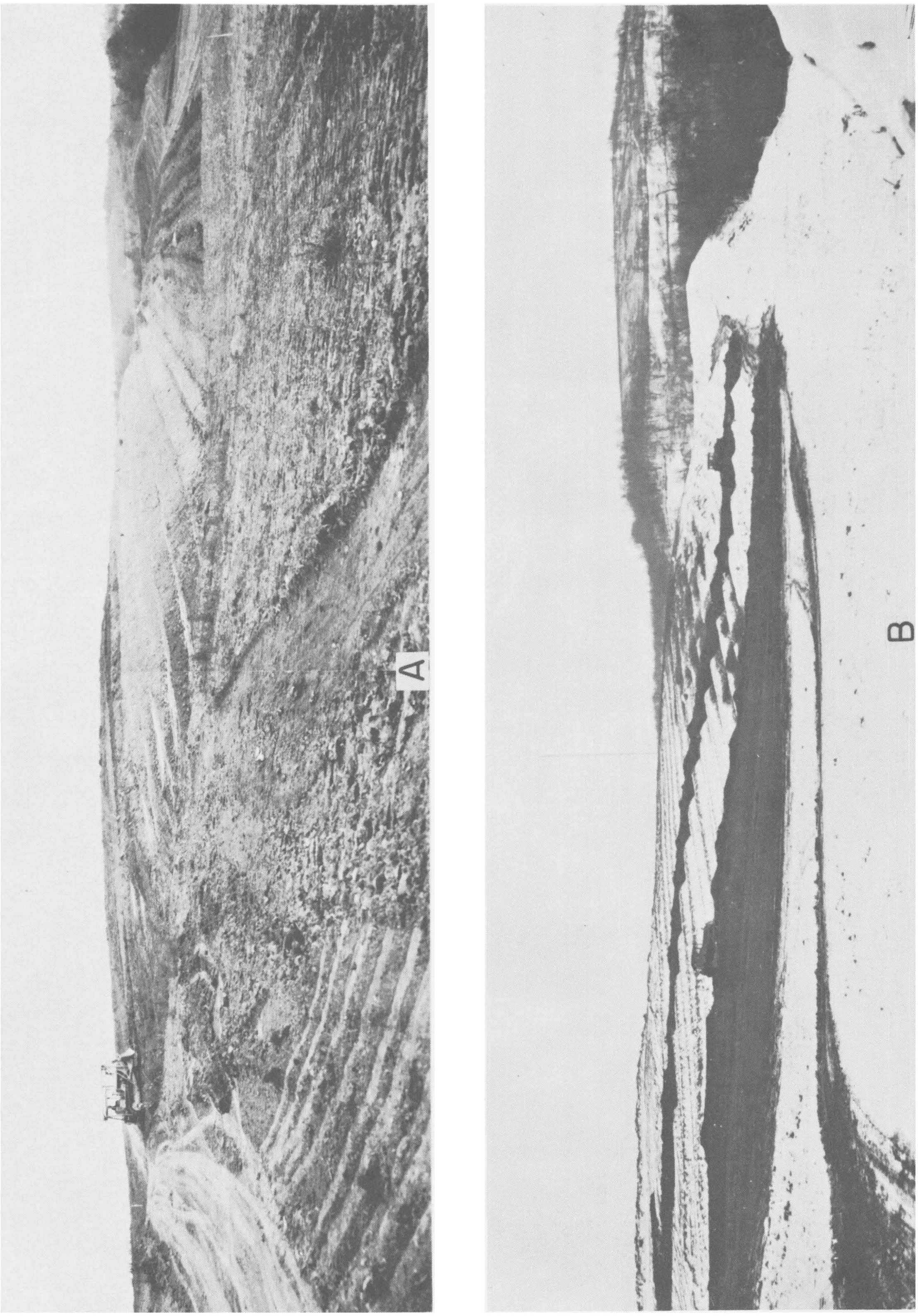


FIGURE 25.—Pulverizing Surface Material for Surface Seal: *A*, Plowing in Contour; *B*, Plowing at 45° to Contour.

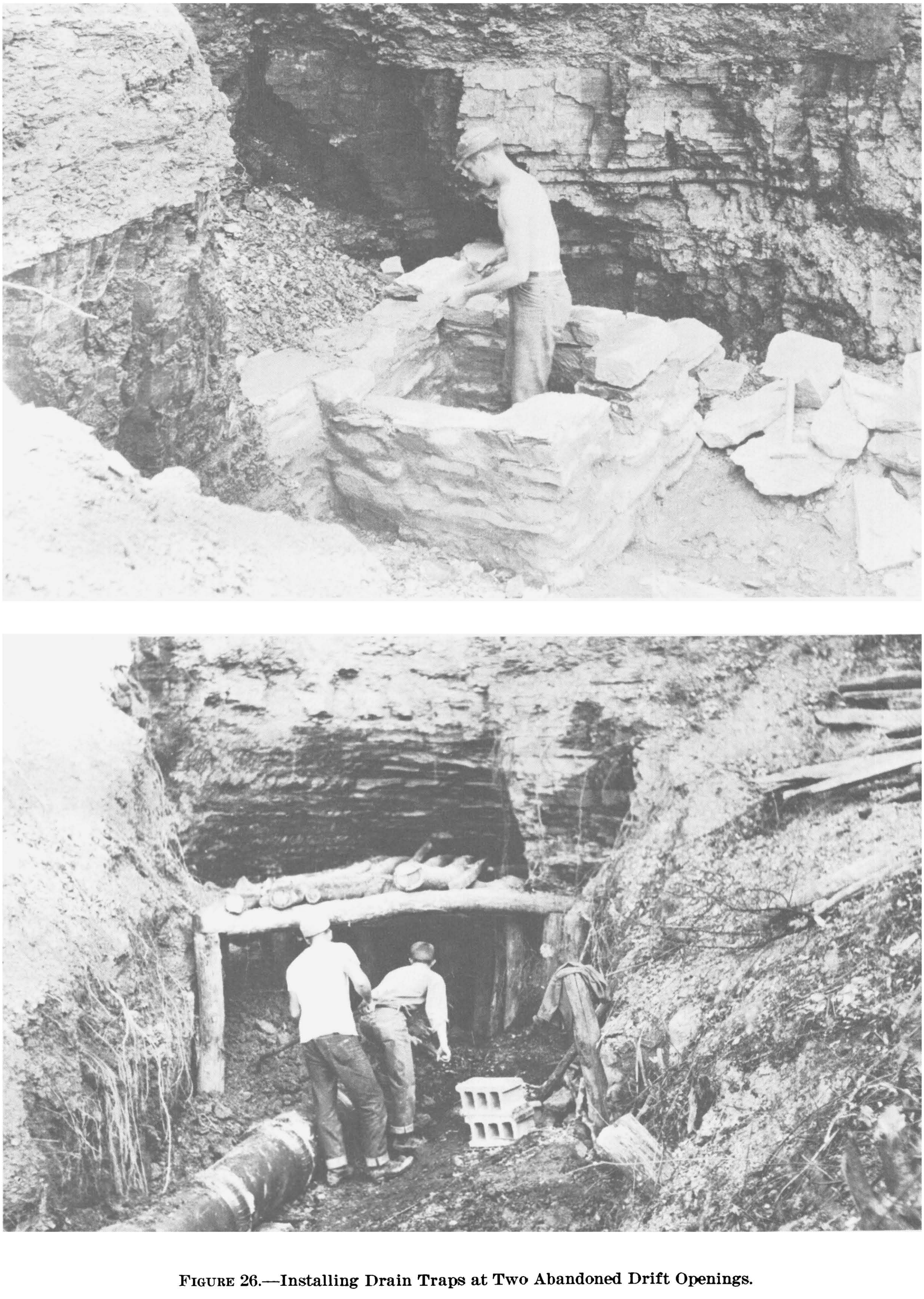


FIGURE 26.—Installing Drain Traps at Two Abandoned Drift Openings.

The first series of cuts is usually made in contours. The second series is made at 45° to the contour cuts. A third series may be made at 45° to the contour cuts but at 90° to the second series of cuts. In this way the area is plowed and crossplowed. The resulting mantle of pulverized earth should be from 4 to 8 feet deep. Figure 25 shows a dozer plowing in contour and at 45° to make the first and second series of cuts. The seal begins about 10 feet vertically below the floor of the affected coalbed and extends to a vertical height of at least 60 feet, if the maximum cover over the bed exceeds 60 feet. After the area has been plowed it is fine-graded by backblading with the angledozer.

CLOSING OPENINGS AND BACKFILLING

All abandoned surface openings into the coalbed are closed. This may require blasting rock and pulling timbers at the mouth of the entry. Surface material is then packed into the opening by pushing with the dozer. Abandoned shafts and drifts are filled with earth material.

At openings where mine water is discharged to the outside it is necessary to install masonry traps that will permit the continual flow of water through the seal and at the same time prevent air from reaching the fire. Water must flow continuously from the mine; otherwise, it may accumulate behind the seal until the hydrostatic pressure is sufficient to weaken, break through, and erode the earth seals, thus allowing air to reenter the fire area. In addition, the possibility of a sudden outrush of water from the area behind the broken seal creates the danger of flooding and damaging residences in the vicinity below. Figure 26 shows views of two trap installations at drift openings. Figure 27 shows construction details of a typical drainage trap used on various projects. It will be noted that the traps can be designed to receive drainage from one or more openings. Figure 28 shows two views of the installation of a trap. Figure 29 is a view of this area after the surface sealing has been completed.

A large percentage of fires in inactive deep mines occurs in the vicinity of abandoned strip mines. In fact, many of them start in the coal exposures made by contour stripping. During the surface-sealing operation all combustible material is removed from the coal exposed along the highwall of an abandoned strip mine for a distance of 12 feet. It is then backfilled with incombustible material to establish an effective and safe seal against the exposed strata. The backfilling is done in this manner to minimize the possibility of a fire in the strip spoil communicating to the coalbed. Noncarbonaceous material is placed against all coal and carbonaceous shales exposed along the highwall. Material, such as clay and shale, is usually available at the top of the strip highwall. This can be dozed directly into the strip cut to form a seal against the coal. The horizontal thickness of the resulting earth dam against the face of the coal should be about 12 feet. (See fig. 30.) The spoil from the stripping operation is then pushed against the newly established highwall face. The earth barrier will prevent propagation of a fire into the coalbed if one should be ignited in the strip-mine spoil. Figure 31 shows how spoil was moved away from the exposed coal and replaced with an incombustible seal.

CONSTRUCTING INSPECTION ROADS

A road should be constructed in the sealed area to provide access to the entire project for subsequent inspection and maintenance work. The road should be at least 12 feet wide and provided with turnarounds at all dead ends. Access should be provided to all locations in the sealed area to facilitate inspection and permit access for light equipment, which may be needed during the maintenance program. Figure 32 is a sketch showing the details of construction of such a road. Figure 33 is a map showing the location of inspection roads, drainways, boreholes, and other important fea-

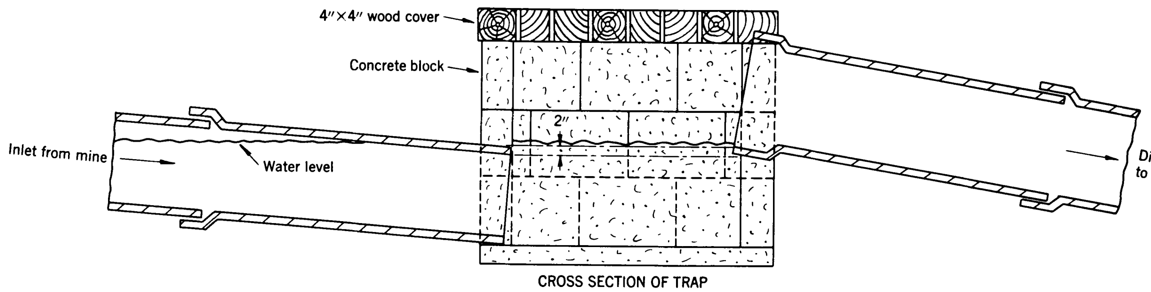


FIGURE 27.—Cross Section of Typical Trap Installation.

FIGURE 28.—Installation of Airtrap To Receive Drainage From Several Locations.

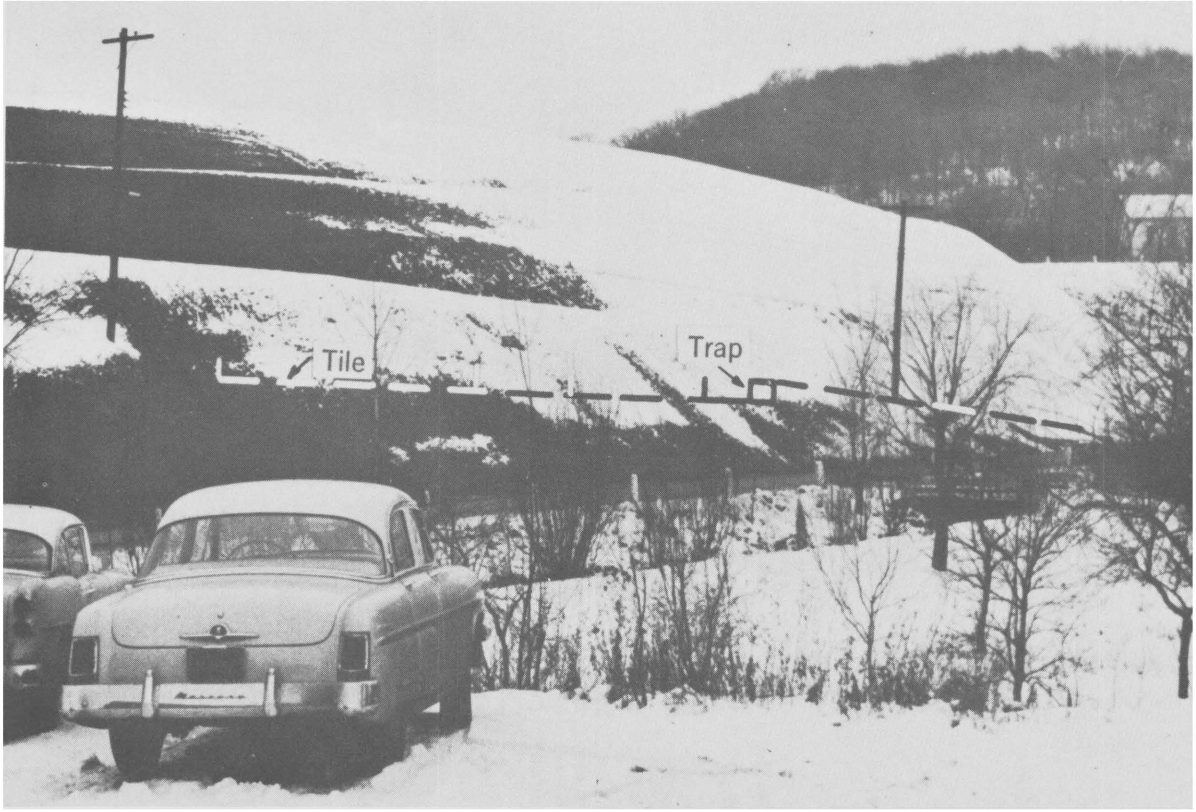


FIGURE 29.—Airtrap Drain Underlying Surface Seal at Coal Outcrop. (Dotted line traces approximate course of pipe; note how subterranean heat melted snow at left.)

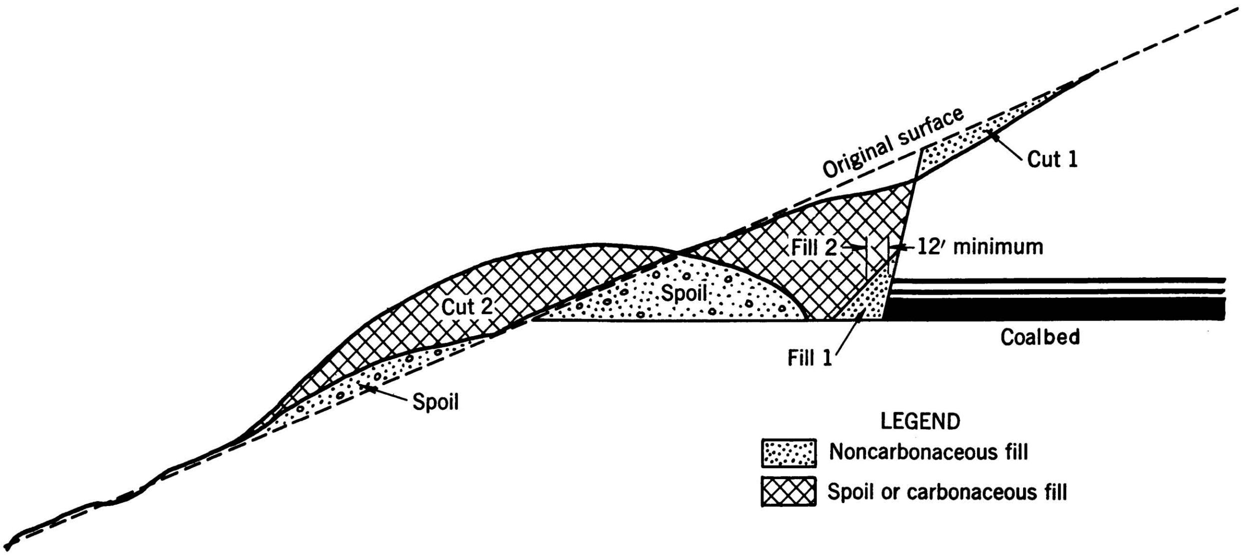


FIGURE 30.—Section View of Strip Mine Showing Recommended Method of Backfilling to Minimize Hazard of Spoil Fire Propagating Into Coalbed.

FIGURE 31.—*A*, *B*, Dozer Making Road Into Strip Pit for Dragline; *C*, Closeup of Refuse Burning on Floor of Strip Pit Adjacent to Exposed Coal; *D*, Dozer and Dragline Loading-Out Fire in Refuse; *E* (p. 55), Dozer Cleaning Up Remnants of Burning Material Before Placing Clay Barrier; *F*, Placing Clay Barrier Between Exposed Coal and Refuse Pile at This Location.

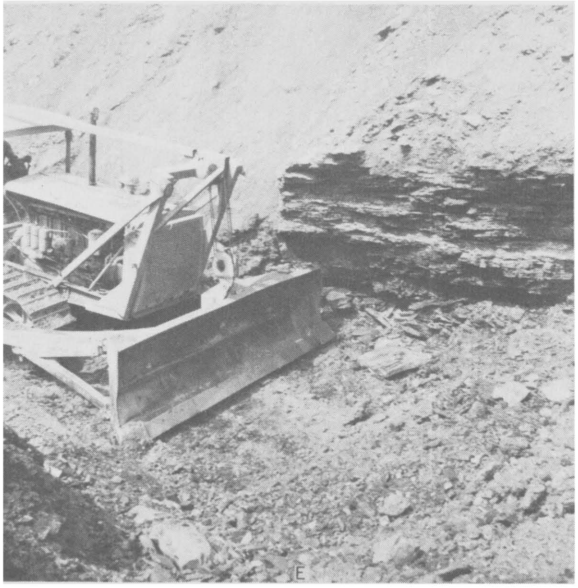
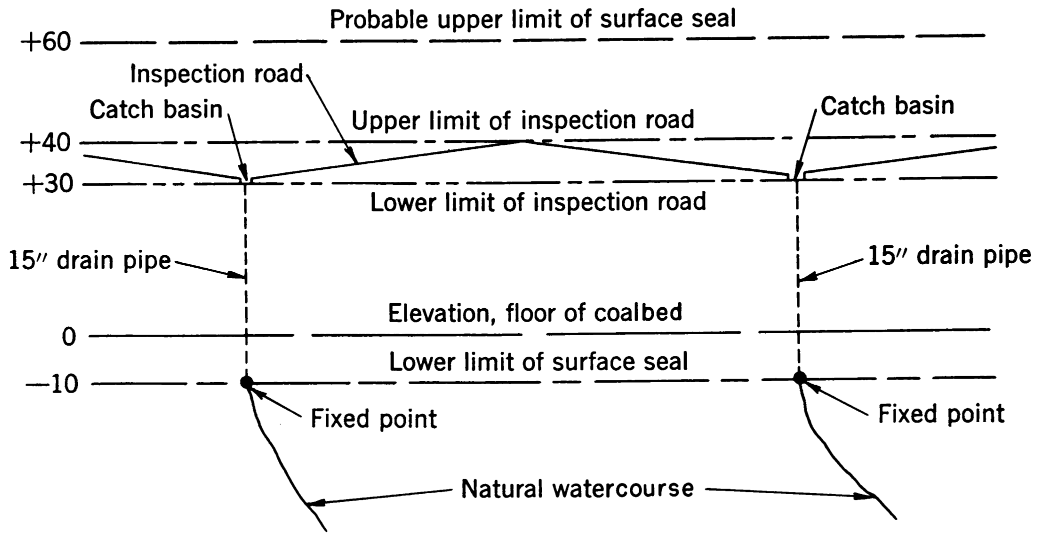


FIGURE 31—Continued

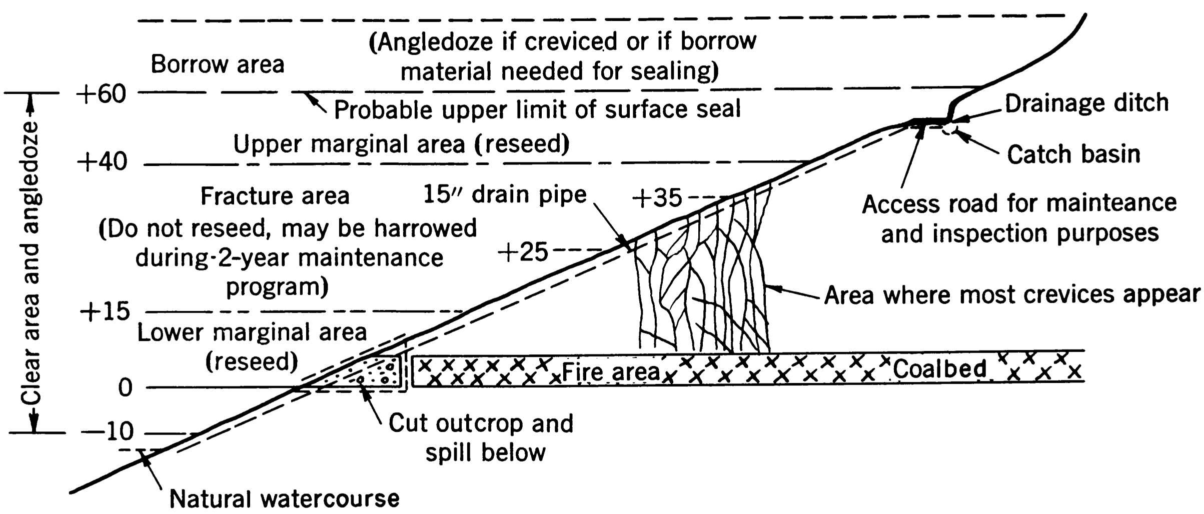
tures installed at one fire-control project. The road need not be hard-surfaced but should be angled into the hillside so the surface of the road will drain into a side ditch. A drainage ditch runs along the inside of the road, and facilities are provided at syncline breaks in the road grade to conduct the water under the road. The grade on the road should not be less than 1½ percent and should not exceed 5 percent unless unusual circumstances make steeper grades necessary. These grade limitations depend on the grade requirements of the unlined drainage ditch alongside the road. A grade of less than 1½ percent is difficult for the dozer to fine-grade on a hillside cut without getting low spots in the ditch. On grades of less than 1½ percent there is the possibility of the ditch filling with silt and allowing the water to break over at some point along the way. At 1½ percent there is usually enough fall to keep the ditch clear. Conversely, an excessive grade in the ditch will cause the water to move at high velocity, and if the ditch is unlined, the water will cut a deep gulley alongside the road. Therefore, where practicable, the grade should not exceed 5 percent.

SURFACE DRAINAGE

Water erosion is the most destructive condition encountered in maintaining the surface seal. During sealing operations several acres of land must be stripped of vegetation and plowed. This land usually will be on a slope ranging from 0° to 25°. The loose earth comprising the seal may be washed out at some locations if drains and ditches are not maintained to provide adequate drainage. The runoff from the sealed area is increased enormously, owing to the vegetation being stripped from the area and the closing of crevices and openings that formerly drained much of the water into old mine workings. The ditches and drains serve two purposes: (1) They prevent runoff from the upper part of the seal and any areas above from washing over the seal; (2) they protect the properties below the seal from damage by water. Provisions must be made to conduct the water to natural drainage courses below the surface seal that are adequate to handle the increased water runoff. Experience has shown that 15-inch, pure-iron, galvanized corrugated pipe is preferable to open channel tile for conducting water down steep slopes. Figure 34 shows an area where a catch basin and pure-iron drainage pipe were installed. The usual drainage plan consists of a ditch along the inspection road, which is at an elevation of 30 to 40 feet above the floor of the coalbed. Figure 35 is a view of a completed surface seal showing an inspection road. The grade of the ditch should range from 1½ to 5 percent as explained in the section on "Constructing Inspection Roads." At low points in the ditch, catch basins are constructed of stone laid in cement mortar. Fifteen-inch corrugated pure-iron pipe is installed under the road and down the slope of the surface seal to a point below the coal outcrop. The discharge should connect to a natural drainage course below the sealed area. The location of these discharge points and the ele-



A. Location of natural watercourses and elevation limits of inspection road determine grade of road and location of catch basins



B. Plan for surface sealing by pulverizing surface

FIGURE 32.—Surface Elevation and Section Views of Inactive-Mine Fire Area.

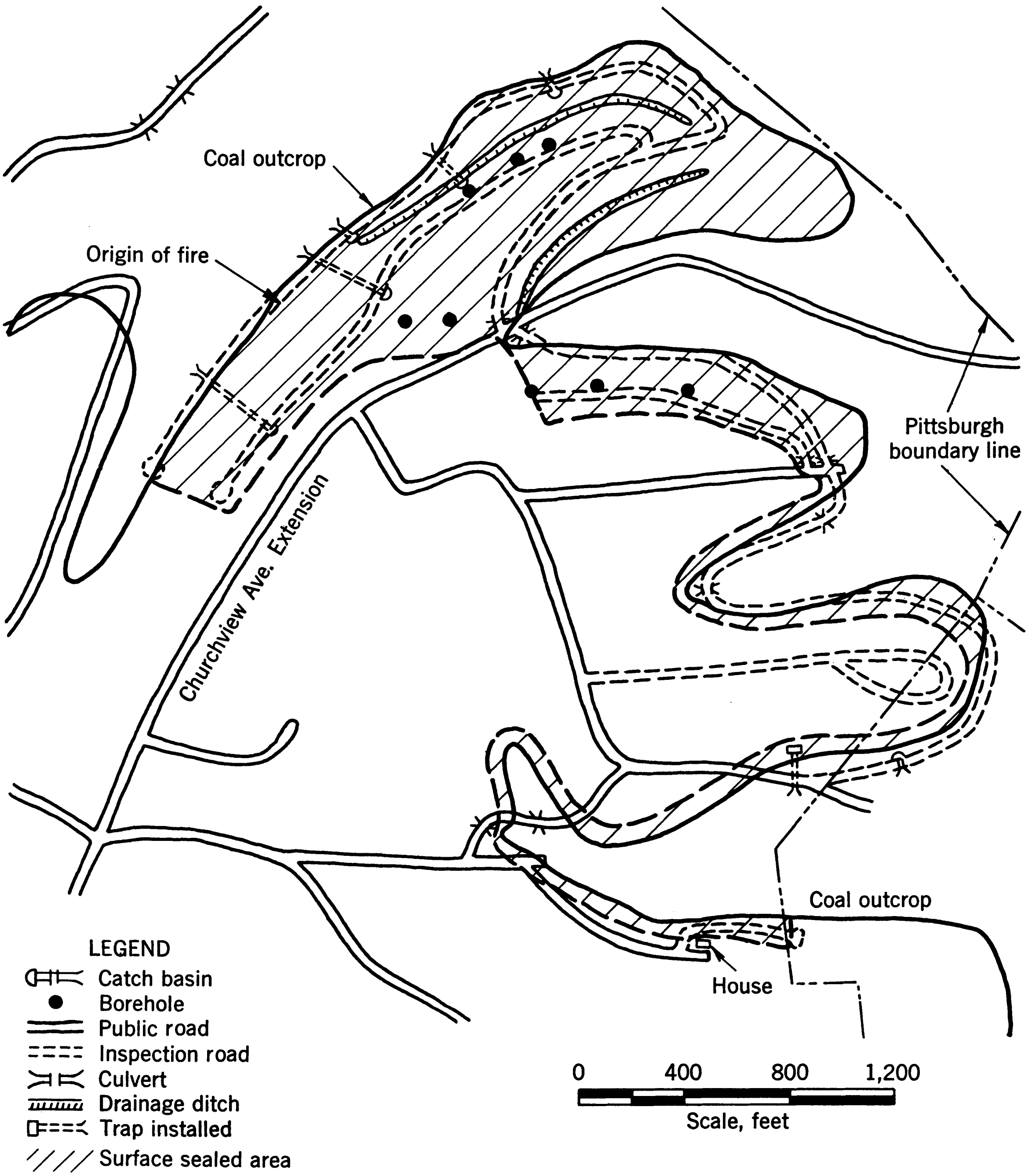


FIGURE 33.—Map Showing Inspection Roads, Drainways, Culverts, Boreholes, and Trap Installed on Churchview Avenue Extension Fire-Control Project.

FIGURE 34.—Before and After Installation of Catch Basin and Pure-Iron Drainage Pipe.

FIGURE 35.—Typical Inspection-Maintenance Road Constructed Over Surface-Sealed Area. (Road also provides surface drainage.)

vation and grade limitations on the drainage ditch determine the location of the ditch and inspection road. (See fig. 32.)

RESEEDING

The sealed area between elevation minus 10 to plus 15 and plus 40 to plus 60, as shown in figure 32, is reseeded with a cover crop to minimize erosion and reduce the runoff of surface water. A barren strip between plus 15 and plus 40 is provided to facilitate subsequent inspection and maintenance, as will be explained in the section on maintenance of the surface seal. However, this barren strip is provided only in the active fire area and not at locations where there is no indication of active fire. In such areas where old mine entries were closed, in abandoned strip mines that were backfilled to close surface openings ventilating the fire, or in borrow areas, the entire cleared surface is reseeded. No attempt is made to salvage the top soil for replacement after the plowing is completed. It is more economical to recondition the surface of the seal by the application of hydrated lime and a balanced fertilizer. The amount used depends upon analysis of the surface material as determined after the plowing. The soil acidity for most satisfactory growth of grasses should not be in excess of pH 6.5. Perennial rye grass is sowed as a cover crop, because it has a vigorous, deep, root structure, which it retains throughout the year. Domestic ryes die in the fall of the year and the roots decay. In late summer, oats and wheat may be sowed to shade the perennial rye grass during germination and early growth. A tractor, spreader, and disk harrow are used for reseeding operations. A typical planting cycle is as follows:

1. When needed, the area is disk-harrowed.
2. Fertilizer and lime are applied separately or together, using a spreader.
3. Oats and wheat may be "hand cast" if used.
4. Area is disk harrowed with blades angled.
5. Perennial rye grass seed is sowed, using about 25 pounds per acre.
6. Area is disk harrowed, with blades straight.

INSPECTION BOREHOLES

Several inspection boreholes usually are drilled into or near the underground fire. This is generally the final operation of the sealing phase. These holes are 6 inches in diameter and extend from the surface into the mine cavities. They are loaded around the perimeter of the known fire or into a known hot area. An indication of the condition of the fire can be obtained by comparing subsequent temperature readings in these holes with the temperature reading taken when the hole is drilled. This will indicate whether the fire area is cooling during the maintenance period.

Temperatures are taken from these holes by lowering a thermocouple with extension wires into the mine cavity and reading the temperature indicated by a potentiometer. The boreholes are equipped with 15 feet of 6-inch steel casing, which is inserted in the hole with about 30 inches extending above the surface. Earth material is tamped between the ground and casing to hold it firmly in place. When the hole is on the perimeter of the fire area it will not usually become obstructed or closed from caving of the walls; therefore, only that portion of the hole through the unconsolidated surface material is supported by casing. A flange is welded or threaded to the top of the casing, and a circular disk cap is bolted over the opening. This prevents circulation of air through the borehole when it is not being used. Figure 36 is a sketch showing the method of casing boreholes.

MAINTENANCE PHASE

The most difficult problem in extinguishing an underground fire by the surface-sealing method is dissipating the tremendous quantity of heat stored in the carbonaceous material and overlying strata. An effective seal will stop combustion by excluding oxygen, but unless the carbonaceous material is cooled it will reignite when air becomes available. Heat loss from the fire area is primarily by conduction through the rock strata to the surface, where it is dissipated to the atmosphere. This is a slow process because of the poor conductivity of the rock strata.

This problem necessitates a maintenance period during which the seal is kept in an effective condition while the fire area cools. The surface seal will require continued maintenance because crevices and sinkholes will develop during this cooling period. Heat that would have been dissipated to the atmosphere by convection currents is now absorbed in the strata. As active combustion is reduced and stored heat is dissipated, the temperature of the fire area decreases. These temperature changes cause expansion and contraction of the strata, resulting in crevices and sinkholes in the overburden. These new breaks in the strata must be closed promptly or the fire will reactivate.

The surface seal should be maintained for at least 2 years. During the first 6 months it requires the most attention. At the end of 2 years, if the seal was installed and maintained effectively, crevicing and sinkholing will have ceased, and most of the temperatures in the inspection boreholes will be at normal ground temperatures (about 55° F.). Those above ground temperature should not be over 120° F. and should show a decreasing trend.

During the maintenance program the seals should be inspected regularly, and if crevices or sinkholes are found, they should be filled as soon as possible. Ditches and drains should be kept in operating condition. A record of inspection borehole temperatures is kept to determine whether the fire is cooling. Melting snow over the affected area indicates the location of heated ground. Figure 37 is a photograph taken during an inspection tour showing in striking contrast the areas where underground heat has melted snow over the surface seal.

Maintenance requires the services of an inspector, laborers who will perform handwork as required, and light earthmoving equipment. A farm tractor equipped with a blade or bucket is sufficient for the work normally performed.

During the maintenance period certain areas of the surface seal may be disk harrowed to pulverize the ground and fill the recurrent crevices. In anticipation of this disking operation the strip of sealed land between elevations plus 15 to plus 40 was not seeded during the surface-sealing operations. (See fig. 45.) It has been observed from previous sealing work that this strip of the surface seal is the area most likely to crevice. Disking operations may not be required; however, the area is given close attention, and the absence or the periodic clearing of vegetation in this critical area facilitates inspection.

SURFACE SEALING BY BORROWING FILL

In this method the fire is controlled by covering all surface openings and crevices with a thick mantle of earth-fill material. It differs from the previously described surface-sealing method in that the surface seal is made by transporting suitable earth-fill material from a borrow pit and depositing it on the affected surface. The method is employed extensively in Western United States coalfields, where a suitable earth-fill material is usually available near the fire area. The seal must be maintained until the fire area has cooled sufficiently to prevent reignition.

ESTABLISHING SURFACE SEAL

The required amount of earthfill material depends upon the thickness of the seal and the extent and location of the underground fire. Preliminary work, which may require mapping and exploratory drilling, should be done to determine these requirements. Borrow pits should be located and measured to determine whether adequate material is available. Bulldozers clear the area of vegetation and grade the slope of the surface over the outcrop and over the burning coalbed. A wide cut or bench is established along the contour below the outcrop. Fill material is hauled to the site in scrapers and deposited on the bottom bench. Successive layers of fill are deposited until a mantle of earth is established over the affected area. (See fig. 24C.) Figure 38 shows

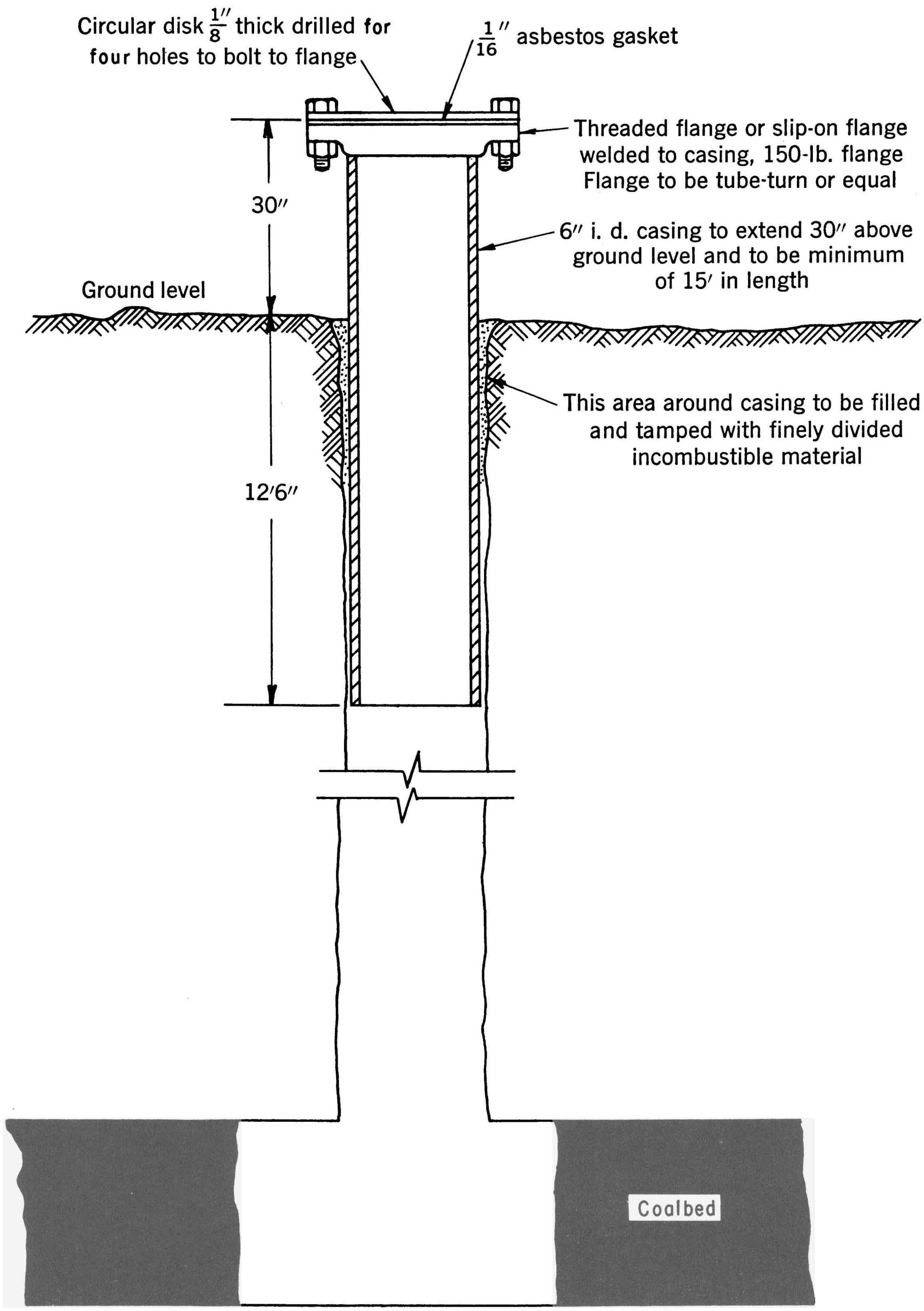


FIGURE 36.—Method of Casing Boreholes.

FIGURE 37.—Melting Snow Gives Evidence of Heat From Fire Area Underneath Highway.

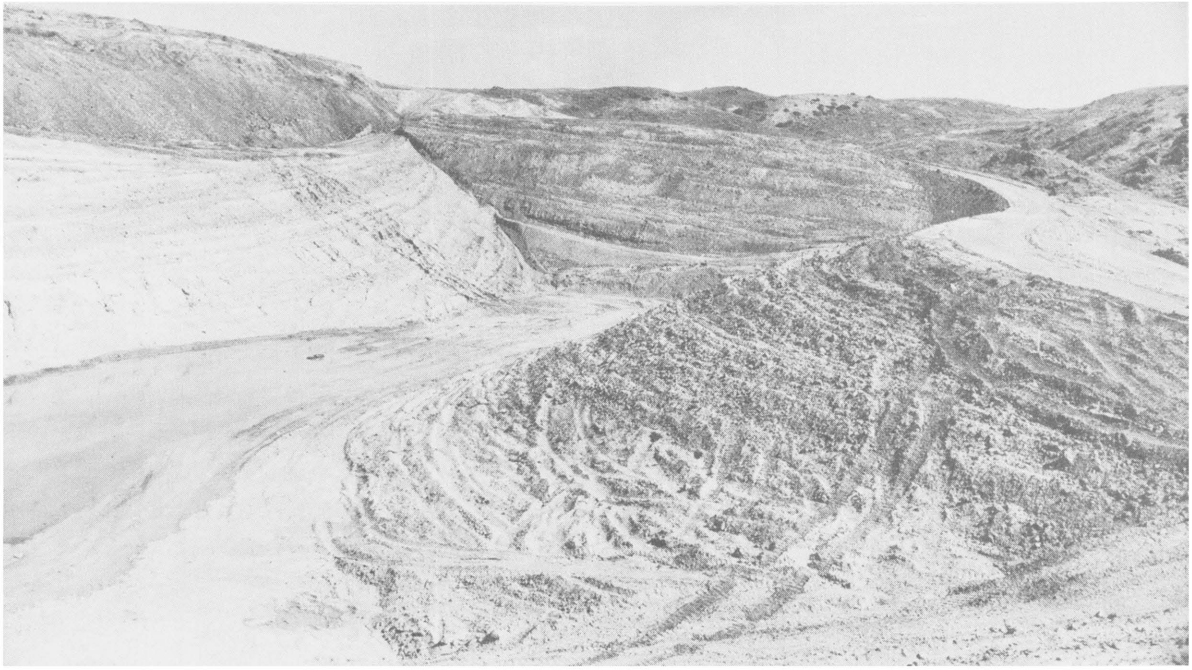


FIGURE 38.—Borrowed Fill Surface-Sealing Project as It Nears Completion. (East and south sections are completed; terracing on north wall (left) is two-thirds complete.)

a surface seal created by laying successive layers of earth over the fire area. The material is laid down in such a way as to maintain a uniform thickness of about 8 feet perpendicular to the surface.

MAINTENANCE OF SEAL

The effectiveness of the seal should be maintained until the fire area has cooled to normal ground temperature. Drainage ditches should be provided to divert surface water from around the seal. Other ditches may be provided where required to prevent surface water from eroding the seal. Inspection boreholes are provided around the fire area to obtain mine-atmosphere samples and temperature readings. These boreholes are provided with a casing at the top of the hole and a cover as described previously.

EVALUATION OF SURFACE-SEALING METHOD

The surface-sealing method is very often the only economically feasible method of attempting to control an abandoned-mine fire extending throughout a large acreage. Its principal advantage is that it offers a method of controlling a fire involving several hundred feet, and at times as much as 2 or 3 miles of outcrop, extending under overburden too deep to be removed economically. The operations can be performed by available earth-moving equipment and conducted on the surface with greater safety. Another advantage is that the sealed area is usually restored in such a way as to become a community asset.

Under some conditions the surface-sealing method is most effective when used with other control methods such as trenching and flushing.

The surface-sealing method as described has been highly successful in controlling underground mine fires. However, there have been a few instances where maintenance work has been neglected or conditions are such that control was ineffective. Effective sealing cannot be accomplished where surface water or sewage is permitted to enter the underground workings of a mine that is on fire. These openings, even when equipped with traps, permit oxygen to reach the fire by aeration and induced flow.

EXAMPLES OF SURFACE SEALING

LLOYDSVILLE PROJECT

The first attempt to control and extinguish a mine fire by the surface-sealing method under Congressional Act was at Lloydsville, Unity Township, Westmoreland County, Pa. Work on this project was begun June 6, 1949, and was divided into two phases. The first part of the program, now known as the initial phase, consisted of (*a*) drilling 22 exploratory boreholes into the abandoned mine to determine the extent of the fire, (*b*) filling sink-

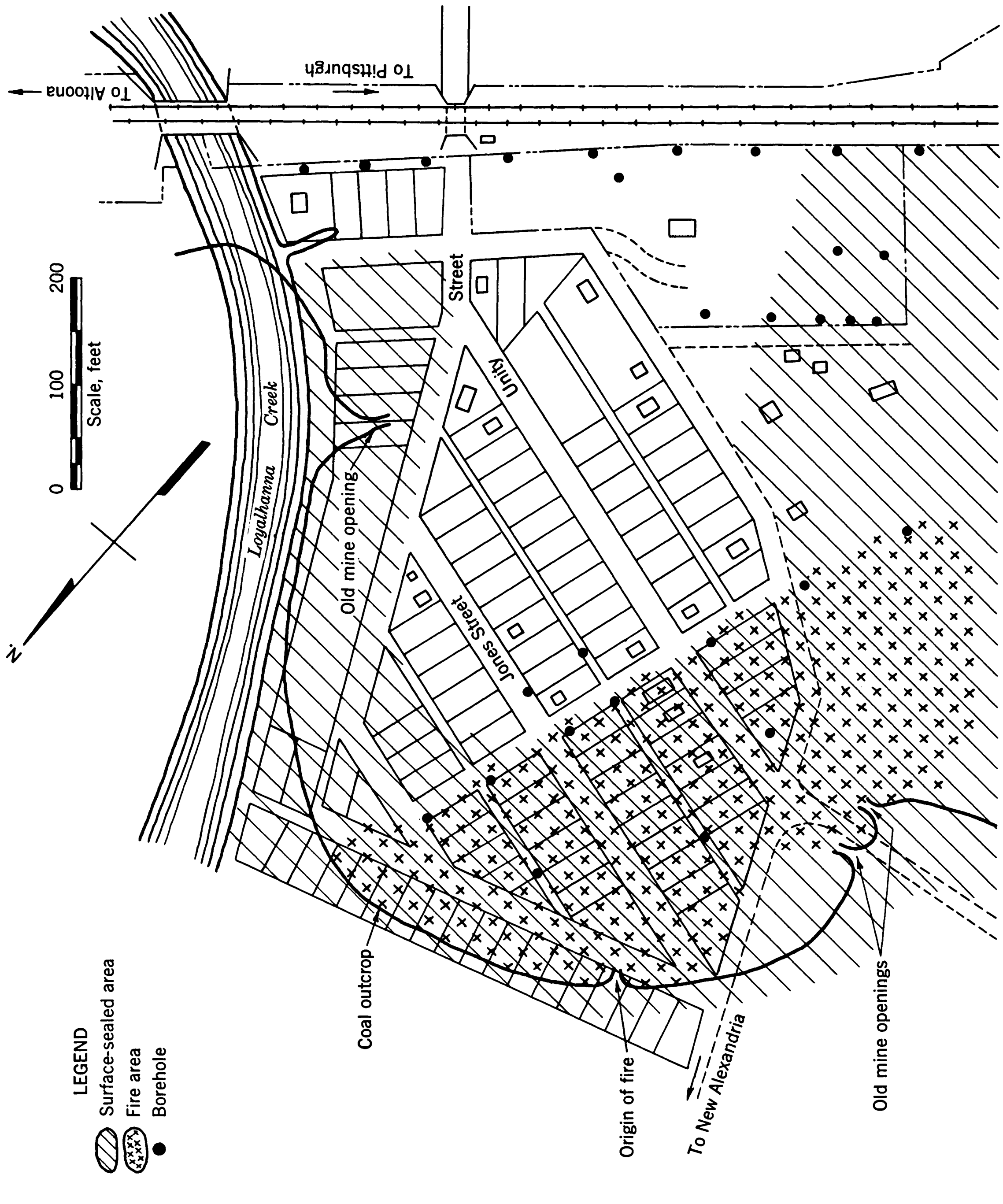


FIGURE 39.—Map of Underground Mine Fire, Lloydsville, Unity Township, Westmoreland County, Pa.

holes and crevices, (*c*) backfilling an abandoned strip pit where the fire was active along the highwall, and (*d*) clearing and leveling the surface to permit subsequent plowing and harrowing. This phase of the project was completed July 12, 1949. Figure 39 is a map of the fire site, and figure 2 shows some of the damage caused by the underground fire to homes and other buildings. The cover over the burning coalbed ranged up to 60 feet, and a number of homes were either over or near the fire.

The second part, or maintenance phase, was begun July 13, 1949, and has been continued on an intermittent basis. Much has been accomplished and learned in retarding the fire and in protecting homes and highways. Many unanticipated conditions have been encountered that have operated against complete extinguishment of the fire. The first of these was erosion of the finely divided earth mantle placed over the fire by storm water, and the second was that the shales found under the eroded mantle could not be broken adequately and pulverized with ordinary plowing and harrowing. Later a ripper was used to break the shales to a depth of about 32 inches, believing that these broken materials would seal any crevice.

The control efforts were successful in extinguishing and preventing the fire from burning under homes and highways where it had been extremely active. However, it was found that air from sewage drains piped into the mine through boreholes was reaching the fire and causing it to propagate and extend to the south toward Unity Run. No persuasive nor legal means have been found to stop this means of waste disposal. Continuing efforts have been and are now being made to control and extinguish the fire. These are explained in this Bulletin under "Research To Develop Fire-Control Methods."

LICK RUN PROJECT

On June 22, 1949, the second project to control and extinguish an underground fire by essentially a surface-sealing method was begun near Bruceton, Pa. This fire burning in the Pittsburgh coalbed was reported to have been ignited in the spring of 1930.

A farmer set fire to brush, which he had piled the previous winter in a coal-mine sinkhole, and the coalbed took fire from the burning brush. Because of worry and anxiety over starting the mine fire, the farmer killed himself some weeks later by tying explosives around his waist and detonating them near the sinkhole through which fire was communicated to the remnants of the coalbed.

At the time of the ignition no attempt was made to extinguish the fire. By 1934 the fire had extended in the coalbed underlying two adjoining farms, so a concerted effort was begun that year by the Federal Civil Works Administration to control the fire. These efforts consisted of closing surface openings and making a fire plug barrier. The plug barrier extended from the outcrop coal back into the hill and involved loading-out all coal and carbonaceous shales and then backfilling with earth. This was done to exclude air from the fire and prevent its extension along the outcrop line. Funds were not available to complete the control program, so the fire burned into Federal-owned lands occupied by the Bureau of Mines.

Beginning in October 1944 a plug barrier was excavated and backfilled with noncombustible material on the Federal-owned property. This program was effective in stopping the progress of the fire along the outcropping coal. The fire near this point, however, subsequently penetrated deep underground to and through contiguous open entries of the abandoned mine. From here in 1949 it extended rapidly toward an active mine known as Montour No. 10 of the Pittsburgh Coal Co. Gases, fumes, and smoke from the fire entered the main intake airways of this mine. The Bureau fire-control engineers were notified. Fire-seal stoppings were erected in the abandoned mine to prevent deleterious gases entering the active mine. This was done by employees of the coal company. Several of these stoppings had to be constructed by workmen wearing oxygen breathing apparatus.

The surface-sealing method employed for the ultimate control of the fire, as previously stated, was begun in June 1949. All work on the project, including surface-sealing maintenance, was completed October 10, 1950.

After 10 years there was no evidence of any fire activity, and it is reasonable to assume that the control work has been successful in eradicating a serious threat to contiguous unmined coal lands, roadways, and other surface improvements.

Figure 40 is a map of the affected area showing the location of the origin of the fire and the areas where control operations were performed. Figure 41 shows before and after views of part of the Lick Run surface seal.

GREEN VALLEY PROJECT

Many of the mine-fire-control projects employ a combination of methods involving surface sealing, flushing, underground seals, or trench and plug barrier. However, for the Green Valley Project, surface sealing was the only method employed. Special mention is

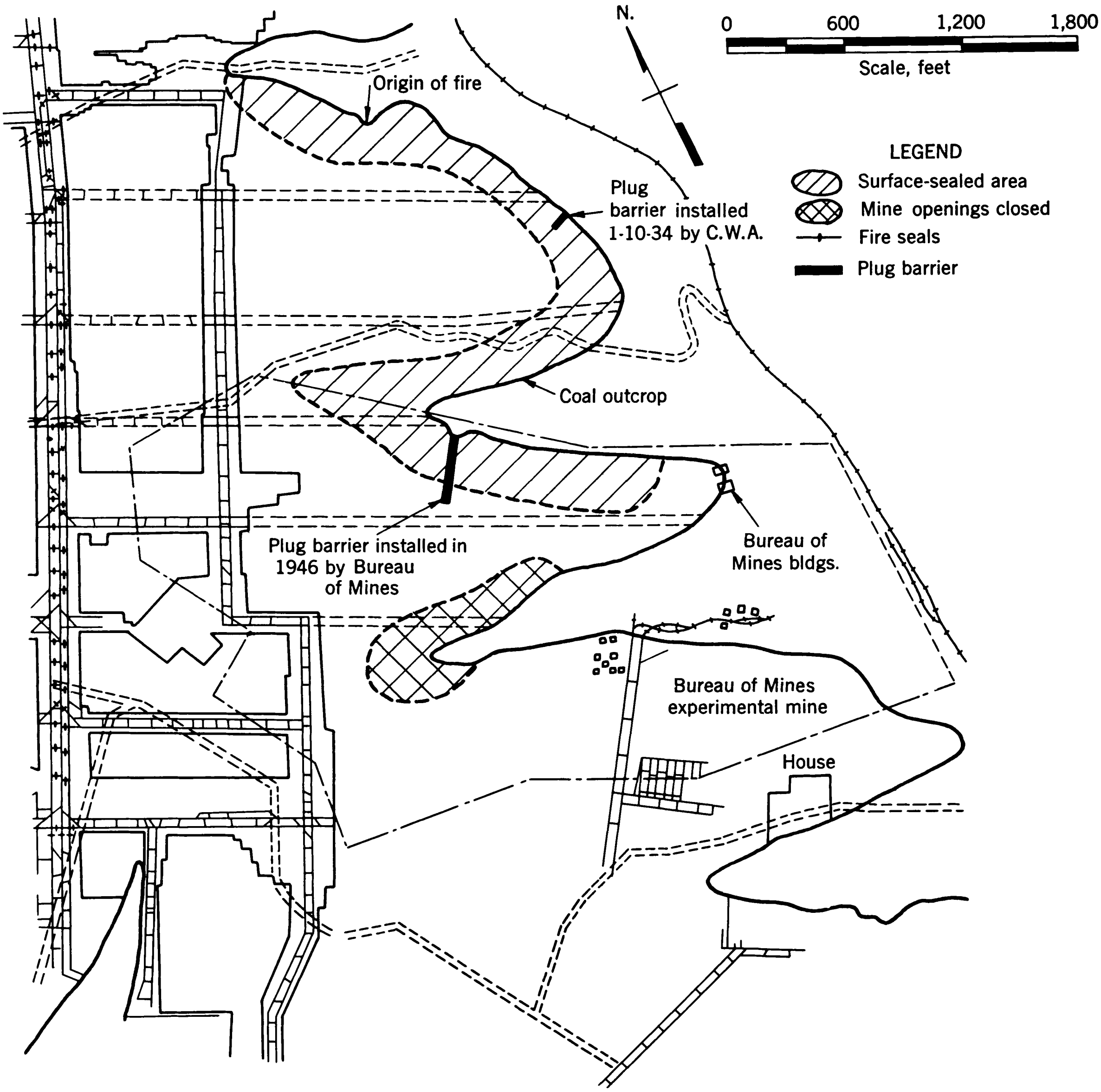


FIGURE 40.—Lick Run Mine Fire, Snowden Township, Allegheny County, Pa.

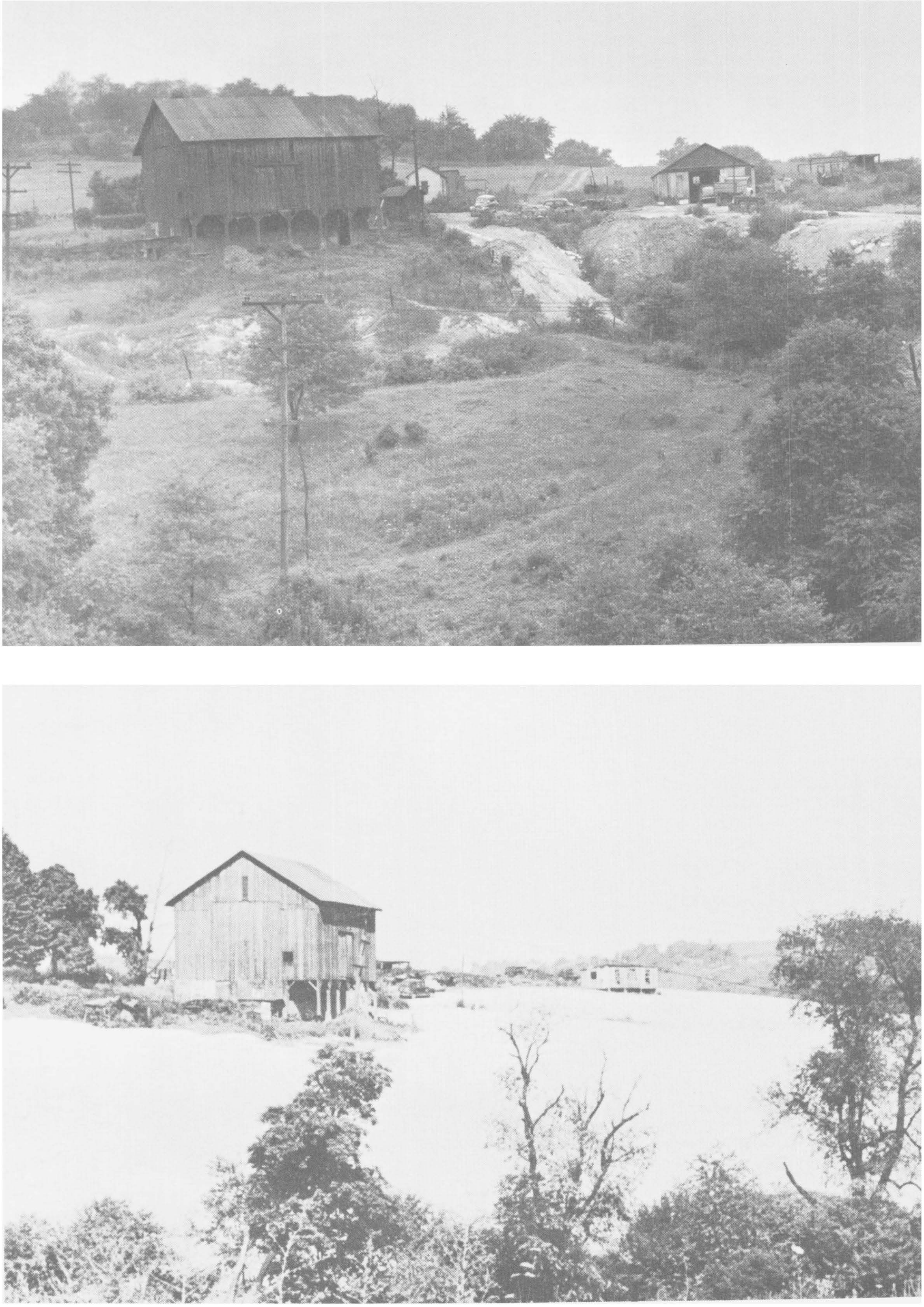


FIGURE 41.—Part of Lick Run Project Before and After Placing Surface Seal.

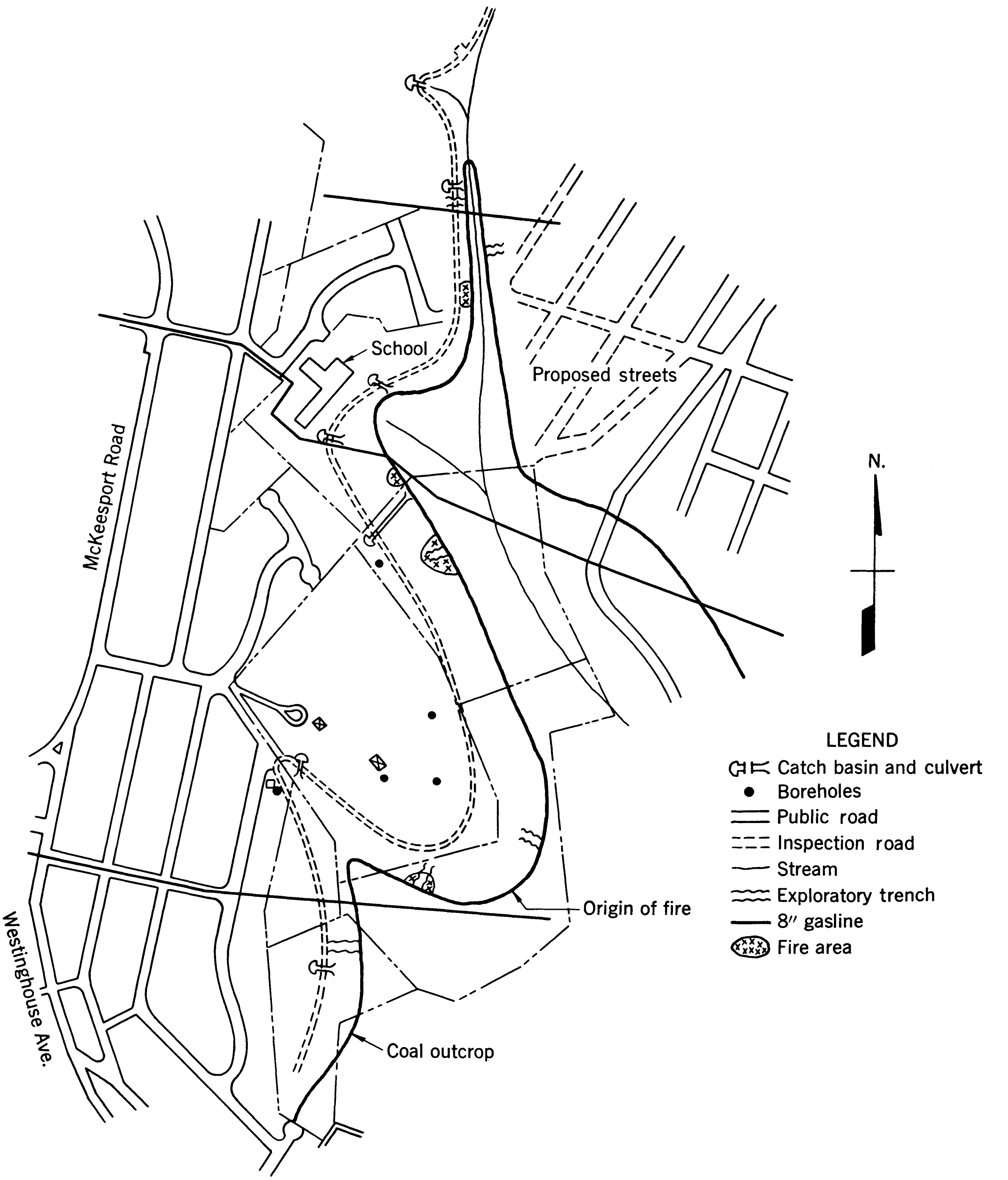


FIGURE 42.—Map of Inspection Roads, Drainways, Culverts, Boreholes, and Exploratory Trenches Installed on Green Valley Fire-Control Project.

made of this project because several hundred new homes and a public school on the surface above the abandoned burning coal mine were endangered by continued propagation of the fire.

Figure 42 is a map showing the location of the origin of this fire and the extent of the area sealed with a blanket of pulverized earth. This map also shows the inspection roads made over the project. Drainage ditches and catch basins made alongside these roads prevent erosion of the seal by storm waters. Underground temperatures measured through boreholes drilled to intersect the coalbed indicate this fire is definitely under control, and it is expected that this fire will be extinguished.

The maintenance work on this project under special contract continued to April 29, 1959. An inspection made about that time indicated that the work of controlling the fire had been successful. However, to protect the investment and to be certain that the fire would not reactivate, the township officials of North Versailles, Pa., agreed with the officials of the Commonwealth of Pennsylvania and the Federal Government and the other two financial contributors that they would continue the inspections and ordinary maintenance for an indefinite period.

YELLOW JACKET PROJECT

A fire in the abandoned Riley & Wesson and Wallace mine on Yellow Jacket Pass, near Meeker, Rio Blanco County, Colo., was controlled by the borrow-fill surface-sealing method. The fire was in the Wesson coalbed, which dips about 60° to the southwest and ranges from 22 to 28 feet in thickness.

The active fire area, located west of State Route 320, extended along the face of a steep hillside for about 1,200 feet in length and 200 feet in width, measuring on the slope. Figure 43 is a contour map showing the location and extent of the fire.

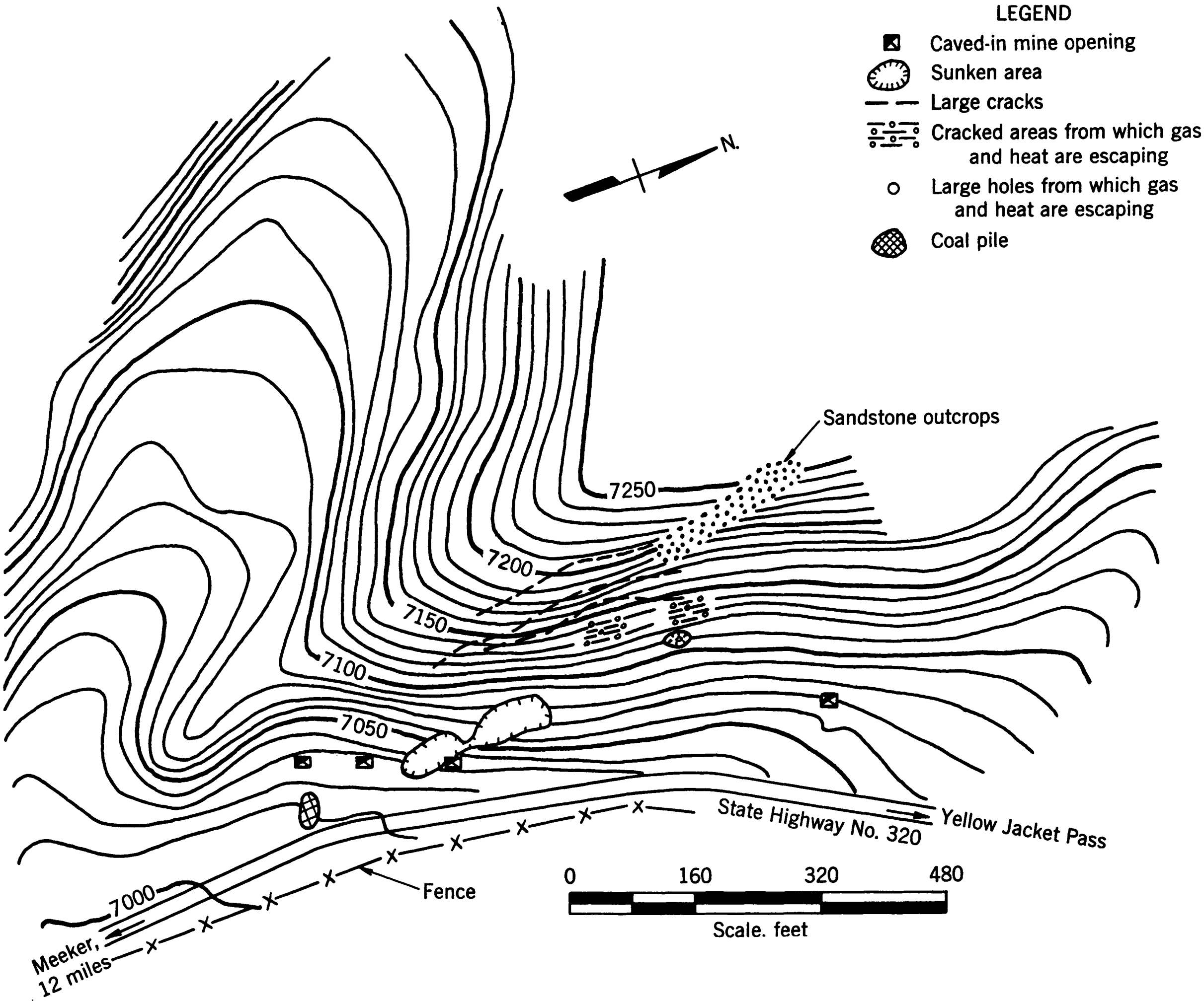


FIGURE 43.—Coal-Crop Fire Project, Yellow Jacket Fire.

The project was begun June 15, 1954, and completed August 21, 1954. Twelve exploratory boreholes drilled to determine both the extent of the fire and the characteristics of the overburden, averaged about 60 feet in depth. It was estimated that 36,869 cubic yards of borrow material was transported to the fire site to form a sealing blanket of finely divided earth over the fire area.

To maintain the effectiveness of this control work: (*a*) Drainage and diversion ditches were constructed to minimize erosion of the surface seal, (*b*) vegetation was cleared from the coal crop near the fire area, (*c*) abandoned mine openings in the vicinity of the fire area were closed, and (*d*) piles of waste coal were mantled with a substantial layer of incombustible material.

UNDERGROUND SEALING

Underground sealing is the principal means of controlling a fire in an active mine when the fire cannot be extinguished by direct attack. It consists of constructing fire-seal stoppings in all entries leading to the fire area to shut off all air flowing to the fire. In an active mine these entries and portals usually are accessible, so the fire can be enclosed completely. Installing stoppings around a mine fire and the subsequent reopening of the sealed area are hazardous operations requiring respiratory protective apparatus, other safety devices and equipment, and precautions against possible explosions and reignitions. Materials, methods, and procedures employed for these operations are covered in other Bureau publications and are not dealt with here except when they apply to the control of fires in inactive mines.

The erection of underground fire-seal stoppings is seldom done to control an inactive-mine fire, because the abandoned entires are not always accessible. Furthermore, mine maps of the affected area are usually not available or adequate for planning such an operation. Where this type of work was undertaken, access was provided to the abandoned entries through an adjoining operating mine, and the underground sealing was done in conjunction with surface sealing. In these instances it was necessary to stop air from flowing to the fire from the adjacent mine; therefore, all entries connecting the adjacent mine with the abandoned mine were closed with suitable stoppings. This also minimized the possibility of fire gases seeping into the ventilating current of the adjacent mine. Upon completion of the underground stoppings the fire area was surface sealed.

Access through the abandoned mine to the stopping site may be difficult and hazardous. Deadly fire gases are encountered in most of the undertakings. These gases may be removed by installing mechanical facilities for inducing airflow if power is available for operating such equipment. In some instances it has been possible to remove the gases by diverting a split of air from an adjoining active mine. If these alternatives are impractical, the hazard may be overcome by equipping men with suitable protective respiratory apparatus.

The roof in the accessways must be made safe for workmen. Sometimes the roof in the abandoned entires will be arched and relatively safe so that only safety posts and brushing are required. In other instances extensive installations of roof supports are necessary.

Preparing the stopping site and bringing in supplies for the construction of stoppings involve a great deal of arduous hand labor, since there is usually no power available near the site, and mechanical equipment cannot be used to transport supplies through the partly closed accessways. Falls at the site of the installation must be loaded-out, and in many instances water must be drained or pumped from the area.

The fire-seal stoppings are of conventional construction where conditions permit. Several types of stoppings are listed [5] with material and construction details. In Bureau fire-control work in inactive mines there have been occasions when it became necessary to depart from conventional construction. These departures were necessary where water had accumulated in low areas of undulating coalbeds or where provision had to be made to drain water from the sealed area. Where water had accumulated at a stopping and could not be drained away, a special wood and plaster stopping was built. A timber set was notched into the ribs and roof of the entry, and a horizontal plank 12 inches wide was nailed alongside the two posts of the timber set so that at least 8 inches of the plank was in the pool of water. Wood planks, extending vertically from the bottom of the pool to the roof of the entry, were nailed to this frame, leaving ¼- to ½-inch spaces between the planks to provide anchorage for the plaster coating. Two coats of wood-fiber plaster were applied to the stopping. The first coat, about 1 inch thick, is permitted to dry, and then a second coat is applied. As long as the water elevation does not fall more than 6 or 8 inches, this stopping provides an airtight seal in the entry. If the water level should fall below the bottom of the horizontal plank, plaster or other sealing

[5] Forbes, J. J., and Grove, G. W., Procedure in Sealing and Unsealing Mine Fires and in Recovery Operations Following Mine Explosions: Bureau of Mines Miners' Circ. 36, 1948, pp. 31–43.

material could be used to restore the effectiveness of the seal.

This construction may be used also to allow water to flow from the sealed area and at the same time prevent the flow of air into the fire, in which case the elevation of the flowing water is fixed by an overflow outlet on the outby side of the seal. Figures 44 and 45 show general work operations required in constructing these stoppings. Several other arrangements that provide an air seal but permit the flow of water from a sealed area have been discussed and illustrated under "Closing Openings and Backfilling." These arrangements can be used in underground entries as well as at outcrop openings.

Water cannot be permitted to build up in the sealed area, since these seals are being used in conjunction with surface-sealing and an accumulation of water in the mine would eventually create a hydrostatic pressure on the earth seals at the outcrop and erode them. This would destroy the effectiveness of the surface seal. Had it been practical to inundate the fire with water by constructing masonry seals at the outcrop and underground this method would have been employed, since it is one of the more effective means of extinguishing a fire.

EVALUATION OF UNDERGROUND SEALING

Underground sealing on cooperative fire-control projects has not been the only method undertaken in controlling an abandoned-mine fire. In abandoned mines near the coal outcrop and under shallow cover it is seldom possible to erect underground seals in all entries around the fire.

Seals were installed on the Lick Run, Pricedale, and Rostraver Township projects in conjunction with other methods of control. In these places active mines were adjacent to the fire area. Underground seals were erected to prevent the flow of air to the fire and fire gases from entering the active mine, and they proved to be effective. Figure 46 shows two seals 3 years after being erected in a mine adjacent to the fire. These seals were constructed as part of the Rostraver Township project and are the same seals shown in figure 44*C* and *D*. Underground sealing was essential in these instances to the success of this project.

Other phases of fire-control work on the Lick Run, Rostraver, and Pricedale projects are described in this Bulletin.

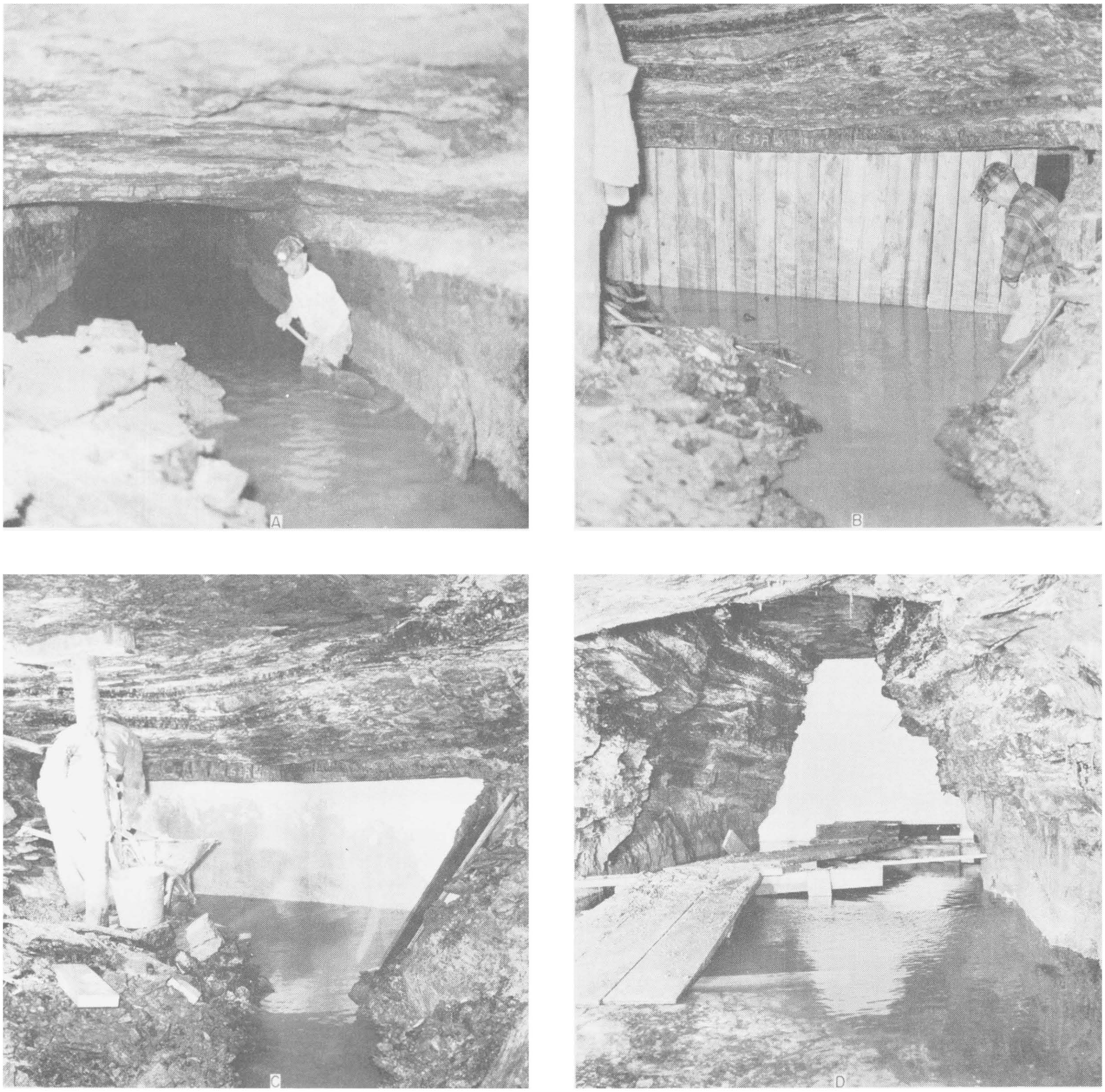


FIGURE 44.—*A*, Attempt To Lower Water Level Before Constructing Fire Seals; *B*, Constructing Fire Seal in About 5 Feet of Water; *C*, Seal Completed Except for Second Coat of Plaster. (About 5 feet of seal under water) ; *D*, Fire Seal and Bridgework Provided To Facilitate Work.

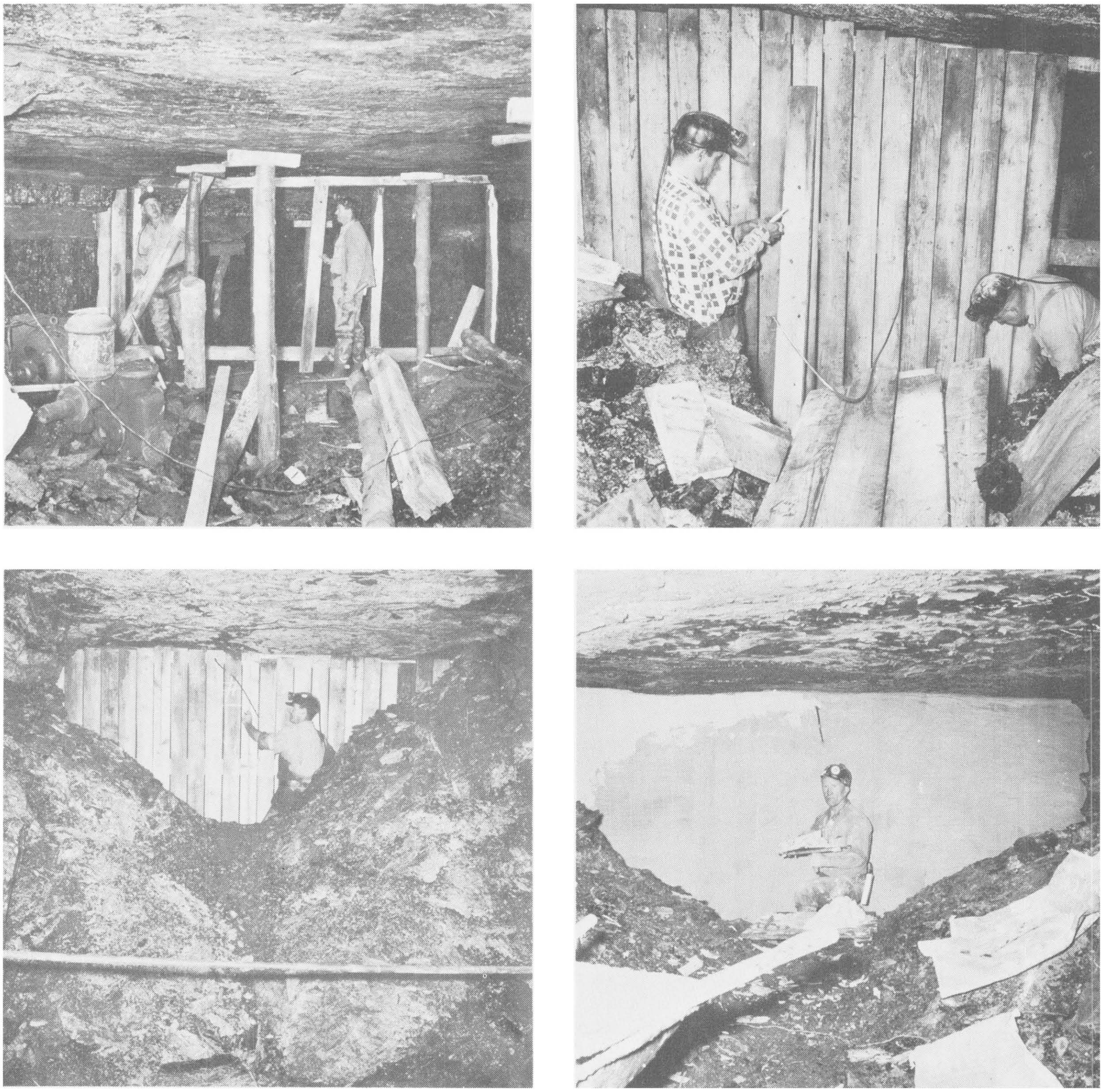


FIGURE 45.—Fire-Seal Stoppings at Various Stages of Construction.

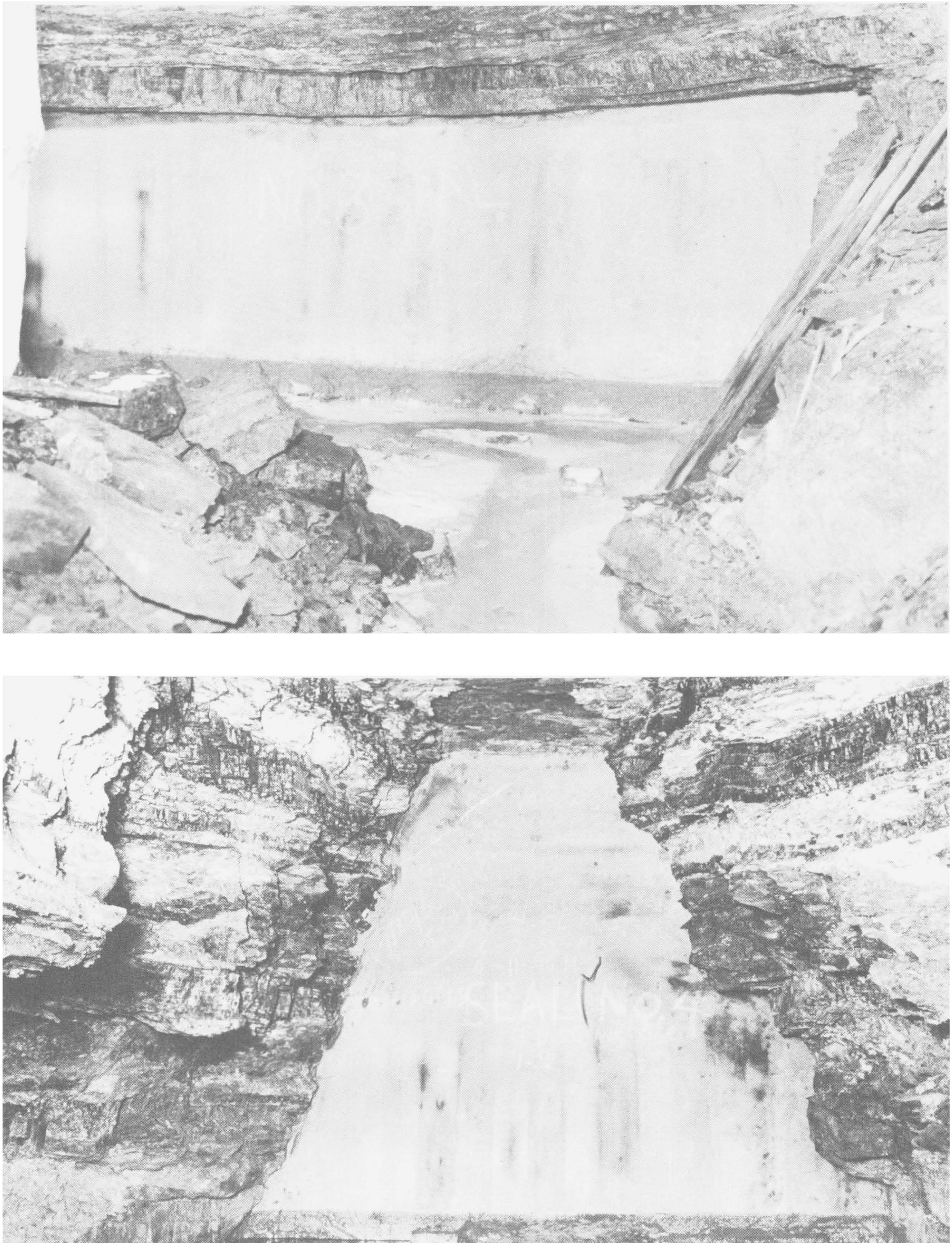


FIGURE 46.—Nos. 3 and 4 Seals 3 Years After Installation. (Same seals shown in fig. 44, *C* and *D*.)

TEMPERATURE READINGS

Fire-area temperatures usually are obtained from boreholes drilled from the surface to intersect the coalbed. Readings are obtained from a mine cavity at or near the bottom of the borehole. It is obvious that the mine-fire temperatures taken in this way will not indicate the hottest temperature of the fire unless by mere coincidence the borehole penetrates burning coal in the mine. Usually the readings indicate the temperature of the air in the mine.

Temperatures are taken for two purposes: (1) Either to locate and delineate the fire area preparatory to fire-control operations, or (2) to get a temperature record to ascertain whether the fire was cooling.

Normal ground temperature is about 55° F., and temperatures several degrees in excess of normal ground indicate that a fire condition may exist in the vicinity. In attempting to locate a fire, it is assumed that the hottest temperatures are nearest the source of heat. However, two conditions mitigate against strict application of this assumption. They are (1) poor conductivity of the coal and strata, and (2) what appears to be a vaporization zone or wide, uniformly heated area resulting from the diffusion of steam throughout the coal and strata. These conditions are sketched in figure 47, which shows hypothetical borehole temperatures that might be recorded in and around a fire area. Temperatures obtained in a solid block of coal are misleading because of the low heat conductivity of the coal. There will be also a great many temperature readings within the range of 180° to 212° F. These may be at varying distances from the fire because of the relatively wide vaporization zone.

The temperature trend indicates better than the temperature itself whether the fire area is cooling. The temperature will change from one elevation to another in a particular borehole, so when keeping a borehole temperature record all readings should be obtained from the same elevation in a particular borehole. Usually the hottest temperature in the hole and the elevation at which it was taken are recorded; then all subsequent temperatures in that hole are taken at the same elevation. Temperatures obtained in this way on different dates can be compared to ascertain whether the temperatures are increasing or decreasing. Increasing temperatures indicate a reactivated fire or its propagation toward the borehole. A decreasing trend indicates that the fire is cooling.

The first attempts to obtain borehole-temperature readings were made with clinical and maximum-minimum-type thermometers. These proved to be unsuitable because the heat in the hole sometimes would melt the glass tubing of the thermometers. They were also too delicate to withstand the rough treatment involved in lowering and raising them through the boreholes. In addition, when using these thermometers there was no way to determine at what point the highest temperature was recorded. For these reasons their use was soon abandoned.

All temperature readings are now obtained by using a thermocouple, extension wires, and potentiometer. A thermocouple consists of two wires of dissimilar metals intimately connected to each other at one end. The other ends are connected through extension lead wires to a potentiometer. When the two metals are connected, a voltage difference is recorded by the potentiometer, and this voltage difference will vary directly with any temperature change that occurs at the thermocouple junction.

The potentiometer used for this purpose is a volt meter of high accuracy and has a wide range of calibration. It is not complex or difficult to operate. Printed instructions, which can be learned readily, are included with the instrument.

Since the voltage generated by a thermocouple is directly proportional to the temperature, the voltage readings can be interpreted directly to degree of temperature. Some potentiometers are direct reading for a specific type of thermocouple; that is, the scale is calibrated so as to give the temperature reading directly in degrees Fahrenheit. Others are calibrated in millivolts. In this latter type the temperature reading can be obtained by comparing the millivolt reading with a prepared chart or table for the particular type of thermocouple used.

Most problems encountered in obtaining borehole-temperature readings are from insulation on the extension wires. This insulation must withstand three destructive forces—heat,

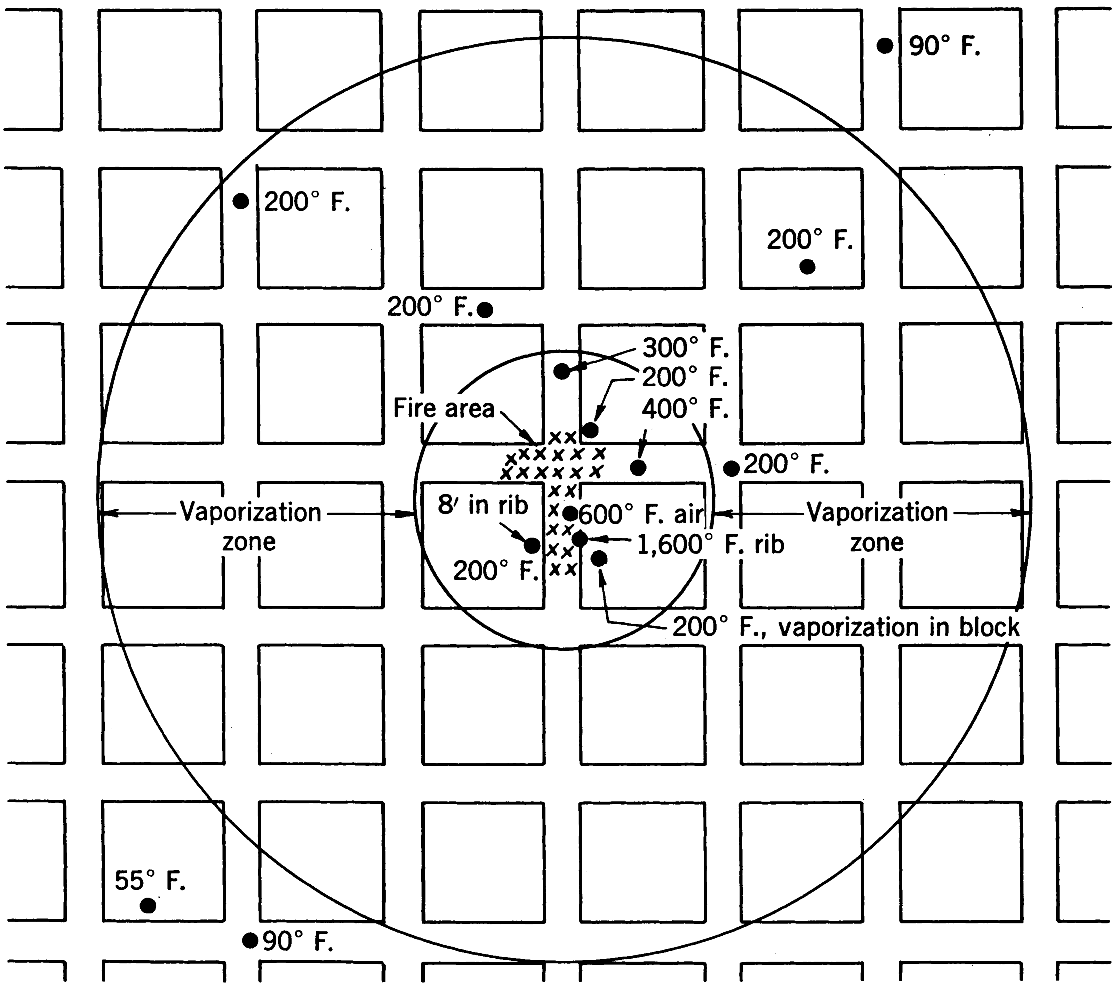


FIGURE 47.—Hypothetical Fire-Area Temperatures Showing How Low Conductivity and Wide Vaporization Zone May Affect Borehole Temperature Readings.

moisture, and abrasion. It also must be flexible enough to permit lowering and raising the wires through the borehole. However, flexibility is not a factor if a permanent installation is made in the hole. The deterioration of the insulating materials results from the heat and moisture conditions in the underground area, whereas abrasion results from lowering and raising the thermocouple through the borehole each time a temperature is taken.

Heat encountered in the boreholes may range as high as 1,600° to 2,000° F., although such readings are rarely obtained. Generally, equipment designed for 1,000° F. maximum temperature is adequate. Twenty-gage iron-constantan, thermocouple extension wires, insulated with a glass-wool braid are used, because they are relatively inexpensive and can be used to record temperatures of 1,000° F. or below. For temperatures above 1,000° F., asbestos, ceramic-bead, or ceramic-tube insulation is used. Glass-wool insulated wires are used where temperatures are expected to exceed 200° F. For taking temperatures below 200° F., Neoprene insulation has proved to be satisfactory because it has high-dielectric, high-moisture and high-abrasion resistance characteristics. Moisture is often present in these boreholes and with the sulfur gases liberated by the fire, forms a dilute conductive solution of sulfuric acid. When this solution bridges the extension wires where the insulation is worn or inadequate, the circuit to the potentiometer is partly or completely short cir-

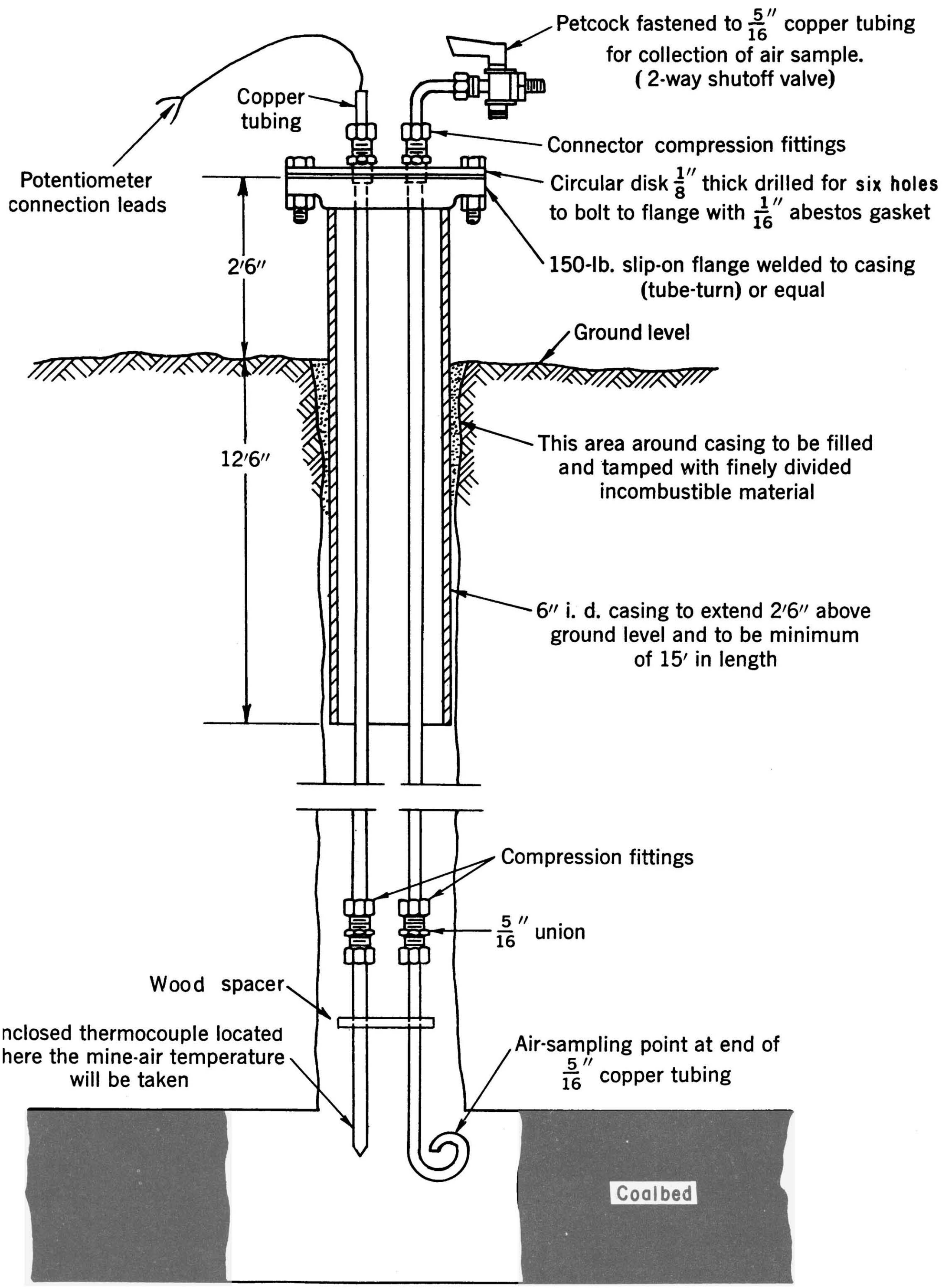


FIGURE 48.—Instrumentation of Borehole To Obtain Air Samples and Temperature Readings From Burning Coal Mine.

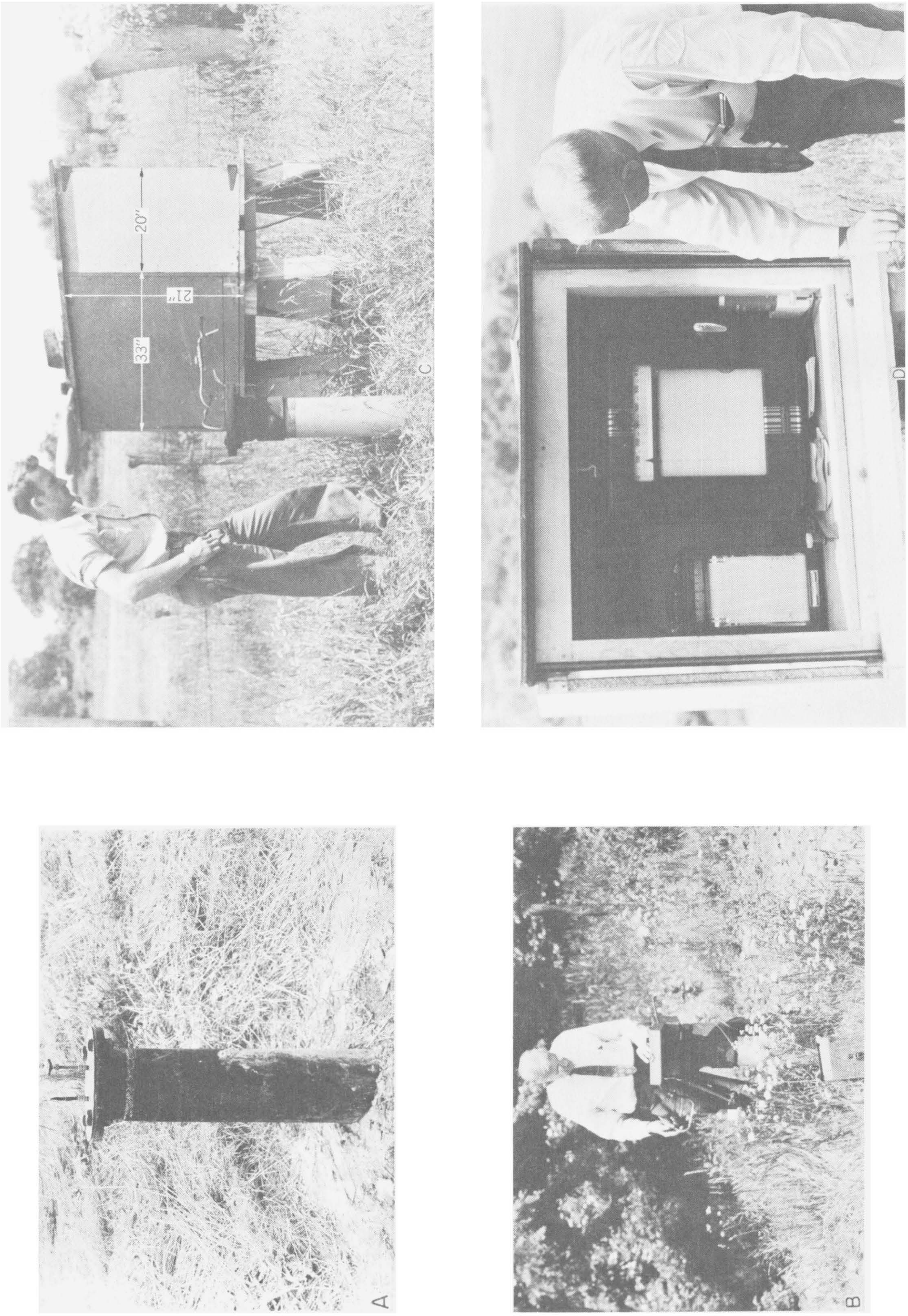


FIGURE 49.—*A*, Permanent Instrumentation of Borehole; *B*, Taking Gas Sample and Temperature Measurement; *C*, *D*, Shelter Provided For and Hookup Made at Borehole for Recording Micromax and Vacuum-Pressure Instruments.

cuited. An accurate reading of the temperature cannot be obtained under these conditions. Moisture and abrasion are therefore important considerations. Neoprene insulation has excellent resistance to moisture and abrasion, and for this reason is used for temperatures of 200° F. or less. However, the Neoprene covering will deteriorate rapidly when the temperature is in excess of 200° F. Glass-wool and asbestos insulations have excellent resistance to heat but poor resistance to abrasion and are also susceptible to moisture short circuiting.

Ceramic beads or tubes have been used for insulating the extension lead wires. Although they will withstand high temperatures, they have no resistance to short circuiting from acid-water solutions. In addition, they are not flexible enough to lower and raise easily through a borehole, and they are unwieldy to transport from hole to hole.

A permanent-type installation can be made that is well protected from heat and moisture and is not subject to abrasion. In this installation the thermocouple and wires are encased in copper tubing, which extends through the borehole into the mine opening. A thermocouple is imbedded in the end of the tube, sealing it from the mine atmosphere. At the top of the borehole the terminals of the extension wires extend through the cap on the borehole casing. Temperatures can be obtained by connecting these leads to the potentiometer without uncapping the borehole. A sketch of one of these installations is shown in figure 48. This sketch also shows an air-sampling tube, which is discussed under "Gas Sampling." The permanent temperature-taking installation is more expensive but more convenient. These installations are subject to deterioration, owing to corrosion of the copper tubing and subsequently of the thermocouple by moisture and acid. Corrosion becomes an important factor in this type of installation because the device remains in the corrosive atmosphere, whereas in the other method the device is withdrawn each time a temperature reading is taken. Under these corrosive conditions it may require frequent replacing. Figure 49 is a view of borehole equipped with a permanently installed gas-sampling tube and thermocouple wires. Collecting a gas sample and measuring the temperature at such a borehole also is shown. Figure 73, *C* and *D*, shows the hookup and shelter provided for continuous recording instruments installed at boreholes to determine pressure and temperature changes in mine-fire areas.

A temperature probe may be used for taking readings at shallow depths in soft ground or fill material. The one used by fire-control personnel of the Bureau consists of a length of ½-inch galvanized pipe with a steel point on one end. Extension lead wires run through the pipe to the thermocouple, which is imbedded in the metal at the probe point. This devise is provided with a knocker arrangement for driving the probe into the ground. Depending upon the compactness of the earth or fill, temperatures may be obtained from a few feet below the surface to the full length of the probe. In practice it is seldom possible to drive the probe more than 10 to 12 feet into the material with the knocker, so temperature taking is generally limited. The knocker device consists of a heavy sliding ring around the pipe which strikes on a smaller ring held in position by set screws. The extension wires protrude from the end of the pipe and are connected to a potentiometer after the probe has been driven into the ground. Figure 50 is a drawing showing the essential parts of the probe, and figure 51 shows several views of equipment used for taking gas samples and in making temperature readings.

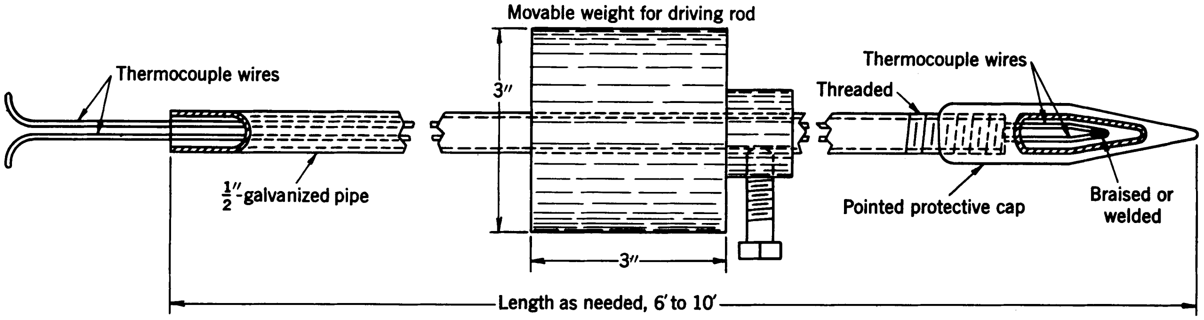


Figure 50.—Probe for Driving Into Burning Fill Material To Measure Temperatures.

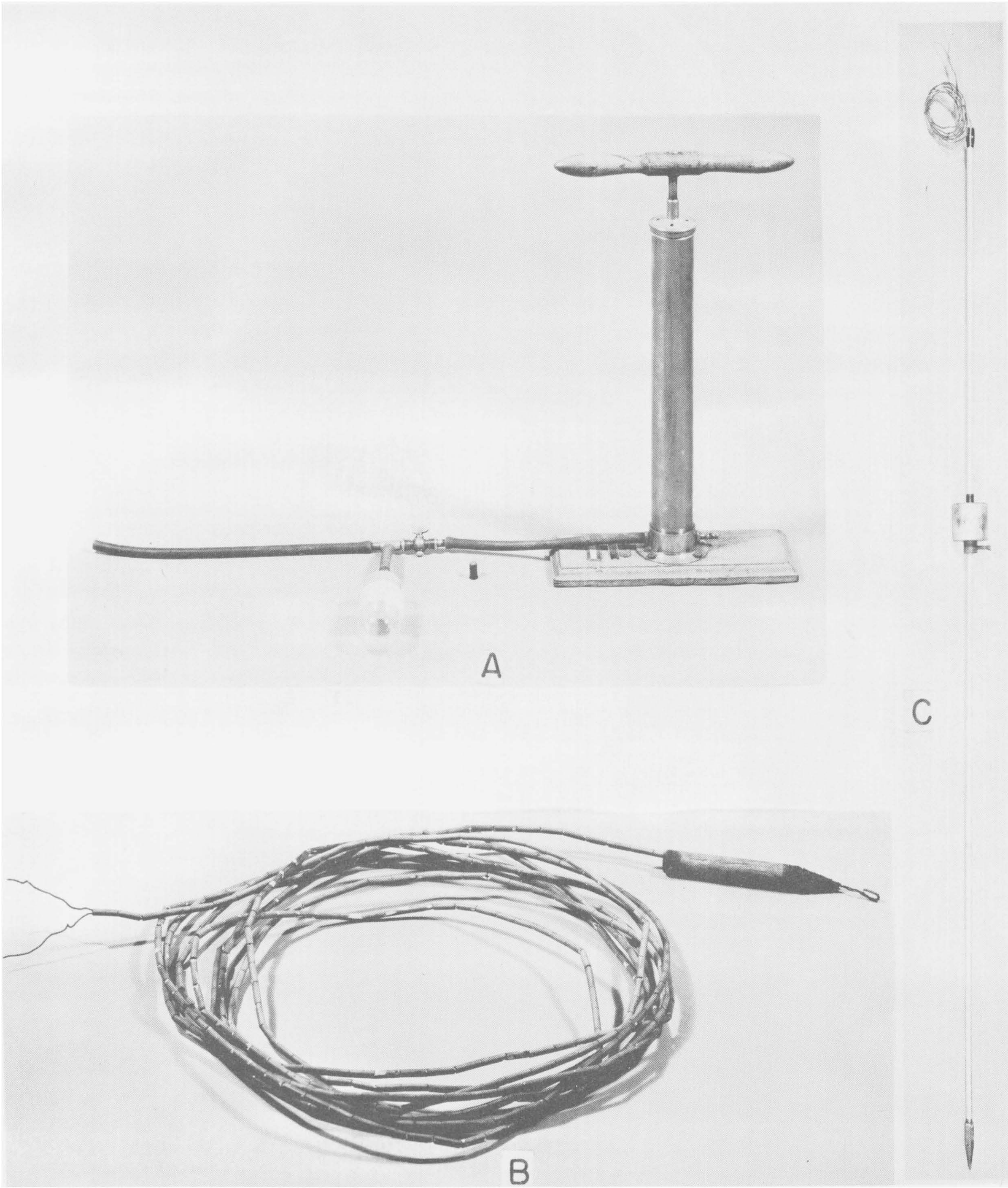


FIGURE 51.—*A*, Equipment Assembly Used for Collecting Gas Samples; *B*, Thermocouple of Ceramic-Bead-Covered Wire; and *C*, Temperature Probe Utilizing Thermocouple in Pointed End.

SAMPLING MINE ATMOSPHERES

The analysis of a representative gas sample from a sealed fire area in an active deep mine indicates the behavior of a fire. The percent by volume of carbon monoxide, carbon dioxide, and oxygen in the sample can be interpreted by experienced persons to provide information concerning the effectiveness of fire-control efforts on a sealed fire. The most important consideration in gas sampling is that the sample be representative of the atmosphere behind the fire seals. If proper devices and techniques are employed, in most instances representative samples can be obtained in deep underground mines. If the samples collected are not representative of the atmosphere around and in the vicinity of the fire, the analysis of such samples can be and in some cases have been dangerously misleading.

In contrast, the collection of representative gas samples from sealed mine fires near outcrops or under shallow cover has been extremely difficult. The same techniques employed in the collection of samples in deep mines have not been satisfactory under these conditions. The principal cause is the difficulty in finding a large cavity or opening in the sealed area from which a sample can be obtained that will be representative of the main body of air in the vicinity of the fire. It has been virtually impossible to obtain a representative sample from boreholes that intersect tightly caved mine openings. The reasons for this are: (*a*) The infiltration of only a minor quantity of outside air into the relatively small borehole column will markedly change the composition of the atmosphere in the borehole, and (*b*) if samples are collected within the borehole by removing the cap or plug at the surface, even though the borehole intersects a large area of the mine, its value will be destroyed by outside air, which immediately begins ventilating the hole.

Because of the difficulty of collecting samples from outcrop and shallow-cover fire areas and the uncertainty as to their quality, a minimum of such samples are collected by personnel engaged in coal-mine fire-control work.

Samples are taken of the mine atmosphere in a sealed or partly sealed fire area for two purposes: (1) To find out how effective the seal is, and (2) to find out whether the fire is still active. The magnitude of the oxygen reading indicates how effectively the area is sealed—a low reading indicates a good seal, and a high reading indicates a poor seal. The presence of carbon monoxide indicates that an active fire is in progress or has been active recently. The detection of hydrogen in the sample may indicate that an active fire exists in the area at temperatures above 480° F., if the fire is in bituminous coal, or 660° F., if the fire is in anthracite.

A more detailed study of other constituent gases is not usually necessary when controlling an abandoned-mine fire by the methods previously described, because there is little likelihood of an explosion resulting from the accumulation of methane in an abandoned mine; and even if this were a possibility it is not likely that there would be any persons exposed to the hazard.

For the most part, mine-atmosphere samples collected by fire-control personnel are analyzed in the Bureau gas-analysis laboratory. The analysis gives the percent by volume of the constituent gases. The sample will consist mostly of nitrogen, oxygen, and carbon dioxide. In addition, carbon monoxide, hydrogen, and hydrocarbons may be found in the sample in varying amounts, depending on the presence and intensity of the fire. Methane may be present in the absence of fire if the abandoned mine is liberating the gas.

If good representative samples can be obtained, they are taken during the maintenance program as a supplement to the temperature record. Fire-area temperatures are a more critical indication of whether the fire is controlled. Hypothetically, a mine-atmosphere sample may be low in oxygen and contain no carbon monoxide, indicating that the fire is being smothered and is no longer active, but if the temperature of any of the coal and strata is above 200° F. the fire very likely will reactivate if atmospheric air is admitted. A fire is therefore not considered to be extinguished until there are sufficient indications that all fire-area temperatures are below 200° F. As stated under "Characteristics of Propagation," the dissipation of heat is usually the most difficult problem in controlling an abandoned-mine fire. Mine-atmosphere samples have value only for indicating how effective the seal is and if active combustion has ceased.

Occasionally the samples are taken from behind fire-seal stoppings erected in abandoned entries near the fire area. Procedures and equipment for sampling mine atmospheres from behind fire-seal stoppings are described.[6] These procedures are followed where possible, and the same equipment used. However, one helpful variation in obtaining a representative sample is to install at least 50 feet of small-bore copper tubing through the seal and into the sealed area. These samples drawn from some distance behind the seal are not affected as readily by any leakage of air through or around the fire-seal stopping as are samples obtained immediately behind the seal.

Most mine-atmosphere samples obtained for abandoned-mine fire-control work are taken from boreholes drilled from the surface. The objective is to intersect mine openings; however, since accurate mine maps are not available and the mine workings are inaccessible to survey, some of the holes may penetrate solid coal. These have little value. If the borehole does reach a mine opening a sample is drawn from the mine through a tube inserted in the bottom of the hole, or a special device known as a mousetrap is used. Several problems are encountered in connection with sampling through a tube. To obtain a representative sample from the mine through a borehole, the end of the sampling device must be in a mine opening leading to the fire. Samples obtained in the relatively small space in the borehole above the mine are too readily affected by leakage of air caused by changes of barometric pressures and flow of ventilating or stack currents created by hot gasses over the fire, the latter occurring when the hole is opened for sampling. Samples obtained in the borehole show wide variations in oxygen content, too frequent and erratic to be reasonably accounted for by changes in the composition of the mine atmosphere.

The preferred procedure for obtaining a representative sample from a borehole is to insert the end of a tube into a mine opening at the bottom of the hole, seal the top of the hole for 24 hours or more, then collect several samples for 1 or 2 days. If the oxygen content of these samples is fairly constant it may be assumed that representative samples are being collected.

[6] Berger, L. B., and Schrenk, H. H., Sampling and Analysis of Mine Atmospheres: Bureau of Mines Miners' Circ. 34 (rev.), 1948, pp. 15–26.

Equipment used for obtaining a borehole sample consists of a length of copper tubing, a double-acting foot pump, a vacuum-type air-sample container, a tee, a valve, and three short lengths of rubber tubing. (See fig. 75*C*.)

A length of copper tubing long enough to extend from the surface into the mine is inserted into the mine cavity. Plastic and rubber tubes will serve the same purpose if the heat in the hole will not destroy them. If copper tubing is used it should be curled at the end to prevent plugging it on the way through the hole to the bottom. (See fig. 48.) At the top of the hole this tube is connected to the arrangement shown in figure 51. Connection is made to the rubber tube on the left so that when air is drawn from the mine it passes through the tee, valve, and foot pump in that order. The vacuum bottle is connected by a short length of rubber tubing to one stem of the tee fitting. The bore opening in the tubing is purged with the valve open. The foot pump draws air in through the tube on the left and discharges it through the orifice on the right. A rubber-bulb hand aspirator also may be used for this purpose. However, long lengths of tubing can be purged more quickly with the foot pump, because it has a greater air capacity and more efficient valves. After the line has been purged the valve is closed; then the stem of the vacuum bottle is broken by bending the tube. This permits mine air to be drawn into the bottle, which is then disengaged from the rubber tube. The broken stem is sealed with the wax-filled cartridge shown in figure 51.

A permanent gas-sampling installation can be made in a borehole, as shown in figure 49*A*. This figure also shows a thermocouple installed in copper tubing placed in the same borehole. The thermocouple tubing and the end of the sampling tube are shown at the same elevation; however, these two locations may not always coincide. To obtain a sample of mine atmosphere and be reasonably certain that it represents conditions, the end of the sampling tube must be located in an opening of the mine, and the thermocouple should be located at the hottest point in the borehole, found by previous exploration. Figures 48 and 49*A* show the terminals of the two tubes at the top of the borehole casing. The sampling tube is equipped with a valve, which is closed when not in use. This installation provides a convenient means of obtaining a sample; however, in a warm steam-laden hole the tube may deteriorate in a matter of a few weeks. If the tube becomes perforated, much of the sample will be drawn from the borehole rather than from the mine opening. For this reason, use of the permanent installation has been limited.

Borehole samples may be obtained by using a device which employs a common snap-type mousetrap to break the neck of the vacuum bottle after it has been lowered to the desired borehole elevation. Details of this construction are discussed.[7] It consists of a vacuum bottle and mousetrap mounted on a block of wood in such position that when the trap is sprung the stem of the vacuum bottle is broken. A lead weight connected to the trigger springs the trap when the lowering string is given a quick jerk. The sample bottle then is withdrawn to the surface and is sealed. The device has several applications, such as in sampling from mine shafts, sewer manholes, gas or water wells, and empty oil tanks. However, its use in borehole sampling in fire areas has had several drawbacks. The most serious of these is the fact that the hole must be open at the top to manipulate and trip the device. This permits ventilation of the borehole. In addition, it requires at least a 6-inch diameter borehole for its insertion, and even in the 6-inch diameter hole difficulty may be experienced in raising and lowering the instrument. In holes deeper than about 50 feet the snap of the trap, indicating that the sample has been taken, may not be heard on the surface. Consequently, there is no certainty that the sample was taken at the desired depth, since it may have been snapped accidentally by the maneuvering necessary to lower it through the hole.

An improved device embodying some of the same principles has been developed. It can be snapped and sealed electrically and is more compact. (See fig. 52.) This instrument has eliminated some of the undesirable features of the original device.

On-the-spot determinations for oxygen can be made at the fire site, using either a quick-check analyzer or a portable oxygen indicator. (See fig. 53.) Aspirating atmosphere from behind a seal or from a borehole is the same when using these instruments as described for taking a sample, but, instead of obtaining a sample for laboratory analysis, an on-the-spot oxygen determination is made with the instrument.

[7] Fene, W. J., Novel Device for Collecting Air Samples in Inaccessible Places: Bureau of Mines Inf. Circ. 7122, 1940, 2 pp.

The principle of operation of the quick-check analyzer depends on measuring the reduced pressure resulting when oxygen is absorbed by chromous chloride from a sample aspirated into the chamber. The reduced pressure is registered on the indicating dial, which is calibrated to show the percentage of oxygen present in the sample.

The portable oxygen indicator consists of a galvanic cell with a zinc and a hollow carbon electrode in an electrolyte designated as "oxylite." The current generated by this cell is inhibited by polarization of the carbon electrode. The mine atmosphere is aspirated through the hollow electrode. Oxygen in the same atmosphere restores the current flow. The depolarizing action produced is variable with the oxygen concentration and is reflected in the electrical indication of the meter. The indicating meter is calibrated to read in percent of oxygen in the aspirated air. This instrument has been used with satisfactory results.

A test for carbon monoxide can be made using a colorimetric detector. This detector consists of a glass tube containing a yellow indicating gel. When an atmosphere containing carbon monoxide is aspirated through the detector tube the indicating gel turns from its normal bright yellow to bright green, darker greens, and finally dark bluish green, depending upon the amount of carbon monoxide present. Using the arrangement shown in figure 51*A*, the colorimetric tube with aspirating devices may be inserted in place of the vacuum bottle. The line is purged with the valve open. The valve is then closed and the mine atmosphere is aspirated through the colorimetric tube. Information concerning the operation and maintenance of colorimetric carbon monoxide detectors has been published.[8] Tests have shown that in all instances where carbon monoxide is definitely present by analysis it will be detected by the colorimetric instrument. This instrument has been used with satisfactory results.

[8] Forbes, J. J., and Grove, G. W., Mine Gases and Methods for Detecting Them: Bureau of Mines Miners' Circ. 33 (rev.), 1954, pp. 54–56.

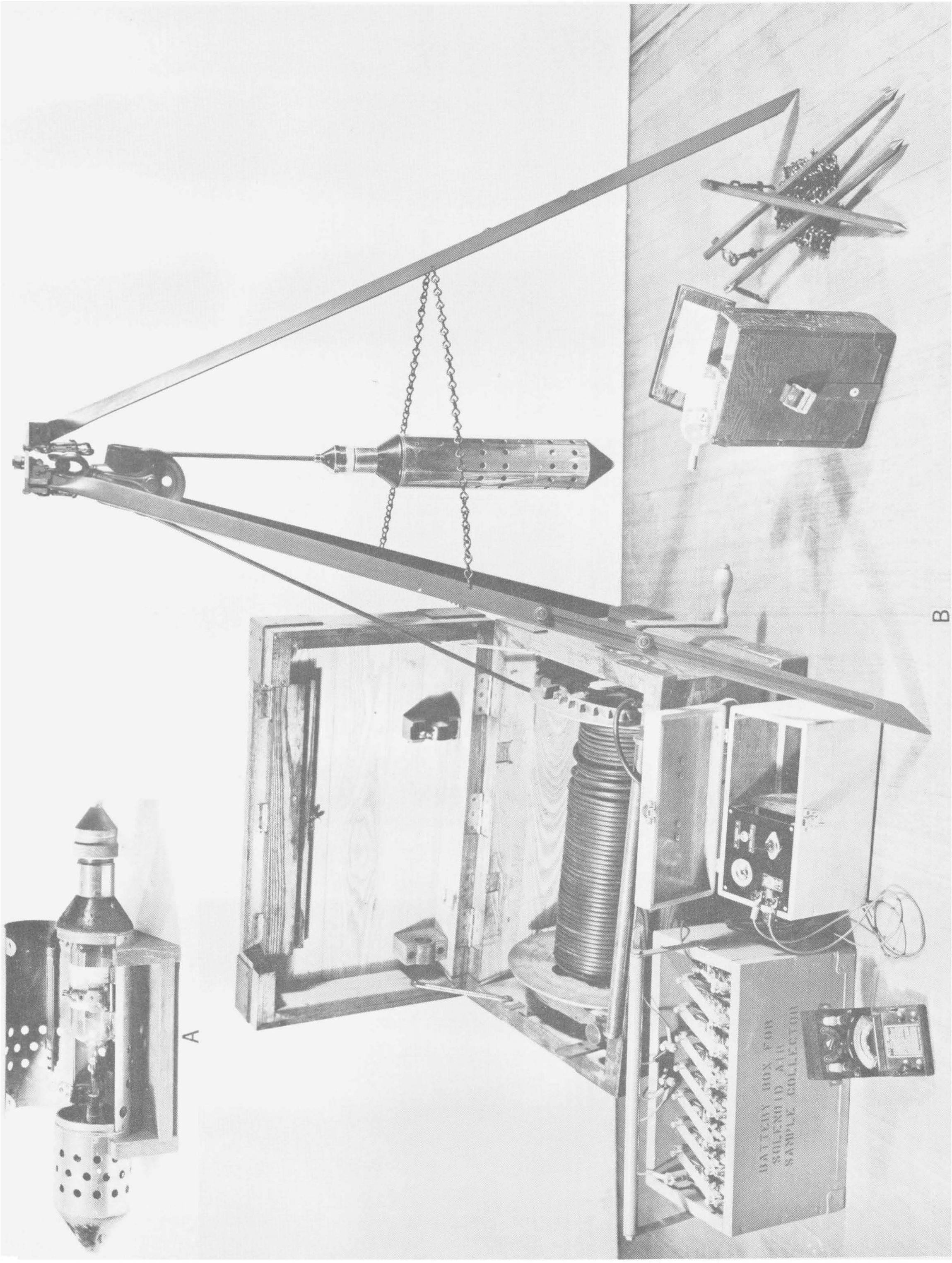


FIGURE 52.—*A*, Details of Gas-Sampling Device; *B*, Electrically Actuated Gas-Sampling Device and Equipment Needed For its Operation.

FIGURE 53.—Portable Oxygen Indicator and Quick-Check Analyzer.

CARBONACEOUS REFUSE AND FILL FIRES

The Bureau of Mines frequently is asked for advice concerning methods of extinguishing combustible refuse and carbonaceous fill fires. Financial assistance for the control of these fires is not provided under the present law; however, the Bureau may advise on methods of control and collect information concerning such methods. As a result of this activity the Bureau has devised procedures and recommended methods, which have been successfully applied. The following information is based on this experience.

The distinction between a refuse fire and a fill fire may seem obscure, since the same type of material is involved for both, and the same methods for control could be employed. But, practically, the distinction between the two has a bearing on the recommended method of control. Refuse fires are in a rather isolated area; the burning material is a waste product, and the land on which it was spoiled has value only as a disposal area. Control of a refuse fire is usually motivated by the desire to eliminate a nuisance and health hazard, which is polluting the atmosphere, or perhaps to prevent its propagation into a coalbed. Fill fires occur in the same type of material, but surface improvements have been made on the fill area so that the burning material is no longer refuse but part of valuable property. The location of surface structures on the fill complicates the control procedure, but at the same time the value of the property warrants more expensive control procedures.

Refuse and fill fires occur in strip-mine spoil, waste from coal mines and coal-cleaning plants, garbage or trash dumps, and fill obtained from excavations in or near the coal outcrop. Some of these materials ignite spontaneously, but most are ignited by an external source of heat or fire. Fires tend to propagate through them because they are loosely compacted, which permits circulation of air. It is known that in some instances fires have propagated in fills containing as little as 12 percent combustible matter. Industrial sites reclaimed by using combustible fill material may be ignited by heat transferred from heating equipment, such as open hearth or forge furnace. These heat sources raise the temperature of the fill ground and accelerate oxidation of the combustible particles. At the same time the elevated ground temperatures tend to create convection currents in the porous material, which draw air through the warm ground. Another frequent source of ignition is the heat from a trash or warming fire burning on combustible fill.

Loading-out, trenching, grouting, and covering to exclude oxygen are methods that have been used to control refuse and fill fires. The precise method to be employed at a particular fire is governed by several factors; namely, the extent, depth, and intensity of the fire, type of material burning, whether any surface improvements are located above the burning material, and whether the fire may propagate and extend under surface structures or to an exposed coalbed.

In controlling these fires a word of caution is necessary. Dousing the fire with a stream of water is ordinarily the first means of attack used by inexperienced persons. This may be hazardous, because the introduction of water into a hot area may produce water gas, a mixture of hydrogen and carbon monoxide. Both of these gases have a wide range of explosibility, and the hazards to life and health from carbon monoxide generally are known. In addition, part of the pile may explode, owing to the sudden conversion of an inrush of water to steam. The application of water in this way has been generally ineffective; this is true whether the water is introduced through crevices extending to the surface or through boreholes drilled into the burning material. The fire may be subdued for a time but may rekindle and burn with renewed vigor. Presumably, a stream of water washes channels in the unconsolidated material, which increases air circulation after watering ceases, and the air admitted through these channels causes the fire to reactivate with renewed intensity. Before introducing a stream of water these possible adverse effects should be considered carefully.

The following procedures have been employed successfully for controlling these fires:

REFUSE FIRES

GARBAGE OR TRASH DUMP

The usual recommendation in controlling garbage or trash-dump fires is to level and compact the dump and cover the entire refuse area with a finely divided incombustible material. A material that does not bake and crevice is most effective. Fly ash or granulated slag are two materials recommended; however, shaley and sandy earth materials have been used with success where the seal is maintained by harrowing. Heavy clays have not proved satisfactory because baking and shrinkage cause crevices, permitting air to reach the fire. The covering method is intended to smother the fire by stopping the circulation of air through the burning material.

Several successful applications of this method are on record. A burning trash dump near Greenville in Mercer County, Pa., was extinguished by covering it with a layer of sand obtained from a nearby foundry. A garbage and trash-dump fire in Jefferson Borough, Pa., was extinguished by covering it with a layer of granulated slag 8 feet thick. In addition to creating an air-pollution problem, this fire had threatened to ignite an exposure of the Pittsburgh coalbed.

In November 1949 in the Borough of Coraopolis, Pa., a fire was burning in a rubbish dump, approximately 75 feet deep and covering an area of about 2 acres. Two costly and unsuccessful attempts were made to control the fire—one using a stream of water from a firehose and another using a dozer to level and spread a layer of clay over the dump. Several months after these control attempts, the fire reactivated, and representatives of the Bureau of Mines were requested to visit the site of the fire and advise on a method for its control. Granulated slag was recommended as a covering material, but this was not readily available. It was learned during the investigation that a waste product known as fly ash was available from a nearby electric generator plant. A sample of this fly ash, analyzed in the Bureau of Mines laboratories, contained less than 3 percent combustible. In addition, it had other desirable characteristics in that it made a relatively impervious cover, and it did not bake and crevice when dry. This material was recommended. So far as is known, this was the first time fly ash was used for this purpose. The fire was controlled by covering it with a blanket of fly ash (about 3,600 tons) approximately 2 feet in thickness.

Sanitary fill is a method of disposing of combustible rubbish, which minimizes the danger of igniting combustible rubbish and causing a fire. This method has been recommended by the Bureau on several occasions and is being employed with good results. It consists of leveling and compacting the rubbish with a bulldozer and then covering it with a layer of earth 3 or 4 feet thick. Leveling, compacting, and covering are performed at the end of each day of dumping. Subsequent layers of rubbish and earth can be placed over the previously filled areas. The earth material used to cover the rubbish is usually bulldozed or transported from a borrow area.

STRIP-MINE SPOIL AND MINE REFUSE

These fires can be loaded-out, trenched and isolated, or grouted, but the expense involved in these operations is usually not warranted by the value of the affected property or the magnitude of the nuisance created by the fire. Therefore, the most practical recommendation has been to cover the fire with a layer of fine incombustible material. If the fire threatens to propagate into the coalbed, it would be recommended that the burning portion be isolated from the coal seam by trenching, and the protected carbonaceous area be covered with incombustible material to prevent future ignitions.

Spoil fires can spread and ignite the coal and carbonaceous-shale exposures in a highwall. Strip mines, which have been backfilled by pushing the spoil against the coalbed, are subject to this hazard. Several such instances have been brought to the attention of the Bureau, and for this reason all backfilling done under the supervision of Bureau personnel requires that a barrier of noncarbonaceous material be placed against the coal and carbonaceous shales before the spoil is pushed against the highwall. It is recommended that all backfilling be done as illustrated in figure 30.

One such fire occurred in Snowden Township, Allegheny County, Pa., near South Park. An abandoned strip-mine area had been reclaimed by backfilling the spoil against the coalbed. It was reported that the fire was ignited in the spoil by burning trash on the grounds. The fire threatened to spread into the coalbed, where it could have caused widespread damage. An isolation trench, 400 feet long and averaging 12 feet in depth and about 20 feet in width, was cut around the burning section of spoil to prevent propagation. Figure 54 shows views of the dozer cutting the trench through the spoil pile. This trench and the spoil area were backfilled and covered with a layer of incombustible material, which minimized the possibility of a similar ignition on the protected side.

Spoil fires may propagate into the coalbed in strip cuts that have not been backfilled properly if there are connecting bridges of spoil that contact the bed. The fire can be prevented from extending to the coalbed if the spoil is pushed away at all points from the exposed coal in the highwall.

Mine-refuse dump fires have been and continue to be a problem in the mining industry.

FIGURE 54.—Trench Made To Isolate a Soil Fire, Which Will Be Back-Filled With Incombustible Material.

They can be extinguished if the expense involved is warranted; but, since the burning material is a waste product and the area involved is of no value except as a disposal area, a determined effort to extinguish such fires rarely is undertaken unless other factors are involved. The danger of the fire spreading into the coalbed, the existence of smoke-abatement ordinances, or the discomfort and harm to persons residing near the area from the pollution of the atmosphere are factors that may force action to control such a fire.

These refuse fires can be loaded-out and cooled with water, but this generally is not done unless the fire is small. An isolation trench will stop the propagation of the fire, but unless the protected portion of the pile is covered an independent ignition is likely to occur on the protected side. Where propagation of the fire threatens surface structures or the coalbed it is usually recommended that the burning portion be isolated by an open trench and permitted to burn out. It also may be advisable to place a protective blanket of incombustible material over the protected area to prevent any future ignition.

Covering the refuse dump with a layer of finely divided incombustible material to exclude oxygen is effective in controlling this type of fire if the proper material is used and the work is properly executed. The covering material should be such that it will not bake and crevice. The use of clay as a covering material has been responsible for many of the failures where the covering method is employed. If clay is used, the seal must be maintained by harrowing the surface periodically to fill in crevices caused by drying and shrinkage. Sand, fly ash, rock dust, or granulated slag are some of the more suitable materials used for this purpose. These materials crumble and fill in crevices as they occur.

A major problem in all covering operations is to hold the covering mantle on the slope of the dump. Where possible, before covering operations are begun, the top of the pile should be leveled and the slope graded to a uniform contour. The entire pile should be covered to the toe of the slope. On slopes greater than 30°, a retaining barrier or terrace should be provided at the toe to hold the cover in place. Provisions should be made also to provide drainways to prevent the covering mantle from being eroded off the refuse pile by storm waters.

Grouting is a method that could be used successfully to control refuse-dump fires, but it has not been recommended because of the high cost of the operation. This method would consist of filling the voids in the porous refuse material by injecting a slurry of lime, rock dust, fly ash, or portland cement. These materials would be introduced in the form of a slurry through holes drilled or driven into the material and would be forced into the material under pressure or by gravity flow. The grouting method is described more fully in this publication in the section on "Carbonaceous Fill Fires."

A water-spraying method for controlling mine-refuse dump fires was used in Great Britain during World War II. Extensive research and development were done in an effort to extinguish these fires, because they served as markers for enemy aircraft. The method is reported to be effective, and consists of the continuous application of a fine water spray over the entire refuse dump. Intense steaming probably results from this application, and there is the possibility of the production of water gas from the reaction of hot carbon and water, which would create an explosion hazard. So far as is known, the method has never been used in the United States for controlling a mine-refuse fire, although a similar technique is being employed on an experimental basis by the Bureau to extinguish an underground mine fire. The following information on this work by the British is quoted from a Bureau of Mines publication:[9]

> A committee of the Midland Institute of Mining Engineers studying "The Extinction and Prevention of Colliery Spoil-Heap Fires" in 1942 presented the following summary of the results of its investigations:
>
> Application of water is very effective when it is distributed through a system of sprays in such a way that it will seep into the burning heap without undue disturbance of the surface.
>
> It cannot be too strongly reemphasized that spraying must be continuous, especially in the early stages, until the fire is controlled, as 1 day's cessation may undo the good work done by a week's regular treatment.
>
> Suitable sprays not likely to choke should be used. Many types have been tried, but those with saw nicks and cone-type sprays produce the best results.
>
> In addition to the cooling effect, water spraying accelerates the weathering of the spoil and tends to wash fine and disintegrated material into the base of the heap, thus producing a more consolidated mass, to the exclusion of air.
>
> So long as tipping (dumping) continues, spraying should be carried on, although it need not necessarily be continuous once the heap has been cooled down. Fresh spoil, if not wetted at the time of tipping, should be well sprayed when tipping has finished at the end of each day.
>
> Many collieries had used water to try to put out fires by (*a*) directing it in bulk through hose pipes, and (*b*) letting it run down prepared holes. Their experience was that fires, subdued for a time, frequently broke out afresh and even with increased vigor.
>
> After more than a year's experience with water spraying, it can be confidently stated that by this

[9] Harrington, D., and East, J. H., Jr., Burning Refuse Dumps at Coal Mines: Bureau of Mines Inf. Circ. 7439, pp. 21–22.

means, when carried out efficiently, dirt-tip fires can be kept under control.

In this country, control efforts have been made by some coal companies in which the surface layers of burning mine-refuse piles were compacted using heavy equipment. Some of these compacting experiments were unsuccessful, primarily because it was impossible to compact the surface of the slope. In these instances if the slope areas had been covered with finely divided incombustible material in addition to compacting the top of the pile, the fire might have been extinguished.

Pumping a stream of water into the fire area is ineffective as it has the same disadvantages mentioned in the introduction to this subject. In addition, portions of burning refuse piles have exploded, owing to a sudden inrush of water into an extremely hot area. When a large quantity of water enters a hot area it is rapidly converted to steam. Since the expansion of the steam builds up pressure in the refuse pile more rapidly than this pressure can be dissipated through the pores of the material, the pile may explode with violence. Three such explosions are known to have had disastrous results. All resulted from the sudden inrush of storm waters. One occurred in central Pennsylvania, one in western Pennsylvania, and another is reported to have occurred in Kentucky. So far as is known, this has never occurred during attempts to control a fire, but the possibility should not be overlooked.

CARBONACEOUS FILL FIRES

Occasionally carbonaceous fill fires are loaded-out where the affected area is small and there are no surface structures over the fire area. This is the most effective method of eradicating such a fire. Incipient fires, and especially those on the toe of a fill slope, generally can be excavated, and the resulting void backfilled with incombustible material.

Where the fire area is of little value but there is danger of fire spreading under valuable surface structures, a barrier trench may be installed to isolate the fire. Then the protected fill area should be covered to prevent other ignitions.

The pressure-grouting method is the most frequently used method for extinguishing this type of fire. It is very effective, and its application does not require dismantling surface structures. Grouting also stabilizes the filled ground and precludes the possibility of other ignitions in the grouted area.

The method consists of forcing a slurry of water and finely divided incombustible into the interstices of the porous fill material. Air is excluded from the fire by filling these voids. Temperature readings should be obtained in the fire area to find the location and depth of the fire. These may be obtained either by drilling boreholes into the fill and inserting a thermocouple or by driving a probe with a thermocouple imbedded in the tip into the fill. Grouting should be started on the perimeter or low-temperature area of the fire and continued in concentric circles toward the high-temperature area. This procedure permits some cooling of the hot areas as the perimeter is being grouted and is a precaution against the formation of water gas resulting from the application of water to a carbonaceous fire at temperatures above 660° F. In this connection carbon dioxide has been used to cool hot areas, but it was not effective chiefly because of the difficulty of introducing the gas into the fill and because of its poor cooling qualities.

Grouting in the hole is begun at the bottom, and the hole grouted in increments as the pipe is withdrawn to the surface. Each increment should be grouted to refusal at a pressure determined experimentally. This usually is in excess of 40 p.s.i. Portland cement, lime, pulverized limestone, and fly ash, or a combination of some of these, have been used as grouting materials. The consistency of the slurry, as related to the percentage of water and solids, should be determined on each job. This is necessary because voids of the fill material may vary at different fire locations. The object is to fill the interstices and at the same time get the maximum radial penetration from each borehole. Mixes of 1,500 to 2,500 pounds of solid material and 400 to 500 gallons of water have been used and were satisfactory.

Several devices have been used to introduce the slurry into the fill material. An early one was a pointed 2-inch pipe with perforations on the side near the tip. This was driven into the fill, and the slurry forced out through perforations in the pipe. This scheme was not entirely satisfactory, because the perforations became plugged with material from the fill; and when high pressures were used to overcome this condition the slurry escaped to the surface around the outer walls of the device. A later development was a pipe with a dispensable point (see fig. 55). The pipe and point were driven into the fill to the bottom of grouting depth. The point was knocked off the end of the pipe by inserting a rod through the pipe. The grout was forced into the fill through the end of the pipe. The hole was grouted from the bottom to the top of the hole by withdrawing the pipe in increments of 18 inches. Good results were obtained also by

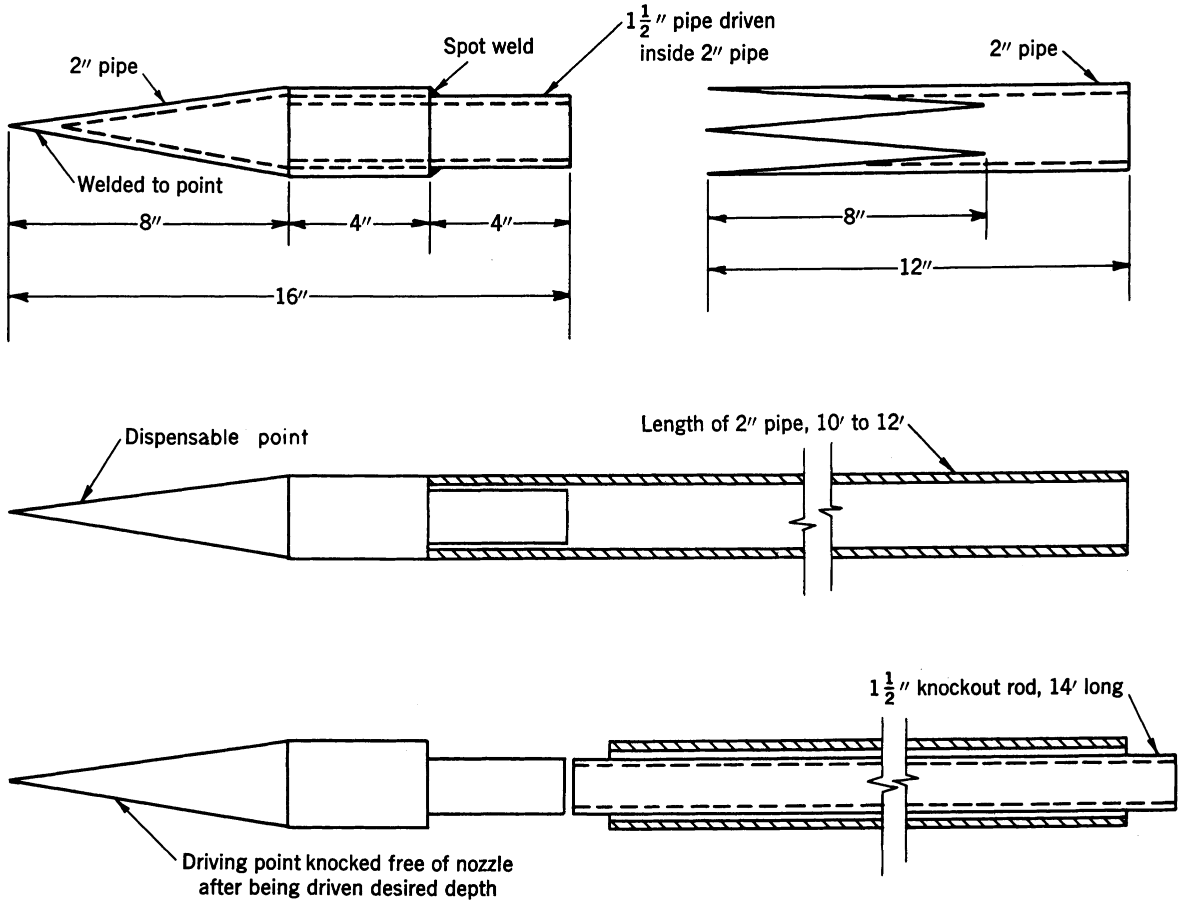


FIGURE 55.—Sketch of Slurry Nozzle With Dispensable Point.

drilling 1½-inch holes in the fill and inserting a 1-inch pipe with a well point on the end. This requires drilling equipment, whereas the other devices are driven into the fill.

The Bureau has advised on several fill fire-control projects, some of which are described below:

A fire in fill under a steel-company plant at Leechburg, Pa., was ignited by the heat of an open-hearth furnace. Fill about 35 feet deep, covering an area of more than 1 acre under the floor of the plant, was affected. A maximum temperature of 1,135° F. was recorded. The fire was extinguished by pressure-grouting with a slurry of lime and water. In excess of 775 tons of lime was used. Procedure was to make holes in the concrete floor with a jackhammer and then drive 6-foot lengths of 2-inch pipe 12 to 24 feet into the fill. The first section of pipe was pointed and perforated on the sides near the point. The slurry was forced into the fill to refusal at pressures varying from 30 to 50 p.s.i.

* * * * *

A fire occurred in a fill area of about 2,500 square feet and 10 feet deep under a petroleum storage plant on Neville Island, near Pittsburgh, Pa. The fill consisted of carbonaceous refuse containing oil-soaked fuller's earth. Hot ashes dumped on this fill ignited the fire. A maximum temperature of 722° F. was recorded in the fire area. The fire was extinguished by pressure grouting with a slurry of water and a limelike refuse material from a nearby plant, which made acetylene. Grouting was done through 2-inch pipes with dispensable points, which were driven into the fill. Fifty-two holes, averaging about 9 feet deep, were grouted. Approximately 1 million gallons of slurry, containing in excess of 640 tons of solids, was pumped into the ground to fill the interstices and voids to exclude air from the fire. Figure 56 shows the location of this fill fire and equipment used for its extinguishment. A worthwhile note in connection with this fire is that a layer consisting of several inches of pulverized limestone was placed on the ground beneath the building shown in figure 56*A* to prevent the underground fire from igniting and destroying the building structure.

* * * * *

A fire involving a section of filled ground about 80 feet in diameter and 25 feet deep occurred under the plant facilities of a steel company in Pittsburgh, Pa. (See fig. 57.) Heat from molten steel spilled from a ladle ignited the fill. A maximum temperature of 1,220° F. was recorded at a depth of 10 feet. The fire was controlled by pressure grouting the area with a slurry of water and portland cement, beginning on the perimeter and continuing in circles of decreasing radius to the focal point of maximum temperature. Grout holes showing a temperature in excess of 200° F. were cooled with carbon dioxide before grouting. This

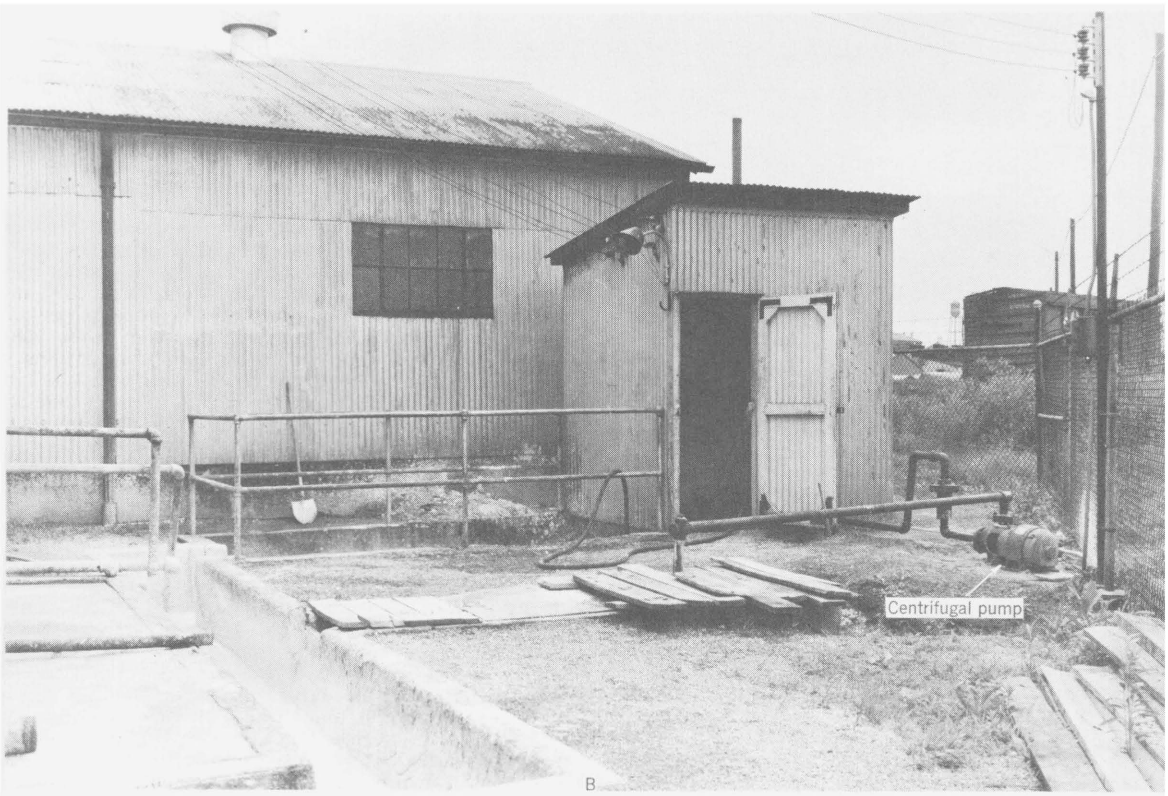


FIGURE 56.—*A*, Fill-Fire Area, Neville Island, Allegheny County, Pa., Showing Layout of Pumping Equipment and Piping System Used To Distribute Slurry To Boreholes; *B*, Pump Used To Transport Slurry From Source Tank To 400-Gallon Tank at Fire Site Shown in Top Photo.

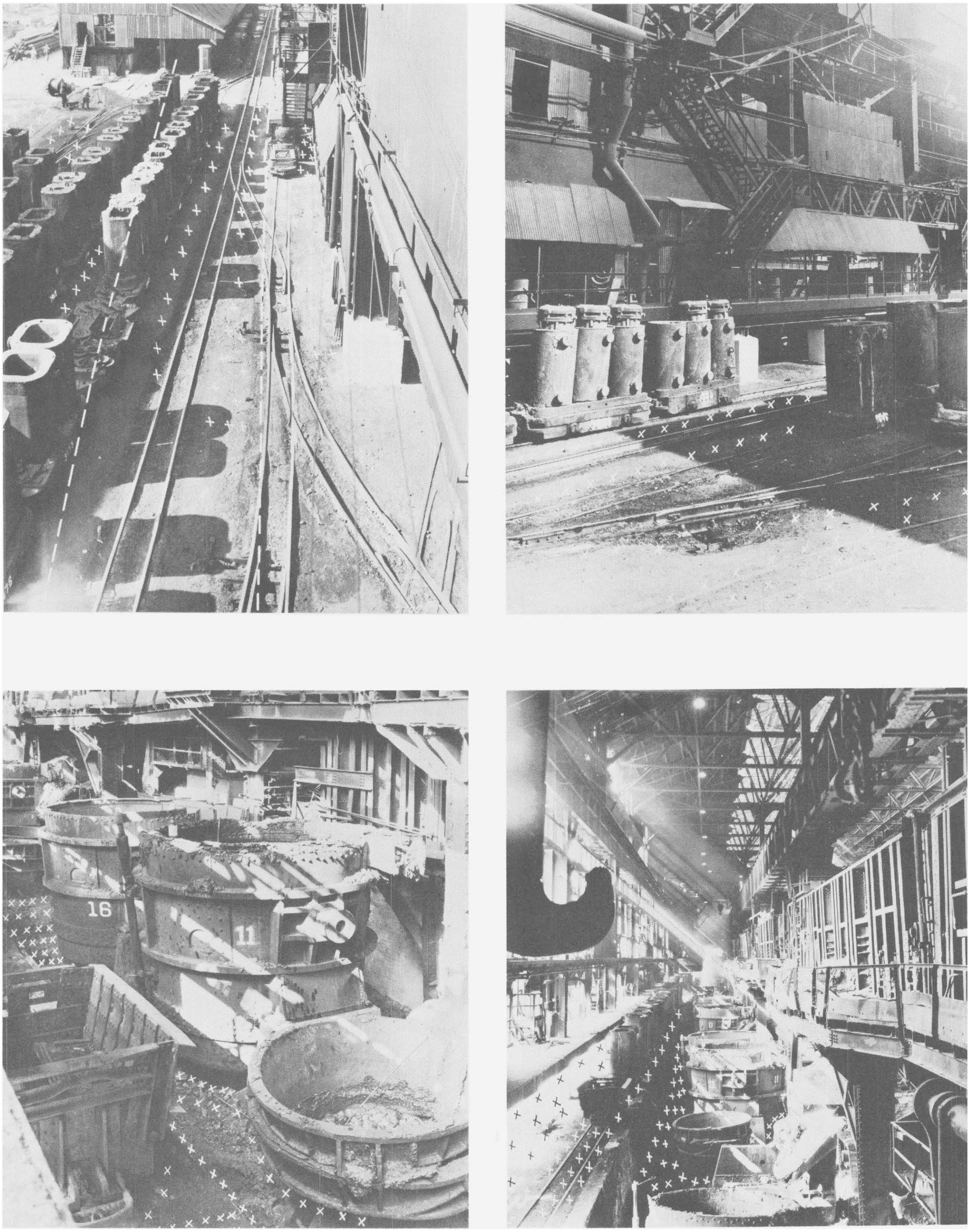


FIGURE 57.—Location of Fire (xxx) in Floor of Large Steel Plant in Pittsburgh District.

operation required 2,375 pounds of carbon dioxide. About 360 tons of portland cement was mixed with water and pumped into 19 grouting holes drilled into the fill.

* * * * *

Combustible fill surrounding an underground railroad tunnel in Pittsburgh, Pa., was ignited by a source not definitely determined. (See fig. 58.) The fire affected a section of the tunnel 150 feet long.

A maximum temperature in excess of 1,000° F. was recorded in the burning fill. The fire was controlled by pressure grouting under the floor and outside the stone walls of the tunnel with a slurry of water and portland cement. The operations took about 1 month and used 300 tons of portland cement.

* * * * *

A fill fire occurred under the main plant of a steel company in Washington, Pa. Holes were drilled through the concrete floor into the fill on 6-foot centers to locate the hot areas. Then a slurry of 25-percent pulverized limestone and 75 percent water, by volume, was pumped into the fill under pressure to refusal at 100 p.s.i. Grouting was begun at the bottom of the fill and the pipe raised in 18-inch increments toward the top of the hole. It was started on the 100° F. circle and extended toward the hottest areas at the center. These operations successfully extinguished the fire and stabilized the building structure.

* * * * *

A fill fire occurred under a manufacturing plant in Pittsburgh, Pa. A surface area of about 10,000 square feet was involved, and the fill was from 8 to 16 feet deep. The fire is believed to have been ignited when lightning struck a surface structure and followed some underground duct work into the fill. The maximum temperature recorded in the fill was 1,400° F. The fire was extinguished by pressure grouting the area with a slurry of water and lime and also a slurry of water and a carbide waste product. About 600 pounds of carbon dioxide was introduced into the fire area through boreholes to reduce temporarily the temperatures in some of the extremely hot holes before grouting. A total of 47 tons of lime and about 4,000 gallons of carbide refuse was used in these grouting operations.

* * * * *

A fill under a manufacturing plant in Pittsburgh, Pa., was ignited by heat from a forge furnace. The burning fill contained about 14 percent combustible. It had been covered with about 1 foot of clay so that the presence of carbonaceous fill was not known before detecting the fire. About 5,000 square feet of area was affected, and the fill averaged 8 feet deep. The fire was extinguished by pressure grouting the area with a slurry of water, portland cement, and pulverized limestone. One-and-one-half-inch holes were drilled into the fill, and a 1-inch pipe with a well point at the end was used to introduce the slurry. The slurry was pumped from a mixing tank by a worm-type pump and forced into the fill to refusal at 80 p.s.i. or until the slurry appeared at cracks on the surface.

SUMMARY AND EVALUATION OF CONTROL METHODS

Six methods of controlling a carbonaceous refuse or carbonaceous-fill fire have been described. Four of these methods—loading-out, grouting, trenching, and covering—have been used successfully. Compacting and spraying are experimental methods that have not been used enough to evaluate their effectiveness; however, they hold promise.

Loading-out all the burning material and removing it is the most effective method. It is usually employed when the fire is of limited extent and there are no important structures over the fire area. A supply of water should be available to cool the material as it is excavated. Incipient fires on the toe of a fill or refuse slope often can be easily disposed of by loading-out.

Grouting to fill voids and exclude air from the fire is a very effective method. It has become a more or less standard recommendation where equipment or plant facilities are located on the fire area. It extinguishes the fire, stabilizes the ground, and minimizes the possibility of reignition. It requires special equipment and skill, but company personnel usually can be trained to perform the operations.

Trenching to surround and isolate a fire is done to keep it from spreading. It has been used to protect surface structures or to prevent propagation into a coalbed. Isolation trenches should be backfilled with incombustible material. The fill area being protected by the trench should be covered to prevent a future ignition. Barrier trenches usually are excavated to the bottom of the carbonaceous material.

Covering with an incombustible mantle or blanket is an effective method if done properly. An incombustible, finely divided material such as lime, pulverized limestone, fly ash, or granulated slag can be used. Materials that dry out and crack, such as clay, should be avoided unless the seal is to be maintained by harrowing or other reconditioning measures. The top of the pile should be leveled and compacted. Slopes on the pile should be less than

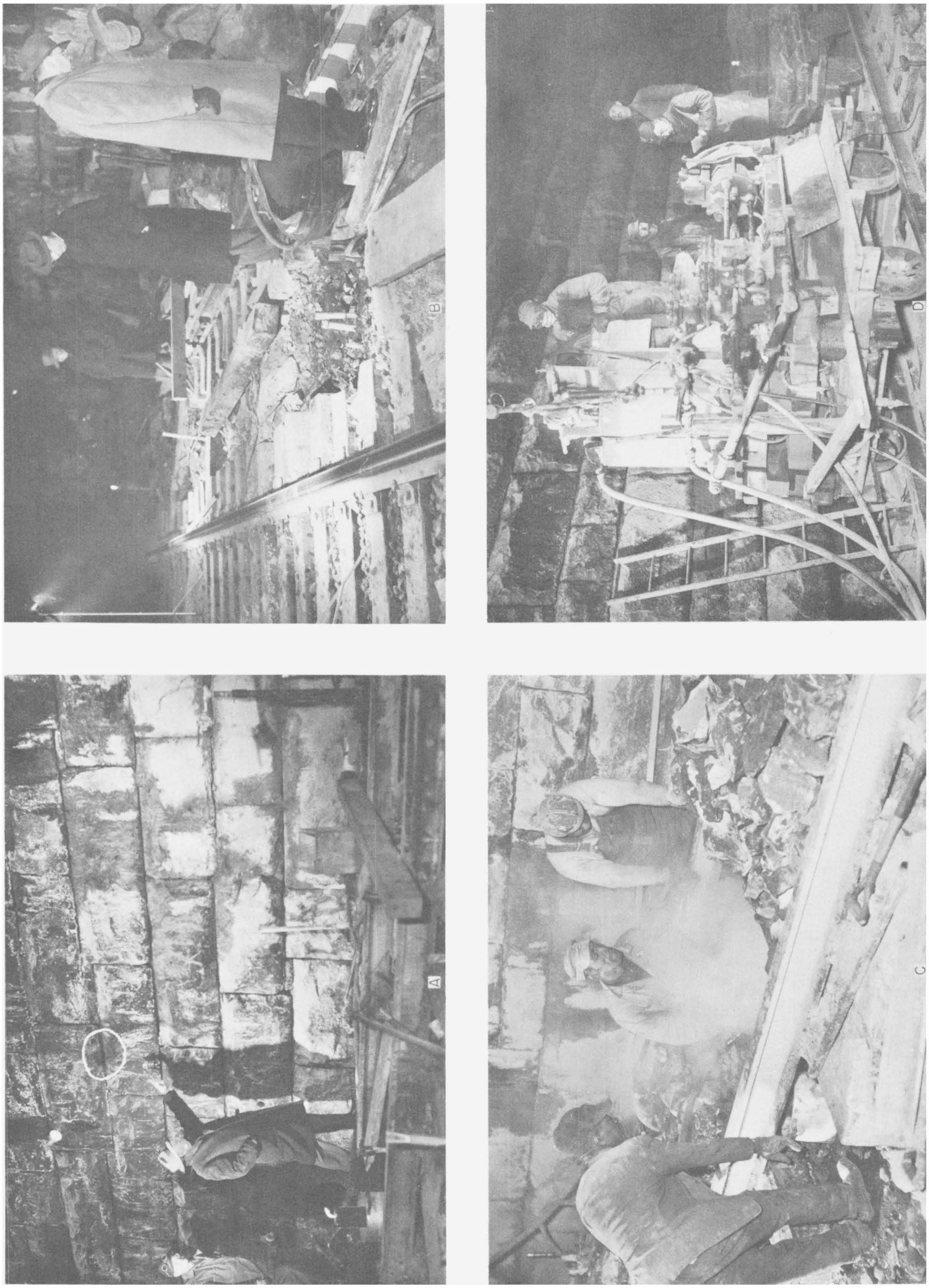


FIGURE 58.—Railroad-Tunnel Fire-Control Project: *A*, Opening in Stone Sidewall From Which Hot Vapors and Gases Evolved; *B*, Grouting Pipes Through Which Slurry Was Pumped Under Floor of Tunnel; *C*, Drilling Grouting Boreholes in Floor of Tunnel; *D*, Some of Equipment Used for Flushing Voids in Fire Area.

30°; otherwise, retaining barriers or terraces should be erected at the toe to hold the cover from sliding. The entire affected area, including the slopes, must be covered. Drainage facilities should be provided to prevent storm water from eroding the finely divided mantle or blanket. Covering is a more or less standard recommendation for controlling rubbish-dump fires, although the method is used to control other underground fires as well.

Compacting the fill material to exclude air is a method similar in principle to the covering method. An attempt is made to create a sealing cover on the mine-refuse pile by pulverizing and compacting the surface. The method holds promise of being effective if the slope of the pile also can be compacted or covered with incombustible materials.

Continuous water spraying of burning mine-refuse piles was utilized in England during World War II to control the visible portions of fires. It was reported to be effective in keeping these fires under control; however, it is not known whether the control was temporary or permanent. Apparently, the method has never been tried in this country, although an experiment being conducted by the Bureau uses a similar method of controlling an abandoned-mine fire under about 50 feet of permeable strata.

RESEARCH TO DEVELOP FIRE-CONTROL METHODS

Research to develop more effective and efficient methods has been made possible by Public Law 738. Section 3 authorizes the Secretary of the Interior to conduct research relating to control methods and to publish the results of such research. Personnel assigned to fire-control work have given this matter serious study and have developed new and more efficient methods in the application of known principles of underground fire control.

The surface-sealing method is one such application successfully utilized in controlling a great number of coal-mine fires under varied physical conditions. However, the surface-sealing method has limits of application, as have all known methods of combating these fires. Therefore, it is necessary to continue research in an effort to devise successful methods of combating fires that defy control by present methods.

An experimental site for conducting research is provided by an abandoned-mine fire at Lloydsville, Pa. In 1949 attempts were made to extinguish this fire by the surface-sealing method, but they were not completely successful. The fire was extinguished in the original fire area, but it spread south to a new location, where it continues to burn. This is the location where experiments are being conducted. The fire is in the Pittsburgh coalbed, which averages about 7 feet in thickness and dips about 3° E. The burning coalbed is under strata ranging in thickness from 17 to 45 feet and underlies about 2 acres of surface. Three experiments were conducted at this site; two are completed and one is in progress. All three were attempts to extinguish the fire with water, so the experiments were essentially tests of three different methods of applying water to an underground fire.

Water is an effective cooling medium, and its cooling capacity is greatly increased when the water is converted to steam. It absorbs heat at the rate of 1 B.t.u. per pound for each degree of heat increase until it reaches a temperature of 212° F. At normal atmospheric pressure the water is converted to steam at this temperature. Upon conversion to steam at 212° F., the water absorbs an additional 970 B.t.u. per pound. Therefore, 1 pound of water introduced at a temperature of 55° F. and raised to steam at 212° F. would absorb approximately 1,127 B.t.u. from the fire. In addition to this cooling effect the steam produced in the underground fire areas inundates the voids to the exclusion of oxygen. In other words, the steam acts as an inert gas diluting the oxygen content of the mine atmosphere. Being in gaseous form, the water vapor penetrates into otherwise inaccessible parts of the mine (especially the higher elevations), thus inundating the mine voids with an atmosphere of reduced oxygen content. Introducing water into the burning underground workings therefore has both a cooling and a smothering effect on the fire.

FIRST EXPERIMENT

In the first experiment water was introduced into the underground openings as a finely divided spray. Boreholes were drilled from the surface to intersect the coalbed. Through each borehole a spray nozzle on the end of a length of ¾-inch pipe was inserted into the mine opening. The opening was sprayed continuously if the temperature was over 212° F., which was considered sufficient to convert the spray water to steam. Water applied to the fire as a fine spray gives the highest possible thermal efficiency because it exposes maximum water surface to the heat of the fire.

A record of the borehole temperatures was maintained during the experiment. The temperature of a borehole was taken as soon as it was drilled and recorded as the original borehole reading. Subsequent temperatures were recorded as indicative of the effectiveness of the spraying operation. A potentiometer and 60-foot lengths of iron-constantan thermocouple extension wire were used to obtain borehole temperatures. Figure 59 is a plan view of the experiment site, showing location of boreholes. Figure 60 shows some boreholes that have been purposely uncapped to show steam issuing from the underground fire.

EVALUATION OF FIRST EXPERIMENT

Evaluation of the experiment was based on the borehole temperature readings, which were the most direct indication of the fire's activity. In this connection much difficulty was experienced in obtaining temperature readings, owing to the caving of the boreholes. The broken condition of the overburden, excessive heat from the fire, alternate cooling and heat recov-

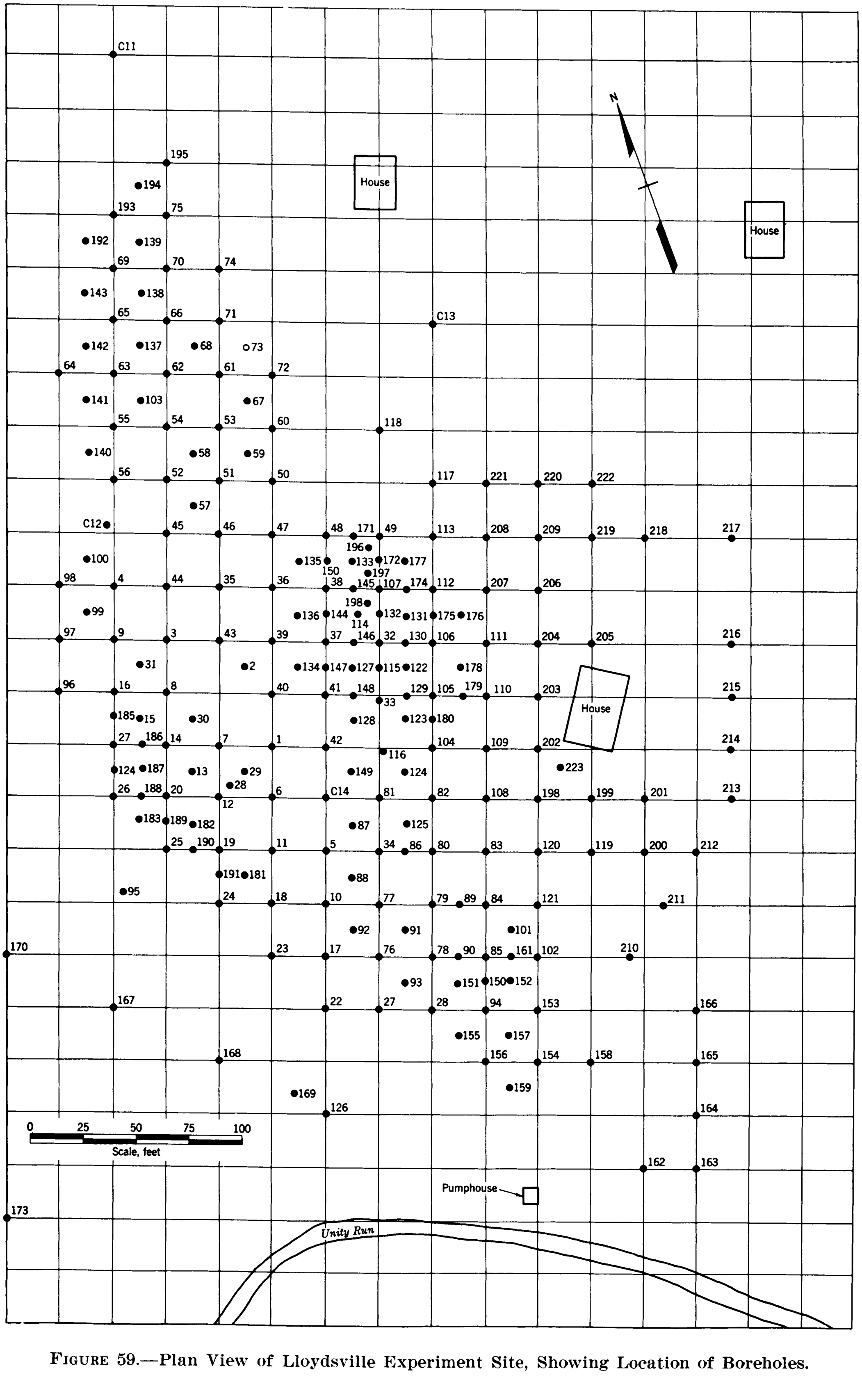


FIGURE 59.—Plan View of Lloydsville Experiment Site, Showing Location of Boreholes.

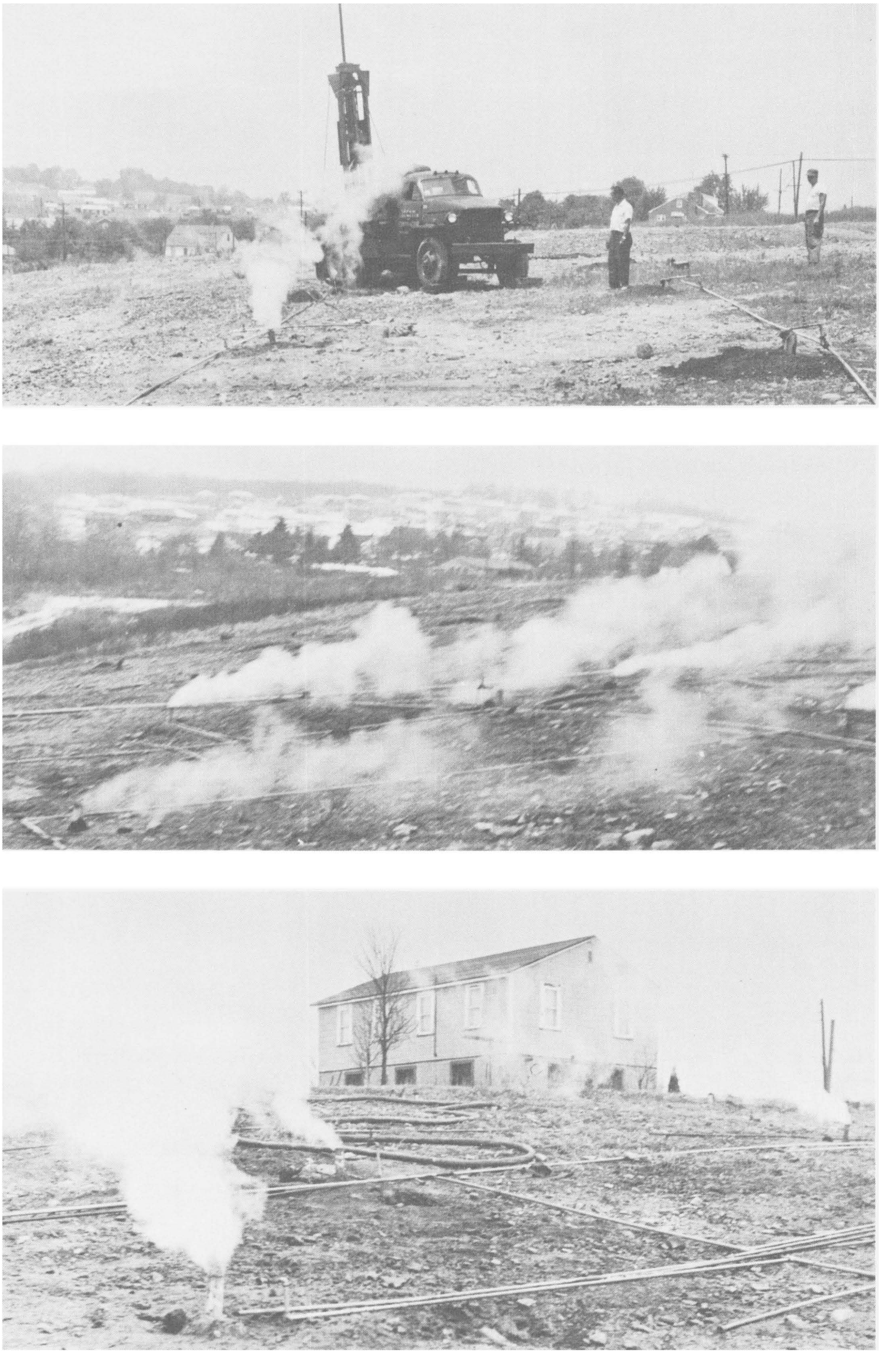


FIGURE 60.—Site of First Experiment. (Some boreholes purposely uncapped to show steam issuing from underground fire.)

ery, and moisture generated by the spraying, caused the walls of the boreholes to cave. Seventy percent of the boreholes caved to 6 feet above their original depth, which had been to the floor of the coalbed. The average cave was about 12 feet. Caving made it impossible to compare the original borehole temperatures with subsequent temperature readings in the caved hole. A number of the holes caved to within 10 or 12 feet of the surface. Under these conditions, the readings were steam temperatures or heated rock temperatures and were not comparable to the original borehole temperatures, which were taken at a point 3 to 5 feet above the floor of the mine.

Although the original and subsequent temperatures were not always comparable, there was enough evidence to indicate that a substantial heat reduction was effected throughout the fire area. In the central area where the fire was first penetrated and where the original temperatures ranged from 500° to 1,000° F., the fire seemed to be extinguished.

Several "shutoff" tests were conducted to determine the extent to which the temperatures would recover during a period when no water was being introduced. The temperatures taken during these tests were comparable, since they were taken from the same elevation in the borehole. Some of these temperatures did not recover appreciably; however, most of the borehole temperatures, especially on the perimeter of the combustion zone, showed progressive increase during the nonspraying test period, indicating reactivity of the fire. These recovery temperatures were considerably below the original temperatures; however, this may have been due to the fact that the original and the recovery temperatures were not obtained from the same depth in the borehole.

On the basis of this evidence, it is concluded that the spraying experiment failed to cool sufficiently all the hot material, although the theory upon which the experiment was based seems to have substantial validity. The principal reason for abandoning the experiment was the inability to maintain an open borehole through which the water spray could be inserted into a mine cavity. Casing the boreholes from the surface to the top of the mine opening would have facilitated the spraying operations by preventing borehole closure from wall caving.

SECOND EXPERIMENT

Owing to the caved condition of many of the boreholes and the resulting difficulty of inserting the nozzles into the burning workings, the spraying operation was abandoned, and another method of introducing water was adopted. This method involved the introduction of a stream of water through the boreholes onto the hot material in the mine. It was theorized that a large quantity of water flooding the broken ground in the caved boreholes would percolate through the crevices and interstices cooling the hot material, and that some of this water would be converted to steam upon entering the fire zone. Steam generated from this application would have a cooling and smothering effect on the fire similar to that noted during the first experiment.

Water was introduced into one borehole at a time through a 2-inch nipple and ell on the end of 100 feet of 2-inch rubber hose. The rubber hose could be connected to a main 2-inch discharge line at several locations so all of the critical holes could be reached. Flooding during one 8-hour day generally was confined to a group of holes in a particular area where the temperatures were highest. During the early stages of this experiment the nozzle was changed from one borehole to another at 10-minute intervals, thereby applying water through a greater number of boreholes. Near the concluding days water would be introduced through the hottest borehole in a group for several hours before switching the stream to another borehole. This would cool the hot hole and adjacent boreholes as well and was suspected of being more effective than the frequent switching method used previously. Only 3 boreholes out of the 222 drilled would not take uninterrupted discharge (estimated at 100 g.p.m.) from the hose, even though some holes had caved to within 10 feet of the surface—a fact attesting to the fractured and creviced condition of the overburden.

EVALUATION OF SECOND EXPERIMENT

The results of the second experiment in controlling the fire was substantially the same as those attained in the first. Hot areas in the vicinity of a borehole could be cooled quickly and held at a temperature ranging from 150° to 180° F. while water was introduced, but in most instances the temperatures would recover when the flooding operations were stopped. This method of applying water cools the area in the vicinity of a caved borehole. However, it would not be effective if the borehole were open into the mine cavity, since water poured through an open hole would fall to the floor of the mine and run off without much effect on the fire.

Only one borehole at a time could be watered by this method, using stream water available near the site; therefore, the entire fire area could not be covered simultaneously. This method required a full-time attendant to switch the hose from one borehole to another at frequent intervals.

THIRD EXPERIMENT

In the first and second experiments, during periods of wet weather, fire-area temperatures showed a consistent reduction independent of the experimental control operations being conducted. It was theorized that this was due to saturation of the overburden above the fire. It was decided to conduct an experiment that would simulate natural rainfall for an extended period by using lawn sprinklers. The experiment is in progress now, so a complete evaluation cannot be made.

Water is being sprinkled continuously on the surface above the fire. The water migrates through permeable strata into the fire zone. This process is expected to have the following effects: (*a*) The water will cool the burning material and the overlying strata, (*b*) the saturated condition of the overburden will minimize air reaching the fire by "breathing" action, (*c*) the conversion of water to steam in the fire zone will cool the fire, (*d*) this steam will also have a smothering effect on the fire by diluting the atmosphere with an inert vapor, and (*e*) expansion of the water to steam will create a slightly higher than atmospheric pressure in the mine, thereby limiting the inflow of air.

The effectiveness of this method will be determined by taking temperature readings from boreholes drilled from the surface into the burning mine. If this relatively simple and inexpensive method is successful it may have application for controlling fires in mine-refuse piles, rubbish dumps, and areas filled with boiler waste, as well as for controlling fires in abandoned mines having permeable overlying strata.

The application of this method is dependent on two major considerations—permeability of the strata overlying the fire zone and availability of water for sprinkling.

Geologists refer to the area between the water table and the surface as the aeration zone. In this zone the interstices of the strata are filled alternately with air and water. During wet periods surface water percolates through this strata to the water table. The rate at which the water moves depends on the composition and the physical condition of the strata. At the Lloydsville site, in addition to its natural porosity, the strata were broken and creviced from the effects of the fire and from previous mining, making it quite permeable. This fact was evident from information obtained during previous experiments at this site.

Water for the third experiment is being obtained from Unity Run, the same tributary from which water was pumped during the second experiment. Under normal rainfall conditions the supply of water is adequate to maintain ground saturation. This statement is based on observations of the amount of runoff from the sprinkled area.

The essential feature of this experimental method is the continuous, uniform distribution of water on the surface above the fire. The plan is to simulate conditions of steady, gentle rainfall. This is accomplished by using sprinklers connected through a piping network to a pump located near the source of water. The system, as now operating with an electric motor-driven pump, strainers, automatic controls, and protective devices, requires a minimum of inspection and service. Figure 61 shows some of the equipment used during this experiment. The services of an attendant for about 2 hours each day of pump operation keeps the system operating satisfactorily.

TENTATIVE EVALUATION OF THIRD EXPERIMENT

The sprinklers were operated for a 5-month period during the summer of 1958; then the operation was discontinued for 6 months during the winter of 1958–59. Sprinkling was resumed for 2 months in the spring of 1959; then a shutoff test was conducted for 2 weeks.

Borehole-temperature surveys showed the following results: At the end of the 5-month sprinkling period, 92 percent of the temperatures were lower than the temperatures recorded before the experiment was begun. These temperature decreases ranged from 10° to 430° F. Two percent of the temperatures showed no change, and 6 percent showed increases ranging from 15° to 35° F. The highest temperature at the end of this period was 210° F. The average temperatures at the end of the 5-month sprinkling period was 113° F., whereas the average temperature before the experiment was 180° F.

At the end of the winter shutoff period (6 months), 50 percent of the borehole temperatures had increased 10°–240° F. over corresponding temperatures at the beginning of this period. Twelve percent has not changed, and 38 percent had continued to decrease in amounts ranging from 5° to 60° F.

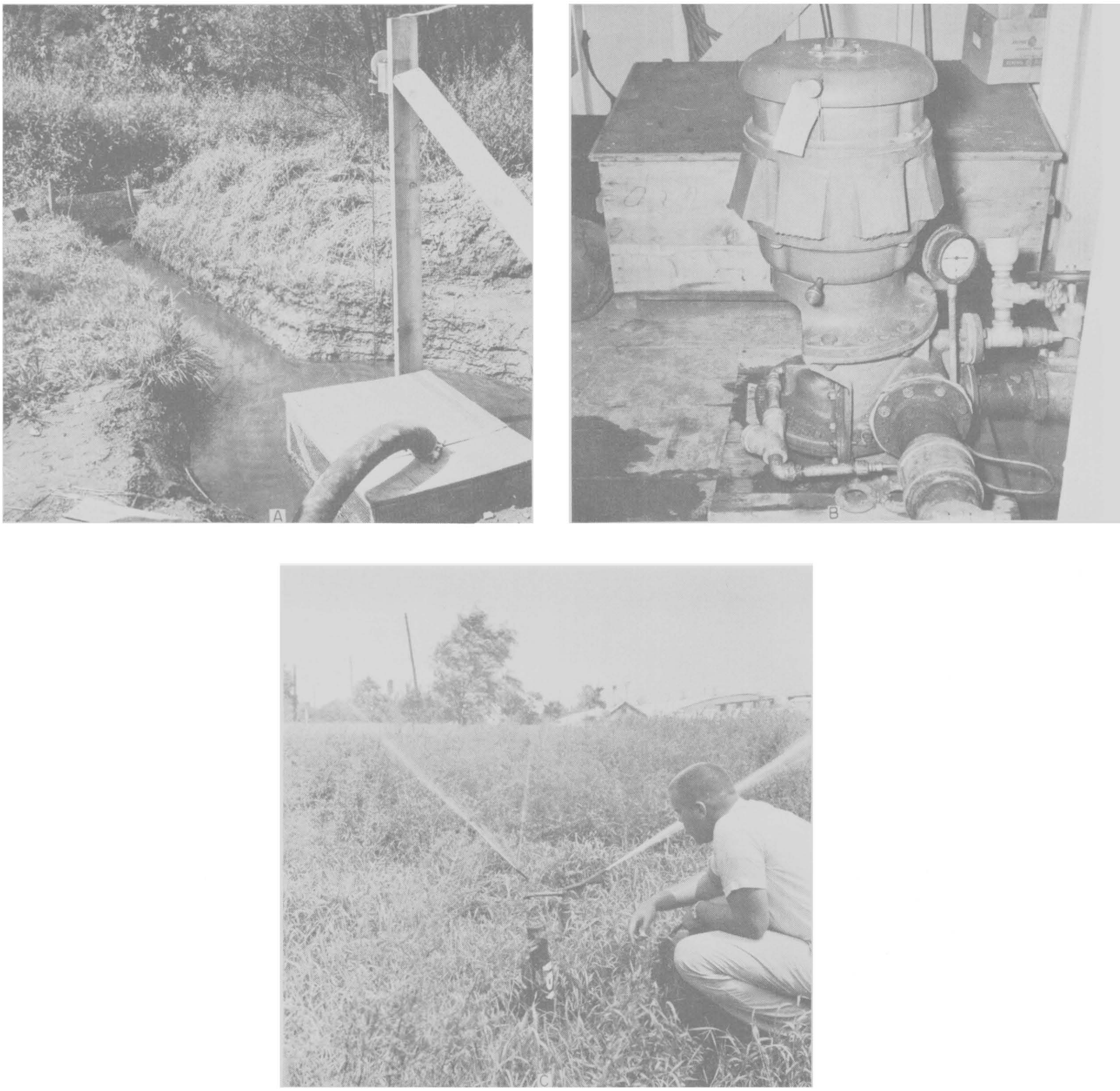


FIGURE 61.—Equipment Used During Third Experiment: *A*, Sump and Canal; *B*, Pump and Motor With Toolbox in Background; *C*, Closeup of a Sprinkler.

At the end of the 2-month sprinkling operation, 56 percent had decreased, 28 percent showed no change, and 16 percent had increased.

During the 2-week shutoff test, 40 percent increased, 32 percent showed no change, and 28 percent decreased.

This temperature data indicate that the underground fire was cooled by sprinkling water on the surface. The method appears to have possibilities for further development, and the experiment is being continued at this writing. A report will be published when the experiment is completed and all the data analyzed.

FOAM EXPERIMENT

This experiment is now in progress. It is being partly financed from mine-fire-control funds, although it is being supervised and conducted by another group within the Bureau. The experiment concerns another method of applying water to an underground fire and has possibilities for application in both active and inactive mines.

Water is carried to the fire in the form of a high-expansion foam by an air current induced to flow through the mine entries. Progress reports on this experiment are available; it also has been demonstrated publicly at the Bureau experimental mine at Bruceton.

FIRE-CONTROL PROJECTS

Seventy fire-control projects were completed under Federal acts from 1949 to June 30, 1959. They are listed in tables 1, 2, and 3.

Forty projects were located in Western United States and Alaska, 7 in eastern Pennsylvania, and 23 in western Pennsylvania and the States of West Virginia, Kentucky, and Maryland.

All work to complete the fire-control projects was performed under the terms and conditions set forth in contracts between the Federal Government and a private contractor, under the general supervision of Government engineers.

The cost of these projects varied widely, depending on the extent, duration, and location of the fire; the presence or absence of surface obstructions; and the physical characteristics of the affected area. The amounts expended ranged from about $2,000 to $545,000, and averaged approximately $47,000.

All fires, except one, controlled in the coalbeds of Western United States and Alaska were located on public land. Projects in the Eastern United States have been on non-Federal lands and were performed by the Federal Government with the financial cooperation of others. The underground mine fires that have been controlled or extinguished in eastern Pennsylvania have been more difficult and, in some instances, more expensive to control than the fires at other locations because of the steeply pitching interconnected multiple beds usually involved in these fires.

Upon completion of a project a report is prepared covering all phases of the work. It also gives a financial statement. This report contains copies of contractual agreements, operations contracts, releases from property owners, maps, sketches, photographs, and a description of the work performed to control the fire. Copies of these reports are sent to cooperating parties and also are available in Bureau files for inspection and review.

Data from several of these reports, with selected maps and photographs, are included in this Bulletin to illustrate a specific method of control.

TABLE 1.—*Fire-control projects in Western United States and Alaska*

Name	Location			Control method	Ownership	Started	Completed
	Town	County	State				
I.H.I. Mine	Rifle	Garfield	Colorado	Plug barrier	Public	4/29/49	7/18/49
North Park	Coalmont	Jackson	do	Barrier trench	do	7/9/49	10/25/49
Moyer Gulch	Gillette	Campbell	Wyoming	Plug barrier; Borrow surface seal.	do	11/3/49	5/25/50
San Juan	La Ventana	Sandoval	New Mexico	Borrow surface seal	do	1/11/51	3/3/51
Laur	Gillette	Campbell	Wyoming	do	do	7/25/50	9/12/50
Little Thunder	Hilight	do	do	do	do	7/22/50	9/13/51
Canfield	Teckla	do	do	do	do	6/18/50	8/5/50
Burning Coal Mine	Bill	Converse	do	do	do	7/19/50	10/27/50
Pyle Dam	Fruitland	San Juan	New Mexico	do	do	4/16/51	9/8/51
Padlock	Gillette	Campbell	Wyoming	do	do	4/19/51	9/28/51
Skull Creek	Craig	Rio Blanco	Colorado	Trench barrier	do	9/13/51	12/2/51
Elk Creek	Weston	Campbell	Wyoming	Borrow surface seal	do	6/3/52	12/6/52
Dugger-Rollins	Delta	Delta	Colorado	do	do	7/8/52	10/1/52
Snake River	Savery	Carbon	Wyoming	do	do	6/17/53	9/17/53
Coal Gulch	Fruita	Mesa	Colorado	do	do	5/18/53	7/22/53
I.H.I. #2 Mine	Rifle	Garfield	do	do	do	6/22/53	8/4/53
Slagle	Dallas	Ouray	do	do	do	5/13/54	6/30/54
La Plata	La Plata	San Juan	New Mexico	do	do	1/20/54	6/15/54
Homer	Homer	Third Judicial Division.	Alaska	Plug barrier	do	9/1/54	10/21/54
Flood Estate	Dos Rios	Mendacino	California		Private	11/24/52	11/30/52
Yellow Jacket Pass	Meeker	Rio Blanco	Colorado	Borrow surface seal	Public	6/15/54	8/21/54
Linwood (Utah)		Sweetwater	Wyoming	do	do	6/8/54	7/20/54
Soda Lake	Rawlins	Carbon	do	do	do	6/21/54	7/11/54
Castle Garden	Moneta	Fremont	do	do	do	7/13/54	8/10/54
Moose Creek	Palmer	Third Judicial Division.	Alaska	do	do	10/11/54	11/20/54
Arizona Black Mesa	Kayenta	Navajo	Arizona	do	do	7/6/55	8/15/55
Onion Lake	Montrose	Montrose	Colorado	do	do	7/18/55	9/15/55
Fuller	Savage	Dawson	Montana	do	do	6/1/55	7/9/55
Terry		Prairie	do	do	do	6/21/56	8/18/56
Alkali Butte	Riverton	Fremont	Wyoming	do	do	7/17/56	10/29/56
Deer Creek		Dawson	Montana	do	do	6/26/56	10/9/56
Glendive Creek		do	do	do	do	7/5/56	8/7/56
Newcomb	Shiprock	San Juan	New Mexico	do	do	10/29/56	12/8/56
Recci		Sevier	Utah	do	do	5/23/57	7/1/57
Two Trees	Broadus	Powder River	Montana	do	do	6/25/57	9/3/57
Poposia	Hudson	Fremont	Wyoming	do	do	8/14/57	10/10/57
Three Forks	Broadus	Powder River	Montana	do	do	6/5/58	6/19/58
Reservation Creek	Ashland	Rosebud	do	do	do	6/23/58	7/26/58
Virgil Weidner	Glendive	Dawson	do	do	do	6/6/58	6/25/58
Hoffman Creek	Price	Carbon	Utah	Borrow seal	do	7/7/58	

TABLE 2.—*Fire-control projects in eastern Pennsylvania*

Name	Location		Control method	Ownership	Started	Completed
	Town	County				
Peach Mountain	Pottsville	Schuylkill	Direct attack	Private	6/11/49	10/14/49
Mount Carmel	Mount Carmel	Northumberland	Surface seal	do	3/1/50	9/–/53
Kulpmont	Kulpmont	do	Plug barrier and surface seal	do	5/8/50	5/24/51
Carbondale	Carbondale	Lackawanna	Flushing bore-holes and loading-out.	do	6/6/50	2/15/51
Shamokin	Shamokin	Northumberland	Surface sealing	do	7/17/50	11/1/50
Tower City	Tower City	Schuylkill	Flushing	do	5/1/52	11/9/54
Swoyersville	Swoyersville	Luzerne	Isolation trench	do	3/25/57	4/28/58

TABLE 3.—*Fire-control projects in western Pennsylvania, West Virginia, Kentucky, and Maryland*

Name	Location			Control method	Ownership	Started	Completed
	Town	County	State				
Lloydsville	Lloydsville	Westmoreland	Pennsylvania	Surface seal, water-spray saturation.	Private	6/15/49	7/12/49
Lick Run Mine	Bruceton	Allegheny	do	Underground seals, surface seal.	do	6/22/49	10/27/49
Cook Plan	Monessen	Westmoreland	do	Trench barrier	do	7/7/49	6/1/50
Fairmont	Fairmont	Marion	West Virginia	Loading-out	do	6/6/50	7/11/50
Ross Farm	Monessen	Westmoreland	Pennsylvania	do	do	6/15/51	2/–/52
Pricedale	Pricedale	do	do	Plug barrier, surface seal.	do	12/–/51	10/29/52
Bedford Dwellings-Bigelow Boulevard.	Pittsburgh	Allegheny	do	Loading-out	do	7/7/52	1/–/53
Agnew Road	do	do	do	Surface seal	do	6/17/53	12/4/54
Southwest Monessen	Monessen	Westmoreland	do	do	do	5/20/53	11/13/53
Carroll Township	Donora	Washington	do	do	do	2/16/54	8/27/54
Baldwin Borough	Baldwin Borough	Allegheny	do	Loading-out	do	4/(?)/53	4/(?)/53
Hempfield Township	Greensburg	Westmoreland	do	Trench barrier	do	9/9/54	11/15/54
Churchview Avenue Extension.	Baldwin Borough	Allegheny	do	Surface seal	do	3/12/56	12/3/56
Jefferson Borough	Jefferson Borough	do	do	do	do	4/18/55	11/14/55
Rostraver Township	Pricedale	Westmoreland	do	Surface and underground sealing, flushing.	do	4/26/56	12/–/56
Green Valley	North Versailles Township.	Allegheny	do	Surface seal	do	7/23/56	4/29/57
Catfish Run	Snowden Township	do	do	Surface seal, flushing	do	5/14/57	2/13/58
Santiago	North Fayette Township.	do	do	Trench barrier	do	5/27/57	8/28/57
Winco Block		Martin	Kentucky		do	1957[1]	
Lookout Avenue	Monessen	Westmoreland	Pennsylvania	Surface seal	do	4/21/58	7/1/58
Division Street	do	do	do	Surface seal, flushing	do	1/10/58	6/24/58
Brisbin Borough	Houtzdale	Clearfield	do	Trench barrier	do	8/18/58	11/15/58
Klondike	Klondike	Allegany	Maryland	do	do	12/5/58	6/–/59

[1] Work done by owner.