YEARBOOK OF THE BUREAU OF MINES

1916

BY

VAN. H. MANNING

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By Van. H. Manning.

INTRODUCTION.

Probably no year in the history of the United States showed greater progress in the mineral industries than 1916. Although this progress was undoubtedly stimulated by the war in Europe, which caused extremely high prices for some of the metals, yet the fact remains that mining is being regarded more as a business and less as a speculation, and the benefits of business methods are becoming evident. Practices that were almost universal a few years ago have been largely abolished, the mining public has been brought to recognize the folly of wasteful and dangerous methods, and there is a gratifying unanimity of opinion in regard to the conservation of life and health, as well as of our mineral resources. The people of the United States realize more fully than ever before the extent and value of the country’s mineral resources and the possibilities that await intelligent and well-directed efforts at utilization.

In the past, economic reasons caused deposits of valuable metals and industrial materials to lie idle; commercial reasons, many of them not truly economic, led to the waste of valuable constituents in many ores; the recovery of minerals from the ground was too often incomplete and accompanied by uncalculated loss; and the treatment of ores in mills and smelters saved altogether too low a proportion of the metals sought.

Now better methods are being tried on every hand, and the unparalleled record of the year is largely due to the success of these efforts. According to the preliminary estimates of the United States Geological Survey the output of metals and minerals in this country in the calendar year 1916 had a total gross value of slightly more than $3,000,000,000. For many metals and minerals the figures broke all previous records, the new records of some products, as compared with 1915 figures, being as follows:

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Production of certain metals in 1916 as compared with 1915.

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<th>1916</th>
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<td>Manganese, tons</td>
<td>9,709</td>
<td>27,000</td>
<td>27.5%</td>
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<td>Iron, tons</td>
<td>55,493,000</td>
<td>75,500,000</td>
<td>34</td>
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<td>Coal, tons</td>
<td>584,619,487</td>
<td>597,500,000</td>
<td>12</td>
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<td>Cement, barrels</td>
<td>86,891,681</td>
<td>94,598,000</td>
<td>6.1</td>
</tr>
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<td>Copper, pounds</td>
<td>1,388,000,000</td>
<td>1,928,000,000</td>
<td>1.4</td>
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<tr>
<td>Lead, tons</td>
<td>561,639</td>
<td>622,000</td>
<td>10</td>
</tr>
<tr>
<td>Zine, tons</td>
<td>605,915</td>
<td>708,000</td>
<td>6.6</td>
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The Bureau of Mines, under the terms of its organic act, as amended, is endeavoring to increase the safety and health of workers in the mineral industries and to promote greater efficiency and the prevention of waste in the mining, preparation, and utilization of the mineral resources in the United States. Although difficulties have had to be overcome, and the available funds have been insufficient to meet all the demands made of the bureau, it is believed that the work accomplished by the bureau has kept pace with the progress of the mineral industry as a whole. The increase of efficiency and the lessening of waste in mining are of high importance, and investigations with these ends in view have been furthered to the utmost, but such work must necessarily come second when there is opportunity for work that will increase the safety and health of the workers in mines and mills.

This bulletin describes in some detail the more important work done by the Bureau of Mines during 1916 in efforts to increase safety and efficiency in the mineral industries. The purpose and organization of the bureau and a review of its work for each fiscal year are presented in the annual reports of the director. Those reports are necessarily summarized; they can not give full details of noteworthy experiments nor describe at length new and improved equipment, apparatus, and devices that are being used by the bureau or have been devised by its engineers and chemists. This bulletin gives descriptions of some noteworthy safety devices and discusses in fuller detail than the annual reports the relation of the bureau’s work to the general problems of safety and efficiency in the mineral industries and the significance of the results that the bureau has been able to achieve.

In order that the scope of the bureau’s activities may be brought out as clearly as possible, and in order to show how these activities apply to mining and other mineral industries, the discussions and descriptions given in this bulletin are grouped mostly according to the investigations carried on by the several divisions of the bureau, as follows: Mining, fuels and mechanical equipment, mineral technology, petroleum technology, and metallurgy.
MINING INVESTIGATIONS.

Under the general title of mining investigations are included accounts of the educational and life-saving work done through the mine safety cars and stations; field investigations of coal and metal mines, with respect to the health and safety of miners and the efficiency of the mining methods in reducing or preventing waste of mineral resources; and the Government inspection of mines on Indian lands and of mines in the Territory of Alaska.

MINE-SAFETY INVESTIGATION.

NEED OF SAFETY MEASURES.

To show the need that has existed for energetic efforts to reduce the loss of life at mines in the United States, a brief summary of the fatalities in coal mining will suffice.

The United States has produced 9,838,300,000 tons of coal under inspection since the first inspection law was enacted in 1870. Complete records for this production show that 54,453 men have been killed by accidents while mining coal.

The number of men engaged in the production of this amount of coal represents the equivalent of an army of 16,500,000 men engaged for 1 year. The number of men killed per 1,000 employed during the 46-year period was 3.30. For every 10,000,000 tons of coal produced 55 lives were lost, or a production of 180,676 tons for each fatality.

That the accident rate is being reduced is evidenced by the fact that the fatality rate in 1915 per 1,000 men employed was 2.95, which was the lowest recorded since 1898. The production of coal per fatality in 1915 was 228,600 tons, which was the largest production per fatality during the history of coal mining in the United States. The number of men at present enrolled in the coal-mining industry is approximately 765,000 a year.\(^a\)

The conservation of human life in mines and industrial plants is of paramount importance and is being considered by legislative bodies, labor organizations, captains of industry, and individual employees. Every fatal accident leaves its impress on the community in the loss of a useful citizen and the provider for a family, with the result that many widows and orphans are rendered public charges for which taxpayers must contribute support. The sufferings and

privations borne by many of the dependents can not be measured by words nor compensated by a money equivalent.

Here is an industry employing 765,000 men, of whom 3 out of every 1,000 are killed each year, and at least 180 per 1,000 are injured to the extent that time is lost and in most cases medical attendance requested. A reduction of 50 per cent in the number of fatalities would result in an annual saving of fully 1,200 lives, to say nothing of the reduction in injuries and sufferings now sustained by nearly 150,000 unfortunates. From the point of view of the humanitarian, no greater good for the industry can be accomplished than to effect this reduction, and it is to this end that the Bureau of Mines is conducting its campaign of education and safety first. Experience is showing that accidents may be reduced in number, although they can not be eliminated entirely.

**EDUCATIONAL FEATURES.**

No method adopted by the bureau for the purpose of interesting the miner in mine-safety work has been received with greater enthusiasm or more widespread appreciation than that of illustrated lectures. The giving of such lectures is part of the duties of every field man of the bureau.

So great has been the demand from both operators and miners for these lectures that, because of lack of sufficient funds, the bureau has not been able to meet it fully. Both lantern slides and motion pictures are used to illustrate different phases of coal and metal mining, sanitary and welfare work in mining communities, rescue and recovery work, and first-aid demonstrations.

Over 43,000 persons attended the lectures of the bureau's field men during the fiscal year ended June 30, 1916, and it is felt that the deep interest manifested by both the miner and operator is evidence that much good has resulted.

This work is only in its infancy, and as the field is broad it will probably demand more attention each year.

**MINE SAFETY CARS AND STATIONS.**

For the purpose of training miners in first aid to the injured and in the use and care of mine rescue apparatus and for facilitating investigations of mine disasters the bureau maintains five stations and eight mine safety cars in the coal and metal-mining regions of the United States. The headquarters of the different cars are situated as follows: Huntington, W. Va.; Evansville, Ind.; Ironwood, Mich.; Pittsburgh, Kans.; Butte, Mont.; Reno, Nev.; Raton, N. Mex.; and Pittsburgh, Pa.

The mine safety stations are at Pittsburgh, Pa.; Jellico, Tenn.; Seattle, Wash.; McAlester, Okla.; and Birmingham, Ala. Each sta-
tion is in charge of a foreman miner, who gives both mine rescue and first-aid training.

The mine safety cars, some of which were Pullman sleeping cars (see Pl. I, A) and some of which were specially built for mine safety service, now have accommodations for about 12 persons besides apparatus for use after mine disasters and for first-aid and rescue training. The cars are transported free of cost to the Government, grateful acknowledgment being herewith made to the following companies for their cooperation in this regard:

*Railroads with which the Bureau of Mines has special arrangements for handling mine safety cars.*

[In effect during 1916.]

Alabama Great Southern Railroad.
Arizona & New Mexico Railway.
Arizona Eastern Railroad.
Arkansas Central Railroad.
Atchison, Topeka & Santa Fe Railway.
Baltimore & Ohio Railroad.
Bellefonte Central Railroad.
Bessemer & Lake Erie Railroad.
Buffalo, Rochester & Pittsburgh Railway.
Buffalo & Susquehanna Railway.
Butte, Anaconda & Pacific Railway.
Canon City & Cripple Creek Railroad.
Carolina, Clinchfield & Ohio Railway.
Central of Georgia Railway.
Central Railroad of New Jersey.
Chesapeake & Ohio Railway.
Chicago, Burlington & Quincy Railroad.
Chicago & Eastern Illinois Railroad.
Chicago & North Western Railway.
Chicago Great Western Railroad.
Chicago, Indianapolis & Louisville Railway.
Chicago, Milwaukee & Puget Sound Railway.
Chicago, Milwaukee & St. Paul Railway.
Chicago, Rock Island & Pacific Railway.
Chicago, Terre Haute & Southern Railway.
Cincinnati, New Orleans & Texas Pacific Railway.
Cincinnati Southern Railroad.
Coal & Coke Railway.
Colorado Midland Railway.
Colorado & Southern Railway.
Colorado Springs & Cripple Creek District Railway.
Colorado & Wyoming Railway.
Columbia & Puget Sound Railroad.
Cripple Creek & Colorado Springs Railroad.
Crystal River Railroad.
Cumberland & Pennsylvania Railroad.
Delaware & Hudson Railroad.
Delaware, Lackawanna & Western Railroad.
Denver & Rio Grande Railroad.
Detroit, Toledo & Ironton Railroad.
Duluth & Iron Range Railroad.
Duluth, Missabe & Northern Railroad.
Duluth, South Shore & Atlantic Railway.
El Paso & Southwestern Railroad.
Erie Railroad.
Evansville & Terre Haute Railroad.
Florence & Cripple Creek Railroad.
Fort Smith, Subiaco & Eastern Railroad.
Fort Smith & Western Railroad.
Golden Circle Railroad.
Great Northern Railway.
Hocking Valley Railway.
Illinois Central Railroad.
Kanawha & Michigan Railway.
Kansas City, Mexico & Orient Railroad.
Kansas City Southern Railway.
Lackawanna & Wyoming Valley Railroad.
Lake Superior & Ishpeming Railway.
Lehigh Valley Railroad.
Louisville, Henderson & St. Louis Railway.
Louisville & Nashville Railroad.
Midland Terminal Railway.
Midland Valley Railroad.
Mineral Range Railroad.
Mississippi River & Bonne Terre Railway.
Missouri, Kansas & Texas Railway.
Missouri & North Arkansas Railroad.
Missouri, Oklahoma & Gulf Railway.
Missouri Pacific Railway.
Mobile & Ohio Railroad.
Monongahela Railroad.
Montana, Wyoming & Southern Railroad.
Munising, Marquette & Southeastern Railway.
Nashville, Chattanooga & St. Louis Railway.
New York Central Lines.
New York, Ontario & Western Railway.
Norfolk & Western Railway.
Northern Pacific Railway.
Oregon Short Line.
Pennsylvania Railroad.
Philadelphia & Reading Railway.
Pittsburgh, Shawmut & Northern Railroad.
Queen & Crescent Route.
Quincy, Omaha & Kansas City Railroad.
Ray & Gila Valley Railroad.
Salt Lake Route.
San Pedro, Los Angeles & Salt Lake Railroad.
Santa Fe, Raton & Eastern Railroad.
Southern Indiana Railway.
Southern Pacific Railroad.
Southern Railway.
Southern Railway in Mississippi.
St. Louis Southwestern Railway.
St. Louis & San Francisco Railroad.
St. Louis, El Reno & Western Railway.
St. Louis, Rocky Mountain & Pacific Railway.
Tacoma Eastern Railroad.
Tennessee Central Railroad.
Texas, St. Louis & Western Railroad.
Toledo, Peoria & Western Railway.
Toledo, St. Louis & Western Railroad.
Union Pacific Railroad.
United Verde & Pacific Railway.
The Virginian Railroad Co.
Virginia & Truckee Railway.
Wabash Railroad.
Western Maryland Railway.
Western Pacific Railway.
Wheeling & Lake Erie Railroad.
Wichita Falls Route.
A. INTERIOR OF BUREAU OF MINES MINE-SAFETY CAR.

B. MINE RESCUE CREW UNDERGROUND DURING RESCUE MANEUVERS AT VANDALIA NO. 20 MINE, LINTON, IND.
Each car when fully manned has a foreman miner to give training in modern safety and rescue methods, a first-aid miner to give training in first aid to the injured, and a district mining engineer and a surgeon to confer with mine operators, mine physicians, and others in their investigative work.

The cars are in charge of practical men, and when funds are available for their operation they move about through the various fields, arousing interest in the movement for greater safety in mining.

In addition to the cars and stations, three motor trucks have been added. The trucks are each equipped with 10 sets of rescue apparatus and supplies sufficient for 48 hours of continuous apparatus work. One is stationed at Pittsburgh, Pa., one at Birmingham, Ala., and one at Seattle, Wash. They are of special value for giving aid after accidents in mines within a radius of 40 or 50 miles of their headquarters, as they can give efficient service on short notice, carrying to a disaster a rescue crew of 10 men ready for duty.

MINE RESCUE AND FIRST-AID TRAINING WORK DURING ONE YEAR.

During the period in which the crews of the bureau's mine safety cars and stations conducted active training in the fiscal year ended June 30, 1916, 62,693 miners visited the cars and stations, 43,060 attended lectures and safety demonstrations, 285 received mine rescue training, 5,598 were given first-aid instruction, and 2,610 received both first-aid and mine rescue training, the total number trained being 8,498, which is an increase of 494 over the previous year. A still better showing would have been made had it not been for the fact that many of the cars were in the shops for repairs for a part of the time.

The training is well received throughout the country; in fact, in Pennsylvania there have been numerous calls for mine rescue instruction which the bureau has not been able to satisfy, owing to its meager force.

It might be mentioned that the casualty-insurance companies have recognized the value of the bureau's first-aid and rescue training by making reductions in their rates for any mine that has a certain number of men trained by the bureau. This action has stimulated the desire for training and will undoubtedly further stimulate it as compensation laws and mine insurance become more general.

The individual miner has recognized the value of the first-aid work not only to his fellow miners but also to himself, for he realizes that a knowledge of first aid may some day enable him to save his own life or the life of some member of his immediate family through the prompt control of arterial bleeding or the protection of wounds *
to prevent infection. It is perhaps largely because the training offers something he considers of personal benefit that the miner has taken so enthusiastically to the work, and in many fields the instructors have had classes of 50 to 100 men at night. Ordinarily these men take the training at night on their own time and after they have done a hard day's work in the mines. In addition, many walk 3 or 4 miles from their homes to the cars at which the instruction is given.

During the past fiscal year, in many local, State, and district first-aid meets, the bureau's men assisted in training competing teams and in organizing the meets.

At each point visited by the bureau's mine safety cars a first-aid society was organized; these are making the training of a more lasting value to the community by insuring a continuance of the instruction.

Frequently rescue maneuvers are conducted underground after a class has been trained in the use of rescue apparatus. These maneuvers are conducted under conditions representing as nearly as possible those likely to be encountered in actual rescue and recovery work. Plate I, B, shows a crew participating in underground maneuvers.

FIELD CONTESTS IN MINE RESCUE AND FIRST-AID METHODS.

Forty-seven mine rescue and first-aid contests and field meets were held during the fiscal year 1916 under the auspices or with the assistance of the Bureau of Mines. A few of these contests were company affairs, but most were intercompany or interstate. In many contests the Bureau of Mines employees arranged and supervised the events, and in nearly all, at the request of the operators and miners, gave the competing teams special instruction and training. Plate II, A, shows a first-aid team that has completed caring for a "wounded" man in a first-aid contest.

These contests were held at points widely distributed throughout the United States from Alabama to Montana, demonstrating the interest and enthusiasm of miners and mine officials in carrying forward mine safety work and in furthering the great movement for greater safety in mining.

ACCIDENTS INVESTIGATED DURING 1916.

In the 89 accidents investigated by Bureau of Mines employees during the fiscal year 1916 there were 285 killed, 3,015 escaped unassisted, and 75 were rescued through the efforts of volunteer miners, company officials, State mine inspectors, and company rescue crews.
A. A COMPETING TEAM IN FIRST-AID WORK.

B. RESCUE CREW ENTERING MINE.

Maneuvers at experimental mine at Bruceton, Pa.
Of the 89 accidents investigated, 68 were in coal mines, 14 in metal mines, 1 in a hydraulic pit, 1 in a quarry, and 1 in a strip pit; a dynamite explosion in the St. Louis sewer tunnel, a cave-in in a New York City subway, a boiler explosion, and an explosion in the new city sewer of Pittsburgh, Pa., were also investigated.

OPERATIONS AT MINE DISASTERS.

Besides giving training in mine rescue and first-aid work, the engineers, foremen miners, and first-aid miners of the mine safety cars and safety stations investigated numerous mine accidents and assisted in actual mine recovery (see Pl. II, B) and first-aid work after mine disasters.

Systematic methods of rescue and recovery work after mine fires and mine disasters are being improved each year, and it is felt that the increased efficiency of such methods has resulted largely from the unceasing efforts of the men trained by the Bureau of Mines or at State or privately owned rescue stations.

A fact worthy of emphasis is that during the fiscal year 1916 no explosion occurred in which a relatively large number of lives were lost. The Bureau of Mines, the mining departments of the various States, the operators, and the miners, through concerted and persistent endeavor, have brought about this gratifying result.

USE AND TESTING OF OXYGEN RESCUE APPARATUS.

The value of oxygen rescue apparatus is becoming more and more appreciated for both rescue and recovery work in mines. There has been a steady growth in the establishment of rescue stations throughout the country, particularly in the western coal fields.

In training miners the Bureau of Mines teaches the use of three types of apparatus—the Draeger, the Fleuss, and the Westfalia. The bureau itself is developing a fourth type, known as the Gibbs. Each of these types has a steel cylinder containing oxygen at a pressure of approximately 2,000 pounds to the inch and a reducing valve that allows a definite quantity of oxygen per minute, at a pressure slightly above atmospheric, to pass from the cylinder to a reservoir from which it is breathed by the wearer. The air exhaled by the wearer flows through to a compartment containing regenerating material, usually caustic soda (sodium hydroxide), by which the carbon dioxide in the breath is removed. The regenerated air joins the stream of oxygen from the reducing valve and is breathed again.
The possibilities and the limitations of such apparatus are becoming more thoroughly understood from year to year. However, during the fiscal year 1916 there were two instances of men wearing apparatus to combat mine fires with presumably little or no previous training in its use. In another instance an apparatus party of only two men made an exploration of considerable length, and one of them lost his life. Until such practices are discontinued the dangers incident to wearing apparatus in irrespirable atmospheres will not be reduced to the minimum.

Some men while wearing the apparatus fail to appreciate the fact that the weight of the apparatus causes them to become exhausted much more quickly than when working without it.

During the fiscal year 1916 tests were made with the four types of mine rescue apparatus mentioned to determine the accumulatio of hydrogen and nitrogen in each type when the "oxygen" used was similar to that furnished the various rescue cars and stations—that is, oxygen mixed with nitrogen up to 3 per cent and hydrogen up to 1.3 per cent. In these tests 170 samples were taken of either the original oxygen or of the air breathed by the wearers, and the test indicated that oxygen mixed with more than 0.2 per cent of hydrogen or 2.5 per cent of nitrogen, might prove dangerous for use in mine rescue apparatus. Because of these tests the Bureau of Mines proposes in buying oxygen for use on its cars and stations to specify that the percentages of hydrogen and nitrogen must not exceed the figure mentioned. These tests also served to indicate the efficiency of the regenerator furnished with the Gibbs apparatus.

Because of the war in Europe the German company making the Draeger apparatus has been unable to procure regenerating cartridges from Germany for use in this country, and it has been necessary to have them manufactured in America. The Bureau of Mines has tested the efficiency of American-made regenerators. Two types were submitted, one containing granular sodium hydroxide and the other containing sheet sodium hydroxide. Generally speaking, all of these generators proved satisfactory, but those containing caustic soda in sheets and having absorbent blotters in the four upper trays showed the best results; they are now being used in the training work of the bureau.

Two tests were made with the Fleuss apparatus to determine whether caustic soda stored for some time in a Fleuss breathing bag was still in condition to efficiently absorb the carbon dioxide exhaled by the wearer. In one test caustic soda stored for one month in the breathing bag was tested; the caustic soda tried in a second test had been left in the bag for two months. Samples taken at the beginning and the end of the storage periods and eight inhalation-air samples
taken in the course of the two two-hour tests of each apparatus were analyzed. The tests showed that the sodium would still act as an efficient absorber, although the carbon dioxide in one sample of the inhaled air was as high as 1 1/2 per cent.

In trials with the Fleuss apparatus, electrolytic sodium hydroxide prepared in the lump form was tested. Eight inhalation-air samples taken in the tests showed the lump sodium to be an efficient absorption agent.

In four tests of the Fleuss apparatus the wearer tried the half mask, intended for use in fire fighting, instead of the mouthpiece. The tests indicated that although the half mask may seemingly have an air-tight fit on a man before he enters the smoke room, inward leakage may occur after he has been in a noxious or poisonous atmosphere for a short time, so that the half mask is not as safe as the mouthpiece.

Tests at Pikes Peak.

An important series of tests of mine-rescue apparatus was made in Colorado to determine, if possible, whether rescue apparatus possessed certain defects that rendered it peculiarly dangerous for use at high altitudes. The first series of tests were made at Manitou, the second at the Half Way House on Pikes Peak, and the third at the summit of the peak. The results indicated that rescue apparatus is not more dangerous at high altitudes than at low. The oxygen supply was sufficient, and, in fact, men wearing the apparatus and getting a constant supply of oxygen from it could make physical exertions of which they were incapable when breathing the natural air because of its being rarefied and containing a less weight of oxygen per cubic foot than the air supplied by the apparatus.

The conclusion reached, therefore, was that the probable cause of the excessive number of accidents with rescue apparatus in mines at high altitudes resulted from neglect in the care of the apparatus, particularly in the renewal of rubber parts that had dried and cracked.

A secondary, but, possibly, more important result of these investigations was the comparison of the Gibbs apparatus with the older forms of apparatus, particularly the Fleuss and Draeger, heretofore used by the mine-rescue crews at the bureau. The results demonstrated conclusively that the Gibbs apparatus adapts itself to the wearer's needs far better than the older forms of apparatus. In endurance tests particularly it was found that this automatic adjustment tends to insure a much longer duration of the oxygen supply and of the power to absorb carbon dioxide than do any of the other types.
DEVELOPMENT OF NEW TYPE OF OXYGEN RESCUE APPARATUS.

As the Gibbs apparatus, which has been developed by W. E. Gibbs, engineer of mine-safety investigations, in cooperation with other members of the Bureau of Mines, seems in several respects to be superior to other types, a detailed description is here presented.

Rescue crews have to do hard work in the poisonous atmosphere of a mine after an explosion or fire, hence the breathing apparatus they wear must be of the best design and construction. It must be absolutely reliable, supply an artificial atmosphere of great purity, be as light as is consistent with strength, and impede the movements of the wearer as little as possible.

The Gibbs apparatus is a self-contained unit carried wholly on the back of the user. It is light and its parts are well protected against injury. A special device feeds the oxygen used, and although plenty is available for the wearer when working hard none is wasted when he is resting. Hence the new apparatus may be worn for a considerably longer time without recharging than can models now in use which furnish a constant volume. An unusually efficient carbon dioxide absorber that liberates little heat is another feature of the apparatus. Caustic soda, which is much cheaper than the potash salt formerly thought necessary, is used as the absorbent.

It is theoretically easy to supply a mine rescue man for two or three hours with an artificial atmosphere from an apparatus of no greater weight than he can readily carry on his back. In practice, however, the construction and operation of such devices offer many difficulties. The knowledge that the failure of any part to respond to the needs of the wearer means his almost certain death places a heavy responsibility on the designer and the constructor.

Normal air contains roughly 20 per cent of oxygen mixed with about 80 per cent of nitrogen and a trace of carbon dioxide. At each inspiration part of the oxygen breathed combines in the lungs with carbon brought by the blood, and the air expired contains about 4 per cent of carbon dioxide (CO₂). The nitrogen of the air is unchanged by the act of respiration and takes no active part in it other than to dilute the oxygen.

For all practical purposes an artificial atmosphere of pure oxygen, or oxygen containing only a small percentage of nitrogen, is actually preferable to normal air in the conditions surrounding mine rescue work. In spite of the general belief that pure oxygen is unsafe to breathe, no abnormal effects attend its use unless it be breathed for a much longer period than that during which rescue apparatus is customarily worn, and even then the only symptom noted is a slight irritation of the bronchial passages.
The amount of oxygen consumed in the body is precisely the same whether the gas is breathed pure or diluted with nitrogen in the form of air. Contrary to the belief held a few years ago, there is no flushing of the face, no feeling of exhilaration, no increase in the pulse rate, nor elevation of arterial tension.

If, however, the oxygen content of the air breathed be materially reduced, unconsciousness and death are almost sure to follow without any warning symptoms, provided the CO₂ content of the air remains low. For this reason it is advisable that breathing apparatus supply an atmosphere rich in oxygen. As much of the oxygen made from liquid air contains 2 or 3 per cent of nitrogen, which remains unchanged and accumulates in the apparatus, analyses of the atmosphere breathed by the wearer generally show a decreasing content proportionate to the length of time the apparatus is worn. If the proportion of carbon dioxide in the artificial atmosphere rises much above 2 per cent, deeper breathing or panting warns the wearer of danger, generally in time to let him get to safety.

Under the best conditions the exploration of mines in which there has been a recent fire or explosion is a hazardous undertaking, not only because of exposure to bodily injury but also because no mechanical breathing device can be made so perfect that it will never fail. Frequent inspection of the breathing apparatus and constant vigilance in keeping it in perfect repair reduce the risk of failure to the minimum.

The elements that enter into the construction of the Gibbs breathing apparatus are shown in figure 1. When the wearer inhales through the mouthpiece a, the valve b opens and oxygen passes from the bag e through the cooler d to the lungs.

On exhalation the oxygen, somewhat diminished in volume and containing about 4 per cent of CO₂, issues from the mouth. The valve b now closes but the valve e opens to let the mixture of oxygen and carbon dioxide pass into the absorber f, where the caustic soda combines with the carbon dioxide to form sodium carbonate.
(Na$_2$CO$_3$), with the formation of some water and the liberation of heat.

From the absorber or regenerator the purified oxygen passes by way of the duct $g$ to the breathing bag $d$, which expands to make room for it. The total volume of gas in the apparatus is now less than the original volume by the amount of carbon dioxide taken up by the absorbing can. After the wearer of the apparatus has taken a few breaths, the bag $c$ collapses enough to permit the weighted lever $k$ to open the oxygen-admission valve $i$, when the bag $c$ fills again automatically.

The heat generated in the absorber is removed from the gas by radiation, partly from the cooler $d$ and partly from the bag $c$ and the connecting tubes.

A reducing valve $j$ lowers the pressure of the oxygen from about 2,000 pounds per square inch in the bottle to a pressure that may be controlled by the admission valve $i$.

A pressure gage $k$ indicates the available oxygen. The gas may be turned off by the stop valve $l$ when the apparatus is not in use.

A relief valve $m$ operates when the pressure in the circulatory system becomes too high.

In order to be practicable, breathing apparatus should be mounted on a suitable frame and be conveniently supported on the user; also, the various elements should be as nearly perfect in operation as mechanical ingenuity and good workmanship can make.

In breathing apparatus as previously constructed the flow of oxygen from the tank of compressed gas has been constant, not because of such a flow being desirable, but because of the difficulty of making a reducing valve that permits the flow to be interrupted.

With such a system the valve must be set to deliver oxygen at a rate that supplies the demands of the wearer when putting forth his utmost exertion. At all other times the supply is excessive and the surplus must be allowed to escape through a relief valve. Besides being wasteful of oxygen, such a system makes the pressure of the atmosphere within the apparatus fluctuate considerably and at times renders breathing difficult.

It was felt that the first step toward improvement should be to design a better reducing valve. A series of experiments led to the construction of a reducing valve that satisfies every requirement. A magnesium casing contains the valve-closing toggles, which are actuated by a flexible metallic bellows. Except for a rubber gasket at the junction of the casing and the toggles, all the parts are of metal. When this reducing valve is attached to a cylinder of gas at a pressure of 150 atmospheres, the pressure inside the bellows, with the outlet closed, is about one-sixth of an atmosphere. This remains constant even after the outlet has been shut several hours. Such a
reducing valve makes it possible to admit oxygen intermittently to the breathing bag in the exact quantity required by the user under conditions varying from complete rest to extreme labor.

All parts of the breathing apparatus are mounted on a frame of steel tubing which is carried on the back. Plate III, A, shows the apparatus in use with its protecting cover of aluminum removed.

The operation of the apparatus is as follows:

On inhalation, air from the breathing bag lifts the inhalation valve $b$ (fig. 1) and passes by way of the flexible tube and mouthpiece to the lungs. Exhaled breath passes to the exhalation valve $e$, thence down a flue to the absorber $f$, where it loses its CO$_2$, thence up through the cooling can $d$, where it loses heat, into the breathing bag $c$.

The absorbing can $f$ has been the subject of much experiment. A form tentatively adopted contained 20 vertical sheets of fine iron-wire gauze, held parallel to each other and one-fifth of an inch apart by spacers. These sheets before being put in the can were dipped in molten caustic soda (NaOH) containing 20 per cent of water. The caustic solidified on the gauze when cold, forming reinforced plates about a sixteenth of an inch thick, between which the expired air passed.

The plates not only absorb carbon dioxide from the wearer's breath but maintain a uniform surface from which the condensed and chemically produced moisture drains away, so that the capacity of the absorber is nearly constant until the active material has all been used. Recently another type of absorber, containing caustic soda in lumps, has been adopted.

A pressure gage or "finimeter," which is read by touch, instead of sight, and sounds an alarm when the oxygen in the cylinder has been reduced to 30 atmospheres, completes the apparatus.

The whole device, which weighs only 30 pounds, or considerably less than other types, is suspended from the shoulders by leather straps. There is a minimum of parts. All the connections have been made without the use of rubber wherever possible.

A simple mouthpiece and nose clip is used instead of a helmet. Experience has shown that the helmet is dangerous, and its use has been abandoned by the Bureau of Mines.

The pressure within the apparatus is maintained slightly above that of the atmosphere by the pressure of a weighted flap, $b$ (fig. 1), on the breathing bag. Consequently, if the apparatus is punctured, or if a crevice in any part of the system opens, the leakage is outward only.

Exhaustive tests of the new apparatus have shown that it permits unusually free breathing; that the air supplied is comfortably cool; that as the front of the body of the wearer is entirely free he is not
hampered in his movements; and that the parts of the device are well protected against accident. The entire apparatus can be quickly taken apart or put together with a wrench and screw driver.

STANDARDIZATION OF FIRST-AID METHODS.

In January, 1916, with a view to standardizing first-aid practices and dressings, the bureau called into conference its staff of consulting surgeons, its mine surgeon, and a representative of the American National Red Cross. The conference decided that the bureau’s first-aid work ought to aim at the following essentials: Efficiency; simple materials for dressing; simple methods of applying dressings; and consideration of cost of material recommended for dressings.

All existing practices and dressings were considered and those that best complied with the essentials named were chosen.

The methods and dressings recommended by the staff are now being taught by all the bureau’s instructors, and bureau publications describing them are being published.

In the past there has been much confusion at first-aid contests, owing to dissimilar dressings being applied. It is hoped that the new standards will go far toward eliminating such confusion.

A number of contests in first aid have already been held under these standards, the first being at Clinton, Ind., on April 1, 1916, where it was evident that the standardization work had already resulted in materially reducing the confusion mentioned.

Suggestions were offered by the standardization committee as follows:

1. That, as far as possible, first-aid training be given under the immediate supervision of a regularly registered and qualified physician.

2. That there be close cooperation with the first-aid department of the American National Red Cross in first-aid work.

3. That all examinations for first-aid certificates shall be held by a qualified physician and shall conform with such standards as may be laid down by the Bureau of Mines.

4. That it shall be the imperative rule in all first-aid contests that the judges shall be regularly qualified physicians familiar with first-aid work.

5. That where it is possible every employee in a mine should be trained in first aid; and if this is impossible, that at least one out of every ten employees, both inside and out, should receive such training.
A. GIBBS OXYGEN MINE RESCUE APPARATUS, WITH COVER REMOVED.

B. TYPICAL APPEARANCE OF ROCK-DUSTED ENTRY IN A COAL MINE.

Note whitened effect on walls.
COOPERATIVE RESCUE AND FIRST-AID TRAINING.

To extend the usefulness of the bureau's work in training miners in rescue and first-aid work a plan for cooperating with privately or State-owned rescue stations has been evolved.

The bureau announced that it would list such stations as cooperative provided their equipment and facilities were found to meet the purpose of training. When a station asks to be placed on the list of cooperating stations a representative of the bureau is assigned to investigate the station and to report on its status. His recommendation is considered before the station is designated as cooperative.

Every cooperative station is allowed to train men so as to qualify them to receive Bureau of Mines certificates for mine rescue and first-aid work if it conducts training according to a schedule similar to that used by the bureau. At the conclusion of the training a formal application is made for an examination and further test of the fitness of the applicants to receive certificates.

When a class is ready for examination the bureau sends to the station one of its engineers or foreman miners, who conduct the examination and directs practical demonstrations in first-aid and mine rescue work. If the records of the examination and work are satisfactory to the bureau, certificates are issued. This cooperation, which is conducted with the least possible cost to the bureau, affords a greater number of miners an opportunity to receive training.

Under this plan cooperative training stations have been listed by the bureau as follows:

Arizona Copper Co. --------------------------------- Morenci, Ariz.
Colorado Fuel & Iron Co. -------------------------------- Jansen, Colo.
Copper Queen Consolidated Mining Co. ------------------ Bisbee, Ariz.
Colorado School of Mines -------------------------------- Golden, Colo.
Detroit Copper Mining Co. ---------------------------- Morenci, Ariz.
Ellsworth Collieries Co. ------------------------------- Ellsworth, Pa.
Knox Mining Co. --------------------------------------- Jellico, Tenn.
Knox Mining Co. --------------------------------------- Rockwood, Tenn.
Missouri School of Mines and Metallurgy ------------------ Rolla, Mo.
Oliver Iron Mining Co. ---------------------------------- Ely, Minn.
Oliver Iron Mining Co. ---------------------------------- Eveleth, Minn.
Oliver Iron Mining Co. ---------------------------------- Hibbing, Minn.
Oliver Iron Mining Co. ---------------------------------- Iron Mountain, Mich.
Oliver Iron Mining Co. ---------------------------------- Ironwood, Mich.
Oliver Iron Mining Co. ---------------------------------- Ishpeming, Mich.
Pennsylvania State College ----------------------------- State College, Pa.
Ray Consolidated Copper Co. --------------------------- Ray, Ariz.
Republic Iron & Steel Co. ------------------------------- Republic, Pa.
Superior Coal Co. -------------------------------------- Superior, Wyo.
Union Pacific Coal Co. ---------------------------------- Cumberland, Wyo.
The following resolutions recommending first-aid training, the study of safety first, and participation in first-aid meets were adopted by delegates of the United Mine Workers of America assembled for the twenty-fifth consecutive and second biennial convention of District No. 11 at Evansville, Ind., on March 27, 1916. The resolutions were probably the first of the kind adopted by that organization:

Whereas the United Mine Workers of America believes in and practices fraternalism as exemplified by the motto, "United we stand, divided we fall"; and

Whereas it is the obligation of every member of our organization to aid and assist a brother in distress; and

Whereas there frequently occur times and opportunities to render such aid and assistance while engaged in the pursuit of our duties; and

Whereas for the benefit of injured mine employees the United States Bureau of Mines has introduced in the mining industry the movement known as first aid to the injured; and

Whereas this movement has proven its valuable and lasting worth by preventing suffering, saving lives, and giving our brothers reliable and efficient first-aid treatment; and

Whereas the United States Bureau of Mines introduced said first-aid movement and has at the cost of time and money been the most potent factor in teaching first aid to the injured: Now, therefore, be it

Resolved, That District No. 11 of the United Mine Workers of America, now in regular session, give the said first-aid movement our most hearty approval and indorsement; and be it further

Resolved, That each member of this organization, as well as the official body, give it their conscientious and whole-hearted support and assistance; and be it further

Resolved, That each member of this organization prepare and fit himself by a course of proper and efficient training in first aid, so that intelligent and efficient treatment may be rendered when a brother is injured; and be it also further

Resolved, That this convention indorse and approve the work of the United States Bureau of Mines in said movement; and be it further

Resolved, That the annual State first-aid contests held in Indiana hereby receive the approval, indorsement, and support of District No. 11, United Mine Workers of America; and be it further

Resolved, That each member of the organization be a constant student and practitioner of safety first.

*Proceedings of the twenty-fifth consecutive and second biennial convention of District No. 11, United Mine Workers of America, 1916, pp. 387–388.*
COAL-MINING INVESTIGATIONS.

PREVENTION OF COAL-DUST EXPLOSIONS BY WATERING OR USE OF ROCK DUST.

Widespread coal-mine explosions start from an ignition of gas or of coal dust or of a mixture of the two. Prevention of such explosions can be accomplished by removing the sources of ignition, or by removing or rendering inert any material that may be ignited. The safest plan is to attempt to do both.

Ignition of gas and dust is possible from open lights, sparks, arcs, or flames from explosives. The use of oil or gasoline permissible safety lamps or miners’ permissible electric safety lamps instead of the common oil lamps, the removal of electrical apparatus from places where ignition may be caused, or safeguarding such apparatus so as to prevent its causing ignition, and the use of short-flame permissible explosives to blast down coal that has been properly mined or sheared are precautions that eliminate largely the possibility of an ignition.

Gas ignition can be prevented by providing ventilation adequate to dilute gas at all points where it is generated and adequate to prevent accumulations of gas. In any mine in which open lights are used, it is desirable that the proportion of gas in the returns should not exceed 0.25 per cent. In the returns of any mine in which permissible lights are used, sufficient volume of air should be introduced so the proportion does not exceed 1 per cent. Ventilation should be so controlled that not more than 2 per cent of gas can be detected at any point in the mine.

In attempts to prevent ignition of coal dust, effort is made to prevent as far as possible accumulations of coal dust, and by wetting the dust to render inert coal-dust accumulations that do occur so that the dust can not be blown into a cloud, or by adding incombustible matter enough to render the cloud nonexplosive.

Coal-dust accumulations can largely be avoided by replacing all shooting off the solid by shooting after the coal has been mined or sheared, using tight cars, loading cars so that the coal will not be spilled over the tops, and frequently cleaning the roads.

There are several ways of rendering coal dust inert by wetting. The air current can be humidified with exhaust steam or sprays either after being preheated by passing over and through radiators, or without preheating. If enough steam is added to saturate the air current at the mine temperature there will be no evaporation of water in the mine. However, in winter it is difficult to keep the current saturated and it is usually necessary to supplement humidifying with some watering.
Watering is used in many mines where humidifying the air current is not attempted. A water car or hose from pipe lines may be used. Water cars are of several types. In one type the water merely dribbles on the middle of the road; in another the water is under pressure and a strong spray is thrown on all surfaces of the entry as the car passes. The use of hose to wash down all surfaces thoroughly is the best method if done frequently enough. In winter it may be necessary to sprinkle throughout the mine every day.

Deliquescent salts, usually common rock salt and calcium chloride, are also used for wetting dust. The former is slightly deliquescent, and does no good except when the air is nearly saturated; then the salt becomes moist and helps to wet the dust. Calcium chloride is more efficient; applied in quantities of about 2 pounds per foot it will keep a roadway moistened for two or three months, depending on how fast the coal dust accumulates. However, this method does not care for dust on ribs, roof, and timbers.

The dry method of rendering coal dust inert, termed rock dusting, has been used only during the past eight years. Applying dry incombustible dust to the ribs, roof, and floor of entries, air courses, and rooms, after they have been cleaned as thoroughly as possible of coal dust, affords efficient protection for a long period, until enough coal dust accumulates to make the mixture of rock dust and coal dust explosive.

Atkinson in 1880 and Garforth in 1886 noted in England, and Rice in 1892 in the United States, that after certain mine explosions the tram roads on which there was much incombustible matter showed hardly any explosion effects. It was noted in Germany that fine sand spread over coal dust appeared to prevent the spread of flame from a blow-out shot. Although these facts were recorded at the time, the idea of using incombustible dust to prevent coal-dust explosions developed slowly. For this development Mr. Garforth was largely instrumental. In 1908, in the experimental gallery of the British Government at Altofts, England, a stone-dust zone 300 feet long extinguished the flame from a 170-foot zone containing much coal dust. Seemingly this was the first occasion on which rock dust was used to check explosions.

At about the same time in France Mr. Taffanel began experimenting along the same lines. In 1911 the United States Bureau of Mines began similar testing on a large scale and for the first time this was done in a real mine.

In 1912 a British commission that was in charge of the Altofts experiments issued a preliminary report recommending the use of rock dust. In their report they mentioned five British collieries that were then trying rock dust; since then through official approval
of the method many mines have adopted the application of rock
dust as a safety measure.

In the United States rock-dusting on a large scale was first tried
in a Colorado mine, where sprinkling had caused roof falls. The
application of dry adobe dust began in March, 1911, and has been
continued to date. The first dusting was by hand, as a blower does
not give a satisfactory coating when the dust is first applied; for
subsequent treatment a rock-dust blower was used. About 10 miles
of entry has been kept dusted now for about four years, at a cost of
about 0.3 cent per ton of coal produced. The dust is obtained from
the country roads in a near-by canyon. It costs $1 per ton, and about
2,500 tons have been used. It all passes through a one-eighth-inch
screen and probably 20 to 30 per cent will pass through a 200-mesh
screen.

The introduction of rock dusting at other American mines has
been slow. In the meantime, by actual tests at its experimental
mine the Bureau of Mines has been determining the proportion of
incombustible that, when mixed with coal dust from the Pittsburgh
bed, will make a nonexplosive mixture. The bureau has deter-
mined that an explosion once started will not propagate through
a mixture containing 64 per cent of incombustible material if not
more than 20 per cent of the dust will pass through a 200-mesh
sieve, and if gas is absent from the air current.

During the latter part of the year 1914 one of the large coal-
mining companies working the Pittsburgh bed agreed to cooperate
with the Bureau of Mines in a test of rock dusting, and certain
localities in one of its old drift mines that produces 1,000 to 1,500
tons of coal daily were selected for test purposes. The mine is in the
Pittsburgh bed, is naturally dry and dusty, and produces some gas.
Calcium chloride, salt, and water are employed to lay dust; electric
lamps and permissible explosives are used entirely.

A carload of limestone dust was purchased as most available
for use. For the localities to be dusted first, short zones of widely
differing character were selected. One zone, about 450 feet long,
was in the main haulageway about 2 miles from the opening
and included a switching point at which there was much bumping
of cars and spillage of coal. Another, about 560 feet long, was in
a nearly level butt entry; a third, about 1,000 feet long, was in
part on a hill where there was considerable spillage and the mules
dug up the roadway considerably. These zones were along roadways
ballasted mostly with coal dust and coal. The loose coal and rock
were cleaned up before rock dust was applied. In a fourth zone
rock dust was applied to a roadway that had been ballasted with
roof shale. Other entries and butt entries dusted later differed from
those already dusted only in that two of them at one time had cal-
cium chloride applied which was still evident in the greater dampness of the roadways.

The first two applications were made to these zones in January, February, and March, 1915. From 4 to 6 pounds of rock dust per linear foot of entry was applied by hand, being thrown on the ribs and roof so as to give a uniform white coating. That which did not stick fell to the floor and there mixed with the coal in the road dust. At intervals, generally one to three months, these zones have been redusted and extensions to other parts of the mine have been made so that in July, 1916, approximately 6,700 feet had been dusted.

About twice a month samples have been taken in the dusted zones with a specially designed scoop. Loose road material to a depth of about 1 inch is brushed into the sampling scoop from a section 6 inches wide, extending completely across the roadway. The scoop contains a 10-mesh screen. Material not passing through this screen is rejected; the undersize is taken for analysis. Dust brushed from a 6-inch wide section of the ribs and roof makes up the rib sample. The road sample and the rib sample considered together represent a complete cross section of the mine entry. In the laboratory all material in these samples that does not pass through a 20-mesh screen is rejected; the undersize is analyzed for moisture, ash, and carbon dioxide, the weights of the samples are recorded, and sizing tests are made with 48, 100, and 200 mesh screens. The sum of the moisture, ash, and carbon dioxide contents gives the amount of incombustible present. From relative weights and analyses the average incombustible content of ribs and floor is calculated; the carbon dioxide content gives an approximate idea of the amount of limestone present; and the sizing tests give a basis of comparison with tests at the bureau’s experimental mine in which mixtures of sized material are used.

For the most part the samples taken have shown conditions to be satisfactory; for example, the average of 69 samples of rib and road dust sections showed a content of incombustible material of 65.2 per cent. It is considered that samples of rib and road dust taken together should show a content of incombustible material of at least 60 per cent when the proportion of 200-mesh coal dust present is not more than 20 per cent of the total coal dust present. Even when the samples fell below the standard given, they indicated conditions much better than in zones in which the wet method of rendering coal dust inert was used. The appearance of a rock-dusted area in an operating mine is shown in Plate III, B.

Limestone dust laid down at the mine cost $2.90 per ton. The labor rate was $2.62 per man per eight-hour day. At these figures, the cost of material and labor for the first application of 5.6 pounds of
limestone dust per linear foot of entry was $1.76 per 100 linear feet. A second application of dust by hand at the rate of 2 pounds per foot cost 62 cents per 100 feet, which, on the basis of four hand applications per year, would make an annual cost of $4.24 per 100 feet of entry. In January, 1916, the same coal company started dusting at two more of its mines. At one of these a little more than 3,000 feet of entry were dusted; in the other more than 7,500 feet.

Rock dusting at coal mines in this country has thus far been in the experimental stage. Costs can be greatly lowered. It is estimated that pulverized rock might be obtained for about $1 per ton by using a small pulverizer at the mine to crush shale available there. Manufacturers are working on a machine that may do away with the need for making the first application of dust by hand; it has been shown that reapplying dust may be done better with a blower or similar machine than by hand. By using shale dust and reapplying it with a blower, it is estimated, on the basis of the costs given above, that $130 per mile a year will safeguard a mine entry, or, roughly, for the mine in question, one-half cent per ton of coal mined.

Objection has been made to using rock dust on account of alleged danger to the miners' lungs. Pulverized shale dust has been shown to be noninjurious by British commissions which have particularly investigated this point. Dust containing free silica or sharp particles of any sort is likely to be injurious. Microscopic examination is a quick method of detecting the presence of sharp points or edges and the likelihood of danger from this source, and the Bureau of Mines has been making microscopic studies of various available materials for making rock dust.

On the whole, tests in this country as well as in Europe have sufficed to show the practicability and suitability of rock dusting as a means of preventing coal-mine explosions.

**MINE AIR IN ILLINOIS COAL MINES.**

The Bureau of Mines, in cooperation with the State of Illinois through the engineering experiment station of the University of Illinois and the State geological survey, is investigating the quality of the mine atmospheres in the coal mines of the State and the effect of different agencies on the air.

Under this general subject three publications have already been printed. A short description of the results obtained in other studies of mine air, reports on which are in the course of preparation, follows.

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STUDY OF RATE AT WHICH METHANE ACCUMULATES.

To obtain further information on the liability of methane accumulating in unsuspected places should the ventilation be temporarily shut off or interrupted, a number of samples were collected in Illinois and Indiana mines while the mine fan was stopped or while the ventilation was interrupted by blocking an air passage. Analysis of the samples showed that in some places where the gases diffused evenly when the fan was running at normal speed, the methane began to accumulate at the roof as soon as the ventilating current was stopped, and within a relatively short time the increase was enough to have greatly assisted in initiating a mine explosion and to have made a nonexplosive cloud of coal dust violently explosive. This investigation is of importance to those mines that practice slowing down the fan or otherwise interrupt the ventilating current before the firing of shots of black blasting powder or dynamite.

OCCURRENCE OF METHANE IN ILLINOIS COAL MINES.

The bureau’s investigations made in cooperation with the State of Illinois have shown that there is a wide range in the amount of methane given off in the coal mines of that State. A large number of samples collected in two long-wall mines near La Salle were entirely free from methane, and the only samples containing methane from these mines showed less than 4 parts in 10,000 parts of air, or less than 0.04 per cent. On the other hand, some of the mines in Illinois may liberate large quantities of methane. One mine working the No. 5 bed in Saline County struck a zone of gas feeders which after 8 days gave off 40 cubic feet of methane per minute, or 57,600 cubic feet per day, from the face of two entries. Forty-eight days later this zone was giving off 24.7 cubic feet per minute. The coal had not been faulted or otherwise displaced but had been subjected to shearing stresses.

To prevent accidents from ignition of fire damp, the tendency in some Illinois mines has been to reduce the interval between the time the mine is examined and the time the men go to work in the morning. Also, more care is being taken to keep men from entering abandoned or caved workings. One method of doing this has been by the use of woven wire and poultry netting barriers with locked gates so that only authorized persons can pass through. (See Pl. IV, A.)

EFFECT OF USE OF EXPLOSIVES ON RETURN AIR.

To determine the effect of the gases from blasting on the mine air, a study was made of the return air current in an Illinois mine where approximately 18,000 cubic feet of air per minute was circulating.
A. Method used in Illinois mine to fence off old workings without interfering with ventilation.

B. Cannon and wiring prepared for an explosion test at experimental mine.
After approximately 1,850 pounds of powder had been used for blasting, analyses of air samples showed that the change in the air was small, there being approximately 0.05 per cent increase in inflammable gases and 0.1 to 0.2 per cent increase in carbon dioxide, with a corresponding deficiency of oxygen. The slight increase of methane would indicate that little methane was liberated by the shooting. The return air was distinctly hazy, and the odor of sulphur made it unpleasant. The mine itself was generating a relatively small amount of methane.

**ABSORPTION OF OXYGEN BY COAL AND ESCAPE OF CARBON DIOXIDE FROM IT.**

A large number of samples of mine air were collected in Illinois mines to determine the ratio between the oxygen absorbed from the air by the coal and the amount of carbon dioxide added to the air. The ratio between oxygen absorption and carbon dioxide emanation was found to vary widely, but the average of a number of analyses appears to establish a ratio of about 3 to 1, or, in other words, while the air was in circulation about three volumes of oxygen were absorbed for one volume of carbon dioxide added.

**WORK AT THE EXPERIMENTAL MINE.**

**CHARACTER OF MINE.**

The experimental mine of the Bureau of Mines was opened in December, 1910, for the purpose of making explosion tests in connection with a study of the origin and progress of explosions of coal dust, of gas (methane), and of mixtures of coal dust and gas. The object was to develop and test methods of preventing or limiting such explosions. The mine is in the Pittsburgh coal bed and is situated on the side of a ravine near Brucontin, Pa., 13 miles from Pittsburgh. The Pittsburgh coal at this point is nearly level and is 5 to 5½ feet thick.

The mine layout as finally developed is shown in figure 2. It consists of two main entries 1,300 feet long; one pair of butts driven 300 and 350 feet to the left of the main entries, from which five rooms are turned; and a single butt entry 100 feet long, turned to the right from the main entry. The inner 350 feet of the main entries has a concrete lining. The purpose of this lining is to facilitate cleaning after explosion tests and to prevent particles of coal dust from the ribs and roof affecting tests with coals from other beds.

At intervals of 200 feet throughout the mine, except in the outer part of the main air course, large instrument stations of concrete are built in the rib. In these are placed measuring and recording instruments during explosion tests. In addition to these large sta-
tions are smaller intermediate stations. All the stations are connected to each other and to the outside by a cable in a pipe embedded in concrete in the rib. The mine has been fully described in Bulletin 56 of the bureau.

INSTRUMENTS USED.

The instruments used are of two general classes—pressure instruments, each of which records the explosion pressure at the point at which it is placed, and circuit breakers, each of which causes a break in the circuit when the flame of the explosion passes, this break being recorded by a chronograph in the observatory. In the latest type of pressure manometer the variation in pressure is recorded by a ray of light acting on a photographic film; the passage of the flame is also photographed on the same film. By means of the time records on the various films it is possible to plot the various records according to time and distance from the origin and to study the progress of the explosion as shown in the pressure and flame records. As the time the flame passes both large and small stations is indicated by the circuit breakers, the velocity between any of these points can be calculated. The principle of the breaking of circuits is also used in ascertaining the time of operation of various protective devices used in connection with the explosion tests.

PREPARATION AND DISTRIBUTION OF COAL DUST.

The coal dust used in the tests is prepared at a grinding house at the mine and immediately before a test is distributed along the entry on side shelves, on cross shelves about 8 inches beneath the roof, and

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on the concrete floor, the usual distribution being at the rate of about 2 pounds of coal dust per linear foot of entry or 0.5 ounce per cubic foot of space. For standard testing an explosion is initiated by firing a blown-out shot of 4 pounds of FFF black blasting powder from a cannon placed on the floor of the main entry and pointed outward. Plate IV, B, shows the cannon and the wiring ready for an explosion test. The upper wires from the bore hole are the shot-firing wires, and the wire passing across in front of the hole is part of the ignition circuit; when the shot is fired this wire is broken, and the time of break, or of the starting of the explosion, is recorded in the observatory. The wires from the cannon pass through a pipe in the rib to the surface at the main opening. The igniting shot is fired electrically from the surface after everyone is out of the mine.

Plate V, A, shows the observatory instruments, called chronographs. Every pen is connected to some circuit, and when that circuit is broken the pen moves sidewise. The time is obtained from a record, made on each drum, of the oscillations of the tuning fork shown at the left of the chronograph.

When the shot is fired a flame about 20 feet long results. The air currents stir up the coal dust from the floor and the sides, causing a thick cloud, which is ignited by the flame. The inflammation of this coal-dust cloud sets up pressures which cause increased air movements and an extension of the cloud, which in turn ignites; this process continues indefinitely as long as there is fine, dry coal dust to be acted on. With pulverized Pittsburgh coal dust the explosion travels the first 150 feet in about 1 second; beyond this point the explosion increases in velocity and pressure until at a point 350 feet from the origin the velocity may be as great as 3,000 feet per second, with a pressure of 40 pounds per square inch. The extension of the explosion for 200 feet more may cause pressures as high as 100 to 120 pounds per square inch, which is about the maximum recorded by the instruments, although in all probability higher pressures have occurred in the explosion zone.

PURPOSES AND CHARACTER OF TESTS.

The first tests at the experimental mine were made to demonstrate to large numbers of visitors that coal dust would explode. Later, the systematic study of explosions was begun. Up to July 1, 1916, 330 tests had been made. In general the tests have been made in order to study these points:

The development of pure coal-dust explosions.
The relative explosibility of various coals.
The influence of the fineness and the quantity of the coal dust.
The influence of small percentages of gas in the air current.
The effect of the presence of rock dust.
The effectiveness of rock-dust barriers for limiting explosions.
The development of explosions in wide places.

In determining the explosibility of various coal dusts mixtures of coal dust and shale dust or other incombustible dust are used. The proportion of incombustible dust is increased until a mixture is found through which an explosion will not travel. The percentage of shale dust required to prevent the explosion is the measure of the relative explosibility of the coal dust.

Two classes of tests, termed ignition and propagation tests, are made. In the ignition test the percentage of shale dust that prevents the mixture of shale and coal dust from being ignited by a standard blown-out shot from the cannon is determined; in the propagation test the percentage of shale dust that prevents propagation of an explosion started in a zone of more explosive dust, or by the ignition of a body of gas, is determined. After determination has been made of the ignition and propagation limits of coal dust in an atmosphere containing no explosive gas, tests are made when small percentages of gas are present in the air current, and the percentage of shale dust necessary, with various percentages of gas, to prevent ignition or propagation as the case may be is thus determined. Explosibility tests of this character have been made with 12 different coals, ranging from low-volatile anthracite to high-moisture lignites.

Another factor that affects the explosibility of coal dust is the fineness. A large number of tests have been made to determine the influence of this factor. With Pittsburgh coal dust the percentage of shale dust required increases from 50 to 80 per cent as the proportion of coal dust fine enough to pass a 200-mesh screen is increased from 10 per cent to 75 per cent. This shows how important is the fineness of the dust in a mine, for the finer the dust the greater must be the precautions taken to prevent widespread explosions.

METHODS OF MAKING COAL DUST NONEXPLOSIVE.

There are two general methods of rendering coal dust nonexplosive—first, by wetting the dust to prevent a cloud of dust from being formed, because only when the coal dust is in a cloud is it explosive; second, by adding to the coal dust enough incombustible dust to make the mixture nonexplosive. The first method is extensively used; the second is comparatively new in the United States. The advantages of using wet dust to prevent coal dust explosions have been pointed out in a preceding chapter.

The first coating is applied by hand and the use of limestone dust gives an entry the appearance of being whitewashed. Later when it
A. CHRONOGRAPHS; INSTRUMENTS IN OBSERVATORY WHICH MEASURE SPEED OF EXPLOSIONS IN EXPERIMENTAL MINE.

B. BLOWING MACHINE FOR ROCK DUSTING IN COAL MINES.
is necessary to redust, the dust is blown into the air current by means of a blowing machine (Pl. V, B) and this dust settles down on ledges and surfaces on top of the coal dust that has accumulated, and keeps the latter from becoming explosive.

Ordinarily only the coal dust in the haulage entries is treated, but the parallel air course may contain considerable coal dust that would propagate an explosion. To obviate this danger, rock dust should also be blown into the air course.

The information gained from explosibility tests of the quantity of shale dust necessary to prevent mine explosions is very valuable in developing the rock-dusting method of rendering coal dust inert; if the explosibility of the road dust be questioned, analysis of samples will show whether the percentage of incombustible in the road dust is sufficient to prevent the propagation of an explosion along that road. Rough determination of the percentage of incombustible dust present can be made quickly with an instrument called a “volumeter,” designed by Mr. Taffanel, of France.

**DEVELOPMENT OF ROCK-DUST BARRIERS.**

As has been indicated, in order to have efficient protection from widespread explosions, rock dusting should be done throughout a mine, as no one can foresee at just what point an explosion may start. As long as rock dusting or watering is satisfactorily maintained there should be no danger of an explosion being propagated throughout a mine; but if the method is used and is not adequately maintained there should be supplementary means of preventing an explosion from spreading throughout the mine and possibly causing the death of everyone in it. So-called “rock-dust barriers,” based on devices tested in France, have been designed by George S. Rice, chief mining engineer of the Bureau of Mines, and tested at the experimental mine. Models of each of several types were developed which in a large number of tests effectively stopped the propagation of explosions.

One of the most easily constructed and effective of these barriers is known as the “trough barrier.” It consists of six or more troughs extending across the entry at intervals of about 6 feet, with the bottom boards held in position by a lever system connected by wires to suspended vanes 100 feet on either side of the troughs. Should an explosion occur the vanes are caused to swing, thus releasing the bottom boards of the troughs so that the dust contents fall to the ground in a dense cloud. This dense dust cloud cools the gases to such a degree as to prevent propagation of flame beyond. Plate VI, A, shows the appearance of a 6-trough barrier set in a mine entry.
The various types of barriers are described in Technical Paper 84 of the Bureau of Mines.

Such barriers are feasible at the entrances to all splits of the air current or sections of a mine, and at points along the main haulage roads, so that if an explosion occurs it will be arrested by the barriers, and will not spread throughout the mine. If an explosion should occur in a particular split in which the dust on the roads was explosive, it would not travel beyond the barrier at the entrance to the split. The men in the split might lose their lives, but the men in other parts of the mine would have a much better chance of getting out safely.

Most of the tests made have been in entries or narrow places, because most explosions are initiated in such places. However, as some explosions start in wide places, a few tests have been made with reference to the development of explosions in those places. These tests indicate that such explosions can be initiated with comparative ease by a single blown-out shot if enough fine coal dust be present. It was also indicated that cut-throughs (break-throughs) near the point of origin hindered the development of the explosion, as they permitted considerable release of pressure at the time when the explosion is just getting under way.

Plate VI, B, shows the effects of an explosion in the experimental mine.

LABORATORY STUDIES OF INFLAMMABILITY OF COAL DUST.

Large-scale tests of the explosibility of coal dust take time and are expensive, so that the desirability of a reliable laboratory test of inflammability is obvious. For some years the development of such a test has been in progress in the Bureau of Mines. The measure of inflammability now used in the bureau is the pressure developed when a definite amount of dust, air dried and ground until its particles are of definite size, is ignited by being blown in a definite way against a source of heat of definite size and temperature.

The apparatus used at present consists of a thick glass bulb connected through a tubulure with a steam-pressure gage, and another tubulure, opposite the first, which is connected air-tight with a small glass funnel whose stem is bent to a right angle. The dust to be examined is placed in this funnel. Between the two tubulures, in the center of the glass bulb, is a rigidly held platinum tube that is heated electrically to 1,200° C. The dust is blown against the platinum tube by a puff of oxygen under definite conditions. The

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A. "SIX-TROUGH" ROCK-DUST BARRIER SET UP IN MINE ENTRY.

B. REINFORCED-CONCRETE STOPPING IN CROSS HEADING BLOWN OUT BY SUCCESSIVE DUST EXPLOSIONS IN EXPERIMENTAL MINE.
pressure developed by the ignition of the dust, which ranges from a few tenths of a pound to 20 pounds per square inch, is registered on the gage. Tests of mixtures of coal dusts and shale dust are also made.

In general, predictions from these laboratory tests of the explosibility of bituminous dusts in mine tests have been satisfactory, but there has not been such agreement between laboratory and mine tests of anthracite and lignite dusts. Further development of the apparatus is being attempted in order to obtain satisfactory results throughout the entire range of coals.

**EFFECT OF MOMENTARY HEATING OF INFLAMMABLE COAL DUSTS.**

Opinions differ as to how flame spreads through a cloud of inflammable coal dust. Some investigators believe that the dust particles burn as a whole, but others hold that during the short period of heating, just before inflammation, combustible gases are distilled from the coal, and that these gases give rise to the explosion. If the latter view is correct, then the readiness with which the gas distills is obviously a factor determining the inflammability or explosibility of the dust.

The plan of the bureau's experiments has been to subject a suspension of dust (dust cloud) to momentary heating sufficient to cause inflammation in air, to repeat the test in an inert atmosphere (nitrogen), and to analyze the atmosphere for combustible gases. The source of heat in some of the tests was an incandescent weight, which was dropped through the dust cloud. The results of such tests indicated practically no distillation of gases from the dust under the conditions of testing.

In work now under way the source of heat is a blast of hot gas. The apparatus used is shown in figure 3. Only the general features
need be described here. A glass rod passing through a rubber stopper in the wide glass tube a bears a copper scoop at the end, on which is placed a little heap of coal dust. The silica tube c passes through the electric furnace b and is joined to a with a piece of rubber tubing. The silica tube is connected with an apparatus (f, h, d, etc.) for furnishing a puff of gas. After the silica tube is heated by the furnace to 1,100° to 1,200° C., the dust is pushed in to the point n, and the blast of gas is suddenly released. This causes ignition of the dust when the system is filled with air.

Pure nitrogen is then substituted for air, and the dust is blown from n into a in the same way. The atmosphere in a is then analyzed for combustible gases.

The results obtained agree with those of the other method. The amounts of combustible gases formed in the inert nitrogen atmosphere under the conditions of test were slight.

THE TESTING OF EXPLOSIVES USED IN MINES.

IMPORTANCE OF TESTING MINE EXPLOSIVES.

The explosives used in coal mines not only cause accidents such as happen in the use of explosives elsewhere, but they have given rise to widespread disasters by igniting explosive mixtures of mine gas and air and of coal dust and air, or both. In addition, the firing of explosives so shakes the walls and roofs of the mines as to cause falls, with their attendant casualties.

In view of the large number of explosives and their wide range in composition and properties, it is obvious that certain of them should prove more suitable for use in mines than others. The problem is to determine which explosives are the most suitable for this purpose and the precise conditions under which they may be used with the greatest safety.

Of course this problem could be worked out in actual mining, but experimental investigations in a working mine are hazardous and slow. To obtain the information sought, in the speediest and most economical manner, laboratory methods are required.

The Bureau of Mines at its Pittsburgh experiment station has equipment for such laboratory testing of explosives. These tests involve chemical and physical examination and the detonation of charges under carefully controlled conditions.

DEVELOPMENT OF PERMISSIBLE EXPLOSIVES.

With the cooperation of explosives manufacturers, the bureau has evolved a type of explosives especially intended for use in gaseous or dusty coal mines. Such explosives, termed permissible explosives,
are tested and approved by the bureau, which also prescribes conditions under which they must be used to be regarded as permissible. Thus the bureau prescribes that an explosive is not to be regarded as permissible unless used with a detonator (blasting cap) of proper strength.

METHODS AND APPARATUS USED IN TESTING EXPLOSIVES FOR PERMISSIBILITY.

The apparatus employed in testing explosives and the methods of using it are briefly outlined in the paragraphs following.

PHYSICAL EXAMINATION.

Every explosive tested for permissibility is examined as to its physical properties, including the determination of the average diameter, length, and weight of the cartridge, whether the cartridge has been dipped more than once in moisture-proofing material, the apparent specific gravity of the cartridge, the weight of the wrapper per 100 grams of explosive, and the color and consistence of the explosive.

When feasible, screening tests are made to determine the sizes of the different ingredients.

Some of the tests made to determine the strength and relative safety of the explosive are described below.

THE BALLISTIC PENDULUM.

The ballistic pendulum, shown in Plate VII, A, is used to measure what is termed the deflection force of the explosive. A charge tamped with dry clay is loaded into a small cannon, shown on wheels in the plate. The charge is fired into the bore of a mortar weighing 31,600 pounds, suspended by means of a stirrup from two cast-steel saddles fitting over a steel supporting beam that rests on nickel-steel knife edges. The amount of the explosive being tested that causes the pendulum to swing as far as does a charge of one-half pound (227 grams) of the Pittsburgh experiment station standard 40 per cent "straight" nitroglycerin dynamite is known as the unit deflection charge. It must be less than 1 pound (454 grams). This test indicates the coal-getting strength of an explosive.

GAS AND DUST GALLERY NO. 1.

The liability of an explosive to produce an ignition of coal dust in a mine is determined by firing it in what is known as gas and dust gallery No. 1 (Pl. VII, B). This consists of a steel cylinder 100 feet
long and 6½ feet in diameter. In part of the gallery are placed sensitive explosive mixtures of gas and air, coal dust and air, or gas, coal dust, and air. The firing of a charge of the explosive in a small cannon into the gallery is similar to a “blown-out shot” in a mine.

An explosive is considered to have passed the gallery test if no one of the prescribed shots ignites the mixture into which it is fired.

In tests 1 and 3, described below, 10 shots are made. For each shot a charge equivalent to the unit deflative charge of the explosive is used; the explosive is placed in its original wrapper, and each shot is tamped with 1 pound of clay stemming.

In test 1, on each trial, a mixture of gas and air containing 8 per cent of gas (methane and ethane) is used.

In test 3, on each trial, 40 pounds of bituminous coal dust is used, 20 pounds being distributed uniformly on a wooden bench placed in front of the cannon, and 20 pounds being placed on side shelves in the second 20 feet of the gallery.

In test 4, five shots, each with a 1½-pound charge, are fired without stemming. A mixture of gas and air containing 4 per cent gas (methane and ethane) and 20 pounds of bituminous coal dust are used. Eighteen pounds of the coal dust is placed on shelves along the sides of the first 20 feet of the gallery, and 2 pounds is so placed in a part of the gallery inclosed by a paper diaphragm that it will be thrown into suspension by an air current.

RATE-OF-DETONATION APPARATUS.

The rate, or velocity, of detonation of an explosive is determined by firing a charge in a covered pit. The explosive ends of the cartridges are cut off and the cartridges are placed in a sheet-iron tube which is suspended in the pit. Through perforations in the side of the tube two wires pass through the explosive at intervals of 1 meter along the length of the tube. A No. 7 electric detonator inserted into one end of the cartridge file detonates the explosive. Each of the wires passing through the charge is electrically connected to a Mettegang recorder (Pl. VIII, A) which has a soot-covered bronze drum revolving rapidly at a known speed. When the explosion breaks the electric circuit through each of the wires passing through the long cartridge, an electric spark makes an impression on the drum. By special devices, distances between these impressions can be measured accurately. The final result, based on the distance separating the wire, the speed of the drum, and the distance between the spark points, is expressed in meters per second and is called the rate of detonation. This rate largely determines the shattering effect of an explosive.

The rate of detonation is determined by three trials with cartridges of the smallest diameter that the manufacturer wishes to use. For
A. METTEGANG RECORDER.

B. BICHEL PRESSURE GAGES AND ACCESSORIES.
a test to be acceptable the entire cartridge file must detonate completely. Similar trials are made with cartridge files having diameters of 1¼ inches.

TEST FOR GASEOUS PRODUCTS OF EXPLOSION.

The gaseous products from firing a charge of an explosive are determined by chemical analysis. A charge of explosive is fired in the Bichel pressure gage, described on page 37. The charge is 200 grams of explosive contained in a weight of original wrapper that is proportional to the largest weight per 100 grams of explosive of all the different sizes of cartridge in which the explosive submitted for test is sold. By means of a No. 7 electric detonator inserted into one end, the cartridge is fired after the gage has been closed and the air exhausted from it. The gases evolved by the explosion are allowed to cool for 30 minutes. After the pressure has been recorded, a differential sample of the gases is drawn from the gage and analyzed. If any poisonous gas is present, it is usually carbon monoxide or hydrogen sulphide. The total volume of poisonous gases from 680 grams (1½ pounds) of the explosive (the permissible charge) is then computed.

An explosive is considered to have passed this test if the total volume of poisonous gases from 680 grams (1½ pounds) of the explosive does not exceed 158 liters (5½ cubic feet) at standard temperature and pressure (0° C. and 760 mm.).

If an explosive that did not fulfill the above requirement were used in a narrow coal-mine entry driven ahead of the ventilating current, the air might be so vitiated with poisonous gases as to impair the health of the miner.

PENDULUM FRICTION DEVICE.

The pendulum friction device (Pl. IX, A) is used for testing the sensitiveness of explosives to frictional impact or a glancing blow. Serious accidents have occurred in charging drill holes with explosives too sensitive to such impact. Tests at the Pittsburgh experiment station have shown that some explosives made from mixtures containing chlorate of potash and carbonaceous combustible materials are liable to explode under this test.

These chlorate of potash explosives have many properties making them desirable for use in coal mines; as for example, a slow rate of burning and a heating effect suitable for the production of lump coal. It would seem, therefore, that there is an opportunity for some manufacturer to produce an explosive of this class that is not sensitive to frictional impact.

An explosive is considered as having passed this test if no explosion, burning, or local cracking occurs in any one of ten trials. In each trial a 7-gram charge of the explosive spread on a grooved
solid steel plate is struck about 18 times by a steel pendulum faced with a fiber shoe (Pl. IX, A). Resting above the shoe is a 20-kilogram weight. The pendulum drops from a height of 1.5 meters.

**CRUSHER-BOARD TEST.**

A crusher-board test is made of explosives denominated low-freezing, extra low-freezing, or nonfreezing. This test gives the compressive strength of cartridges that have been brought up to room temperature, as compared with the compressive strength of cartridges that have been kept at a low temperature for several hours. Explosives denominated "low-freezing" are kept at 35° F.; those denominated "extra low-freezing," at 0° F.; and those denominated "nonfreezing" are kept at still lower temperatures for several hours prior to the test.

**STORAGE TEST.**

The two-months' storage test is the final test made in determining permissibility. For an explosive to pass this test at least four out of five cartridges of the smallest diameter submitted must detonate completely when fired after two months' storage at the Pittsburgh experiment station.

In practice the test is made by firing separately five cartridges suspended in air in a gallery. Electric detonators of the grade recommended by the manufacturer are used for the tests. As these tests are considered to be more severe than those made in a cannon, no further tests are made if there is complete detonation in each of five trials.

However, if some of the cartridges fail to detonate completely, the number thus failing is noted, and the same number of fresh cartridges are fired separately in a cannon so charged that there is an air space between the bore hole and the explosive; the number and the nature of the failures are noted. Fresh cartridges equal in number to those failing are taken and separately loaded without air space and fired as before. Should there be two or more failures, the explosive fails to pass the test.

**SUPPLEMENTARY TESTS.**

The explosives that pass all of these tests for permissibility are submitted to further tests in order that the manufacturer and user may have complete information. The additional tests are made as follows:

**FLAME TEST.**

In the flame test the flame from the explosive is photographed in order to show its length and its duration. The test is based upon the belief that the greater the length and the duration of the flame of
A. PENDULUM FRICTION DEVICE.

B. SMALL LEAD BLOCKS. A, BLOCK BEFORE TEST; B, C, D, E, F, BLOCKS AFTER TEST, SHOWING EFFECT OF DIFFERENT EXPLOSIVES.

C. TRAUIL LEAD BLOCK AFTER TEST, AND SECTION SHOWING EXPANSION OF CAVITY BY EXPLOSIVE.
an explosive the greater is the chance of such a flame igniting inflammable or explosive mixtures of gas or coal dust in a mine. Too great emphasis must not be placed on length and duration of flame as an indication of permissibility, for both the length and the duration of the flames of certain nonpermissible explosives are less than those of some of the permissible explosives, but the other variables, particularly the temperature of the flame, are of importance and must be taken into account.

EXPLOSION-BY-INFLUENCE TEST.

The explosion-by-influence test determines the sensibility of an explosive to the explosion wave produced by the detonation of an equal mass of the same explosive and transmitted through the air. In this test two cartridges of the same explosive are placed a predetermined distance apart. One cartridge is fired by means of an electric detonator. If the second cartridge is detonated by the detonation of the first cartridge, the test is repeated with the second cartridge farther away. If the second cartridge is not detonated, the test is repeated with the second cartridge nearer the first. By proceeding in this way, the minimum distance between cartridges at which the first cartridge does not detonate the second is established within 1 inch.

BICHSEL PRESSURE GAGE.

The Bichel pressure gage (Pl. VIII, B) is used for determining the maximum theoretical pressure that could be developed in a bore hole by an explosive. The essential features of this apparatus used are cylinders in which the explosive is fired, instruments by which the pressure developed in these cylinders is recorded, and a device by which the heat distribution, or dissipation, is ascertained.

The apparatus actually employed consists of two stout cast-steel cylinders. The chamber of one cylinder measures 19 inches (48.3 cm.) by 7.87 inches (20 cm.); the chamber of the other measures 25.25 inches (64 cm.) by 7.87 inches (20 cm.). The heads of the cylinders are provided with lead gaskets, and are secured in place by heavy stud bolts and an iron yoke, as shown in Plate VIII, B. A system, of sheaves and suspended counterweights is provided to aid in detaching the heavy heads from the cylinders and in mounting them on the specially designed wagons so that access may readily be had to the interiors of the cylinders.

As the air is practically excluded from a bore hole in coal or rock when it is filled with a charge of explosive, these conditions must necessarily be simulated in experimental tests. Therefore, when explosives are fired in the cylinders the air is almost entirely removed from them with a pump.
The charge of explosive is placed in the gage and fired electrically, and the pressure is recorded by suitable instruments.

BOMB CALORIMETER.

The heat liberated by the detonation of a known weight of explosive is determined in a bomb calorimeter, shown in Plate X, A.

SMALL LEAD BLOCKS.

The small lead block test determines the relative quickness of an explosive, as indicated by the compressive effect exerted by an explosive when exploded unconfined on the upper end of a small cylinder of lead. In making this test, a small steel disk placed on the lead cylinder receives the immediate impact of the detonation. The deformation of the cylinder is taken as a measure of the disruptive effect of the explosive. (See Pl. IX, B.)

TRAUZL LEAD BLOCKS.

The Trauzl lead block test is designed to measure the comparative disruptive effect of explosives fired under moderate confinement. Equal weights of different explosives are confined by means of a fixed quantity of stemming in bore holes of definite size made in lead blocks (Pl. IX, C) of prescribed character and, when thus confined, are exploded by means of similar detonators. The measure of the test is the increase in the volume of the cavity in the block caused by the pressure exerted by the explosive.

IMPACT MACHINES.

The large and small impact machines (Pl. X, B) are used in the determination of the relative sensitiveness of explosives to the impact produced by falling weights.

SUITABILITY TESTS OF EXPLOSIVES.

Suitability tests are made to determine the suitability of explosives for use in metal mines and quarries. They are the same as those for permissibility, with the following exceptions:

The ballistic pendulum test is made in duplicate, but no limits are set on the result representing the unit defective charge.

No gallery tests are made.

The rate of detonation test is made in duplicate. The electric detonator used must have a strength not less than that of a No. 6 electric detonator.

In the test for gaseous products of explosion the explosive is fired with an electric detonator of not less strength than that of a No. 6. When detonated in the gage the explosive, to be satisfactory, must not
evolve poisonous gases in quantities that may be considered harmful to the health of the miners.

No flame photograph is made.

TESTS OF DETONATORS.

The methods of testing detonators have been described in Bulletin 52. The nail test, one of those described, can be readily performed by anybody desiring to determine the relative strength of detonators. This test depends on the bending of a nail by firing a detonator or electric detonator in close proximity to it.

Recently the Bureau of Mines has developed a method of determining the probability of detonation when a detonator is fired. An insensitive dynamite is obtained by mixing 40 per cent “straight” nitroglycerine dynamite with varying quantities of wood pulp. The different mixtures are formed into 1½ by 8 inch cartridges. The detonator to be tested is inserted into the end of one of these cartridges, the cartridge is suspended in the air, and the detonator is fired.

Usually if three cartridges detonate completely, another mixture is used containing less nitroglycerin and more wood pulp. This procedure is continued until such a mixture is obtained that only part of the cartridges prepared therefrom detonate completely. Enough of the mixtures containing the same quantity of nitroglycerin is prepared so that at least 25 trials may be made. The number of cartridges detonating completely out of the total number of trials made with the same insensitive mixture determines the probability of detonation. The results are usually compared with the results obtained with some standard detonator tested at the same time.

SAND TEST.

Another direct test for determining the strength of detonators has been designed by the engineers of the bureau, and is known as the sand test. The detonator is embedded in the center of standard 30-mesh quartz sand contained in a block of steel having a cylindrical cavity. Two cylindrical steel covers are provided—one with a single hole in the center for the passage of a fuse when detonators are tested, and one with two holes for electric wires when testing electric detonators. The device is shown in Plate XI.

The detonator is fired with a fuse or electrically, and the quantity of sand pulverized is taken as a measure of the strength of the detonator. This test, besides being quantitative, enables an experimenter working on reinforced detonators (those in which part of

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the mercury fulminate or other initiating explosive is replaced by an organic nitro compound or nitrate) to determine whether complete or partial detonation has been brought about, the result being shown by the amount of sand crushed or by the unexploded nitrate or nitro compound found after the shot was fired. The test offers great possibilities for studying the sensitiveness to detonation of explosives and is a distinct aid to manufacturers and users of detonators.

ADOPTION OF PERMISSIBLE EXPLOSIVES AND SAFETY DEVICES.

In its educational campaign for greater safety in mining, the Bureau of Mines has earnestly advocated the use of approved explosives and equipment. Too much stress can not be placed on the need of safeguarding the 1,000,000 men employed in the mining industry in the United States.

As an example of the importance of adopting safety measures may be cited the decreased fatality rate from explosives in bituminous coal mines in the 7-year period 1909–1915 in comparison with the increased use of permissible explosives. Thus, in 1909, there were 122 fatalities due to explosives, whereas in 1915 the number had been reduced to 76, or almost 50 per cent. In 1909 the amount of permissible explosives used in coal mines was, in round figures, 9,000,000 pounds, and in 1915 the amount used had reached 22,000,000 pounds.

PROGRESS IN REPLACEMENT OF BLACK BLASTING POWDER BY PERMISSIBLE EXPLOSIVES IN ILLINOIS AND INDIANA.

In the coal-mining region designated by the Bureau of Mines as the central district, the bureau has been making special efforts to induce the operators to adopt the use of permissible explosives. It has assigned an assistant mining engineer to the work of education and demonstration. The results in Illinois and Indiana are mentioned specifically as typical.

PERMISSIBLE EXPLOSIVES IN ILLINOIS.

Permissible explosives were not introduced into Illinois until 1909. They are now being used exclusively in 20 mines, which are among the most modern in the State. These mines have a daily output of over 50,000 tons, and employ about 9,000 operatives, or approximately 11.5 per cent of the total coal-mine employees of the State. During the fiscal year ended June 30, 1915, the number of pounds of permissible explosives reported in the Illinois coal reports as used in Illinois coal mines was 1,342,334. Approximately 7,680,000 tons of coal was produced by the use of such explosives, or 14.3 per cent of the State total produced by all explosives.
In most of these mines black blasting powder was formerly used, but a change to permissible explosives was made to procure relief from numerous fires and explosions. Thus, in one mine 5,372 fires were recorded in a 14-month period. Since the introduction of permissible explosives, fires and explosions have been practically eliminated and many other advantages have been gained, such as less injurious effects upon the roof, elimination of "blown-out" and "windy" shots, lower cost of explosive per ton of coal, and fewer accidents in handling explosives. At the same time the sizes of coal obtained have not been materially affected. The consensus of opinion among mining men in the State is that where the coal is properly undercut and "snubbed" permissible explosives can be successfully used with little if any increase in the amount of slack coal over that produced by black blasting powder.

The State of Illinois cooperated with the Bureau of Mines in the work, and a report on the use of permissible explosives in Illinois coal mines is to be published by the bureau.

PERMISSIBLE EXPLOSIVES IN INDIANA.

In Indiana, permissible explosives are used exclusively in two mines, one of which is in Sullivan County and the other in Knox County. These mines represent a total daily capacity of 5,000 tons and are thoroughly modern. Permissible explosives were introduced when the screen-coal basis of payment was in force. The results obtained have been entirely satisfactory.

USE OF PERMISSIBLE ELECTRIC LAMPS.

The increased use of electric lamps by miners has been a large factor in increasing safety in mines, particularly in decreasing the possibility of gas ignitions by open lights. Prior to the fiscal year 1916 three types of electric lamps had been given the bureau's approval, having passed the requirements for safety and practicability. Five more approvals were given during the fiscal year, two of which, however, were for lamps of almost identical design. Seven of these approvals are for cap lamps and one for a hand lamp.

The increased use of such lamps has been due in most part to the desire of companies to decrease the hazard of fire-damp ignition by open lights. Prior to the development of miners' electric safety lamps there was usually great opposition to replacement of open lights by oil or gasoline safety lamps because of the great reduction in illuminating power; but the miners' electric safety lamp gives so much more light than the gasoline or oil-burning safety lamp that the old objection to replacement of open lights has been largely overcome. The scale agreement between miners and coal operators in
one large coal-mining district calls for installation of miners' electric lamps in gaseous mines as rapidly as the lamps can be obtained. In one State the law requires the replacement of open lights by permissible electric lamps.

Another factor influencing the installation of miners' electric lamps is the attitude of the insurance companies in decreasing premiums at mines on account of less liability of mine explosions where miners' electric lamps are in use. At the end of the fiscal year 1916, electric lamps were being installed at the rate of 2,500 a week.

**IMPROVEMENTS IN MINE HAULAGE.**

**DANGERS OF ELECTRIC HAULAGE IN DUSTY MINES.**

The hazard of electric haulage in dusty mines has not been generally recognized. Wherever there is a possibility of an explosive dust cloud being formed, the presence of electric equipment that may furnish a spark or arc to ignite the cloud is a grave menace to safety. At least one large explosion was caused by the ignition of a dust cloud when a trip was wrecked and an arc resulted from the displacement of the trolley wire and the consequent short circuiting of the current.

Great care should therefore be taken to see that the coal dust on haulage roads has been made inert either by wetting or rock dusting, as described on previous pages.

Care should also be taken to see that the trolley wire is securely supported at short enough intervals so that displacement of wire is less likely in the event of a wreck.

**CHARACTER OF IMPROVEMENTS.**

Probably the greatest change in mine haulage equipment in recent years will result from the development of the storage-battery locomotive. The claimed advantages for its use are the increased safety resulting when it replaces electric haulage using trolley wires, and the lower cost and increased speed of haulage resulting when it replaces mule haulage. With respect to safety, the elimination of the trolley is unquestionably an increase in safety. However, the storage-battery locomotive in its present development should not be regarded as being safe for use in gaseous mines. The possibilities of sparking or arcing are numerous, and therefore ignitions of gas accumulations, should such accumulations occur, are quite possible. In addition there is an added menace due to the evolution of hydrogen in the batteries. It is known that at least one local explosion in a charging station was due to the ignition of gas evolved from batteries.
The Bureau of Mines is now working on specifications for making storage-battery locomotives explosion proof, and it is hoped that the development of locomotives that will be practically safe for operation in gaseous places will result.

Many companies at the present time are making comparative tests of the efficiency and cost of storage-battery locomotives and other forms of haulage. Should such tests generally result favorably, a great advance in the importance of the storage-battery locomotive industry will undoubtedly result.

**COOPERATIVE WORK IN CALIFORNIA.**

Mine inspection in the State of California is carried out under a cooperative agreement between the Bureau of Mines and the industrial accident commission of the State, whereby a mining engineer of the Bureau of Mines occupies the position of chief mine inspector of the State. He is assisted by an able corps of deputies who are appointed by the State after an examination to establish their qualifications. California is the only State in which mine inspection is carried out under such an arrangement. The work of the mine inspector essentially concerns metal mining, because practically no coal is mined in California. There are in all approximately 14,000 men employed in mines, quarries, and ore-treatment plants in the State.

In 1915 the bureau’s engineer drew up a set of tentative mine safety rules, copies of which were printed and distributed throughout the State. Operators, miners, and those interested in mining were given a chance to comment on these rules at public hearings, after which a final draft was made and adopted by the industrial accident commission, to become effective January 1, 1916.

The workmen’s compensation, insurance, and safety act of the State of California gives the industrial accident commission the power to make and enforce safety rules and regulations, to prescribe safety devices, to fix standards, and to order the reporting of injuries. Thus, the mine safety rules, although not enacted into law by the State legislature, are in effect the same as laws, for an offender against these rules renders himself liable to prosecution for maintaining an unsafe working place.

The mine safety rules, as adopted by the commission, cover every detail of operation in and about mines. They may be said to be somewhat drastic, but are tempered by a provision that “in cases where, in the opinion of the industrial accident commission, the enforcement of any rule would not materially increase the safety of employees, and would work undue hardship on the operator, exemptions may be made at the discretion of said commission, but such...
exemptions must be in writing to be effective, and can be revoked after reasonable notice is given in writing; provided, further, that the rules shall not apply to the operation of mines employing three men or less on one shift, or to gold dredges, hydraulic mining operations, or surface placer mining, except where the rules specifically provide for the inclusion of these classes of mining in their provisions."

At the beginning of 1916, when the mine safety rules went into effect, the safety movement was young in the State of California. Mine operators were unused to State supervision and in some respects many of the mines were not being operated in accordance with these rules. It would have been impossible immediately to change conditions in the mines. The commission adopted the policy of meeting the operators halfway, being reasonable in its demands, and affording all assistance practicable for the betterment of conditions.

It was thought possible that there might be objection to many of the rules and that some dissatisfaction might result. However, the months during which the rules have been in force have brought forth surprisingly few complaints. Furthermore, it has been necessary to grant only few exemptions under the rules. The work of improving conditions and of installing safety devices, as provided by the rules, has gone forward steadily and rapidly, and the operators of the State are to be congratulated on the cooperation that they have given the industrial accident commission.

During the first six months there was not a single case where it was necessary to invoke the law because of the refusal of any operator to abide by the mine safety rules. Operators generally agree that there has been a vast improvement in conditions.

The chief mine inspector, in an effort to be of assistance to mine operators, issues a monthly bulletin pertaining to safety and efficiency in mines. In this bulletin is published a list of sketches of safety and efficiency devices that may be obtained by California operators free of cost. In addition, a campaign has been started among the miners to procure their cooperation in preventing mine accidents. The efforts in this direction embrace an organization known as "the miners' safety bear club." This club was organized for the purpose of getting in close personal touch with the miner so that information of value could be imparted to him. This club was organized in March, 1916, and by the end of June it had nearly 5,000 members. Monthly letters containing valuable information regarding accident prevention are written to the miners.

From January 1 to June 30, 1916, under the operation of the mine safety rules the number of deaths, as compared with those during the first half of 1915, materially decreased.
It is probable that in the course of a year a few minor changes may be made in the rules. As a whole, the system of mine inspection appears to be sound, and without question it has resulted in the prevention of many serious and fatal injuries to the miners of California.

STATISTICS OF ACCIDENTS IN THE MINERAL INDUSTRIES.

To enable the Bureau of Mines efficiently to carry out its duty of increasing safety in the mineral industries it was early evident that the causes of accidents would have to be studied in order that effective remedies and safeguard could be devised. Accordingly the bureau began the compilation of statistics of accidents in the mineral industries.

When the bureau was established no accurate and comparable statistics of mine accidents were available for all the mining States. Many of the States had an inspection service, but as each State had a different system of classifying accidents the collected figures were not precisely comparable and could not be readily used as a basis for efforts to increase safety in mining.

Limited funds have restricted the bureau's efforts to collect accident statistics, but through the hearty cooperation of State mine inspectors it has been able to compile an annual statement of coal-mine fatalities and, through the cooperation of mine and quarry owners, to publish statistics of metal-mine and quarry accidents. The bureau has also compiled annual statements of the production and distribution of explosives by States and has collected accident statistics for coke ovens, ore-dressing plants, and smelters.

Under a cooperative arrangement with all State coal-mine inspectors a monthly report of coal-mine fatalities, showing the number, cause, and distribution by States, is published shortly after the close of each month.

All of the coal-mine fatalities (over 50,000) reported by State mine inspectors since the beginning of inspection by each State have been tabulated by causes, calendar years, and States, the figures covering the mining of more than 89 per cent of all the coal produced in the United States since 1807. A bulletin containing these figures placed for the first time all reported coal-mine fatalities on a calendar-year basis under a uniform classification.

The bureau has records covering a five-year period for metal mines and quarries and a three-year period for coke ovens and metallurgical plants. Although based on reports voluntarily furnished by the operators, the reports present reasonably accurate data from which to devise plans whereby accidents may be reduced and the mines made safer. The figures, although not absolutely complete, are directly
comparable, being on the same basis and by calendar years for each State. This uniformity is highly desirable, as it permits intelligent comparison of the figures for the various States.

During the fiscal year 1916 a bulletin, mentioned above, on coal-mine fatalities in the United States from 1870 to 1914, was issued. In this bulletin are classified 53,000 fatalities as obtained from a systematic search through the various State mine inspectors' reports. Although it is possible that the records during the earlier inspection periods were not complete, yet sufficient data have been accumulated to determine the principal causes of coal-mine accidents. Accidents as related to coal mining by machines have also been studied and tabulated in detail in Bulletin 115.

Data are still lacking concerning the number of nonfatal injuries in the coal mines, but sufficient material has been collected in the metal-mining industry to allow a fair estimate of what may be expected in the coal mines. In order that more detailed information concerning the nonfatal injuries may be obtained, it will be necessary to develop further the cooperative agreement with the State mine inspectors and State compensation bureaus so that such information may be obtained in addition to data regarding the coal-mine fatalities now reported by the State mine inspectors.

Some States do not require a record of injuries or a report to any individual, insurance board, commissioner, or inspector, whereas other States have strictly enforced laws requiring such reports. Furthermore, the fiscal years are not uniform. The bureau in its efforts to procure more of the data above mentioned called a conference of State mine inspectors, Federal officials, and representatives of compensation commissions and insurance companies in Washington on February 24–25, 1916. A tentative schedule was prepared for uniform mine statistics, in which, among other things, reporting of accidents by calendar years was recommended. This schedule and a report of the conference have been distributed to the inspectors, mining companies, and others interested in mining statistics, with a request for further suggestions and recommendations. These recommendations will be taken up by a special committee, and it is hoped that this committee will be able to recommend some standard forms for mine statistics which may ultimately be adopted by each and every State interested in mining.

In addition to the monthly reports on coal-mine fatalities, a report on accidents in metal mines\textsuperscript{a} and a report on accidents in quarries,\textsuperscript{b} each for the calendar year 1914, were published; also a report on the


production of explosives during 1915<sup>a</sup> and a report on coke-oven accidents in 1915<sup>b</sup> were issued.

**SUPERVISION OF MINES ON SEGREGATED INDIAN LANDS.**

**BUREAU OF MINES CHARGED WITH INSPECTION.**

Under date of February 11, 1913, the Secretary of the Interior issued an order charging the Bureau of Mines with the inspection of the physical operation of mines on Indian lands in the United States, with special reference to mines in lands belonging to the Choctaw and Chickasaw Indians of Oklahoma and known as segregated Indian lands. Accordingly the bureau established an office at McAlester, Okla., and placed it in charge of an experienced engineer with instructions to study the various conditions existing in that field and to draw up suitable rules and regulations covering the operation of the mines on the Indian lands, and also to cooperate with the Office of Indian Affairs in passing upon applications for leases on the Indian lands, upon applications by the mining companies to reserve from sale certain parts of the surface of their leases for use in mining operations, and upon other questions relating to the rights of the Indian lessors.

Most of the applications for reservations of surface were filed and passed upon prior to the beginning of the fiscal year 1916, but just prior to the offering for sale of the remainder of the surface of the segregated lands in December, 1915, some of the lessees made application either for additional reservations or for changing the existing reservations, relinquishing part and taking other lands instead. These reservations were made as requested. During the year operating coal companies made several applications to purchase the surface of the segregated coal lands.

**PERMISSIBLE EXPLOSIVES ORDER.**

On May 4, 1914, the Secretary of the Interior issued a further order requiring that "on and after August 1, 1914, only such explosives as * * * have been designated 'permissible explosives,' shall be used in any coal or asphalt mine on the segregated coal and asphalt lands * * * in Oklahoma." The order further provided that explosives other than permissible explosives might be used if fired by an electric system from without the mine.

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The time for taking effect of this order was afterwards extended to January 1, 1915.

In accordance with an agreement reached at a conference held in Washington in April, 1916, between the Director of the Bureau of Mines and a committee of Oklahoma coal operators, a number of requests for temporary exemption of mines from the operation of the permissible explosives order of the Secretary of the Interior have been received; and as rapidly as possible the mines mentioned will be reexamined and reports rendered.

On the whole, the permissible explosives order has produced very good results, although these results are necessarily slow in developing. There have been fewer shot-firer accidents and fewer mine fires from explosives used than in previous years.

SUPervision of MInes on ALLotted Indian Lands.

During the fiscal year 1916 there were 42 formal and informal conferences held with officials of the Indian Office in regard to proposed and present operating mines on lands allotted to individual Indians as opposed to segregated Indian lands allotted to the two tribes previously mentioned. In about 90 per cent of the instances it was necessary to make field inspections in order to ascertain whether the bonus and royalty provided were sufficient. Most of these inspections are made jointly with the chief oil and gas inspector of the Five Civilized Tribes, who submits a report to the Indian Office after consulting the representative of the Bureau of Mines.

The leases on allotted Indian lands cover the mining of a wide variety of metallic and nonmetallic minerals, including lead and zinc, gold and silver, glass sand, gravel and sand, coal, and asphalt. The leases for precious metals have not as yet resulted in the development of anything but prospect holes. The same is true of the lead and zinc leases outside of the Miami lead and zinc district in northeastern Oklahoma. The coal and asphalt leases cover coal leases exclusively, as practically all of the important asphalt deposits are on segregated lands. The coal mines on allotted Indian lands are being inspected as fast as possible.

In all, applications for examination of 22 tracts of allotted lands were received at this office during the fiscal year 1916. These applications were divided as follows:

Coal and asphalt, 13 tracts, embracing a total of 1,500 acres; application for removal of restrictions, 4 tracts, embracing a total of 200 acres; application for sand and gravel leave, 1 tract, embracing 280 acres; gold, silver, copper, lead, and zinc leases, 2 tracts, embracing a total of 60 acres; application for report regarding damage
to surface by water from mine workings, 2 tracts, covering 340 acres. In all a total of 2,380 acres were examined. In addition, an examination was made at the request of the probate attorney at McAlester, Okla., as to the advisability of canceling two leases held on allotted lands.

Although these tracts of land are small, and do not usually require much time for an inspection, yet they are situated in widely scattered parts of the State, and an inspection trip to a given tract and return to McAlester, Okla., may require the greater part of a week.

WATER, OIL, AND GAS WELLS ON THE SEGREGATED COAL LANDS.

Although the regulations under which the surface of the segregated coal lands was sold provided that the locations for all water wells, as well as for oil and gas wells, be approved by the representative of the Bureau of Mines and the State mine inspector, few applications have been filed asking for such approval. There have been to date only three applications for approval of water wells, all of which have been passed upon. These wells are only 20 to 30 feet deep and are unimportant.

Under date of May 13, 1915, application was made to the Bureau of Mines for permission to drill an oil and gas well on the segregated coal lands near Coalgate, Okla. There were no mines, however, within several miles of the place where drilling was contemplated, and a diamond-drill hole put down some years ago showed no coal within a half mile of the proposed well. This information was brought out as a result of a careful inspection. The application was approved, the approval being conditioned upon the applicant submitting to the district engineer of the bureau a log of the well, showing the different strata through which the well passed, in order that it might be determined whether coal existed under this part of the segregated lands. The drilling resulted in a dry hole. There are at present no oil or gas wells on the segregated lands, though on the allotted Indian lands in the Henryetta district there are oil and gas wells. The protection of working mines from gas wells is given careful attention by the bureau's McAlester office, in cooperation with the State inspector of mines and the inspectors of the petroleum division of the bureau. A written form of agreement covering oil and gas well drilling operations on allotted Indian coal lands, to be signed by both the coal-land lessees and the oil and gas lessees, has been prepared, in cooperation with attorneys, and is usually readily entered into by both coal and oil and gas lessees when their leases cover the same tract of allotted Indian lands.
SUPERVISION OF OIL AND GAS LEASES IN RIVER BEDS.

During the fiscal year 1916 the district engineer of the bureau for the southwestern coal-mining district has continued work as representative of the Federal Government on the supervisory committees appointed by the Federal judges in the eastern and western judicial districts of Oklahoma. This committee has charge of the physical operation of oil and gas wells operating in the beds of the Cimmaron and Arkansas Rivers, pending the suits to determine the rightful owners of the oil. The State of Oklahoma and the Federal Government each has one representative on the supervisory committee. In each judicial district there is a receiver appointed to receive the royalty in dispute.

This work has produced large returns in cash, although the time required of the district engineer to do this work has at no time amounted to more than two to four days a month.

MINE INSPECTION IN ALASKA.

GENERAL CONDITIONS IN THE TERRITORY.

Shortly after the Bureau of Mines was established in 1910, the Secretary of the Interior authorized the bureau to take charge of the inspection of mines in Alaska, and Congress has for several years provided for the employment of a Federal inspector of mines for Alaska who is under the supervision of the Director of the Bureau of Mines and renders an annual report to the Secretary of the Interior through the director.

The report for the fiscal year 1916 shows that the year was particularly prosperous for the Territory, owing to the war demand for its metals and fish, the construction of the Government railroad, the opening of the coal lands to lease, the taking up of considerable areas by homesteaders, and a particularly long and dry summer which favored crop growing during 1915.

The war demand which raised the price of metals forced the production of the operating mines far beyond the ordinary figures, caused the reopening of others that had been idle since the fall of the price of copper in 1907, and stimulated both capitalists and prospectors to discover promising prospects.

The construction work on the Government railroad gave employment to several thousand men and assured transportation to remote parts of the Territory, previously almost inaccessible on account of the excessive cost of freighting. The railroad is thus opening new fields both to the miner and to the farmer.

The opening of coal lands outside the Bering River and Matanuska coal fields for free-use 10-acre permits has offered a cheap coal for
local use, and, although the larger tracts in the Bering River and Matanuska fields have only recently been laid out in units for leasing, it is hoped that the development and production of coal in these fields will be rapid, leading to the manufacture of coke and eventually to the erection of smelting and other plants.

**FIRST-AID AND MINE-RESCUE ORGANIZATION.**

First-aid training made rapid progress at Juneau, where several hundred miners were given more or less instruction. At the Panama-Pacific Exposition, during September, 1915, a team representing a large gold-mining company tied for fourth place in competition with 25 other teams, many of which had had previous experience in competitive work and years of training.

**MINERAL PRODUCTION.**

The production of placer gold fell off slightly during the fiscal year, owing to the exhaustion of some of the richer placers, but the lode gold output was considerably increased by the opening of large low-grade properties near Juneau. The production of copper more than doubled in tonnage and trebled in value. Antimony, which is found associated with the lode gold of the Fairbanks district and previously was shipped only intermittently, was eagerly sought by ore buyers, and tin, marble, and gypsum ran about the same as the year before. A small amount of oil was produced at Katalla, but lack of transportation facilities and financial difficulties prevented the company operating there from producing on a scale of any magnitude.

The mineral output of Alaska in the calendar year 1915, according to the United States Geological Survey, includes the following totals: Copper valued at $15,139,129; gold valued at $16,702,144; silver valued at $543,393; tin, lead, antimony, marble, gypsum, coal, and petroleum valued at $469,503.*

**COAL LEASES.**

Local users of coal in the immediate vicinity of the various coal fields have been prompt to take advantage of the act of October 20, 1914, authorizing the issuance of permits to mine coal, without payment of royalty, from 10-acre tracts. Some two dozen permits have been granted. These cover areas from Juneau to Candle Creek, north of Nome, with the majority along the shores of Cook Inlet. Operations have also been resumed on groups of patented ground in the

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*Preliminary estimates by the Survey show the following figures for the calendar year 1916: Copper, $32,400,000; gold, $17,050,000; silver, $950,000; lead, tin, antimony, tungsten, petroleum, marble, gypsum, and coal, $350,000.
Bering River field, and private capital is to construct a railroad to that field.

To furnish a supply of fuel for the Alaskan Engineering Commission, a 5-foot bed on the west bank of Moose Creek in the Matanuska field, about a mile and a half upstream from the railroad right of way, was opened.

The Bering River and Matanuska fields were opened for leasing in May, 1915, and the time for the return of bids was extended into the fiscal year 1916.

GOVERNMENT RAILROAD.

The Government railroad under construction from the coast to the interior has been laid to the central part of the Matanuska coal field and will be advanced along the main line or by spurs. The docks at Seward were rebuilt and the Alaska Northern has been rehabilitated between Seward and Kern Creek. Track has been laid about 15 miles southeast of Anchorage to Potter Creek on Turnagain Arm. From Matanuska Junction 30 or 40 miles of track has been laid along the main line, and in the Susitna Valley between Montana Creek and Indian River over 70 per cent of the right of way has been cleared. Work at Nenana has proceeded up the Nenana Valley to unite with the line coming up the Susitna at Broad Pass and up the Tanana Valley toward Fairbanks.

WORK OF THE INSPECTOR.

The mines tributary to Cook Inlet, Prince William Sound, the Copper River, Juneau, and Ketchikan were inspected during the fiscal year 1916. An examination was made of the Matanuska coal field during the summer of 1915 to subdivide the field into leasing blocks, and the Federal inspector made a trip to Washington, D. C., early this spring in connection with the same work. While in Washington the inspector attended the safety-first exhibition as a delegate from the Territory. His reports on the mining and mine inspection in the Territory for the calendar years 1915 and 1916 are in course of publication by the Bureau of Mines.

PROSECUTIONS.

One case for not reporting serious accidents was brought in the name of the Territorial inspector by the Federal and Territorial inspectors. The case charged a mining company with not reporting a gas explosion in which two men were seriously burned. The court dismissed the defendant, as the Territorial law did not define a serious accident.
SAFETY, SANITATION, AND HEALTH INVESTIGATIONS IN METAL MINES.

PULMONARY DISEASE AMONG MINERS IN JOPLIN DISTRICT, MISSOURI.

During the latter part of 1914 it became possible to take up, in cooperation with the United States Public Health Service, an investigation of siliceous dust and its effects on the health of miners in the Joplin district, Missouri. Complaints that had been made indicated that a large percentage of the miners were suffering from tuberculosis as a result of breathing mine air containing large quantities of dust.

A mining engineer of the bureau and a passed assistant surgeon of the United States Public Health Service made a preliminary survey of conditions during the latter part of 1914. Their activities embraced mines in Jasper, Lawrence, Newton, and Greene Counties, Mo., and outlying districts in Kansas and Oklahoma. It soon became apparent to the investigators that the trouble was chiefly confined to what is known as the sheet-ground mines in Jasper County, so that the greatest amount of time was devoted to this particular district.

While the representative of the Public Health Service devoted his time chiefly to determining the prevalence of pulmonary trouble, the bureau’s mining engineer visited the principal sheet-ground mines for the purpose of studying mining conditions and determining the quantity of dust that existed in the mines by reason of the various operations of mining.

The investigators procured the active cooperation of State and county officials and of various societies and individuals. The mining engineer was aided by the three State deputy mine inspectors of the district. At the suggestion of the investigators an organization known as the Southwestern Missouri Mine Safety and Sanitation Association was perfected.

On the completion of the preliminary investigation a report was made setting forth the causes of dust in the mines and offering suggestions for the improvement of conditions. It was also recommended that laws be enacted providing for the use of dust-abating devices, and that an intensive educational campaign be carried on among the miners and their families with a view to pointing out the dangers of breathing the siliceous dust in the mines.

At the request of many prominent operators of the district, the two investigators returned to the district early in February, 1915, for the purpose of assisting in an educational campaign and pursuing the investigation of underground and surface conditions. A clinic was opened and miners were examined and advised free of cost by the representative of the Public Health Service. The bureau’s engineer
remained in the district until July 19, 1915, during which time he was enabled to make a thorough investigation of the details connected with the production and abatement of siliceous dust in the mines. He also took an active part in the educational work, addressing, in small groups, practically every miner in the sheet-ground district, calling their attention to the dangers of breathing the dust and soliciting their cooperation in bettering conditions. Public meetings were held, at which a total of 2,700 miners were addressed. At these meetings moving pictures pertaining to sanitation and safety and slides showing magnified particles of siliceous dust were exhibited.

In the end the active cooperation of a large proportion of the miners was obtained. At first they were inclined to regard lightly the warnings and suggestions offered, but when they learned, through the agency of the many addresses made to them, the dangers of the situation, they were not long in getting behind the movement to remove the cause of the trouble. In March, 1915, the Missouri State Legislature enacted into law bills providing for better sanitary conditions in and about the mines, the installation of spraying devices, and the building of sanitary wash and change houses.

The outstanding features and results of the investigation were as follows:

Although miner’s consumption was due to the siliceous dust, many other factors were responsible for the consequent tuberculous infection, the chief of these probably being poor living and housing conditions. Seven hundred and sixty-one premises occupied by miners were visited and revealed that overcrowding, lack of cleanliness, and especially an absence of sanitary privies were common.

It was determined that siliceous dust existed in varying quantities in all of the sheet-ground mines, and that this dust was composed of particles of flint that contained usually more than 90 per cent of siliceous residue. The dust particles are sharp edged, often blade-like or knife-like in shape. Owing to their chemical composition they do not dissolve after having been taken into the lungs. This fact, together with the shape of the dust particles, makes it possible for them to penetrate the cell walls of the lung tissue, thus preparing a place for the lodgment of tubercular germs.

The size of the siliceous dust particles was studied. A number of microscopic slides were made from the sputum of miners afflicted with miner’s consumption, in which the siliceous dust could be plainly seen. The majority of dust particles were 3 to 5 microns in diameter and smaller, hardly any being larger than 8 microns; it would appear then that it is the very fine dust that is dangerous, because only these fine-sized particles can penetrate into the lung cells, a conclusion in harmony with that reached by investigators in South
African mines, who declare that no particles larger than 22 microns in diameter permanently affect the lung tissue.

A preliminary report was published by the bureau, and the final report will be published at an early date.

The results of this work have been of great benefit to the miners and operators of the Joplin district. Although the work done resulted in intensive efforts to remove the cause of the trouble, it is not to be expected that the disease will be immediately eradicated. Several years may pass before the real benefits will be felt. The immediate results have been a decided improvement in sanitary conditions and almost a complete elimination of the cause of the trouble.

A great factor in the results obtained was the educational work that was carried on, not only among the miners, but also among the operators. The miners were shown the dangers of breathing siliceous dust, and the operators were convinced that poor sanitary conditions and dusty mines resulted only in making their employees unfit for the arduous tasks that miners are called upon to perform.

SILICOSIS AMONG MINERS IN BUTTE, MONTANA.

In May, 1916, the Bureau of Mines, in cooperation with the Public Health Service, undertook, in the mines of Butte, Mont., an investigation into health hazards, particularly silicosis. It was thought that the investigation would closely parallel that carried into effect in the Joplin region, but as the investigation has developed its scope has necessarily widened, and it is probable that before definite conclusions can be reached careful study must be made not only of dust conditions and of methods of allaying the dust, but also of problems of ventilation, heat, humidity, etc., which appear to have a direct bearing on health conditions in general as well as on silicosis. There are approximately 40 large mines in Butte, many of which have men working to depths as great as 3,300 feet, and there are approximately 15,000 miners in the district. Progress reports are being made from time to time, and a final report will be made on completion of the investigation.

HOOKWORM INFECTION IN THE DEEP MINES OF THE MOTHER LODE, CALIFORNIA.

As a result of the work of several practicing physicians, it became evident that some of the miners in the deep gold mines of the Mother Lode in California were infected with hookworm. As hookworm infection is a communicable disease, the State board of health was desirous of stamping it out, and as the infection in mines might be regarded as an industrial injury, the industrial accident commission of the State was anxious to eradicate it. The Bureau of Mines
has been charged with investigations looking to improving conditions that impair the health of miners, and as miners who become infected in one State may spread the infection to miners in other States, the bureau was doubly interested in preventive measures. The three agencies mentioned arranged for a cooperative investigation of hookworm infection among miners in the California mines. The largest share of the expense of the investigation was borne by the California State Board of Health; most of the field work was done by the Bureau of Mines.

SERIOUSNESS OF HOOKWORM INFECTION IN THE DISTRICT.

The investigation showed that the infection, although widespread, is at present, in many cases, not far advanced. The hookworm is an insidious parasite. It does not actually kill, but extends its influence in a quiet, cumulative manner, and in different directions. A man can not enjoy normal health while the worms are hooked to the inside of his intestines and daily sucking his blood. This fact was illustrated by the testimony as to improved physical condition given by some of the miners after taking the hookworm treatment. It should be remembered that although a miner with hookworm may not be seriously affected himself, there is always danger of his spreading the infection if he commits a nuisance in a place favorable to the development of the eggs.

Fecal specimens from 1,096 of the working men from eight Mother Lode mines were microscopically examined for hookworm eggs. Of the 1,096 examined 337, or 31 per cent, were infected with hookworms.

CAUSES OF INFECTION.

A report of the investigation, now in course of publication by the Bureau of Mines, shows that the source of all hookworm infection—discharges from the bowels—is spread by inadequate or inefficiently maintained toilet facilities, and that hookworm larvae can gain entrance to the body through the mouth or through the skin after it has been broken, and can bore through the intact skin at whatever place infected dirt happens to come in contact with the body. A miner can not do his work without getting dirt on his hands and clothing; therefore his safety lies in keeping the dirt of the mines as noninfectious as possible.

RECOMMENDATIONS FOR PREVENTION.

As a result of the investigation a number of recommendations for preventing future infection of the mines and for minimizing dangers from existing infectious areas were made. These provide for physical examination of all mine employees in the Mother Lode mines; treatment of infected miners; issuance of a "hookworm certificate"
showing a miner to be free from the infection; detailed improve-
ments of toilet facilities; extermination of rats from the mines; san-
itary eating places; sanitary drinking fountains or sanitary water
kegs; effective mine drainage; improved wash and change houses;
and instruction of the miners as to the causes, nature, and prevention
of hookworm.

INVESTIGATION OF LOW-GRADE COMPLEX ORES IN THE
SILVERTON DISTRICT, COLO.

In response to numerous requests for assistance in evolving suit-
able processes for treating the low-grade complex sulphide ores of
the Silverton district, Colo., the bureau undertook an investigation
of these ores. Late in May, 1913, a junior geologist of the Bureau of
Mines was sent to the Silverton district to conduct the investigation.
The ore deposits are vast and the problems to be solved are compli-
cated by the fact that the ores represent the lean stumps of previously
worked bonanza ore bodies.

These are for the most part intimate mixtures of all the common
sulphides carrying appreciable values of silver and at times gold, and
hence require both concentration and separation. On account of their
complex nature, mill recoveries and separations have been at many
mines so poor and imperfect that the mines could not be profitably
operated. The purpose of this investigation is to get at the relations
of the minerals in the ores and the manner of occurrence of the
precious metal content in order that the causes of the difficulties en-
countered in milling may be ascertained and means found whereby
the recoveries can be increased and the separations improved. If
this can be accomplished, it will make possible the reopening and
profitable working of many mines in that region that are now idle.
Moreover, the problem is not restricted to the region in which the
investigation is being made, but is one that is encountered in many of
the western mining districts, and its solution will consequently yield
as widespread benefits.

The bureau's representative has carefully studied the conditions in
the district and has collected many samples of the various ores.
From these samples polished sections were made for a metallo-
graphic study, which has already yielded much valuable information
as to the composition and character of the ores and the reasons for
the low recovery obtained by the concentrating methods used. The
next step will be investigation to ascertain the proper means of con-
centration. Though the bureau is somewhat handicapped by a lack
of facilities for such work, the investigations are expected to yield
suggestions of practical value to the operators of the Silverton dis-
trict and to owners of similar ores in all parts of the United States.
COPPER MINING IN NEW MEXICO.

It is a far cry from the unsystematic and haphazard methods of early mining to the carefully organized, strongly financed, and efficiently planned mining efforts of to-day. Many large mining companies now work as systematically as the best manufacturing enterprises. Study and the publication of results obtained inevitably help the mining industry as a whole. Problems solved in one mining district mean that some other district will become prosperous.

In Bulletin 107, entitled "Prospecting and mining of copper ore in Santa Rita, N. Mex.," the bureau presents the results of a study of a most important phase of metal mining, namely, the open-cut method, where steam shovels are employed to load the ore.

CODIFICATION AND Annotation OF MINING LAWS.

One of the activities of the bureau has been the collection, codification, and annotation of the various American and foreign mining laws, statutes, and decisions.

It was believed that the bureau could well serve the mining industry by a complete collection and a systematic grouping of the mining statutes. The United States statutes relating to the location of mining claims on the public domain have been enforced since 1872. Various amendments have been added from time to time, and all these have been variously construed by the several courts, Federal and State. Up to the time of the organization of the bureau no effort had been made to collect and arrange these various acts except in the United States Revised Statutes of 1878, and practically nothing had been accomplished in the way of a general codification of the original statutes and the various amendatory acts with the construction placed thereon by the various courts. The chaotic condition of these mining statutes was regarded as a handicap to the metal-mining industry, as the location of mining claims and the operation of mines of precious metals depended on these statutory enactments.

The first general legal work of the bureau was a complete collection, codification, and annotation of all congressional enactments relating to minerals, mineral lands, and mining. This work was completed in 1915. The results are printed in two large volumes containing in all 1,875 pages, entitled "United States Mining Statutes Annotated," and published as Bulletin 94. The work includes every enactment of Congress from the original ordinance of 1875 to the day of its publication and all sections of the Revised Statutes of the United States relating to the subject of mines. The statutes are grouped according to their general subject matter, and the statutes in each group are arranged in numerical or chronological order. In
addition to the sections of the Revised Statutes of 1878 and the acts
relating to metal, coal, and oil and gas are included statutes bearing
on the mining industry in Alaska, Indian lands, and the Philippine
Islands and relating to lead mines, pipe lines, railroad grants, rights
of way, salines and salt springs, settlers’ relief acts, State and public
grants, stone lands, timber cutting for mining purposes, town sites,
tunnel acts, and withdrawals.

All sections of the Revised Statutes and all statutes at large not
covered by them and statutes since enacted are thoroughly annotated.
These annotations consist of carefully prepared abstracts of deci-
sions of all courts and public offices in which any of these sections
or statutes have been construed and applied.

The annotations are arranged under each section or statute and
are grouped under prominent and appropriate title lines with a view
to the logical sequence of the various subjects or titles and consist of
plain provisions of law intelligible alike to miners and laymen. The
annotations exhibit the present status of each particular section or
act and its present-day application to the subject of mines and min-
eral lands. They show that the courts have cured obvious defects,
made clear many uncertainties, and aided the practical application
of the statutes in the matter of locating mining claims upon the pub-
lic lands.

The decisions abstracted for the purpose of the work are found in
the United States Supreme Court reports; the various Federal court
reports; the decisions of the General Land Office as reported in vari-
ous volumes; the decisions of the Attorney General; and the reports
of the various metal mining States, including in all not less than
1,000 volumes.

It has been a matter of regret to the director that free distribution
could not be made of this work to all persons requesting it; but the
cost of publication for so large a bulletin required that it should be
sold for a sum sufficient only to cover the actual expense of printing
and binding, $2.50.

CODIFICATION OF STATE MINING STATUTES.

The bureau is now engaged and has well under way a companion
work proposed to include the mining statutes of every State arranged
in chronological or logical order, with annotations following the plan
and style of those in the United States mining statutes. This work
will show the relative merits of the mining laws of the various States
and is intended to aid in obtaining, so far as practical and possible,
uniform mining laws.

Practical miners are more or less migratory. In passing from
State to State they are confronted with different systems of laws
and they must necessarily learn the leading features and know
more or less of the rules and regulations under which they work in the different States. It is believed that this is not only a cause of annoyance but is in fact a source of many accidents resulting in injury and loss of life. With a uniform system of laws throughout all the coal-mining States and a like system in the metal-mining States, miners may pass from one State and from one mine into another and ply their vocation as miners without embarrassment and with safer and saner results in their operations.

**RULES AND REGULATIONS FOR METAL MINES.**

Along this line of uniformity of mining laws and regulations the bureau takes pride in saying that in connection with the efforts of the American Mining Congress there have been worked out and given to the public uniform rules and regulations for metal mines. As early as 1906 the American Mining Congress appointed a committee consisting of W. R. Ingalls, chairman, J. Parke Channing, James Douglas, James R. Finley, and John Hays Hammond to draft a modern law governing quarrying and metalliferous mining which could be recommended to the several States for adoption, in the hope that the passage of such a uniform law would tend to lower the number of fatal and serious accidents. This committee, after the organization of the Bureau of Mines, worked in harmony with the bureau and has recently reported a draft of an ideal metalliferous mining act, including a general system of rules for the control of all metal mines, with general safety precautions. The bureau has the satisfaction of knowing that the rules and regulations thus recommended have been adopted by operators of some of the largest mines in the metal-mining States, and it is believed that sooner or later a substantially uniform law will be enacted by the several States.

**IMPROVEMENTS IN COAL-MINING METHODS.**

Efforts are being made in the different coal-mining districts to increase both safety and efficiency. In some districts progress has been more rapid than in others. However, the general interest in safety and the general desire to do everything possible to improve conditions is most encouraging.

**WESTERN PENNSYLVANIA.**

The room-and-pillar system of mining is in general use in this field. In some districts a panel system with about 25 rooms driven on each side of the pair of entries is usual. Most of the rooms are 20 to 24 feet wide and the pillars are 15 to 24 feet wide. In the system used most extensively rooms 280 feet long are driven off one side when advancing, the pillars being drawn as soon as rooms reach the
full distance, and 200-foot rooms are driven off the other entry in retreating. Under heavy cover there has been some difficulty in winning all the pillar coal on the retreat. In consequence, at some mines, the butt entries are 450 feet apart, the advance rooms are 350 feet long, and the 50-foot pillar on the other side of the pair of entries is taken when entry pillars are withdrawn. This modification has given greater success.

In the Pittsburgh district another development in mining methods is the use of a long-wall system of mining by a company not working the Pittsburgh coal. The coal is soft, the bed is about 3 to 4 feet thick, the cover is heavy, being 700 to 1,000 feet thick, and the roof breaks badly and often to a considerable height. The coal is mined from a 300-foot face and little shooting is necessary.

The adoption of miners' electric lamps, after a number had been approved by the Bureau of Mines, is proceeding rapidly. About 80,000 portable electric mine lamps approved by the bureau were in use in coal mines in the United States on January 1, 1917.

Shot firing by shot firers is being adopted extensively. In many mines assistant foremen act as shot firers. This practice gives the shot firer more authority, and should make for greater safety.

One large company uses permissible explosives exclusively, and another company uses them in about one-half of its gaseous mines. The general use of these explosives has been retarded somewhat by increased cost.

The coal-dust menace is generally combated by watering or the use of deliquescent salts. One company, in cooperation with the Bureau of Mines, has recently tried making the coal dust inert by the use of rock dust, with satisfactory results. The protection is much greater than by watering and the cost is not excessive. A wider adoption of dusting is probable if suitable grinding plants are constructed.

A large number of central rescue stations have been installed in western Pennsylvania, largely as a result of rating systems adopted by insurance companies and the educational work of the Bureau of Mines. Safety committees, frequent inspection, well-devised rules and regulations printed in several languages and distributed to the miners, abundant danger signals, mechanical safeguards for machinery, block signals for electric haulage, underground escape ways for the men in the larger mines using safety lamps, and well-organized first-aid and rescue teams are other features making for safety in the coal mines of western Pennsylvania.

Also, much work has been done toward improving the miner's living conditions by providing pure water, new dwellings, and better sanitation, and by encouraging the establishment of churches, schools, and playgrounds.
OKLAHOMA.

Since the beginning of coal mining in Oklahoma the general practice has been to shoot the coal off the solid. The mines are worked by the room-and-pillar method. Since the Secretary of the Interior issued orders covering mines on the segregated, or Indian, coal lands, there has been a decided trend toward better mining methods. In a few mines the advancing long-wall system, using machines, has been introduced with seeming success. With this method practically all the coal in the seam is recovered, in contrast to a recovery of only 50 to 60 per cent with the room-and-pillar mining. Various companies are introducing machines for undercutting the coal and are using permissible explosives for blasting. These improvements will undoubtedly work to the advantage of the industry.

A lack of electric power has handicapped the introduction of some improvements, but a central power company is now making arrangements for extending its lines to the various mines.

COLORADO AND WYOMING.

Shooting off the solid with black powder was an almost universal practice in Colorado and Wyoming until a few years ago. At present nearly all the larger companies mine the coal with machines or with hand picks, and in many mines permissible explosives are used. The room-and-pillar system is generally employed, modified by panel methods to meet differing conditions of cover, roof, and dip of bed. Most of the larger mines use electric current, each mine usually generating its own power. Both Colorado and Wyoming have been singularly free from coal-mine disasters in recent years, and this advance is largely attributed to better methods of mining.

Considerable attention is being paid to rendering coal dust harmless, both by humidifying and sprinkling, and by using rock dust. Open lights were formerly used in practically all mines, but now both electric lamps and flame safety lamps have been widely introduced.

Some of the larger coal companies have their own rescue cars, with attendants constantly at hand. During the past year much work has been done for the welfare of the miners. Clubhouses, washhouses, etc., have been introduced in many coal-mining communities. That measures for the welfare and safety of coal miners in Colorado are bearing fruit is indicated by the lessening number of fatal accidents. For the calendar year 1916 these amounted to 43, as compared with 63 for 1915, in spite of the fact that the coal output for 1916 was approximately 20 per cent more than for 1915.
SOUTHERN APPALACHIAN FIELDS.

The southern Appalachian fields include southwestern Virginia, eastern Kentucky and Tennessee, and northern Alabama and Georgia. Most of the mines in Alabama are opened by slopes, the room-and-pillar system is used, and the coal is shot off the solid with black powder. The use of panels has recently been introduced in some mines working pitching beds, the entries being driven along the strike of the seam, right and left from the slope, at intervals of about 1,000 feet, and at intervals of 1,000 feet along each level entry panel roads are driven up the dip. From the panel entries the rooms are turned at right angles parallel to the strike of the bed.

In Kentucky, Tennessee, and Virginia little coal is mined at great depths, and most mines are opened by drifts. The room-and-pillar system is used, the thickness of the pillars varying from a few feet to more than room width, according to the depth of cover. In some districts the pillars have been too thin, and parts of some of the mines have been lost through squeezes. The proportion of coal shot from the solid is annually becoming less and the number of mining machines is increasing.

Many of the mines are small and use mule haulage, but the larger mines use electric haulage. A few mines use tail rope.

Some mines still use furnaces for ventilation, but furnaces are gradually being replaced by fans of modern type.

Permissible explosives are being introduced gradually. Additional attention has been given to alleviating the coal-dust hazard, principally by means of water cars and watering systems. The increasing demand for better coal and the higher cost of production have caused many operators to consider improved mining machinery and methods, so that conditions in the industry as a whole show decided improvement.

CENTRAL INTERIOR FIELDS.

Operators in the central interior fields, including Indiana, Illinois, western Kentucky, Iowa, and northern Missouri, are tending to readjust their mine layouts to the panel system and to adopt mining methods that will increase the percentage of coal recovered. Storage-battery locomotives for gathering coal are being used more and more, and the introduction of the combination trolley and storage-battery locomotives has attracted considerable interest. Stripping operations in Illinois are very active, the latest plants using revolving steam shovels with 90-foot booms, the buckets having a capacity of 5 cubic yards. Further use of electric power generated by central stations is planned. Mines developing the deeper coal beds, especially in Indiana, are finding more gas, so that the necessity for giving closer attention to ventilation is evident. In the newer
mines the three-entry system is being adopted in preference to the two-entry system commonly used.

**WEST VIRGINIA.**

The year 1916 has been a period of great activity, the output of coal and coke has been large, and the general tendency has been toward the adoption of safer and more economical methods of mining. The topography of the coal-bearing area of the State is mostly rugged; hence some of the beds mined outcrop at 900 feet above a near-by stream, whereas others have shafts 600 feet or more deep. Room-and-pillar mining, with two, three, and four entry systems is used, the latter two being confined, as a rule, to large mines. So far as known, no long-wall mining is done in the State. Room-and-pillar mining with panels is especially adapted to many of the beds, on account of their being continuous, free from bad faults, and lying practically level.

Some of the most improved mine-ventilating plants in the United States are in West Virginia, many of the fan houses being of steel, stone, or concrete. As a result, the fire hazard at fans has been reduced to a minimum. In most of the recent plants the fans are not placed in direct line with the main airways. Stoppings of noncombustible material are required on all main airways. Rope haulage is used to some extent, but mechanical haulage is chiefly through electric locomotives. Steam, gasoline, and compressed-air locomotives are also used. Mule haulage is generally confined to gathering the coal. There are many small, isolated power plants, but centralized power stations are gaining favor. Many mines are served by hydroelectric plants.

In order to prevent accumulations of coal dust underground, the general custom is to remove loose coal and dust as fast as possible. Sprinkling systems are installed in a great many mines, and various methods of humidifying the mine air are practiced. In mines that generate explosive gas, permissible explosives only are used. Except where permission has been granted by the district mine inspector, shooting off the solid is expressly forbidden. Permission is not granted where conditions favor, even remotely, the initiation of an explosion by solid shooting. Shot firers are employed in gaseous mines. The use of coal dust or other inflammable material for stemming is forbidden by law.

In 1897 there were only 16 machines in use, whereas to-day more than 55 per cent of the total output of coal is won by mining machines.

First-aid and mine rescue training was conducted in the State by the Bureau of Mines during seven months in the fiscal year ended June 30, 1916. The first-aid work in particular was received with enthusiasm both by the miner and the operator.
ANTHRACITE DISTRICT OF PENNSYLVANIA.

Mining methods in the anthracite district are governed by the dip of the beds, their depth and thickness, and the character of the roof and floor. Where the coal is comparatively flat, ordinary room-and-pillar mining is employed, and the double-entry system is generally used. Considerable attention has been given to columnizing pillars, with reference to those of workings in overlying or underlying beds, with marked success. In heavily pitching seams, where the coal is not too thick, the so-called battery method is employed. In practically all the field the hazards of mining are increased by the presence of fire damp. Because of gas, the great extent of the mines, and the many rolls, folds, and faults, careful attention is given to ventilation. Fans are used almost exclusively. Most of the fans are of the Capell type, large diameter, and relatively low speed, but in the past 15 years many small-diameter high-speed fans have been installed.

There are three general types of haulage employed—mule, rope, and motor. Mules are used largely for gathering the loaded cars from the chambers. On account of the large number of slopes and planes rope haulage is much employed. During the past few years, however, the electric motor has come into wide use, both for gathering and for main haulage work.

In most mines it is not practicable to undercut the coal before blasting, so that shooting off the solid is the general practice. However, machine mining has been introduced in horizontal beds at some mines within the past few years.

As regards safety and health, the chief improvement in mining practice in recent years has been the introduction of better lights. Carbide lamps have largely superseded oil-fed torches in open-light mines, and many mines have adopted approved flame safety lamps. Large numbers of electric cap lamps are in use and have proved so satisfactory that more will undoubtedly be used.

Practically every mine in this field has a first-aid team. Both miners and operators show great interest in first aid, and it is probable that hundreds of men each year owe their lives to the efficient first-aid service. Several of the larger companies maintain fully equipped cars for rescue work, fire fighting, and hospital purposes, and there are many privately owned rescue stations in charge of specially trained men.

Living conditions have probably always been better in the anthracite field than in most coal-mining districts, but have greatly improved in recent years. Progress in bettering conditions that bear on health, safety, and efficiency continues, and the outlook for further improvement is particularly bright.
FUELS AND MECHANICAL-EQUIPMENT INVESTIGATIONS.

IMPORTANCE OF INVESTIGATION OF FUELS.

Last year the people of the United States burned some 500,000,000 tons of coal. If this coal had been used with the highest efficiency, it is probable that some 125,000,000 tons, or 25 per cent, would have been saved. Such figures convey an idea of the possible saving to the people of this country through the proper preparation and handling of coal and through the development and utilization of efficient coal-burning equipment. With a view to realizing greater efficiency in the preparation, treatment, and use of the fuels burned in this country, Congress has appropriated funds for investigations to be made by the Bureau of Mines and for the publication of the results of these investigations.

CHARACTER OF INVESTIGATIONS.

Such work naturally divides itself into two general investigations, one having as its object the raising of average efficiency in the general use of fuels and the other relating directly to Government plants. As the results of the general investigations may be applied to the power plants of the Government, tests of a fundamental character are made with the object of clearing up misapprehensions as to the nature and properties of the many available fuels and as to the principles of combustion and heat generation and the transmission of heat to any desired place.

During the past 10 years there has been a much closer scrutiny of the combustion process in all kinds of fuel-burning equipment. For a long time engineers concentrated attention upon the improvement of prime movers—the steam engine, the gas engine, and other internal-combustion engines—the burning of coal under boilers and in gas producers being somewhat neglected. Technical training in our colleges placed relatively small emphasis on the principles and the process of combustion, as compared with a study of the details of prime movers. The more evident facts of combustion seemed so simple as to offer little inducement for an intensive study of the process, but, as a matter of fact, the burning of a fuel is by no means
a simple process, and the misconceptions that have resulted from a too casual study of the phenomena have led engineers to construct uneconomical and ineffective devices. The clearing away of these misconceptions can come only by knowledge of the actual facts, and for that reason the Bureau of Mines has been making a careful study of the combustion process.

The nature of coal has also been misunderstood by many users. Coal is an extremely complex substance, behaving quite differently under different conditions of combustion, and as the United States is extremely rich in a great variety of mineral fuels, it would seem necessary that furnace practice and design should vary with the characteristics of the fuels used. As a matter of fact, the variety of coal-burning equipment now existing is the result of ill-advised experimentation rather than rational design, and the engineer has been unable to find quantitative figures that would enable him to design a furnace for a given fuel with the same assurance of success that he has in the design of a bridge or other structure. Studies of this intimate kind are usually beyond the possibility of private investigation, but are believed to be most essential to the efficient use of the fuel resources of the country.

The attempt to decrease the cost of power has led to the development of internal-combustion engines using either gas or liquid fuel, and these engines have a much higher efficiency than the usual steam engine. However, they also use a much more expensive fuel, so that their use is confined to certain relatively narrow fields. One characteristic of these engines is that their high efficiency varies through a relatively narrow range whether they are large units or small units, whereas the economy of the steam engine varies through a wide range, and the most efficient types have efficiencies comparable with those of many internal-combustion engines.

The possibilities of the more efficient use of steam machinery are therefore very large. Large turbo-generating units and efficient boilers are now available that return as useful electric current ready for distribution nearly 20 per cent of the potential energy in the coal. Although the average efficiency of all kinds of steam-power plants in the United States can be only a matter of guess, it is quite probable that the average is somewhere in the neighborhood of 5 or 6 per cent of the energy of the coal transformed into useful energy ready for distribution; so that if it were possible to elevate the average efficiency to something near the maximum now attainable in steam plants, about three times as much energy would be available for the productive industries of the country as is now obtainable from the coal burned. Anything that can be done, therefore, to raise the general average of efficiency by the production of more efficient furnaces, heat-absorbing devices, and steam engines will be in the line of con-
structive conservation of our natural resources. The work of the Bureau of Mines in its fuel investigations and in its study of heat transmission is directed toward increasing this efficiency.

**VARIETY OF FUELS AVAILABLE.**

The adherence to the use of certain fuels is many times largely a matter of habit, and as the favorite fuel becomes more and more expensive a change to other forms of fuel is made with considerable difficulty. Looked at in a broad way it is not economical to transport high-grade coal through long distances into districts where fuels of lesser value are to be had in abundance, when, as a matter of fact, the cheaper fuels could be satisfactorily used if the user would show a little patience and ingenuity. The suitability of fuels for use in any locality is therefore a matter of public education in which the Bureau of Mines takes a deep interest. As an illustration, the substitution of coke for anthracite coal in many localities is desirable on the score of economy, and the bureau desires to stimulate the use of coke as a domestic fuel because of its cleanliness. The bureau is also endeavoring to stimulate the use of coal gas, another form of smokeless fuel, instead of water gas, because during the past year some 20,000,000 barrels of petroleum was required to enrich the water gas used. The price of petroleum has so increased and the demands on our petroleum resources are so great as to make the use of this product undesirable for services that can be performed by other fuels.

New methods of using fuel are also being proposed, and the bureau desires to be informed as to the technical success of these methods in order to give correct information and thus conserve not only capital but also the fuels by quickly finding the special field particularly adapted to each new method. This function was well illustrated in the introduction of the gas producer, which not many years ago was a new device in the United States and concerning which the Bureau of Mines gave information in the early stages of development. This device has already found its field of usefulness, and newer methods of using coal are now being presented. Just at present there is great interest in powdered fuel, which will doubtless find its special field of usefulness.

**GOVERNMENT FUEL PROBLEMS.**

Another field of work for the bureau is in the application of good engineering to the fuel problems of the Government itself. The Government fuel bill is somewhere in the neighborhood of $8,000,000 per year. Some of this fuel is burned under efficient conditions that make the practice well above the average of the country, but many of the Government plants are antiquated and have suffered from
lack of a consistent engineering policy. For these plants the Bureau of Mines acts in the capacity of a consulting engineer in fuel problems having to do with the purchase of the most suitable fuel that the particular market affords and in recommending practices and equipment for the more efficient use of such fuel. It has been found advantageous to have engineering advice on these special problems from a source not too intimately connected with the local administration of a particular plant, and as the bureau is making a special study of such fuel problems it has been able to render service to Government plants scattered all over the country.

**IMPORTANCE OF INVESTIGATIONS OF MINING EQUIPMENT.**

The safe and economical conduct of mining operations depends very largely upon suitable mechanical equipment. New devices are continually being proposed, some having elements of danger not at all apparent. When a good device has been tried and dropped because of some unforeseen limitation as to safety the art suffers a considerable loss, and in the beginning of the development of new appliances it is highly desirable that there be careful investigation and that the development be directed toward safety.

This need applies peculiarly to electrical devices, and for that reason the Bureau of Mines is especially directed to investigate the use of electricity in mines. The great flexibility and ease of transmission of electric power, and the relatively cheap cost of electrical equipment has led to the wide use of electrical devices for coal cutting, transportation, and hoisting. However, some of the equipment is so designed as to increase the dangers of mining. A large part of this danger can be eliminated by suitable design and proper oversight and operation. Electrical devices are therefore carefully investigated by the Bureau of Mines, with the object of aiding development along safe lines. For this purpose the bureau issues an approval of any device that meets the specifications prepared by the bureau. This approval system applies particularly to miners’ electric lamps, to explosion-proof motors, switches, and coal-cutting machines. In addition, motors for general service and storage-battery electric locomotives are under investigation by the bureau.

Old and well-known equipment is frequently the source of potential danger. Through its long use many of the dangers have become thoroughly known, but there are some not so evident that will yield their secrets only to long and careful special investigation, and for that purpose the bureau is providing, at its Pittsburgh plant, laboratories for the investigation of mining equipment. These laboratories are in course of construction and will be occupied during the coming year.
BOILER-FURNACE INVESTIGATIONS.

CONSUMPTION OF COAL IN UNITED STATES.

As has been mentioned above, the various branches of industry in the United States consume annually over 500,000,000 tons of coal. If the average price of coal at the place of consumption be assumed to be not less than $2 per ton, the total value of the coal consumed annually in the United States is considerably over $1,000,000,000. The Federal Government alone annually uses coal to the value of about $10,000,000. This huge quantity of coal is used for various purposes. However, the largest part of it, amounting to considerably over one-half, is used for power production in large central stations, small isolated power plants, locomotives, steamboats, and many manufacturing plants. Smaller quantities, that amount to millions of tons in all, are used for metallurgical and chemical purposes, and for the production of coke.

In all these uses of coal the efficiency of the processes that are employed is low, and seemingly there are good chances for improvement. Thus, for example, in the most efficient large power plant of to-day scarcely 20 per cent of the heat in the coal consumed is converted into mechanical power, and in the small power stations the efficiency frequently drops below 10 per cent. In the process of producing coke in the beehive coke ovens, most of the volatile matter, representing about 30 per cent of the total heat in coal, is discharged into the atmosphere. Thus the coking process not only wastes the volatile matter but contaminates the atmosphere for miles with poisonous fumes. Surely when such a large sum of money is expended annually in clearly wasteful processes, investigation by the Federal Government into the possibilities of reducing the wastes by improving the processes is not only desirable but seems imperative. The expenditure for the coal is so large that the saving of even a small percentage means the saving of large sums of money. If any investigation should result in a saving of only 0.1 per cent, such saving would still amount to $1,000,000 annually, a sum that would cover the expense of an extensive investigation. Usually a much larger saving than 0.1 per cent can be brought about by merely calling the consumers’ attention to the large wastes attending the different processes.

By properly conducted tests and research work, more efficient processes can be substituted, and a saving measured not in fractions but in whole numbers can be accomplished.

TWO GROUPS OF BOILER-FURNACE INVESTIGATIONS.

The boiler-furnace investigations of the Bureau of Mines comprise both field and laboratory investigations.
The field investigations are made at the different plants belonging to the Government and at plants belonging to private companies cooperating with the bureau. These investigations are made under actual operating conditions. Their object is mainly to determine the efficiency of the processes used in the plants and the possible methods of reducing the wastes.

The laboratory investigations consist of such research work as can not be done with commercial apparatus under actual operating conditions and for which special apparatus must be designed. Laboratory investigations with special apparatus are necessary because of the nature of the many processes. The result of such processes are affected by several factors which vary independently in the actual operation of commercial apparatus, so that it is impossible to determine the effect of any one factor. It then becomes necessary to design a special apparatus in which all the factors except the one under observation can be kept constant. Thus, for an example, an investigation of the effect of the diameter of the tubes in a locomotive boiler on the efficiency of the boiler may be cited. If such an investigation were made with an ordinary hand-fired locomotive, by using successively sets of tubes of different diameters and running tests with each set of tubes, the results of the test would show not only the effect of the diameter of the tubes, but also the effect of the construction and the performance of the furnace, the effect of variation in coal, the effect of the skill of the fireman, and the effect of many other minor factors.

Under such testing conditions the effects of the various factors would be so intermingled that it would be decidedly difficult to tell with any accuracy the effect of the size of the boiler tubes on the efficiency of the locomotive; moreover, such tests would be expensive. To get accurate and reliable data the disturbing effects of all the factors except the size of the tubes must be eliminated. To eliminate the effect of the condition of the road, of the engine, and of the engineer the tests can be made only when the locomotive is standing in the railroad yards. To eliminate the effect of nonuniform coal fuel the boiler can be fired with natural gas of uniform quality; to eliminate the fireman and the variation in furnace conditions the gas and the air can be fed into the furnace at a uniform rate, the temperature of the products of combustion and their velocity through the boiler tube being thus kept constant, so that only the effect of the variation of the size of the tube remains.

Similar methods of elimination of undesirable variables are applied to other problems in laboratory investigations. Many people object to laboratory investigations on the ground that they are made with small apparatus, but such investigations need not be limited to small-size apparatus. A large apparatus can be used as well. The matter
of size usually depends on the funds available for such investigations. If the funds are sufficient an apparatus as large as commercial equipment can generally be used. The main requisite for the successful investigation of any laboratory apparatus is that all conditions can be easily controlled so that any number of the factors can be kept constant and any single factor can be varied through a desirable range.

LABORATORY INVESTIGATIONS OF BOILER FURNACES.

In studying the utilization of fuels there are mainly two processes to be considered, namely, the production of heat by the combustion of the fuel and the application to industrial processes of the heat produced. Thus a large part of the problem of efficient fuel utilization resolves itself naturally into the investigation of the combustion of fuels and the investigation of the transfer of heat from the products of combustion to where the heat is needed. For these reasons the work of the bureau's laboratory tests of fuel has been along two main lines—studies of combustion and studies of heat transmission.

OBJECT OF COMBUSTION INVESTIGATIONS.

The general object of the combustion investigations is to obtain definite information on the combustion process and thus enable furnace designers to determine the proportions of a furnace to burn economically any given fuel under any given conditions. The information heretofore available on the combustion process is not definite enough to permit rational furnace design, or, at least, is not as definite as the information available to the designer of machinery. Thus, for instance, the tensile strength of steel may be known to be 60,000 pounds per square inch of cross section, and when a machine part that will be subjected to a given tensile stress is being designed, the part can easily be proportioned to withstand the working stress with any desirable factor of safety. When, however, a furnace to burn a given coal at a given rate to any desirable degree of completeness is to be designed, only meager information is available. Such data as are at hand are rather qualitative than quantitative; that is, the data are mostly given in such terms as "large" or "small" or "short" and not in so many feet or so many pounds. As a result of this lack of definiteness one designer will design a furnace with 3 cubic feet of combustion space to each square foot of grate area, whereas another designer makes the same ratio 8 to 1, both furnaces being intended to burn the same coal at the same rate. We know that a furnace to burn Illinois coal must have a larger combustion space than a furnace of similar design to burn Pocahontas coal, but we do not know what the exact figures expressing the difference should be.
We also know that to burn 1 pound of coal we must supply 14 to 20 pounds of air, some of this air being supplied through the grate and the rest over the fuel bed, but we do not know what proportion must come through the grate and how much of it should be introduced over the fuel bed. As a result of this absence of accurate data many furnaces are in use that have only inadequate provision for the introduction of air over the fuel bed, and some that have no such provision, the air supply depending on the accidental admission of air through the holes in the fire or on leakage around the firing door and through cracks in the wall. These examples illustrate the lack of definiteness of the information now available for a furnace designer, and show the desirability of combustion investigations.

The bureau's fuel-efficiency laboratory is studying the process of combustion in the fuel bed and also in the combustion space of coal-burning furnaces, and is determining some of the quantitative data mentioned above.

COMBUSTION IN FURNACE FUEL BED.

Combustion in the fuel bed is studied by means of a small vertical furnace having 1 square foot of grate area. The air admitted through the grate is supplied under pressure and is measured with an orifice. Provisions are made for taking gas samples and measuring temperatures in the fuel bed at intervals of 1½ inches from the grate. Thus, the composition of the gases and the temperature at the various heights show the process of combustion in the fuel bed. The small furnace was selected for this study in order to make possible accurate gas sampling and temperature measuring in the fuel bed. The grate area was nearly as large as in a small house-heating boiler. Supplementary work with large furnaces confirmed the results obtained with the small furnace.

EFFECT OF CLINKERING.

The same laboratory furnace is used for investigating the relation between the fusibility of coal ash and the clinkering of coal in furnaces. Some fuel men have argued that the value of a coal as fuel depends directly on the fusibility of its ash, the lower the softening point of its ash, the less its value as a fuel for steaming purposes. Also, some fuel experts have insisted that the melting point of the ash should be embodied in the specifications for buying coal, saying that it is as important as the heating-unit determination, and a few men went so far as to advise disregarding the heating-unit determination and advocated the buying of coal entirely on the basis of the softening point of the ash. The fact of the matter is, however, that it is by no means settled that as the softening point of
ash drops, clinker troubles increase. When making tests at Government plants one of the bureau's engineers noticed on several occasions that coal giving trouble from clinker had ash of a higher softening point than another coal that did not give any trouble from clinker. Consequently the cause of clinker trouble appears to be more complex than would at first appear, and it would seem that the time has not yet arrived for placing the softening point of ash into coal specifications, because a great harm could be done unjustly to many coal-mine operators.

It is for these reasons that the bureau is studying the relation between the softening points of coal ash and the clinker trouble. The small furnace has been selected because the same furnace conditions can be easily reproduced for all the coals that may be subjected to the study.

COMBUSTION-SPACE INVESTIGATIONS.

The process of combustion in the combustion space of a furnace is studied with a furnace having 30 square feet of grate area and a combustion space 3 feet by 3 feet in cross section and about 40 feet long. Samples of gases are collected at intervals of 1 to 5 feet along the path of gases through the combustion space. Temperatures are also measured at the same cross sections. The composition of the gases and the temperature indicate the progress of combustion in the space. A detailed description of the combustion investigations and the results are given in Bureau of Mines Technical Papers 63\textsuperscript{a} and 137\textsuperscript{b}.

PROCESS OF COMBUSTION.

The process of combustion, beginning at the surface of the grate and progressing through the combustion space, is shown in figure 4. The curves represent the variation of the percentage of the different gases and indicate the process of combustion. Thus the atmosphere at the surface of the grate contains 21 per cent oxygen—that is, the full proportion in the air. As the air passes through the lower layers of the fuel bed the oxygen is rapidly used in the combustion of the coke and entirely disappears 3 to 4 inches from the grate. The carbon dioxide content is zero at the top of the grate but quickly rises and reaches a maximum of about 12 per cent 3 to 4 inches above the grate—that is, at the same point where the oxygen disappears. Beyond this point the carbon dioxide decreases. The combustible gas, consisting mostly of carbon monoxide, starts with zero at the


Figure 4.—Composition of gases in the fuel bed and in the combustion space. The gases at the top of the fuel bed contain no free oxygen and a high percentage of combustible gases, which burn in the space beyond the fuel bed after oxygen has been admitted. This diagram is a generalization of the results of many tests.
Thus in the hand-fired furnace, or in any furnace into which coal is fed from the top, there are three zones of different reactions. In the lowest 2½ or 3 inches the coal is oxidized to carbon dioxide, and this layer is therefore called the oxidizing zone. In the layers above the oxidizing zone the carbon dioxide is reduced by contact with hot coke to carbon monoxide; therefore, the layer is called the reducing zone. In the layer at the surface of the fuel bed the volatile matter is distilled from the fresh coal, and therefore this layer is called the distillation zone. These different zones are not sharply separated, but merge into one another, particularly the reducing zone, which probably extends through the distillation zone. These different zones of the fuel bed are shown at the top of figure 4.

Thus far the combustion in the fuel bed had been considered. The gases rising from the fuel bed contain 20 to 32 per cent combustible matter, 5 to 8 per cent carbon dioxide, and practically no free oxygen. Besides the combustible gases there are soot and some tars, the latter decomposing quickly into soot and gases. Air must be added to all of these combustible materials rising from the fuel bed, and the combustible materials must be mixed with the air and burned in the combustion space beyond the fuel bed. Thus in the combustion space occur two processes, namely, mixing and burning. The changes taking place in the combustion space are indicated in figure 4 by the curves extending beyond the fuel bed. The figure shows that the oxygen above the fuel bed quickly rises, the combustible matter drops, and the carbon dioxide increases about at the same rate as the combustible matter drops. The combustible matter approaches the zero line as the process of combustion nears its completion. It should be noted that the process of combustion in the combustion space is not as rapid as it is in the fuel bed, and that to obtain nearly complete combustion in any given furnace a considerable volume of combustion space must be available. As the combustion space determines the completeness of the combustion of coal, and therefore to a large extent also the economy in the utilization of coal, the correct relation of the size of combustion space to the completeness of combustion for any given coal, burning under any given set of conditions, is of much importance in the art of furnace design.

**SUMMARY OF DEDUCTIONS.**

Following is a summary of deductions from the investigations so far conducted by the Bureau of Mines:

The fuel bed in almost any coal-burning furnace acts primarily as a gas producer. In a hand-fired furnace when the fuel bed is level and 5 inches or more thick, the gases rising from the bed contain 25 to 32 per cent of combustible gases, about 5 to 8 per cent of CO₂
and no free oxygen; in other words, the gases constitute a fairly good producer gas.

Only about 6\(\frac{1}{2}\) pounds of air per pound of coal can be forced through the fuel bed, no matter how fast the air is blown through. When the quantity of air thus supplied is doubled the rate of combustion is doubled, when the quantity of air is quadrupled the combustion is quadrupled also, and so on, the weight of air per pound of coal burned remaining nearly constant at 6\(\frac{1}{2}\). This means that the rate of combustion depends on the rate of air supply through the grate. This relation is true for all fuels, including anthracite and coke.

When the fuel bed is level and 5 inches thick at least one-half of the air required for the complete combustion of the coal must be supplied above the fuel bed. This air should be supplied as near to the fuel bed as practicable, and should be introduced in many small streams at high velocity in order to facilitate mixing. The combustible gases rising from the fuel bed represent 40 to 60 per cent of the total heat in coal, so that it can be said that on the average one-half of the combustion of coal takes place in the fuel bed and one-half in the combustion space.

The completeness of combustion of the gases depends largely on the size of the combustion space. Coals having different composition require different sizes of combustion space for the same completeness and the same rate of combustion. Roughly speaking, the combustion space should be proportioned to the product of the percentage of the volatile matter multiplied by the quality of the volatile matter, the ratio of the volatile carbon to the available hydrogen being taken as an indicator of the quality of the volatile matter. The size of the combustion space is also approximately proportional to the percentage of oxygen in moisture-free and ash-free coal.

The percentage of excess of air giving the best results in any steam-generating apparatus varies with the size of the combustion space and the kind of coal. Of two furnaces burning the same fuel but having different sizes of combustion space, the one with the larger combustion space gives the best results with lower excess of air than the one having the combustion space smaller. Similarly of two furnaces exactly alike in size, but burning different coals, the one burning the coal lower in volatile matter and oxygen gives the best results with lower excess of air than the furnace burning the coal higher in volatile matter and oxygen.

The volatile matter leaves the fuel bed as complex hydrocarbon compounds which at atmospheric pressure and temperature are in a liquid or semiliquid state. In the absence of sufficient oxygen for their complete combustion, the tars are quickly decomposed by the high temperature into soot and light gases such as hydrogen and car-
bon monoxide. The formation of carbon monoxide is due to the presence of carbon dioxide and a small supply of oxygen. At a distance of 1 or 2 feet from the surface of the fuel bed only a small amount of hydrocarbons can be found in any state, gaseous, liquid, or solid. The solid substance present in the flames is mostly soot with only a trace of tars. All hydrocarbons are unstable at high furnace temperature and unless a sufficient air supply is quickly mixed with them at the time they are distilled to insure their complete combustion, they are quickly decomposed, causing the deposition of soot. It is therefore useless to search for hydrocarbons several feet from the fuel bed. Methane, which is perhaps the most stable hydrocarbon, is found only in traces 1 foot from the surface of the fuel bed. The persistence of carbon monoxide in furnace gases is not due to the difficulty of burning it, but to its constant formation by the reaction between soot and carbon dioxide. This is the reason why carbon monoxide is found in the furnace gases after all other forms of combustible have practically disappeared.

Soot, which is the principal constituent of smoke, is formed at the surface of the fuel bed by the heating of the hydrocarbons in the absence of air. It is not formed by the hydrocarbons striking the cooling surfaces of the boiler. As a matter of fact, under ordinary conditions of operation only a small trace of the hydrocarbons ever reaches the surfaces of the boiler. Any hydrocarbon that reaches the surface of the boiler is kept from decomposing by the cooling effect. The cooling surfaces do not cause the formation of soot; they merely collect the soot and prevent its combustion.

Soot or smoke is formed at the surface of the fuel bed by the absence of oxygen. Therefore, to prevent soot sufficient air should be mixed with the volatile matter at the time of distillation. Any air added later is usually added too late. In other words, to obtain smokeless combustion, the distillation of the volatile matter must take place in a strongly oxidizing atmosphere. This is one of the main reasons of the success of most mechanical stokers in burning smoky coals without smoke.

**HEAT-TRANSMISSION INVESTIGATIONS.**

Inasmuch as the largest part of the coal consumed in the United States is used for making steam, the heat-transmission investigations of the Bureau of Mines fuel-efficiency laboratory are planned and conducted with especial reference to steam boilers. The object of the investigations is to obtain data that will enable engineers to design more efficient boilers. Once the boiler is designed, made, and set up, little can be done by the operator to improve its efficiency as a heat absorber. The operator can exercise more care in burning the coal with the most economical air supply, thereby making more heat
available for the boiler, but he can do little to make the boiler absorb a larger percentage of the heat available for absorption. In the past the design of steam boilers was considered in regard to mechanical strength and not the efficiency of heat absorption. Thus, fire-tube boilers were made with tubes 6, 4, 3, and, in locomotives, even 2 inches in diameter, seemingly no thought being given to the effect of the size of the tubes on the efficiency of the boilers. The idea seems to have prevailed that the amount of surface was the main factor in the efficiency of a boiler and that the arrangement of the heating surface had little to do with it, that is, that a 4-inch tube would absorb as much heat as a 2-inch tube as long as the two tubes had the same amount of heating surface, and as long as the same weights of hot gases at the same initial temperatures were forced through them.

About nine years ago the Government's experts showed boiler tubes having a small diameter were more efficient than boilers with tubes of large diameter, but the exact relation between commercial sizes of tubes is not known. This exact relation between the size of tubes and boiler efficiency is one of many other factors now being determined by the bureau's fuel-efficiency laboratory.

The effect of boiler scale on the boiler efficiency is another important problem confronting the steam-boiler operator. A great deal has been written about it, but no really authoritative data are available to substantiate certain statements that are frequently made in engineering literature. This problem is another part of the heat-transmission investigations.

The bureau's heat-transmission investigations are made principally with an apparatus especially designed for that purpose. The apparatus consists mainly of a horizontal tubular boiler having a shell 20 feet long and 30 inches in diameter. Different sets of tubes ranging from 1 to 4 inches in diameter are being used in this boiler. The length of the boiler and of the tubes is being varied from 20 to 5 feet in steps of 5 feet.

The boiler is fed with the products of combustion from burning natural gas. The volume of the gas and that of the air used in combustion are accurately measured and controlled. The temperatures of the products of combustion entering and leaving the boiler are also measured. The control of the temperature is such that it can be kept constant at 1,000° or 1,200° C. within less than 10° C. The velocity of the gases through the boiler can be kept constant within about 5 per cent. All the factors during a test can be so controlled that closely accurate data can be obtained.

Matters already investigated or to be studied are as follows: Initial temperature of products of combustion; velocity of products of combustion through boiler; diameter of tubes; length of tubes; thickness of wall of tubes; pressure of steam in boiler; retarders in
tubes; boiler scale on the water side of tubes; soot on the gas side of tubes.

Besides the work outlined above, many special observations are made in connection with tests with this apparatus and in connection with tests of commercial boilers. These observations furnish much valuable information. Thus, a series of experiments was made on the accuracy of the measurement of temperatures of gases in boiler tubes and boiler settings. The temperature of the metal of the different parts of a boiler was determined while the boiler was in operation, a determination that requires the development of new methods of doing the work.

**SUMMARY OF RESULTS.**

Following is a summary of the results so far obtained from the heat-transmission investigations.

The path of the heat travel from the hot products of combustion to the boiler water consists of three distinct parts, namely, from the hot products of combustion to the dry surface of the heating plate; from the dry surface through the metal of the plate to the wet surface of the plate; and from the wet surface to the body of the boiler water. Of these three parts of the path the first part is by far the slowest, and is the one responsible for the slow rate of heat transmission in steam boilers. This fact is shown strikingly by figure 5, which indicates the temperature drop along the path of heat travel in a Heine boiler at the place where the hot gases enter among the tubes when the boiler is worked at about 30 per cent above its rated capacity. The temperatures were obtained by actual measurements. The figures show that by far the greatest temperature drop is from the hot gases to the gas-side surface of the boiler tube.
Inasmuch as the resistance to the heat travel is proportional to the temperature drop, the resistance through the metal of the tube into the boiler water is insignificant. Therefore, anything that increases the rate of heat transmission from the hot gases to the dry surface of the heating plate almost directly increases the rate of heat transmission into the boiler water. It appears that the heating plate of a boiler can transmit any amount of heat that can ever be imparted to it by the hot gases.

The rate of heat impartation by the hot gases to the heating plate of the boiler is closely proportional to the temperature difference between the gases and the dry surface of the heating plate; to the velocity of the gases flowing over the surface; and to the density of the gases. As the temperature can not be raised beyond a certain limit, and as raising the temperature reduces the density of the gases, the velocity is the most important factor in increasing the rate of heat impartation from the hot gases to the heating plate of the boiler. Therefore, with any given temperature the capacity of the boiler can be increased at will by increasing the velocity of the gases.

The efficiency of a boiler as a heat absorber can be increased by reducing the diameter of tubes in fire-tube boilers and by placing the tubes closer together in water-tube boilers. By so doing the unit gas passages are made smaller in cross section so that the average distance of the particles of hot gases to the heating plate is shorter, and therefore heat is imparted to the plate at a faster rate. In order not to reduce the total cross section of the gas passage the number of unit passages can be increased. Thus, in a fire-tube boiler the desirable results can be obtained by using a larger number of smaller tubes.

The measured temperatures of the gases inside the boiler setting are usually too low on account of heat being radiated from the measuring instrument to the surrounding boiler surfaces. The larger the diameter of the instrument, the larger is the error. The best results are obtained when an exposed thermocouple of very fine wires is used. The hot junction should not have a bead but should be of nearly the same diameter as the wire itself. The measurements obtained with large thermocouples may be in error by hundreds of degrees.

**FUEL-EFFICIENCY INVESTIGATIONS.**

The selection of fuel for Government plants is often governed more by considerations as to its suitability under the existing conditions than by the comparison of guaranteed heating value or ash content. The Bureau of Mines conducts many tests for the purpose of obtaining information as to the suitability of various fuels for use in different kinds of equipment. On the basis of the information obtained it is enabled to give advice to other Government bureaus or depart-
ments as to the most desirable fuel to be purchased for use in the equipment available. This same information is also of use in making recommendations for the selection of new equipment for installation in Government plants, with the end in view that the new equipment may be suited to the greatest possible number of coals in the local market, especially the cheaper coals.

The suitability of any particular fuel may be determined by its tendency to cause smoke emission or to produce objectionable clinkers under some conditions, or by other factors. Frequently, however, a fuel considered unsatisfactory by the operating force in a given plant may, when differently handled, prove to be suitable. This statement applies to power plants or heating plants of considerable size, but is just as true when applied to residence heating conditions and equipment. Consequently the bureau frequently has to conduct service tests with some of the coals offered for a Government power or heating plant before recommending which fuel shall be used.

During the past year tests of this sort were carried out in four power plants in Washington, D. C., and also at two of the United States Indian schools. The coal for most Government plants is purchased on a specification basis, and the practice is to purchase the fuel showing the lowest guaranteed cost per million British thermal units, providing it is suitable for the plant conditions. At two other Indian schools new power plants or extensions to existing plants were to be made, and plans and specifications for this new work were examined by the bureau. In each case changes were recommended so as to make the equipment operate more efficiently and at the same time make it suited to the largest number of the fuels available.

A similar service is being rendered to the superintendent of the Government Hospital for the Insane in Washington, where acceptance tests and inspections of new stoker and coal and ash-handling equipment are being made.

Requests are also made of the bureau to make examinations of power-plant conditions and to indicate wherein these conditions can be improved or better results obtained. A case of this sort that occurred during the past year was that of the District pumping station, at Washington, D. C. The inquiry for this plant covered not only possibilities of greater economy in the utilization of fuel and steam, but also included the question as to the advisability of a change in fuel and in stoking equipment. In order to answer the inquiry it was necessary to conduct evaporative tests and to study the distribution of the steam used.

In addition to the tests relative to the selection and use of fuel carried on at other Government plants, requests are made by different departments of the Government for information obtained
from tests conducted at the bureau’s experiment station in Pittsburgh. During the year 1916 several such problems have received attention. A series of tests to determine the comparative evaporative performance of two types of heating boiler such as would be used in post-office buildings were carried out for the Treasury Department. The purpose of this study was to ascertain whether one type would show fuel savings sufficient to make advisable its use in preference to the other.

Another and much larger problem in which the War Department is interested is that of the relative values of various fuels for domestic heating purposes. On account of the widely separated locations of the army posts a great variety of fuels are used and, since the intention is to furnish for officers and men a fair allowance of fuel for the conditions at their respective stations, information as to the relative values of these fuels under the conditions of use is of importance. The department therefore requested that the bureau conduct tests in several heating boilers, for which they supplied a large number of samples of coal, wood, and oil. The results obtained will furnish information of interest and value not only to the War Department but also to householders throughout the country.

The extent of the interest of the householder in this question of the selection and use of fuel for domestic heating was well illustrated by the demand for a report published by the bureau during the past year entitled, “Saving fuel in heating a house.” This report discussed briefly and generally the more important factors influencing the consumption of fuel in residence heating. The tests now being conducted will furnish the basis for other reports which will discuss much more fully the effect of some of these factors. For instance, the importance of employing proper methods of handling fires has been strikingly shown by the tests being conducted, and experience with a wide variety of fuels will furnish data on how different coals should be handled and will show what losses may occur from improper methods of operation.

Another report completed and issued during the year was one relating to tests of apparatus for indicating or recording the content of carbon dioxide contained in chimney gases. Equipment of this character has been purchased for many Government power plants and for a much larger number of commercial power plants, but there was little information available as to the accuracy of the instruments, the conditions affecting their accuracy, or the amount of attention necessary to keep them in running order. The report covers tests of seven different kinds of apparatus. A similar series of experiments is to be carried out with several types of apparatus for observing

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judging, or recording the density of smoke emitted from power-plant chimneys. Both of these general kinds of equipment may be classed as apparatus to enable the engineers in charge of fuel-burning plants to supervise more closely the work of the operating force and thereby reduce unnecessary losses of fuel.

INSPECTION OF GOVERNMENT FUEL PURCHASES.

The importance of supervising more carefully the Government's coal purchases was early recognized, as coal was being purchased according to reputation and trade name rather than on the basis of its quality as measured by contained moisture, volatile matter, and ash, and by heating value and efficiency, as shown by use. Coal was purchased simply as coal, and no check was had on the character and quality supplied the consumer. Under the supervision of the Bureau of Mines uniform specifications have been developed. These prescribe in detail definite requirements for coal purchased by the Government. The plan of purchasing on the specification basis was first adopted by the Treasury Department in 1906, and this method of purchase has since been extended until the plan—variously modified in form but the same in principle—has been adopted by all the departments of the Government, and is applied to almost all contracts large enough to warrant sampling and analysis and heating-value tests. The value of the coal purchased annually by the Government under specifications prepared by the Bureau of Mines or under the advice of the bureau is now not less than $7,800,000.

The work of fuel inspection includes the collection, analysis, and testing of samples representing coal purchased for the Government under specifications in order to ascertain whether the deliveries conform to the contract stipulations. In such a contract a bidder guarantees the quality of the coal he offers, and the quality guaranteed by the successful bidder becomes the standard of his contract. Analyses of samples of deliveries determine whether the coal delivered is of the guaranteed standard. If it is not, the price to be paid is proportionately decreased; if the coal is of higher quality, the price is proportionately increased.

A number of the States, many of the larger cities, and a large number of corporations and business concerns in different parts of the country have followed the general plans adopted by the Government for the purchase of its coal.

During the fiscal year 1916 a considerable number of samples of coal submitted by the States of New York, Indiana, Minnesota, Maine, Alabama, and Maryland were analyzed and tested. Authority for doing such work for State governments is given the bureau under its new organic act.
At the request of the Navy Department, the mining and shipping facilities of mines from which purchase of coal for that department is proposed are carefully examined by engineers of the bureau, and samples collected in each mine are analyzed at its laboratories. Requirements as to ash and volatile-matter contents are fixed, and these requirements must be met in all shipments. Occasionally samples are collected as the coal is being loaded on ships, and if it is not up to the standard, the contractor is promptly notified that his coal must comply strictly with the contract specifications. If he fails to ship coal of specified quality, his contract is annulled. Coal purchased under such specifications and used on naval vessels amounts to about 700,000 tons a year.

In order to determine the award of a particular contract, or to advise other bureaus and departments of the Government how a particular coal can be utilized most efficiently, or to ascertain what coal can be burned to best advantage in a particular type of furnace, or what changes in equipment will enable a particular Government building or plant to use efficiently the cheaper coals locally available, the bureau conducts steaming tests at its experiment station in Pittsburgh or cooperates with local engineers in conducting tests.

During the fiscal year 1916, 6,495 samples were analyzed. Each analysis was checked by duplicate determinations, and the laboratory sampling was checked by analyzing a duplicate sample. In addition, 172 samples of peat were tested in cooperation with the Minnesota State Geological Survey.

The success of the specification method depends largely on correct sampling of deliveries, for unless the samples are representative, the analyses and tests, however accurate, are worthless. Each year the local employees of Government power and heating plants are becoming more efficient in collecting samples and are thereby insuring the success of the specification method of purchase. However, experience and time will be required to perfect specifications and methods of sampling and analysis that may be used universally. Success now rests almost entirely on sampling. Improper sampling leads to controversies and to condemnation of the specification method. Mechanical devices for preparing and reducing samples are needed, for thereby the personal equation can be largely eliminated. The Bureau of Mines is developing such devices.

USE OF COKE FOR DOMESTIC PURPOSES.

In an investigation of the use of coke as a domestic fuel, information has been collected from coal-gas companies, from by-product coke companies, and from dealers handling domestic coke. Inspection trips have been made in the West and in the East. Coke manu-
facturers, fuel dealers, and householders have been interviewed concerning coke and its adaptability for household purposes. The information thus obtained has been prepared for publication.

Briefly, the general conclusion is that coke makes an excellent fuel for residence heating when properly handled, and in many sections its use for this purpose is increasing rapidly. Within the past five years there has been a remarkable development in the domestic utilization of coke and during the winter of 1915–16 the demand for coke for household use far surpassed all previous records and exceeded the supply.

**PRELIMINARY LIGNITE INVESTIGATIONS.**

One of the most important and far-reaching lines of investigation being carried on by the Bureau of Mines pertains to the proper systems of mining and the most efficient and economical methods of utilizing our fuel supplies and the various products derived from them.

In the west central and western States there are vast deposits of lignite, the extent and importance of which have been little appreciated. Economic methods for the development and utilization of these deposits and their important by-products have heretofore been given little scientific study.

For these reasons and in view of the fact that the Government controls great tracts of land underlain with lignite or immediately adjacent to lignite deposits, the Bureau of Mines has begun, in cooperation with the School of Mines of the University of North Dakota, in a small way, some preliminary investigations of certain phases of the lignite problem.

The meager funds that could be devoted to this work have not made possible any extended investigations, but the necessarily limited introductory work that has been done has demonstrated, beyond a doubt, the great economic importance of lignite and its products and has shown that adequate provision should be made for more extended research.

What has been accomplished in this preliminary experimental work leads to the belief that great improvements can be made in the methods of utilizing lignite as a fuel in the manufacture of briquets and in the production of cheap gas for power and other purposes. In addition to this, a large number of valuable by-products may be obtained by a variety of suitable methods of treating lignite.

Some of the phases of work during the past year are outlined below.

**GAS FROM LIGNITE.**

Tests as to the production of gas from lignite have been made by several methods under a variety of conditions of temperature, time,
and other modifying factors. The lignites have been found to yield much gas, its quality and character varying, of course, with conditions of production. There is little doubt, however, that this gas can be used for many purposes such as for power, heat, and light. The power tests indicate that it can be successfully employed to drive gas engines and that in such western lignite regions as are without water power, power can be produced at such a low figure as to exert a marked influence in the development of a variety of industries dependent upon a cheap and abundant power.

The gas thus used would, of course, be in the nature of a by-product. There can be obtained about 10,000 cubic feet of this gas from a ton of dry lignite, and in the unpurified state it has a heating value of 300 to 400 British thermal units per cubic foot. Under proper methods of treatment lignite can be used successfully also for producer gas.

**LIGNITE BRIQUETS.**

Because of the characteristic tendency of lignite to slack on exposure to air and the large amount of moisture it contains as mined, this fuel will not successfully stand long storage and can not be profitably shipped long distances from the mines.

After the lignite has been dried and the gases and other products removed there is left a residue that does not coke but has a high fuel value, and when properly briqueted produces an excellent free-burning fuel which will stand storage and transportation. The proportions of volatile matter and fixed carbon can be regulated by the degree to which carbonization is carried on. If a fuel with short flame, similar to anthracite, is desired, the carbonization is continued until nearly all of the gas and volatile matter has been removed, but if the briquets are to be used where a rather long flame is desired, the carbonization is carried only so far that sufficient gas and volatile matter for the desired length of flame will be left.

**AMMONIUM SULPHATE FROM LIGNITE.**

The preliminary work thus far carried on indicates that there can be obtained as a by-product from the carbonization of the lignite in the production of gas probably about 20 pounds of ammonium sulphate per ton of lignite. This material is valuable as a fertilizer and has other industrial uses.

**LIGNITE TAR.**

A considerable quantity of lignite tar is derived as a by-product from carbonization. This crude tar carries a variety of important products, which vary in character and amount with the temperature and time of carbonization. Among these crude-tar compounds may be mentioned a series of oils, a large proportion of which are among
the so-called "light oils," and a variety of tar acids, such as phenols and several others of value.

The preliminary work thus far indicates the probability of an unusually large yield of these tar acids from lignite, which is seemingly much larger than that obtained from the corresponding bituminous coke-oven tar, so that these by-products appear to be of much importance. The crude tar has an unusually oily, penetrating character and seems well adapted to immediate use as an admirable wood filler.

Although there is evidence that certain varieties of dyestuffs are obtainable from lignite and lignite tars, the limited investigations so far made have not made it possible to take up the study of lignite dyestuff products.

After the various oils and acids have been removed from the crude tar, considerable pitch of a superior quality is left which seems unusually well adapted for several important commercial uses, as well as for the briquetting of the residue.

LIGNITE OILS.

During the past year, in addition to a study of the problems and products already mentioned, a little preliminary research has been made of the derivation and character of oils obtainable from lignite. Although this work has had only a beginning, it is of promise in view of the quantity, variety, character, and commercial value of several of these oils.

Crude heavy oil is obtained in considerable quantity from the distillation of lignite tar. If the tar has been produced from the carbonization of lignite at a temperature of about 1,200° F., yields of heavy oil of 2 gallons and more per ton of residue have been obtained. This crude oil no doubt contains several grades, but it has not been possible to take up the further subdivision and purification of this oil. The flash point ranges from 105° F. for the lighter to 120° F. for the heavier products. This oil could seemingly be used for a variety of fuel purposes.

Some tests have also been made of the use of this crude heavy oil in connection with the concentration and flotation of certain ores, and under proper conditions it has given some gratifying results.

By the direct distillation of lignite at low temperature (about 700° F.) a totally different variety of rather light oil is obtained in considerable quantity. Yields amounting to 5 to 6 gallons per ton of dry lignite have been obtained, and it is quite possible that this yield can be materially increased.

It will be noted that the temperature of distillation is exceedingly low and the yield of light oil relatively large. The cost of produc-
tion, therefore, may be expected to be moderate. This light crude oil has a low flash point, and is seemingly a valuable fuel oil in the crude form, as it could doubtless be used with only partial refining for internal-combustion engines, but on further refining it yields other important grades of oil, among which might be grouped a crude benzol or benzol equivalent, which is highly volatile. Yields of 2 gallons and upwards have been obtained per ton of dry lignite. As this is easily obtained from the crude light oil of low-temperature distillation its cost of production should be relatively low.

On account of its highly volatile character and its freedom from heavier hydrocarbons, this oil would seem to be a valuable product for automobile and other similar types of gasoline engines. The most economic method of obtaining this product is worthy of thorough investigation, for it is easily obtained in considerable quantity, and the carbonized lignite left after distillation is an excellent fuel.

CONCLUSIONS.

Thus, the limited preliminary work thus far done on lignites and lignite products indicates that the possibilities in connection with the utilization of lignite and the development of its by-products and of associated industries are very encouraging and are worthy of thorough investigation and research, in view of the great extent of the lignite fields and the great importance of the lignite products, not only to the western areas themselves but to the whole country.

ELECTRICITY IN MINES.

During the past year the mining industry has shown an unusual interest in the bureau's work in connection with mine electrical equipment. The bureau has approved and developed more equipment than in any preceding year. During the fiscal year 1916 the bureau turned into the United States Treasury as fees from electrical tests the sum of $2,189.82.

INVESTIGATION OF PORTABLE ELECTRIC MINE LAMPS.

Four complete lamp investigations were made during the fiscal year 1916, and approval was granted to each of the following lamps:

The Manlile lamp, Approval No. 11.\(^a\)

The Concordia hand lamp, Approval No. 12.

The Wico lamp, Approval No. 14.

The Concordia cap lamp, Approval No. 15.

The General Electric Co. lamp, Approval No. 13.

The Hirsch Co. lamp, Approval No. 16.

\(^a\) Approval rescinded for cause Apr. 23, 1917.
Approval No. 10, issued to the Edison Storage Battery Co. for its cap lamp, was extended twice during the year to cover improvements made by the manufacturer. Two brands of bulbs in addition to the brand originally approved for the Edison lamp were examined and approved.

The operators of coal mines are adopting with surprising and gratifying rapidity portable electric mine lamps approved by the bureau. It is probable that more than 100,000 approved electric lamps will be put into service in coal mines during the next 12 months.

**Investigation of Explosion-Proof Motors.**

Two types of explosion-proof coal-cutting equipment were completely tested, and approvals Nos. 101 and 101–A were issued to the Goodman Manufacturing Co. to cover the 210 and 500 volt sizes of their type. The approval of the other type of machine tested was withheld pending certain mechanical and electrical modifications. In addition, approvals Nos. 100 and 100–A covering equipment of the Sullivan Machinery Co. were extended to cover improvements.

The Sullivan Machinery Co. developed, in cooperation with the bureau, an unusually efficient and safe plug connection for use in gaseous mines. This plug constitutes a unique device for breaking with perfect safety in the presence of gas comparatively large electric currents at voltages not in excess of 650 volts.

A new gallery for the testing of explosion-proof equipment was designed and erected. This gallery will greatly decrease the time required for making the tests of explosion-proof motors. There are now on file 13 applications for the testing of explosion-proof equipments, and one application for the test of a general-service motor, the development of which the bureau has been urging for several years.

**Rules for Installing and Using Electrical Equipment in Coal Mines.**

During the year a set of proposed safety rules for the use of electricity in bituminous coal mines was proposed by engineers of the bureau and published as Technical Paper 138. About 15 conferences were held between the bureau's engineers and prominent mining engineers and coal-mine operators, and a comprehensive research was made of the carrying capacity of bare copper wires for mine use. Many changes suggested by mine operators and by mining engineers of the bureau were incorporated. The proposed rules have received favorable comments from some of the largest coal-mine operators, and have been reviewed and recommended for trial by the American Institute of Electrical Engineers.
EXPLOSION-PROOF STORAGE-BATTERY LOCOMOTIVES.

The interest that has been manifested by mine operators in the development of storage-battery locomotives for mines and the fact that the use of storage-battery locomotives will eliminate the trolley wire (the most dangerous piece of electrical equipment in mines) has led the bureau to undertake the preparation of specifications for explosion-proof storage-battery locomotives. Representatives from a large proportion of the manufacturers have conferred with the bureau and professed their interest in the bureau’s purpose and their intention of cooperating. They suggested that the bureau prepare a set of specifications embodying the requirements that the bureau considers to be essential for an explosion-proof storage-battery locomotive. These specifications are completed, and have been submitted to the manufacturers of storage-battery locomotives and to several of the larger coal-mine operators, whose cooperation has been solicited and promised.

DEVELOPMENT OF A DURABLE MINE-LAMP CORD.

During the past year the bureau has developed a durable mine-lamp cord for the use of portable electric mine lamps. Up to the present time this part of such lamp equipment has been its weakest feature, and little success has seemed to attend the efforts of the lamp manufacturers to improve the cord. The bureau solicited the assistance of the manufacturers of electric wires and cables, and after the bureau had provided them with such information as it had at hand at that time regarding the best design to follow, the bureau’s experts made tests of all of the different designs of lamp cords that the manufacturers submitted. The investigation is now complete, and 400 samples of 26 types of cord have been tested, involving a total of 47,000,000 slattings of the cords. The result of all this work has been the development of a cord 40 times as durable as the best cord tested prior to the undertaking of the research. This development means that the cord has been raised from the position of the weakest part of the lamp equipment to that of one of the most durable and reliable.

ELECTRICAL METHANE DETECTOR.

For several years the bureau has been developing an electrical methane detector. The results of the work have been gratifying and the detector promises to become a device that instantly will detect less than 0.25 per cent of gas. The sensitiveness and durability of the instrument are beyond question; some difficulty has been experienced in making the sensitive part of the instrument durable and reliable, but the results obtained recently have been encouraging.
INVESTIGATIONS OF MINE AND NATURAL GASES.

Important work was done during the fiscal year 1916 on a process for the absorption of gasoline from natural gas. This process consists of bringing so-called "dry" natural gases, which contain a very small percentage of gasoline vapor that can not be handled by the ordinary compression method, in contact with a petroleum distillate much heavier and of higher boiling points than gasoline, thereby causing the oil used to absorb gasoline from the natural gas. This absorption may take place in suitable towers or through a specially designed apparatus for absorbing vapors or gases in liquids. After the oil has absorbed the gasoline from the natural gas it is pumped to a steam still, where the gasoline is separated from the oil by fractional distillation. Then the oil is pumped back through heat exchanges and cooling coils to the absorber to receive another charge of gasoline. In other words, the oil acts simply as a carrier of gasoline from the absorber to the still and is used over and over again. The process is continuous, as the oil traverses a circuit and the natural gas is continually passing into and out of the absorbers. By the process millions of cubic feet of natural gas can be utilized for gasoline extraction that hitherto have been considered too lean, the estimated output of gasoline by the process being 100,000,000 gallons each year.

The Bureau of Mines did not initiate work on this process, for one of the large gas companies installed it in 1913, but the bureau is the first body to conduct elaborate experiments for the benefit of the public. These experiments demonstrated the fact that it is not necessary to perform the absorption at pressures above 30 pounds per square inch unless the pressure of the natural gas is high. As many millions of cubic feet of gas can be used at low pressure the bringing of this fact to the public is of great importance. A comprehensive report discussing in detail the many tests that were made is to be published soon.

Another achievement has been the development of a gas detector for mine use. This is considered to be the first practical, accurate, and simple gas detector for use in mines. A test requires less than two minutes, and an accuracy of 0.1 per cent can be obtained. The instrument is made of metal and weighs less than 2 pounds. It has been described in a preliminary article by one of the bureau's experts.

The first model, which is now in the hands of a company that is placing it on the market, is meant for use with the miners' cap lamp battery, many thousands of which are found in American mines. About 200 detectors are in actual use in mines. Another model to

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follow will contain small dry cells included in the body of the instrument, and perhaps a third model containing a very small storage cell so that the operation of the device will be independent of a source of electrical energy not contained in the instrument itself.

The development of the device has been somewhat slow because a great deal of time has been spent in making it explosion proof, and this object is believed to have been accomplished. The device has other uses besides detecting dangerous atmospheres in mines. For instance, it can be used in detecting different combustible gases like natural gas, artificial illuminating gas, hydrogen, acetylene, or other gases in air wherever they may accumulate and wherever it may be desirable to test for them.

The bureau's chemists have done further work on the measurement of natural gas at high pressures. Each year in the natural-gas industry many millions of cubic feet of gas are measured under pressures up to 300 pounds or greater, and the assumption has always been made that the gas follows the law for a perfect gas as regards the relation of pressure to volume. This simple law, called "Boyle's law," states that the volume of a gas times the pressure applied to the gas is constant at all pressures. However, this law does not always hold, and the neglect of proper correction for variations has resulted in the erroneous measurement of many millions of cubic feet of natural gas. The Bureau of Mines determined the deviation from Boyle's law for many samples of natural gas, and also for the constituents that comprise natural gas, in order to show the proper correction to be applied in natural-gas measurements. The results of this investigation will be found in Bureau of Mines Technical Paper 131.

NITRATION OF WATER-GAS TOLUENE.

An investigation of the nitration of water-gas toluene was undertaken in view of the rather prevalent impression that toluene obtained in the manufacture of water gas is unsuitable for the manufacture of trinitrotoluene, because of the presence in it of hydrocarbons of the aliphatic series whose removal can not be effected by the usual methods of purification. It was further anticipated that a similar difficulty would be encountered in efforts to utilize toluene prepared by processes involving the cracking of petroleum.

However, early in the course of the investigation it became apparent that aliphatic hydrocarbons, if present at all in any sample under investigation, were present in negligible amounts, as far as these affect nitration. Consequently, the investigation became a more general one, embracing the nitration of any good grade of toluene.

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and it was continued with the purpose not only of working out the conditions under which the best yield of trinitrotoluene could be obtained from the sample of toluene in hand, but also of developing a method that might be capable of successful industrial application to the nitration of any toluene of approximately the same degree of purity. The need of such an investigation was emphasized by the incompleteness of published details with respect to methods already applied successfully in the industries. The data available in the literature on the nitration of toluene, although valuable and suggestive, did not afford a satisfactory basis for comparing the merits of different manufacturing processes with respect to quantity and quality of yield of trinitrotoluene.

Investigation of various conditions affecting the nitration of the toluene and the yield of trinitrotoluene have resulted in the development of a method of nitration by which a good yield of high-grade trinitrotoluene is obtained. The results of the investigation are embodied in Technical Paper 146a of the bureau.

CONSTITUTION OF COAL.

Closely related to other investigations in progress in the bureau is the investigation of the chemical nature of the organic constituents of coal. Information derived from such an investigation of the nature of coal is of importance in its relation not only to pure science but especially to the determination of the factors that govern the coking property of coal, the spontaneous combustion of coal, and the inflammability of coal dust; to the correct interpretation of the changes that take place during the destructive distillation of coal; and to the intelligent and economical utilization of coal in the industries. Progress in such an investigation is necessarily difficult on account of the complexity of the coal substance and the great resistance that it offers to the ordinary physical and chemical methods of study.

On the chemical side, the method followed in the bureau has involved the separation of the constituent substances of coal as far as possible by means of extraction with organic solvents and the subsequent study of the separate portions thus obtained. A preliminary investigation along these lines is reported in Technical Paper 5b of the bureau.

Previous to the resumption of a second investigation a few months ago, a large amount of coal from the Pittsburgh bed had been extracted with pyridine, the pyridine extract had been fractionated by

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means of other organic solvents, and several of these fractions had been examined in some detail. The investigation has been continued during the latter part of the present fiscal year, and further progress has been made in the effort to identify some of the constituents of the coal previously separated by means of solvents.

**WORK OF THE BUREAU'S ANALYTICAL LABORATORY.**

At its Pittsburgh experiment station the bureau maintains a general analytical laboratory which is engaged principally in making the necessary analyses and tests that are constantly required in connection with the study of fuels and with the mine-accidents investigations that are being conducted at the station or in the field.

Naturally, the analysis and testing of coal and coke comprise the larger proportion of the work done at the Pittsburgh laboratory. The laboratory is equipped with the most improved apparatus for the complete and accurate analysis of coal, coke, lignite, and peat. During the year the bureau's equipment was increased by two new constant-temperature calorimeters, which are capable of giving the highest precision in determining the heating value of fuels. The work done in this laboratory during the year may be classified as follows:

**ANALYSES OF MINE SAMPLES OF COAL.**

In order to obtain adequate and comparable information on the value of the fuel resources of the country, the United States Geological Survey and State geological surveys, in cooperation with the bureau, have for a number of years been collecting mine samples of coal in various parts of the country. From time to time these analyses have been collected and tabulated in reference to their sources for publication in the bureau's reports. These publications form a library of ready reference to which busy operating engineers or purchasing agents of railroads, steamships, and large industrial concerns may turn and determine in advance the probable quality of coal available in any given locality.

The first of this series of publications, Bulletin 22, contains all analyses of mine and car samples of coal collected between July 1, 1904, and June 30, 1910.

The second, Bulletin 85, contains the analyses made between July 1, 1910, and June 30, 1913.

The third bulletin, covering the period from July 1, 1913, to June 30, 1916, is nearly ready for publication.

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\(^a\) Lord, N. W., and others, Analyses of coals in the United States, with descriptions of mine and field samples collected between July 1, 1904, and June 30, 1910: Bull. 22, Bureau of Mines, 1912, 1,200 pp. (in two parts).

\(^b\) Fieldner, A. C., and others, Analyses of mine and car samples of coal collected in the fiscal years 1911 to 1913: Bull. 85, Bureau of Mines, 1914, 444 pp., 2 figs.
DETERMINATION OF COMBUSTIBLE MATTER IN STONE DUST.

In connection with the investigations on the limiting and prevention of dust explosions in coal mines by scattering stone dust in the mine passageways it became necessary to determine accurately the percentages of combustible carbon and hydrogen in clays, shale, limestone, and other materials that might be available for such use. Obviously, material that contains the least combustible matter is best adapted for the purpose mentioned. The usual methods of determining total hydrogen and carbon or ash do not give sufficiently accurate results, as they do not differentiate between combustible organic carbon and noncombustible organic carbon from the carbonates, nor do these ordinary methods distinguish between the organic hydrogen and the hydrogen in any combined water present in shales and clays. A simple method has therefore been devised whereby only the true combustible is determined.

DETERMINATION OF INCOMBUSTIBLE MATTER IN ROAD AND RIB DUSTS.

In applying stone dust for limiting explosions in mines it is necessary to determine quickly and on the spot the approximate percentage of noncombustible matter in the road and rib dusts in order to determine how much additional limestone or shale dust is required to prevent propagation of dust explosions.

For this purpose the Tafannel volumeter has been modified and combined with a convenient portable field equipment.

As shown in Plate XII, C, this outfit consists of the volumeter a, pipette b, balance c, sampling scoop d, sampling cloth e, alcohol can f, combined carrying case and table g, etc.

The determination of the incombustible matter is made as follows:

Twenty-five cubic centimeters of alcohol is measured into the volumeter flask with the pipette and is followed by 20 grams of the dust to be tested. The graduated tube is then inserted in the flask and the dust and alcohol thoroughly mixed by shaking; 25 c. c. more of alcohol is then added from the pipette through the stem of the volumeter, all adhering particles being carefully washed down. After 1 minute the scale reading of the meniscus is taken, and by reference to tables the percentage of incombustible is obtained.

DETERMINATION OF MOISTURE IN COMMERCIAL SHIPMENTS OF COKE.

In cooperation with the committee on coke of the American Society for Testing Materials experiments were made to develop methods of determining moisture in shipments of coke. It was found that the moisture in coke could be determined by much simpler
A. ELECTRIC BRASS-MELTING FURNACE DEVELOPED BY BUREAU OF MINES.

B. GAS WASTING FROM WELL BECAUSE OF INEFFICIENT DRILLING EQUIPMENT.

C. VOLUMETER FOR DETERMINING PROPORTION OF INCOMBUSTIBLE MATTER IN MINE DUSTS.
methods than those required for coal, owing to the fact that the water in coke is all superficial moisture and in no way combined with the coke substance.

As a result of these experiments the bureau recommends that the moisture in coke be determined by drying the sample to constant weight at any temperature between 105° and 200° C. The sample should not be crushed to pieces smaller than 1 inch. No special oven is required. The foundryman may use a core oven to advantage, or a warm place in the boiler room. The principal precaution to be observed is to dry the sample as quickly as possible after it is taken and to keep it in a tight container while it is conveyed to the place for drying. The experiments have further shown that wet coke can not be crushed without losing moisture. The results of this investigation will be published in a technical paper of the bureau.

**DETERMINATION OF NITROGEN IN COKE.**

In connection with by-product coking investigations with special reference to the yields of ammonia under various conditions, it is frequently necessary to determine the nitrogen remaining in the coke. The usual methods of determining nitrogen in coal are exceedingly tedious when applied to coke; therefore experiments have been undertaken with a view to devising some shorter method to apply to coke determinations.

The action of various catalytic and oxidizing agents is being tried, and it is hoped so to modify the Kjeldahl method as to shorten the time of digestion considerably.

**CHLORIDES, CARBONATES, AND ORGANIC SULPHUR IN AMERICAN COALS.**

Certain coals, especially the English coals, contain chlorides. These chlorides seem to affect the brick ovens and clay retorts used in the manufacture of coke and illuminating gas. A series of analyses for chlorine and also for organic sulphur and carbonate carbon in coal has been made. In the coals tested thus far only traces of chlorine have been found. Organic sulphur, however, is a rather general constituent of American coals, in some of which it comprises half the total sulphur. The largest proportion of carbon in the form of carbonates, has generally been found in coals from the interior field, Illinois, Indiana, Missouri, and western Kentucky.

**FUSIBILITY AND CLINKERING OF COAL ASH.**

The high rates of combustion that are used in modern boiler furnaces have greatly increased fuel-bed temperatures and consequent trouble from clinker formation, especially in certain types of me-
chanical stokers in which the fresh coal is pushed up into the hot fuel bed. There is, therefore, a demand for a simple, duplicatable laboratory test whereby the clinkering tendencies of various coals may be graded numerically.

The fusibility of the ash, as indicated by the temperature at which it softens or deforms when molded in the form of Seger cones, has been generally regarded as offering some indication of the clinkering properties of a coal. It is, however, now well known that the results of this test are greatly affected by the shape of the test piece, the rate of heating, and especially by the nature of the atmosphere—whether oxidizing or reducing—in which the ash is heated. Experiments were made showing the effect of the various fuel-bed gases, such as, oxygen, carbon dioxide, carbon monoxide, hydrogen, and water vapor, on the fusion of ash. The highest temperature of fusion was found in an oxidizing atmosphere, and the lowest temperature of fusion in an atmosphere that was partly reducing, such as to reduce the iron to the ferrous state in a nonmagnetic slag. This type of slag is generally found in fuel-bed clinkers, and therefore indicates the condition under which the laboratory test should be made.

Two furnaces and methods of operation have been devised to make these softening-temperature tests so as to obtain nonmagnetic slags, as follows: (1) Fusion in an atmosphere of hydrogen and water vapor in a molybdenum electric furnace, and (2) fusion in a gas furnace operating with an insufficient air supply the unburned CO and hydrocarbons from the gas forming the reducing atmosphere.

This latter form of furnace gives in general somewhat higher results (up to 100° C. higher) than the electric furnace with an atmosphere of hydrogen and water vapor. However, the gas furnace is so much cheaper to build and operate that, in spite of the greater variability in the results, it will probably find more general commercial use than the electrically heated furnace. In operating the gas furnace a reducing atmosphere must be maintained by using the least air that will support combustion enough to attain the desired temperatures. It is necessary merely to suspend the fused cone from a thread in the field of a strong electromagnet to determine whether the cone has any appreciable magnetism. If the cone shows more than a trace of magnetism, the atmosphere is not reducing enough and the test should be repeated with a larger excess of gas.

The results of this investigation are being compiled for publication in a bulletin.
DETERMINATION OF FERROUS, FERRIC, AND METALLIC IRON IN SLAGS AND CLINKERS.

In order to determine the state of oxidation of the iron in clinkers and in cones fused in various atmospheres, it was necessary to determine the amounts of iron present in the three possible forms, namely, metallic iron, ferrous oxide, and ferric oxide. The three following methods were studied: (1) The copper sulphate method; (2) the mercuric chloride method, and (3) the bromammonium-acetate method. The latter was found most accurate, although for certain purposes where only the percentage of metallic iron is desired the first two methods are applicable. As the textbooks on quantitative analysis make no reference to methods for determining metallic iron, this work should be of considerable value to anyone desiring to make such determinations. The details of the work will be outlined in a technical paper of the Bureau of Mines.
MINERAL-TECHNOLOGY INVESTIGATIONS.

INVESTIGATION OF RADIIUM AND OTHER RARE METALS.

Until three or four years ago radium was more or less a scientific curiosity, the amount in existence being small, and scattered among a reasonably large number of people. The result was that no one person had what would now be considered a reasonable amount of the material. Some men, such as Sir William Ramsey and Sir Ernest Rutherford, possessed something like 200 milligrams of radium metal, all of their intensely interesting and valuable scientific work having been done with this amount. The reason for the dearth of radium was that the ore supply was limited, and, moreover, methods of manufacture were expensive. With the advent of the successful use of radium in cancer therapy, the demand for radium increased, and about this time carnotite ore began to be shipped from southwestern Colorado and eastern Utah to Europe where the radium was extracted. The Bureau of Mines became interested in the country's uranium deposits, and started an investigation, the results of which were published in Bulletin 70 of the bureau. The report showed that the largest deposits of uranium-bearing ore in the world were situated in southwestern Colorado and eastern Utah, although this fact was not generally known in either of these States. In fact, it was not until Bulletin 70 appeared that the real value of these deposits was publicly appreciated.

RADIIUM EXTRACTION BY BUREAU OF MINES.

After it had been shown that a considerable ore supply was available, it became advisable also to show that the treatment of radium-bearing ore and the refining of the material obtained were feasible in this country. This necessity culminated in the cooperative arrangement between the Bureau of Mines and the National Radium Institute, whereby the Government was able to experiment on the treatment of carnotite ore, and incidentally to retain in this country a supply of radium for two of our important hospitals. This work was begun in 1914–15 and has been continued in 1916. The result has been that more than eight grams of radium has been obtained at a cost of less than $40,000 per gram. This radium is not for sale but is being used in the General Memorial Hospital in New York and in the Howard A. Kelley Hospital in Baltimore.

This amount is more than seven times as much as the total amount owned and in use in this country before the work began. The scale on which the radium extraction has been carried on is indicated by the fact that the production in a single month has been twice as large as the amount of radium in the possession of Rutherford or Ramsey, and until a few years ago the amounts they had at their disposal were considered relatively large. Not only has this large amount of radium been conserved to this country for the use of cancer treatment and for scientific purposes, but all of the details necessary for the treatment of carnotite ore have been worked out and published for the benefit of anyone interested. Little had previously been published concerning the method of treating radium-bearing ores and the refining of the salts obtained, but Bulletin 104 of the Bureau of Mines gives information not only as to the treatment of the ore, but also as to methods of analyses and details concerning the refining of the crude radium salts obtained. After the work had been started it was found that the generally known methods of analyses for radium were not applicable for commercial purposes, and one of the earliest and most important parts of the work involved an investigation of methods of analyses that would be applicable to the existing conditions.

The radium plant was operated until January, 1917. At that time the contract between the National Radium Institute and the Bureau of Mines was completed. A certain proportion of the radium produced has been retained by the Bureau of Mines under its agreement with the institute. Part of this will be used for scientific work, and part for medical work in connection with cancer. There are a considerable number of problems in connection with radium that have not only a scientific value but also a commercial bearing. The material retained by the bureau will give an opportunity for the study of a number of these problems. In addition, a considerable amount of radioactive lead, ionium, and actinium concentrates have been obtained, and methods for further concentrating and refining these will be studied, and the material obtained will be valuable for scientific work.

**TREATMENT OF CARNOTITE AND OTHER RADIUM-BEARING ORES.**

The actual work of mining carnotite ores, which was started in 1914 in cooperation with the National Radium Institute, was continued in 1915 under the direction of the bureau's engineers. A bulletin on the work will soon be issued. There has been mined in all about 1,000 tons of shipping ore, averaging over 2 per cent $U_3O_8$, and in

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connection with the mining of the commercial ore, about 2,000 tons additional of low-grade milling ore heretofore wasted, containing an average of 0.85 per cent $U_3O_8$, has been produced and concentrated. A concentrating plant was built at the mines at Long Park, Paradox Valley, southwestern Colorado, and has been operated on a commercial scale, turning out about 300 tons of concentrates averaging 3 per cent $U_3O_8$. Waste ores of this grade have heretofore been left on the dump, but it has now been definitely proved that such ores can be made into a commercial product by dry concentration. An enormous waste may be thus eliminated, as ores of this grade have not heretofore been profitably marketed either as ore or as concentrates. The forthcoming bulletin will describe the mining and concentrating methods in detail and give costs.

The mines department of the National Radium Institute has furthermore purchased, under the cooperative agreement with the Bureau of Mines, about 300 tons of shipping ore, which gave a limited market to the individual miner at a time when the European war had eliminated all other purchasers. The concentration method as demonstrated by the bureau should be of great benefit to the carnotite industry, as it will enable the miner to make the mining of this rare ore more profitable. He necessarily must mine a large amount of low-grade ore at the same time that shipping ore is produced. By concentration this waste product may be utilized, the output of radioactive ore being thus largely increased.

The bureau has also obtained for investigation over 100 tons of low-grade pitchblende ore, together with over 7 tons of high-grade pitchblende. Most of this ore was mined at Quartz Hill, Gilpin County, near Central City, Colo., and has been kept in storage in Denver for some time. The poorer ore was so low in its uranium and radium content that it could not be chemically treated without further concentration. The Colorado School of Mines at Golden offered the use of its mill to the Bureau of Mines, and experiments for the concentration of this ore have been conducted there with the apparatus available. Most of this ore was exceedingly low grade, consisting chiefly of iron pyrite, silica, and less than 0.5 per cent $U_3O_8$ in the form of pitchblende. The concentration of this ore has been successfully accomplished and a considerable saving has been made, although it is hardly feasible to treat commercially such low-grade ore. On the other hand, it is believed that more careful hand sorting of this low-grade ore would yield a better product for which a ready market may be found.

INVESTIGATION OF RARE METALS AND THEIR ALLOYS.

A considerable amount of work was also done during the fiscal year 1916 on the treatment of molybdenum-bearing ores. Molybdenum is
a metal that until recently has been mainly used in the chemical industries, but its use as an alloy for special types of steel demands attention also. The metallurgy of molybdenum has been little understood and the methods used have been expensive. Two types of ore are commonly found in the West, namely, molybdenite or molybdenum sulphide, and wulfenite or lead molybdate. The former frequently carries impurities, mainly copper, which must be separated from the molybdenum in order that the latter can be sold. Wulfenite contains not only lead, but sometimes gold, vanadium, and other metals, and therefore its metallurgy is somewhat complex, as any really successful method should obtain all of the valuable substances present.

General problems in connection with uranium, vanadium, tungsten, molybdenum, and other rare metals will be investigated, particularly as regards the ore supply, methods of concentration, and ore treatment. It has already been pointed out that a small quantity of copper in molybdenum ore is sufficient to prevent the sale of such ore, and the same thing applies to certain impurities in tungsten ores. The question of cheap and efficient methods for the elimination of such impurities would put on the market ore that at present can not be sold to advantage.

Many of the rare metals form alloys, both among themselves and with the commoner metals, and the alloys have a great commercial value. For example, tungsten when added to steel gives to the steel certain qualities that cause the product to be in great demand for the manufacture of cutting tools for lathes, etc. Recently uranium has been successfully substituted for a large part of the tungsten in tool steel to the seeming improvement of the product and it is reported that uranium steel is showing remarkable endurance when used for the liners of cannon. Some alloys of the rare metals containing no iron at all have shown interesting properties, and much research in regard to these and other alloys should be undertaken.

The bureau contemplates further investigations of the mining and concentration of all the rarer metals, such as tungsten, molybdenum, antimony and quicksilver, in order to utilize ores of a grade that has been discarded in many of the mining districts of the West. The European war, which has cut off many of our supplies heretofore imported, has aroused much interest in the conservation of our minor metal resources. The development and application of processes for saving the low-grade rarer minerals offer special inducements, and as all investigations carried on are made especially with the view of preventing waste and utilizing low-grade products, this work should be of great benefit to the mining industry.

Many mineral specimens have been sent to the Bureau of Mines for identification, and although under the law the bureau has no authority
to make analyses, great assistance has been rendered to prospectors and miners by simple identification of the material. Although most of the specimens sent in are of no value, it can be stated that a number of deposits have been opened as a result of the proper identification of some of these minerals, and the results have been gratifying.

**STUDIES OF NONFERROUS ALLOYS.**

The nonferrous-alloy investigations of the bureau are being conducted by one alloy chemist and one assistant alloy chemist at Cornell University, Ithaca, N. Y., under a cooperative agreement with the university by which the facilities of the chemical laboratories, and in particular of the extremely well-equipped electric-furnace laboratory, are available for the bureau's work.

The problem under investigation concerns mainly the metal losses in the nonferrous-alloy industry, particularly in the brass industry. This work has been in progress nearly four years, starting with a study of existing methods of brass melting to ascertain the metal losses, fuel consumption, crucible life, etc., in the various types of fuel-fired furnaces. The results of this study are given in Bureau of Mines Bulletin 73.

From the point of view of the theorist, electric melting of brass should offer marked advantages over existing methods, mainly in the reduction of losses of zinc from alloys high in zinc content, such as yellow brass, manganese bronze, and German silver, in lessened danger of oxidation in the melting of such alloys as the bronzes and red brasses, and in the possibility of replacing the present method of melting in crucibles of comparatively small capacity, with attendant high labor cost, as used in brass rolling mills, by a method capable of using much larger melting units.

The correctness of the theory of the decreased melting losses in electric furnaces of suitable types has been established by a long series of experiments in various types of furnaces.

**DEVELOPMENT OF ELECTRIC BRASS-MELTING FURNACE.**

The problem then became one of finding an electric furnace capable of reducing the metal losses and giving the other advantages of electric melting with such a high consumption of electric power as to make its commercial operation show an over-all saving in melting cost. Almost any electric furnace will melt brass. Many types will reduce zinc losses, though some will not. But to find a furnace that combines all the required factors of metal saving, power

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efficiency, low upkeep cost, reliability, and general applicability to the needs of the brass industry has been no light task.

In the search for such a furnace many types have been built and operated by the bureau on an experimental scale.

Several commercial firms have made tests of electric brass furnaces on a commercial scale, and almost every one of these firms has cooperated fully with the bureau, allowing representatives of the bureau to attend these tests. Neither the laboratory experiments of the bureau nor the trials by private parties showed much promise of commercial success until the fiscal year 1916. During that period, however, two different types of electric furnaces tried by private parties have shown promise. One of these types is fitted only for use with material low in zinc, and its margin of saving over present methods is somewhat problematical under normal conditions. At the present price of crucibles it may profitably replace crucible furnaces under favorable conditions.

The other type of furnace is applicable to alloys high in zinc, and although so far tried only in small sizes offers great promise for certain phases of the brass industry. It has its distinct limitations, however.

The bureau has built and operated on a laboratory scale a third distinct type of electric furnace which has shown marked promise. This furnace promises to meet conditions for which the other two types are not well suited.

The laboratory furnace developed by the bureau is shown in Plate XII, A. The furnace rests on a track set on brick piers. Below the furnace track is another track on which a buggy runs to carry ingot molds. The furnace is rocked back and forth by the projecting handles shown. Adjustable electrodes between which an electric arc is formed are introduced at the ends of the furnace along its axis. The opening shown closed by the clamp in Plate XII, A, constitutes a combined charging door and pouring spout.

Arrangements have been made with a large central electric power station for the building and cooperative testing of a furnace of the type worked out by the bureau. The bureau is keeping in close touch with the progress of the other types of commercial furnaces and hopes soon to be able to publish a report that will bring out the possibilities and limitations of electric brass melting. It seems almost a certainty that in a few years electric brass melting will have a strong foothold in the brass industry and that the electric furnace will prove a means of notably decreasing the Nation's loss of metal in brass melting, which in normal times is about $3,000,000 a year and in the past year of large production and high metal prices has probably been nearer $10,000,000.
The American Institute of Metals is officially cooperating with the bureau in its work. Great interest has been shown in the electric brass furnace work by brass founders, rolling-mill men, and electric-power companies.

**PYROMETER DESIGNED BY BUREAU.**

In the work on the electric brass furnace it became necessary to measure satisfactorily the temperature of the molten metal. For such service a pyrometer that will combine accuracy, long life, and speed of reading is essential. No pyrometer on the market is fully satisfactory for this purpose, but in the bureau's work one was devised that has given good service for laboratory use.

Figure 6 shows the details of the bureau's pyrometer. The protecting tube consists of a nickel tube which is tipped with molybdenum and encased in a tube made of silfrax (graphite coated with SiC), as shown in the figure. The thermocouple consists of a platinum element and a platinum-rhodium element carried in Marquardt porcelain insulating tubing, as shown. The graphite and molybdenum only come in contact with the molten metal, and neither is attacked by it. The nickel tube resists oxidation. The small molybdenum tip heats up quickly, the lag of the device averaging 50 seconds in metal at 1200° C. with the tip
cold at the start. Other nickel tubes are threaded into the lower one to give a tube 3 or 4 feet long, and the outer end is fitted with any suitable handle.

Temperature control is of vital interest to the brass founder and to the rolling-mill operator, as on the temperature rests not only the quality of the goods produced, but also to a greater or less degree, the metal losses, fuel consumption, etc. The bureau has, therefore, taken up the problem of finding a pyrometer for use in molten brass and bronze which will not only serve the requirements of the laboratory but also the needs of the foundry and the rolling mill. This problem seems now to be in a fair way to satisfactory solution.

**MELTING OF ALUMINUM CHIPS.**

Another problem dealing with metal losses in nonferrous alloys has been a study of methods of melting aluminum chips such as are produced in the machining of the aluminum alloys used in motor-car construction.

These fine chips are hard to remelt without excessive loss, a 40 per cent loss being not uncommon. This loss costs the Nation in normal times about $200,000, and in the past year, on account of the extraordinarily high price of aluminum, has probably been nearer $600,000.

Several refiners have been able to get a recovery of 85 to 90 per cent of the metal content of the chips, but knowledge of the necessary details of the methods has been confined to a very few. The bureau has studied the various methods in detail, with the cooperation of several prominent refiners, and the results of the work, published in Bulletin 108, a will, it is believed, inform anyone having to deal with this problem how to procure high recoveries and avoid excessive loss.

An interesting point in this work was the establishing by a series of experiments that the reason commonly accepted for the difficulty of melting aluminum chips without high losses—oxidation of the metal within the furnace—is probably far from being the main reason. The main cause of trouble seems to be the lack of ready coalescence of the metallic globules, which means that the problem is one of colloid chemistry applied to metals.

The cooperation of Prof. W. D. Bancroft of Cornell, an authority on colloid chemistry, was of great value in the work on this problem.

**PRODUCTION OF FERRO-URANIUM.**

Another problem, allotted to the Ithaca laboratory because of its facilities for electric-furnace work, is the study of the production of

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ferro-uranium. Uranium oxide having been produced as a by-product in the radium cooperative work of the bureau and the National Radium Institute, the best method for the utilization of this uranium was sought.

It is understood that uranium steel has recently found use abroad in gun liners, although chemical and metallurgical literature is singularly barren of information on the subject. The results of the investigations undertaken by the Bureau of Mines are to be published as a technical paper.\(^a\)

**CERAMIC RESEARCH.**

**COMMERCIAL REFINING OF GEORGIA KAOLIN.**

During the past fiscal year the bureau has devoted its attention to only one ceramic problem, the commercial refining and use of the kaolins of Georgia by the control of the colloidal material in them, and the utilization of the prepared clay in the manufacture of vitreous china and wall tile.

Notwithstanding the fact that this country possesses enormous deposits of secondary kaolins, especially in Georgia and in South Carolina, this material has not been considered available for the manufacture of white ware, and our ceramic industries have been dependent on imported china clay. For the five years previous to 1915 the annual imports of English china clay from Europe were in excess of 250,000 tons, at an average cost of $6 per ton.

The question, "Why can not American kaolins be substituted for English china clay?" has been frequently asked and more often since the beginning of the present European war, which has threatened to cut off the supply of clays imported from Europe. The answer to this question has invariably been that the domestic kaolins are not so pure and uniform in composition as the imported clays.

The demand for white-burning American clays is of such economic importance that it was considered desirable to determine whether some of our vast deposits of impure white clays could not be refined sufficiently to permit their being substituted for the foreign materials.

The mechanical methods of refinement used hitherto have not yielded products of the desired degree of purity and uniformity. It was decided, therefore, to attack the problem with the methods of colloid chemistry.

It is well known that the addition of small amounts of alkalies to clay-and-water systems has a deflocculating action; that is, it effects a disintegration of the clay grains, or increases the dispersion of the system. The amount of clay held in suspension is increased

and the viscosity of the system is correspondingly decreased. Acids and salts have an opposite effect, causing an increase in the viscosity of the system and a flocculation and rapid settling of the clay particles. The fact that alkalies when added to clay-and-water systems cause deflocculation may be applied to the purification of Georgia clays. The impurities in the kaolins are coated with clay, so that it is impossible to settle out the impurities without a great loss of clay. When the clay-and-water system is dispersed, as by the addition of an alkali, the impurities are free to settle out.

Investigations of methods of refining secondary kaolins were conducted in the Washington laboratory of the bureau in 1913–14. It was found that by thoroughly deflocculating kaolin from the Dry Branch district of Georgia, with a small-measured quantity of caustic soda, the impurities could be settled out with great ease. The product showed considerable improvement in color when made into hard fire-glazed porcelain bodies.

In order to determine whether some practical method of refining the secondary kaolins of Georgia on a commercial scale could be devised, the Bureau of Mines arranged a cooperative agreement with the Georgia Kaolin Co., of Dry Branch, Ga., covering investigational work, which was begun in March, 1915. The effect of additions of different amounts of various alkalies, acids, and salts on Georgia kaolin suspensions was studied, the change in the viscosity of the system being taken as a measure of the effect of the electrolyte added. The electrolytes used included hydrochloric, sulphuric, and acetic acids, alum, caustic soda, sodium carbonate, and sodium silicate.

FACTORS STUDIED.

The investigation included a study of the factors affecting both the initial and the minimum viscosity, such as predrying and blunging, under the conditions of a commercial plant. It was found that caustic soda caused the greatest drop in viscosity of any of the reagents used. Of the coagulating agents tested, hydrochloric acid proved to have the strongest action, being slightly greater in its effect than sulphuric acid.

PROCEDURE IN INVESTIGATION.

In order to insure the successful operation of the refining process developed, suitable equipment for the refining of 50 tons of crude kaolin was installed at an operating mine in the heart of the Georgia clay field. The refining process was carried on under the same conditions that would have prevailed if the ordinary clay miner had been using the process. The refined white product obtained was sent
to a number of the most prominent users of such clay, and was found to possess properties so different from those of the crude kaolin that an additional investigation was necessary to insure the successful utilization of the refined product.

With this object in view an experienced ceramic engineer was sent to two pottery works where the refined kaolin had been shipped; mixtures were made that yielded products of a quality equal or superior to those made from imported material. Two private commercial plants are now being equipped for the refining of Georgia kaolins by this process.

Whether the work already done by the Bureau of Mines will suffice to demonstrate how this process may be applied commercially to all the clays in the South Carolina and Georgia district is a matter of speculation. Doubtless some of the crude clays in that district will not respond to this treatment. In fact, some are known, but the bureau would hardly be justified in undertaking a special investigation to cover their commercial purification until the extent of their occurrence is established. However, preliminary work has been conducted so that as soon as such proof is furnished, the work of practical adaptation of the process to these special clays may be effected with the least possible delay.

STONE-QUARRY INVESTIGATIONS.

PURPOSE OF THE INVESTIGATIONS.

In 1914 a cooperative agreement was entered into between the United States Geological Survey, the Bureau of Standards, and the Bureau of Mines for a study of the stone-quarrying industry of the country. The work undertaken by the Bureau of Mines had for its chief objects the promotion of safety and efficiency, and the elimination of waste in the industry, as well as a study of the technologic methods used and the problems involved.

IMPORTANCE OF THE QUARRY INDUSTRY.

There are approximately 3,000 quarries in active operation in the United States, employing in all about 100,000 men. Quarrying is, therefore, an industry of considerable magnitude. One can scarcely overestimate the importance of quarry products in the Nation's life and work.

Quarries supply, in the form of building stone, the most permanent and attractive of all structural materials. When this fact is appreciated more fully by architects and builders, natural stone will replace much of the cheap and temporary material of which many buildings are now constructed, and as a result buildings will have greater
beauty and permanence, and the ultimate cost will be less than where cheaper materials are employed. For interior decoration natural stone excels all other materials in color effect and in capability of being shaped into artistic designs. For monuments or sculpture nothing can take its place. For the production of Portland cement, which is now indispensable in many lines of industry, millions of tons of rock are quarried annually. Street and road construction, for which millions of dollars are spent every year, depend to a great extent upon quarry products, both for crushed stone and for cement. The production of lime, ground limestone, and gypsum for soil amendment, and limestone for blast-furnace flux, is continually increasing in magnitude.

It is evident, therefore, that in attempting to safeguard the lives and health of quarry workers and to promote the highest efficiency and economy in the quarry industry, the Bureau of Mines has initiated a movement that directly benefits a great group of industries and a vast multitude of individuals and that indirectly benefits many more.

During the fiscal year two reports on stone quarrying were published by the bureau.

ACCIDENT PREVENTION URGED.

The first publication, "Safety in Stone Quarrying,"\(^a\) appeared in September, 1915. Its purpose was to point out to the stoneworkers of the country the chief sources of danger, particularly in the marble-quarrying industry, and to emphasize ways and means of materially reducing the number of casualties. The death rate due to accidents among quarrymen for the year 1913 was 1.72 per 1,000, which is higher than in most European countries for which records are available.

In studying the causes of accidents it was found that they could be grouped in three main classes. In the first class are the many accidents from faulty equipment. In this class may be placed boiler explosions, falls of derricks, and accidents due to insufficiently protected rotating machinery, electric wires, and quarry stairs and ladders. A second cause of accidents is faulty methods, such as improper handling, loading, and firing of explosives, and dangerous methods of handling rock or overburden. The third group comprises accidents that result from carelessness on the part of employers and employees. The report has received favorable comment from quarry operators, and the bureau has received requests for many extra copies to be distributed among quarry superintendents.

INVESTIGATION OF MARBLE QUARRYING.

A second publication, “The Technology of Marble Quarrying,”\(^a\) was issued in March, 1916. At the time this was the only publication in the English language that took up a specific branch of the quarrying industry and dealt with it exhaustively.

IMPROVED METHODS RECOMMENDED.

An important feature of this report is the emphasis placed upon the influence that rock structures should have upon quarry methods. This consideration has been generally overlooked by quarry operators, with consequent heavy but preventable losses. For example, in quarries having inclined open-bed planes that make the maintenance of level floors impossible, it has been customary to construct supports in order that channeling machines may be operated on level tracks. Some of the more progressive companies have recently operated channeling machines on inclined tracks placed flat on the slanting quarry floor, without costly supports. A “balance car” overcomes the effect of gravity. This improved method, as shown by careful records, has resulted in a 50 per cent increase in efficiency in certain quarries of this type.

Other structures that influence quarry methods are “joints” or cracks which commonly intersect marble deposits in two directions, approximately at right angles. If marble blocks are intersected by such seams, their value is greatly impaired, and consequently an effort is always made to quarry sound blocks. Many quarrymen have taken no pains to determine the compass direction of the major joints, and consequently the channel cuts commonly cross them at oblique angles, and thus many blocks are unnecessarily marred by seams. The bureau has emphasized the fact that in the processes of channeling or wedging out blocks the cuts should be made parallel with and at right angles to the joints. The advantage of such a method is shown in figure 7. It may be readily seen that when channeling is properly conducted, as indicated at B in the figure, most of the joints can be eliminated entirely and blocks of sound marble obtained.

REDUCTION AND UTILIZATION OF WASTE.

The problem of waste has received special notice. The presence of vast piles of waste marble at many quarries indicate the two important phases of the problem: First, the desirability of reducing waste by introducing improved quarry methods, and, second, the need of utilizing accumulations of waste material. The bureau has shown that the proportion of waste may be reduced by intelligent prospecting and by separating blocks in accordance with rock structures.

Blocks containing imperfections may be employed for riprap, road building, lime burning, soil amendment, furnace flux, rubble, and various other uses.

Figure 7.—The economy of channeling in accordance with joint systems. A, Plan of channeling without reference to the direction or spacing of the joints, involving great waste of marble blocks; B, plan of channeling in which channel cuts are made parallel with and, as far as possible, coincident with joints, avoiding waste of blocks.

REDUCTION OF LOSSES DUE TO “STRAIN BREAKS.”

An important feature of the report is a detailed record of a successful method of reducing the excessive loss due to “strain breaks”
in marble quarries. The rock in many quarries is under compression, and as the compressive strain is relieved locally in quarrying, the partly severed blocks break into irregular masses, the fractures often being accompanied by loud reports. A method of avoiding the excessive waste due to the production of these irregular fragments is described. It is advised that rows of deep, closely spaced, vertical drill holes be projected in a line across the quarry in such a manner that the rock may expand and partly close the drill holes, thus giving relief from strain without the destructive fracturing. One Tennessee marble company has already tried this method, and has thereby greatly reduced the proportion of waste marble, and thus effected a saving of several thousand dollars. It is believed that several valuable quarries that have during recent years been abandoned on account of excessive strain breaks could be reopened and worked profitably if the methods proposed in Bulletin 106 were adopted.

**Importance of Keeping Cost Records.**

The report puts stress on the fact that waste reduction and efficiency of operation can not be achieved if definite cost data are not kept. The point is emphasized that the majority of quarrymen fail to keep definite cost records, and as a result they are unable to properly judge the efficiency of methods and machines. The introduction of more modern methods of quarrying is therefore frequently discouraged by the inability of the operator to test their efficiency. To facilitate the keeping of technical records a complete system of marble-quarry accounting is given.

**Sandstone Quarries Examined.**

During the summer of 1915 a study of sandstone quarrying was begun. About 55 sandstone quarries were visited by the bureau’s quarry technologist, and investigations were made of all phases of the industry. A special study was made of the physical properties and imperfections of sandstone and their effect on quarry operations. Methods of quarrying bluestone and ganister were also observed.

It is worthy of note that these investigations disclosed a condition of excessive waste in many sandstone regions, the proportion of waste in some instances reaching 75 per cent of the gross production. The gravity of this condition is intensified by the limited number of uses for which waste sandstone may be employed. The imperative need and the means of so improving quarry methods that the proportion of waste may be greatly reduced are emphasized. A study of the
cause and prevention of accidents was conducted in conjunction with the efficiency and waste investigations. The result of the studies and observations made are embodied in a report.\(^a\)

**OTHER RESEARCHES BEGUN.**

During the latter part of the fiscal year similar investigations were begun at the fluxing-limestone quarries in the vicinity of Buffalo, N. Y., and the cement-rock quarries of eastern Pennsylvania and northern New Jersey. Observations at the small number of quarries already visited indicate that the problems involved in the quarrying of these types of stone demand careful study, and that a detailed discussion of quarry methods, particularly those relating to blasting, would be of material benefit to the industry.

PETROLEUM INVESTIGATIONS.

IMPORTANCE OF PETROLEUM PRODUCTS.

The average person fails to realize the importance of petroleum and its products in the ordinary routine of the world's work, yet every man, woman, and child in America is dependent in some measure upon petroleum and natural gas. There is scarcely a phase of our national life in which we do not find petroleum products used—they drive our battleships, deliver our merchandise, pull our trains, heal our wounds, color our garments, smelt our ores, carry our mails, cook our meals, and increase our knowledge of the outdoor world. They illuminate the magazine we read and the book we study; they carry us home from the office, and make chewing gum for the children.

Every industry makes some use of petroleum or its products, and to list all of the uses would not be feasible here. It is sufficient to say that petroleum is essential to the commercial development of the country, and that if our supply were cut off to-day, our industrial progress would be brought almost to a standstill. It has been said that when petroleum is gone, electricity will take its place, but, although electricity will furnish power for our industries and lights for our homes, it will not lubricate even the machinery needed for its own generation.

The Navy is dependent on the petroleum industry not only for lubricating oils but to an increasing extent for fuel. Battleships that use oil as a fuel can carry larger armaments, and have a greater range of action than those that use coal. Petroleum is thus vital to our national defense and perhaps to our national existence.

LIMITATIONS OF SUPPLY OF PETROLEUM.

What shall we do when our supplies become depleted? Although this country has large known reserves of petroleum, these supplies are limited. At our present rate of consumption our estimated supplies are sufficient to meet our present needs for a comparatively short period, conservatively estimated to be from 25 to 30 years, taking no account of the increasing demand for petroleum and its products. This estimate not only includes the oil fields already known and developed, but makes liberal allowances for undiscovered fields in prospective oil territories. It should not be thought that our petroleum supply at the end of that period will be cut off abruptly,
for the wells will continue to produce through a declining output for many years. On the other hand, the shortage of petroleum is beginning to be felt now. A good measure of the accuracy of these estimates, which were made more than a year ago by the Department of the Interior, is the result of the search for oil the past year. Owing to the demand for crude oil, more territory was prospected and more wells were drilled in search of petroleum in the Mid-Continent field than in any previous year. During the year 1916 there were approximately 15,000 wells drilled in that field, as compared with 6,000 wells drilled in 1915, yet the production to-day will not equal that of two years ago, in 1915, nor have any large new oil fields been developed.

What effort have we made to conserve this supply and to utilize it to its greatest advantage? We have made little effort until very recently to do these things. We have been wasteful, careless, and recklessly ignorant. We have abandoned oil fields while a large part of the oil was still in the ground. We have allowed tremendous quantities of gas to waste in the air. We have let water into the oil sands, ruining areas that should have produced hundreds of thousands of barrels of oil. We lacked the knowledge to properly produce one needed product without overproducing products for which we have little need. We have used the most valuable parts of the oil for purposes to which the cheapest should have been devoted. For many years the gasoline fractions were practically a waste product during our quest for kerosene; with the development of the internal-combustion engine the kerosene is now almost a waste product in our strenuous efforts to increase the yield of lighter distillates.

This country is producing about two-thirds of the world's output of crude petroleum and has produced approximately 2,750,000,000 barrels since the drilling of the first oil well by Col. Drake in 1859. Our future supply from both proved and prospective oil fields, based on geological possibilities, is estimated to be approximately 7,402,-000,000 barrels, which will last us only about 25 years at our present rate of consumption. We are exporting 20 per cent of our production, using approximately 25 per cent as fuel under boilers, and of the remainder probably one-fourth is wastefully utilized. Thus 70 per cent in all is being used in a manner that must be considered anything but conservative for so valuable and so scarce a product.

As an example of wasteful utilization, a large proportion of our artificial gas is made from petroleum, notwithstanding the fact that coal has been and is used for this purpose, and would be used altogether except for the reason that the gas manufacturer is able to buy petroleum cheaper. At the present rate of production it is estimated that our coal supply is adequate for many centuries. Clearly we
should not use our petroleum for fuel under boilers or for gas manufacture, or in any way to compete with coal, when the oil supply is so limited.

GROWING CONSUMPTION OF GASOLINE.

Gasoline is indispensable to our present industrial progress. At the present time there is a greater demand for gasoline than for kerosene, fuel oil, or any of the other petroleum products. There are now over 3,500,000 automobiles in use in the United States. The manufacturers are turning out approximately 1,500,000 new machines this year, and expect to increase the number each succeeding year. The average consumption for each automobile is more than 10 barrels of gasoline a year, and it is estimated that this country will need more than 2,000,000,000 gallons of gasoline for the year 1917. Where is this gasoline coming from?

METHODS OF PRODUCING GASOLINE.

The situation can be partly met by converting some of the less valuable products of crude oil into gasoline. The Bureau of Mines early realized the importance of this conversion and during the year 1915 one of its chemical engineers, Dr. Walter F. Rittman, discovered a “cracking” process by which gasoline, as well as benzene, toluene, and other desirable products can be made from kerosene and other crude oil distillates. Other cracking processes have been invented but they have been privately owned and not readily available to the small refiner. The Bureau of Mines hopes to make the Rittman process available to every user.

It is estimated that during 1915, 2,000,000 barrels of gasoline was made by cracking processes, some refineries obtaining as high as 35 per cent of gasoline from some oils. During the year 1916 it is estimated that 5,000,000 barrels of gasoline will be manufactured by cracking lower grade products. This output is all the more striking when it is considered that these 5,000,000 barrels will be made from oils that in the past did not enter into the making of gasoline.

The Bureau of Mines has for a number of years realized the importance of taking steps to introduce methods by which wells may be drilled more economically and with less waste of oil and gas to increase the amount of oil that may be extracted from an ordinary formation, and above all to conduct investigations that will bring about a greater efficiency in the utilization of this precious commodity. To carry on work along these lines the petroleum division of the Bureau of Mines was organized, and up to July 1, 1916, had spent about $100,000 in this work. The manner in which this money has been expended and the resulting benefits to the public form an interesting study for anyone interested in the petroleum industry.
ORGANIZATION AND WORK OF THE PETROLEUM DIVISION.

The petroleum division of the Bureau of Mines is divided into four sections, as follows: (1) Cooperative and administrative work, (2) production technology, (3) engineering technology, and (4) chemical technology. The cooperative and administrative section supervises the work of the division, conducts its correspondence, and carries on work in cooperation with other governmental agencies.

The section of production technology conducts investigations with a view to increasing the proportion of petroleum and gas recovered from the earth and carries on studies regarding the exclusion of water from the oil sands and the prevention of other underground wastes. The section also investigates current oil-field practices throughout the country with a view to the more general adoption of the most efficient and economical methods of producing the oil and caring for it. Men with long practical experience in drilling and caring for oil properties are held ready to advise oil operators who desire expert opinion as to the best methods to be used in solving any difficult problem.

The section of engineering technology conducts investigations as to the design, construction, and operation of pipe lines, storage tanks, earthen reservoirs, and similar problems connected with the engineering side of the petroleum industry. A special study has been made of steel storage tanks and of the loss of oil in storage, including both losses by evaporation and losses by fire. Also, the section has studied in detail the manufacture of gasoline from natural gas.

The section of chemical technology studies methods and practices for refining and treating petroleum and its products and is the section in which the Rittman process was developed. This section carries on research work in connection with the refining and testing of petroleum, and is working on the study of the processes for deriving oil from shales with a view to determining the future economic possibility of the oil-shale industry. This is a large and important field of work, and it is expected in the future to materially assist in introducing new practices in refining that will, to a certain extent, aid in the efficient utilization of our petroleum.

COOPERATIVE AND ADMINISTRATIVE WORK.

The purposes of the petroleum division have been three: First to place before the public the significance of the tremendous waste of oil and gas and if possible to cooperate with State legislative bodies and Federal bureaus to reduce and to prevent excessive wastes of oil and gas; second, to carry on investigations whereby a greater percentage of the oil may be extracted from the sands; and, third, to
place in commercial use various methods that will insure a greater utilization of this country’s petroleum resources.

Millions of cubic feet of natural gas and millions of gallons of oil have been wasted for days and days in a careless and reckless exploitation of our oil and gas fields. The productive districts in this country have now been fairly well defined, and in spite of the constantly increasing demand for these unrivaled fuels the production must within a comparatively short time begin to decline. Hence, it is of the highest importance to the Nation that the remaining supplies of these fuels be protected and the tremendous waste in their production be prevented, and it is this end that the administrative and cooperative section holds in view.

Many of the States have already recognized the need of preventing waste and have enacted laws for that purpose. Unfortunately, however, such legislation has in many instances proved ineffective, because it did not have the confidence of oil operators and because it was difficult to enforce. The Bureau of Mines is in a position to bring together producers and marketers of petroleum and natural gas so that their cooperation may be obtained and measures to lessen wastes may be made effective.

EXAMPLES OF AID TO STATES.

A few months ago when the people of Oklahoma realized the tremendous waste of natural gas and oil in the prolific Cushing field, it became necessary for the State legislature to prepare and enact into law a bill making it compulsory for the oil operators to conserve these resources. The assistance of the Bureau of Mines was requested and was promptly given. The law is now in force and is spoken of as one of the best conservation laws in the United States.

The bureau stands ready at any time to furnish any possible similar assistance to any organization or State for the purpose of conserving petroleum and natural gas.

Another interesting example of assistance given by the Bureau of Mines also concerns the State of Oklahoma. The commercial club of a small but thriving city, realizing that much of the surrounding district’s prosperity depended upon the conservation of its oil and gas, requested that the bureau recommend to them a practical man whom they could employ for the purpose of enforcing the regulations of that State in connection with the conservation of its petroleum resources. The committee asked that this man be allowed to work under the supervision of the Bureau of Mines. A man was finally appointed, his salary and expenses being paid from moneys subscribed by the commercial club and by representatives of the various industries in the community, and under the bureau’s direction many millions of cubic feet of natural gas have been conserved and saved
for the future, while in the near-by districts, where no such close scrutiny was given the oil and gas operations, all the gas has either been blown into the air in an effort to find oil or has been dissipated in the porous formations underground. The Bureau of Mines desires to see more of this sort of work done, as it not only results in the conservation of oil and gas but insures the future prosperity of many of the industries upon which such cities are dependent.

INTERDEPARTMENTAL COOPERATION.

Cooperative work has been carried on with such Federal departments and bureaus as the Navy Department, the Department of Justice, the General Land Office, and the Indian Office. The bureau's petroleum division seeks to act as the technical advisor of the Government and of the people in all matters relating to the technology of production, engineering, and refining of petroleum and natural gas.

PRODUCTION TECHNOLOGY.

The section of production technology of the bureau's petroleum division studies the drilling of oil and gas wells and the production of oil and gas.

PROBLEMS IN DRILLING GAS AND OIL WELLS.

The drilling of oil and gas wells is not a simple matter, and only a small percentage of the people of this country realize that it costs thousands of dollars to drill a hole over half a mile deep for the purpose of discovering oil and gas. Many oil wells are nearly a mile in depth. Oil and gas exist ordinarily in porous formations at varying depths below the surface, and if it were possible to drill wells for oil and gas in the same way that wells are drilled for water, not so many problems would be encountered. But the holes must be drilled through caving formations and through formations containing great quantities of water or gas under high pressure. Heavy pipe ranging in diameter from 4½ to 20 inches must be used to prevent the caving of the formations and to exclude water from the drill hole.

There are two general methods in use in the United States for drilling oil or gas wells—the standard or cable-tool method, in which a percussion drill is used, and the rotary system, in which, as the name implies, the drilling is done by rotating a string of pipe on the end of which is a bit that cuts through the formations in the same manner that a drill bit cuts through a piece of metal.

With the standard method the first drilling is done with a large tool called a "bit," which is raised by powerful machinery and allowed to drop, grinding up the rock. As soon as the hole reaches a depth at which caving begins, a heavy "string" of casing is
screwed together and set on the bottom of the hole, and another bit of a smaller size, which will go inside the casing, is lowered into the well, and drilling is resumed in the smaller sized hole. When found necessary the bit is removed and a long string of casing, smaller in diameter than the first casing, is set on the new bottom of the hole and operations continued with the smaller bit. This is done until the oil sands are encountered, the strings of casing resembling a great telescope.

Many difficulties are connected with drilling such wells, and the bureau's engineers are continually studying the problems of operators in different fields of the United States. These engineers are sent from field to field to advise with operators when requested to do so. In this way the Bureau of Mines disseminates much information of value to the oil operators.

NEED OF TECHNICAL CONTROL IN WELL DRILLING.

As outlined above, the drilling of oil and gas wells is a difficult engineering operation; it requires the expenditure of much money and labor, and demands high engineering skill. However, all drillers and many operators are not familiar with the most efficient methods of drilling through gas-bearing formations and often do not adequately protect oil and gas measures from contamination by water or from underground dissipation. For this reason and because of the great volumes of oil and gas being wasted, the bureau undertook to introduce into Oklahoma new methods of drilling that would result in a conservation of oil and gas. Some specific instances of wells at which large volumes of gas were wasted follow.

EXAMPLES OF GAS WASTE.

In 1914 one of the first wells drilled in the north Cushing field wasted an average of 14,000,000 cubic feet of gas each day for 67 days, or a total of 938,000,000 cubic feet. A little later the same well struck another sand and wasted about 40,000,000 cubic feet of gas each day for seven days, or a total of 280,000,000 cubic feet. From these two sands this well wasted 1,218,000,000 cubic feet of gas, which, if it had been sold at the average price of gas consumed in the United States at that time would have brought $182,700, and even if the producer had sold the gas at the customary field price he would have obtained from its sale over $25,000, or more than enough to drill a well. This amount of gas wasted is equivalent to about 60,000 tons of coal, or about 250,000 barrels of oil, and is sufficient in volume to furnish over 12,000 families with gas for one year. Had this well been the only one to represent waste, it would not have been
so regrettable, but as a matter of fact the gas wasted by this well was only a small proportion of the total amount wasted in the Cushing field.

For instance, a well near by, drilled at nearly the same time, in less than a month wasted 1,655,000,000 cubic feet of gas, equivalent to about 80,000 tons of coal. Still another well within two months wasted 600,000,000 cubic feet of gas, and another in 32 days wasted 1,000,696,000 cubic feet of gas. The total combined waste from these four wells was over 5,000,000,000 cubic feet, equivalent to over 250,000 tons of coal, or enough to supply over 50,000 families for one year. If this gas had been sold at the average price of gas consumed in this country it would have brought the seller more than three-fourths of a million dollars.

During the year 1913 it is estimated that in this one field in Oklahoma an average of not less than 300,000,000 cubic feet of gas was wasted daily, or more than 100,000,000,000 cubic feet of this ideal fuel was allowed to waste during the year. This is equivalent to about 5,500,000 tons of coal, and would have met the wants of nearly 1,000,000 families for 1 year. If the gas had been sold at the rate of 15 cents per 1,000 cubic feet, the sellers would have realized over $15,000,000, and even if the producers had obtained only 3 cents per 1,000 for the gas, which is the prevailing field price, they would have realized over $3,000,000 from its sale. Not only was the gas allowed to waste, but such tremendous volumes of this inflammable material hung over the oil fields that automobiles were not allowed to enter, and in many cases disastrous fires were started, resulting in the loss of life and property.

All this gas was wasted in order to produce about 30,000 barrels of oil daily; in other words, at the prevailing price paid by domestic consumers for such fuel, gas worth about $75,000 a day was needlessly wasted to obtain a daily oil production valued at less than $25,000.

EFFECTIVE METHODS DEMONSTRATED BY BUREAU OF MINES.

The Bureau of Mines sent engineers to this field to reduce the waste by teaching an efficient drilling method. In a few months it was proved beyond doubt that wells drilled through these tremendously productive sands need not waste so much of the gas. The method demonstrated not only conserved the gas and kept it underground where it could not be wasted, but rendered the field safe for workmen and for visitors, and also greatly reduced the time of drilling wells, for previously when an operator struck a high-pressure gas sand he had to allow the gas to needlessly waste into the air until the
pressure had declined enough to allow him to continue drilling. An example of the waste of gas is shown in Plate XII, B. This well was wasting 50,000,000 cubic feet of gas daily and had a closed-in pressure of nearly 800 pounds.

The method of drilling advocated by the Bureau of Mines is called the "mud-laden fluid" method, and is described in detail in Bulletin 134 of the bureau. In short, this method may be outlined as follows:

METHOD OF USING MUD-LADEN FLUID IN DRILLING.

The term "mud-laden fluid" is applied to a mixture of clayey material that will remain suspended in water for a considerable time and is free from sand, limestone cuttings, or similar materials.

ACTION OF MUD FLUID ON POROUS FORMATIONS.

The action of mud-laden fluid in a sand or other porous formation can be likened to the action of muddy water going through a filter. In any filter that has been used for some time it will be found that most of the sediment from the water has been deposited on the surface of the filter, but some of it has entered the filter, the proportion diminishing with the distance penetrated. The distance to which mud from the fluid in the well will penetrate a porous formation depends partly on the combined pressure produced by the column of fluid and the pump, and partly on the consistence of the fluid and the porosity of the formation. At first the fluid will enter the formation, but finally the mud will clog the pores and no more water will go through. Ordinarily, if a thick fluid is used on the sands encountered in the well, it will not penetrate to any great distance even under high pressure, but if the fluid is too thin it may not clog the pores readily and will act more like clear water, which may enter a sand indefinitely. Occasionally a very coarse sand, a fissured formation, or a porous limestone is found into which even thick fluid may penetrate for some distance.

When a well has been treated with mud fluid the contents of each formation is confined to its original stratum, so that there can be no movement of oil, water, or gas either from the sands into the well, from the well into the sands, or from one sand into another. Thus waste and intermingling are prevented, corrosive waters can not reach and attack the casing, and the strata are entirely sealed off from each other as they were before the well was drilled.

CONSISTENCE OF FLUID TO BE USED.

The consistence of the fluid should be varied according to the conditions for which it is to be employed. Most frequently mixtures
with a specific gravity of 1.05 to 1.15 are used in drilling. When
the fluid is not used to drill in, thicker fluid is often employed, which
has the advantages of greater weight and of clogging the pores of the
sand more readily. Experience soon enables the operator to judge
the consistence of fluid required for practical uses.

The operator who is unfamiliar with the use of mud-laden fluid
is likely to use it too thin. This has been the cause of much trouble
in Oklahoma. Such fluid acts almost like clear water. It will not
clog the pores of the sand readily and hence will be forced into them
for considerable distances, and in some instances near-by wells have
been affected. It is also likely to cause caving and is injurious
to the sand, or it may not have sufficient weight to overcome high-
pressure gas. The only limit on the thickness of the fluid that may
be employed is whether it can be handled by the pumps, for it must
be a fluid and not a pasty clay.

MUD FLUID CONTRASTED WITH OTHER METHODS.

The mud fluid is used in Oklahoma at present in drilling wells and
in protecting formations behind casings and plugging wells. The
careful use of mud fluid has proved of inestimable value in drilling
oil wells; it prevents dissipation of gas underground as well as escape
at the surface by confining the water, gas, and oil to the strata in
which they originally occur.

Mud fluid may be used in wells that have been improperly cased to
obviate the bad results which ordinarily follow this practice. An
example of improper casing is shown in figure 8. If mud fluid had
been placed behind certain of the casings in the wells shown in the
figure, waste of gas would have been prevented.

Mud fluid has proved to be of value in plugging wells, and if it
were used more constantly there would be no such waste as that
shown in Plate XIII, A, which shows a gas well that was improperly
plugged. After the well had been abandoned the gas pressure forced
a leak, and gas-laden water flowed from the hole.

It is estimated that in the north Cushing field only about 10 per
cent of the recoverable gas was actually utilized for any purpose,
whereas if the operators had used the mud-laden fluid system of
drilling it would have been possible to utilize 80 per cent of this gas.
Since the introduction by the Bureau of Mines of this process even
larger percentages of gas have been utilized.

An attempt has been made to impress upon the oil operators of
Oklahoma and of some of the other States the fact that formations
containing only a small amount of oil should be carefully conserved
and protected because the day of the big oil gusher will soon be past
and oil operators will then be drilling new wells to sands now comparatively small in production, and moreover they will be making money from such wells.

Figure 8.—Diagram showing how gas may be wasted by improper casing. The gas is in sufficient volume and under enough pressure to overcome the water; it works up, from the sands of highest pressure, behind the casing and back and forth through the other formations. Much of the gas is lost, and its pressure is greatly reduced. Some of the gas may reach the surface and escape in the air.
A. WASTE FROM IMPROPERLY PLUGGED GAS WELL.

B. TEXAS OIL FIELD, SHOWING WELLS THAT COST THOUSANDS OF DOLLARS EACH.

C. REMAINS OF OIL-STORAGE TANK DESTROYED BY FIRE.
COST OF OIL WELLS AND NEED OF EFFICIENT DRILLING METHODS.

In the drilling of oil wells, with the expenditure of vast sums of money, many problems arise. Plate XIII, B, shows the Sour Lake oil field in Texas. Each well shown cost thousands of dollars, and required many weeks of labor in drilling. After oil is discovered many more problems are encountered by the producers in extracting the oil from the ground. At some wells as soon as the drill penetrates the oil sand, oil and gas in tremendous volumes are expelled from the hole, and if the producer is lucky enough to have storage tanks, he may make money easily while the well is flowing.

Oil properties are unlike mining properties, where a certain amount of ore is mined each day and that amount can be increased by putting more men to work. Very often an oil well "comes in" at a high rate of production which lasts for a number of months, gradually diminishing in daily output, however, as the underground pressure in the oil sand is released. As a result the well makes a constantly diminishing daily production, and oftentimes after a few months it becomes necessary to place tubing in the well and pump the oil from the sands. Some wells produce for many years, but often one-half of a well's total production is obtained the first year, and it requires all the rest of the years of the well's life for the operator to obtain the remaining half of the oil.

It has been estimated that oil operators are obtaining only a part of the total oil stored by nature under their lands. Estimates of the total amount extracted range from 10 to 70 per cent, 90 to 30 per cent being left in the ground. It is estimated that this country in the future will produce over 7,000,000,000 barrels. If the Bureau of Mines is able to cause the adoption of practices whereby this production is increased by 10 per cent it will cause an increase in the ultimate production of 700,000,000 barrels or a sufficient amount to meet the present demand for about two years. Placing the same price per barrel on this crude as was obtained for the crude oil throughout the United States for 1915, there would be a saving to the country of $450,000,000. Even an increased ultimate production of 1 per cent would yield a total net saving of $45,000,000, a sum far in excess of any amount which will be spent by the Government for investigations of petroleum and natural gas.

EFFORTS TO INCREASE OIL PRODUCTION.

The engineers of the bureau are making extensive investigations with a view to recommending the most feasible methods of increasing the extraction of oil by the use of compressed air or the use of a vacuum. The principle of one of the most promising of these proc-
esses is the forcing of compressed air into the porous oil sand, thus forcing the oil in every direction from the point of entry of the air. The oil is then pumped from the wells near by. In some cases partial vacuum is put on the sand by the use of suction pumps. These pumps draw the oil and gas toward the well to which the pumps are attached.

Water is the oil man’s greatest enemy. The filtration of water into the oil sands means either a total loss of the oil or a comparatively short flow. This has been true with hardly an exception for every oil field in the world. In many oil fields divided among a number of operators there are great differences in the methods used to get the oil, and occasionally an operator who has had very little experience and does not realize the harm he is doing does not carefully exclude from the deep oil sands the water in the shallow sands. The water not only ruins his well but rapidly spreads from well to well, decreasing the amount of oil recovered, “cuts” the oil, and spoils the field.

The Bureau of Mines has already issued a report on the cementing of oil wells, which means the exclusion of water from the oil by the use of cement. This practice is followed almost universally in the California fields and in some of the Texas fields, and the bureau hopes by conducting extensive work to induce operators in other fields to adopt similar methods. As our petroleum resources are limited, we can not afford to allow great quantities to be ruined because some operator has been neglectful in the methods he has used in finishing his well. The bureau is to issue a report on the methods used for excluding water from oil sands as practiced in all the fields of this country, which will be written with a view to recommending the best practice to be followed under varying conditions in different fields.

CORROSION OF WELL CASINGS.

The corrosive effect of underground water on casings is another difficulty that oil men must combat. Casing in oil wells is used primarily to exclude water and loose material, and as some underground waters contain acids, casings in such wells are rapidly corroded and water runs through them into the oil sands. The casings may be protected from the corrosive effect of water by the use of mud-laden fluid, but in case operators desire to use some other method to obviate this difficulty, the bureau hopes to be able to suggest alternatives.

ENGINEERING TECHNOLOGY.

STUDY OF EVAPORATION AND FIRE LOSSES.

The section of engineering technology of the petroleum division is studying evaporation losses and fire losses in connection with the storage of oil with a view to reducing these losses by suggesting improvements in the design and protection of tanks. The magnitude of evaporation losses may be realized by considering that out of 50,000 barrels stored in one tank in Oklahoma between 2,000 and 2,500 barrels was lost by evaporation in five months. There are probably between 3,000 and 4,000 large oil storage tanks in Oklahoma to-day, and although they do not all now contain oil, and it is not reasonable to suppose that such tremendous losses occur from every tank, the evaporation loss is undoubtedly appalling. In addition to this loss, many tanks are lost by fire caused by lightning during certain seasons of the year, and it is a common occurrence in the oil fields during a thunder shower to see a great tank containing thousands of barrels of oil rapidly burning. Plate XIII, C, shows one of these tanks after such a fire. Not only is the oil lost, but the tank itself has no value.

STUDY OF METHODS OF TRANSPORTING OIL.

Transportation of oil is being studied, including the influence of temperature and viscosity on the capacity of pipe lines, the influence of pressure and soil conditions on the life of pipe lines, and the proper power equipment for pipe lines. Pipe lines are expensive; they cost between $5,000 and $10,000 a mile, depending upon the conditions under which they are constructed and upon the topography of the country that they traverse. When it is remembered that pipe lines have been laid from Oklahoma to the Atlantic coast and to the Gulf coast, and that practically all the Pennsylvania and West Virginia oil fields are connected by pipe lines to the great refinery centers on the Atlantic coast, one realizes what tremendous engineering problems are involved in the construction of these lines and what vast sums of money are invested in them.

CHARACTER AND UTILIZATION OF "WET" GAS.

When oil is produced it is almost always accompanied by more or less gas which ordinarily comes from the same sand. The gas usually contains some of the lighter portions of the oil itself. Such gas is known as "wet" gas, and if it is produced with the oil it is called "casing-head" gas. A few years ago one could go through almost any oil field in this country and see great volumes of this gas
escaping from the oil tanks. No one could see any way in which it could be utilized, although at some wells it was trapped and used for fuel under boilers. It was soon learned, however, that by compressing this wet gas and cooling the compressed product gasoline of high gravity was precipitated. A few years ago gasoline was not so expensive as it is now, and inasmuch as the so-called "casing-head" gasoline was more or less dangerous on account of its volatility, not many people cared to handle it. However, after the automobile came into its own and gasoline became so expensive, the use of casing-head gasoline began to be more and more common.

**PROCESSES FOR MAKING GASOLINE FROM CASING-HEAD GAS.**

Casing-head gasoline is made by two different processes, the compression process and the absorption process. In the compression process the wet gas is compressed by large machines to a pressure between 200 and 300 pounds to the square inch. The compressed product is then cooled and the "wet" parts of the gas condensed. The high-gravity product is then mixed with low-gravity distillates and kerosene, which can not be utilized by themselves in automobile engines. However, the addition of the light-gravity gasoline gives the resulting mixture a volatility sufficient to permit ready combustion in automobile motors.

The absorption process of making gasoline may be used for casing-head gas or for gas that does not occur with the oil. This process is based upon the fact that when the wet parts of the gas are forced through certain kinds of oil used for absorption, the oil absorbs the light particles of gasoline carried by the gas. These are later recovered from the oil by heating it, the gasoline being driven off and the high-gravity product being condensed. The product of the absorbers is blended with a heavier distillate as is the product from compressing casing-head gas.

During the year 1915 approximately 1,500,000 barrels of gasoline was made by these methods. The value of this gasoline is about $5,500,000, showing the magnitude of an industry based upon a product that until a short time ago was allowed to waste into the air. This engineering problem is being thoroughly investigated by engineers connected with the Bureau of Mines.

**INVESTIGATION OF GAS TRAPS.**

The engineering-technology section of the bureau's petroleum division is also investigating the most efficient gas traps for oil wells, with a view to recommending a type for universal adoption.
CHEMICAL-TECHNOLOGY STUDIES OF PETROLEUM.

One of the most important results obtained by the section of chemical technology was the development of the Rittman process which allows a greater percentage of gasoline to be obtained from petroleum than was obtained by other processes. This greater percentage is obtained by subjecting the heavier distillates of petroleum "cracking," which involves the rearrangement of the molecules of oil by subjecting them to high temperatures and pressures. The bureau of Mines early realized the importance of this process and as result of the studies carried on by Dr. Rittman important discoveries were made which bid fair to greatly increase the present supply of gasoline. The Rittman process has proved to be of unquestionable value, although unfortunately not many refineries have installed the necessary equipment for utilizing it.

One of the large fields in refining is that connected with the so-called unsaturated hydrocarbons. Petroleum practice of the past has always dealt with saturated hydrocarbons, namely, those that are not washed out by sulphuric acid. From the chemist's standpoint, the saturated hydrocarbons are inactive, whereas those constituents that are unsaturated are most active chemically, and can be used as a source for building up a great variety of products. The Bureau of Mines desires to extend the scope of such work and recommends its field of research because of its tremendous possibilities.

DEVELOPMENT OF RITTMAN PROCESS.

Another investigation that the bureau desires to continue is the development of the Rittman process. With the present limited appropriations made for petroleum investigations the bureau has not been able to carry on investigations in the field of possible by-products to be made from the cracking of oils. It seems clearly possible to make such by-products as special lubricating oils, aromatic hydrocarbons, and other hydrocarbons that can be used in making paints and antiseptics. During the past year the Rittman process for making gasoline has passed beyond the experimental state and may be considered a commercial process. During the experiments carried on by the Standard Oil Co. of New Jersey at the Rittman process Corporation's plant at Pittsburgh, as much as 100 barrels of oil a day was treated in a 11-inch cracking tube, such as is described in Bureau of Mines Technical Paper 161, with a recovery of 40 percent gasoline having an end point of 165° C., whereas the end point of what is now termed gasoline is nearer 200° C.

The independent refiners have been slow to take up the process, and consequently its development has been retarded. The Bureau of
Mines has been handicapped in that it has not had a plant at which it could carry out tests on a commercial scale. The licensees, as a rule, are not interested in developing the chemical possibilities of the process so much as in obtaining the products they desire. If the maximum progress is to be made in the development of the Rittman process, it seems necessary for the Bureau of Mines to control a plant at which commercial quantities of oil can be treated and to which persons interested in the process can send carload lots of oil to be tested before they invest in the construction of a plant. The labor costs of making such a test should be charged against the applicant for the test.

**CONTENDED INVESTIGATIONS.**

In the future the bureau hopes to investigate sulphuric acid residues from the refining of petroleum; the possible by-products obtainable from acid sludges and cracked oils; and the internal-combustion engine fuels, which will involve the testing of various grades of such fuels for the purpose of determining relative efficiencies and satisfactory end points and other limits. The bureau also hopes to investigate and prepare specifications for lubricating oils and to standardize, as nearly as possible, the methods of testing petroleum and all its products. The best method of analyzing crude oil must be studied. Gasoline, which is one of the Nation’s greatest necessities, is being thoroughly investigated, and thousands of analyses are being made to determine the grades of gasoline being used in different parts of the United States, so as to enable the Bureau of Mines to furnish expert information to State governments and private individuals as to the essential properties of gasoline for various uses.

During the past year the increasing demand for gasoline has been met in four ways: By stimulating production; by the use of a cracking process controlled by the Standard Oil Co.; by increasing the end point from 150° C., the end point of a year ago, to an end point as high as 200° C., which has permitted the use of large quantities of distillate that was formerly considered to be naphtha and kerosene stock; and by blending casing-head gasoline with heavy naphtha or light kerosene stock. It is impossible to count upon an increased production of crude to keep pace with future increases in the demand; likewise it is impossible to expect a much further raising of the end point without a decided change in engine designs, for the reason that the present end point includes most of the products that can be heated up to their vaporizing point without cracking, and if the products are heated above their cracking point objectionable decomposition products are formed. The casing-head gasoline industry will probably never furnish more than 10 per cent of the total
production of gasoline; therefore, the only possible way of keeping pace with this increased consumption of gasoline is by means of cracking the heavier oils. We are to-day using efficiently—that is, for gasoline and lubricating purposes—not more than 30 per cent of our oils. The other 70 per cent is used in competition with coal or exported to foreign countries and is generally sold for less than the cost of production. The gasoline problem before the public to-day can probably be most efficiently solved by cracking this 70 per cent of petroleum, thereby increasing the yield of gasoline from our present oil production by 100 to 200 per cent.

**EXTRACTION OF OIL FROM OIL SHALES.**

The question is being asked daily what this country is going to do when our petroleum resources are exhausted. We have as yet untouched our great reserves of shales that contain oil. These shales are found in many parts of the United States, and tremendous reserves are known in Colorado, Utah, and Wyoming. There is only one country in the world where oil shales are being utilized for the production of oil—Scotland, where little petroleum occurs and where the demand for petroleum is great. Some of our shales are much richer in oil than are the Scotch shales, and are conservatively estimated to contain many times the amount of oil that has been or will have been produced from all the porous formations in this country.

To obtain the oil from oil shale it is necessary to heat the shale in great retorts. The oil is the result of destructive distillation and is driven off in the form of vapor and is later condensed by cooling. As stated above, this process has never been used in this country because of the lack of necessity, for our oil reserves are great, and it would not be commercially economical to invest money in retorts for distilling from oil shale oil that would have to compete with the crude oil obtained by other methods. But this condition will not last forever. In fact, it is thought that it will be only a very short time until the oil-shale industry will be one of magnitude.
METALLURGICAL INVESTIGATIONS.

GENERAL REMARKS.

For an intelligent understanding of the work and plans of the metallurgical division of the bureau, some knowledge of its history is necessary.

Owing to the lack of any appropriation for the purpose, the bureau did not take up metallurgical studies until 1911, when modest beginning was made by establishing a laboratory at San Francisco, Cal., chiefly to study the smelter-fume problem, which was then a particularly live issue between a number of the western smelting companies and the neighboring agricultural interests.

A considerable part of the expense of the investigations centering at the San Francisco station has from the beginning been met through cooperative arrangement with the industries and communities most directly interested.

In 1912 Congress gave the bureau its first appropriation of $50,000, and in later years this has been increased to $100,000. Federal metallurgical investigations will be further supplemented by the work of the new mining and metallurgical experiment stations recently authorized under the Kern-Foster bill. This bill provides for ten new stations, not more than three of which are to be established in any one year. Congress has appropriated $75,000 for the work of the first three stations, which began their investigation in 1916. They are situated at Fairbanks, Alaska; Tucson, Ariz.; and Seattle, Wash.

The first year's work in these new stations, both in mining and metallurgy, is being given chiefly to making a thorough survey of the specific needs of the territory they are to serve, to planning and installing the necessary equipment, and also, what is perhaps most important of all, to bringing the bureau's own personnel into close cooperative acquaintance and contact with the local mining and metallurgical interests so as to insure the intelligent guidance of the bureau's efforts toward the real needs of the community it is to serve.

It was not until 1916 that a distinct division of metallurgy was officially recognized in the bureau, and the scattered pieces of metallurgical work previously undertaken under other divisions was collected under one head to form the nucleus for a more comprehensive and carefully proportioned program.

With this much by way of introduction and explanation as to how the bureau's metallurgical work started, and bearing in mind the unifying process now being brought to bear upon these somewhat
scattered elements, we may turn to a more detailed description of the bureau’s work on metallurgical problems during the fiscal year 1916.

**GENERAL STUDY OF THE IRON INDUSTRY.**

As iron is the most important of all metals, and the one of which this country is the leading producer, with 40 per cent of the world’s output to its credit, it may seem that the bureau has given the iron industry scant attention in comparison with other studies. However, this seeming oversight has been due chiefly to a realization of the magnitude of the problems involved and the inadequacy of present appropriations for more than a small start on the work. Furthermore, the iron and steel industry is predominantly in the hands of large industrial interests fully able to work out their own technical problems. Therefore it has been felt that there was not the same urgency in proffering Government assistance in this direction as there has been in the industries representing smaller and more scattered control and individual effort.

Still, even in the iron industry an attempt has been made to pick out the phases in which the public itself was most directly interested and to give those features such attention as the funds and facilities at hand would justify.

As a general basis for public understanding of the iron industry, and to serve in answering many of the questions coming to the bureau from all sides regarding the fundamentals of the industry as a whole, a popular report, entitled “The Story of Iron,” has been practically completed. The report aims to cover the general history and evolution of the iron industry. The work is both historical and technical and notes the progressive steps and methods in the development of iron manufacture with special reference to the United States; it also cites various noteworthy discoveries, improvements, and processes.

**INVESTIGATION OF SAFETY IN IRON AND STEEL INDUSTRY.**

In conformity with the bureau’s general policy of promoting safety and welfare in the industries which it touches, it has been making a study of accidents at iron and steel plants with a view to determining the principal causes of such accidents and to developing equipment and practice to lessen them.

Since 1906 a few firms have been actively engaged in accident reduction in their plants, and since 1910 the iron and steel industry has been increasingly putting more and more insistence upon the elimination of dangers and the lessening of the accident risk in the occupation. In 1909–10 the Federal Department of Labor conducted an intensive investigation into the accidents and accident prevention
in the industry. In the main, the report of the investigation was statistical and it showed unmistakably the unusual as well as the ordinary causes of accidents characteristic of blast furnaces and steel works plants. It showed that, in addition to accidents occurring by reason of falls, falling objects, railroad equipment, machinery, hand labor, etc., causes not essentially different from those encountered in other occupations, a considerable proportion of the accidents were caused by strictly occupational hazards, which might be classed as metallurgical accidents. Among these, asphyxiation from gas, burns from cinder and hot metal, and injuries from explosions, breakouts, and slips in the furnaces are typical of the industry.

It was felt that the work peculiarly open to the Bureau of Mines was a study of the metallurgical accidents, because little intensive related study had been devoted to them, and because the other aspects of safety work were being adequately taken care of by State departments, the National Safety Council, and by the efforts of the majority of the large companies. The bureau's work has accordingly been largely concerned with the hazards peculiar to the industry.

The investigation of accidents and of safety devices at blast furnace plants has been finished. It has necessitated much travel—all districts of the country, with the exception of the Colorado district, having been visited at least once—many interviews with men managing, operating, and working at the various blast furnace plants, the compiling of considerable information on operating and constructional features, the study of hundreds of accidents, and the observation of furnace methods and practice. The result of this investigation is represented in four reports submitted for publication. One constitutes a manual of safe practices for furnace foremen and men. A second is devoted to asphyxiation from blast-furnace gas. A third report treats in detail of blast-furnace breakouts, explosions, and slips.

In cooperation with the Pennsylvania department of labor and industry, an investigation has been made of the hazards at furnace plants in that State and the findings, constituting an analysis of the accident risk and methods and means of prevention, have been submitted for publication. The report takes up the entire field of accidents about blast furnaces, and every type of accident is illustrated by the description of an actual occurrence, together with discussion of means best calculated to prevent it.

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COOPERATION OF UNITED STATES PUBLIC HEALTH SERVICE.

In the safety investigations, as in other divisions of the work elsewhere noted, the bureau has had most important and cordial cooperation from the Public Health Service through the detail of surgeons.

To aid in improving hygienic conditions a plan was formulated for the investigation of the health of workers in the steel and metallurgical plants of the Pittsburgh district. The investigation began April 16, 1915, and terminated March 15, 1916. During that time seven of the largest and most representative steel plants, employing approximately 55,000 men, were visited. A general survey of each plant was first made and data were collected on such subjects as the sanitary condition of the plants as a whole, the character of the work performed by the employees, the amount required, and the conditions under which it was performed as far as each of these might affect the health of steel workers.

A detailed study was then made of each condition observed that might injuriously affect the employees’ health, with a view to devising ways and means by which these health hazards could be eliminated or minimized. A report has been prepared for publication.

CORROSION INVESTIGATIONS.

ECONOMIC LOSSES DUE TO CORROSION.

The corrosion of metals is receiving constantly increasing attention in the metallurgical world on the part of both the manufacturer and the user. For a time we were inclined to believe that modern conditions of service and the demand for production by present-day methods made short life inevitable. Fortunately scattered examples of long-lived products, and the activities of certain investigators and producers, showed that improvement in material was within the bounds of probability. Such improvement has been marked within recent years, and it seems likely that we have by no means reached the limit of advancement in quality. Again, the better understanding of the underlying causes of corrosion is opening new avenues of attack for solution of the problem.

That the rusting of iron and steel is one of our serious economic and conservation problems is now generally admitted. If we assume an average life of steel of 33 years, the depreciation charge of 3 per cent represents in this country a yearly loss of 1,000,000 tons of product, valued at $30,000,000 to $40,000,000 for the crude or semifinished material alone, exclusive of correlated fabricating costs. The inevitable rusting of steel may be justly claimed to be the bulwark of the zinc industry, as 60 per cent of the metallic zinc used in this
country is for galvanizing iron and steel articles, representing an annual outlay of $20,000,000 in an endeavor to protect metals from inevitable decay. Enormous amounts of paint are used in a like endeavor. About 5,000,000 tons of coal is needed in the production of steel to replace the annual waste and 1,000,000 more for the zinc that is annually lost.

No estimate can be made of the value of the brass, bronze, copper, aluminum, nickel, tin, and other metals and alloys used in machinery parts, as sheathing, for plating, etc., to protect steel or as a substitute for it in places where it would be used but for its lack of resistance to atmospheric attack. A less definite sum is represented in the capital, labor, and material charges for steel construction of a cost design necessitated by the fact that the corrosion of iron and steel destroys any assurance that we may utilize the full measure of the valuable properties of the metal for an unlimited term of service.

CHARACTER OF BUREAU'S INVESTIGATIONS.

The bureau commenced its systematic studies of corrosion some two years ago, largely on account of the great importance of the subject in mines where pipes, hoisting cables, tracks, and, in fact, well-nigh every piece of underground iron and steel equipment exposed to unusually severe conditions of rusting.

Extensive investigations in the field have been made to determine the resistance of various grades of material, including protective coatings, under the effect of a wide range of conditions in actual use but it would be difficult in the present brief compass to give an serviceable idea of this material as a whole.

What will be perhaps even more interesting to the general reader is some idea of the theory that has for a long time dominated the whole field of practical corrosion studies but which the recent investigations of the bureau's staff have shown is inadequate.

NATURE OF CORROSION OF METALS.

The mechanism of corrosion is of extreme importance as underlying any investigation of the problem. Its study involves research of an electrochemical and metallographic nature. This phase of the problem has of late years received the minor share of attention partly because the commercial interests are primarily concerned with tests that will prove superiority for their particular products and partly because the electrolytic theory of corrosion has been rather generally accepted, and in consequence most investigators have assumed that the scientific aspects of the problem were largely solved.

The electrolytic theory of corrosion is based on simple and well understood principles; their application to corrosion phenomena in
volves modifications of detail only. For the generation and continuance of electrolytic action certain factors are essential, namely, two dissimilar electrodes, each of which must be an electrical conductor; an electrolyte in contact with both electrodes; a metallic connection external to the cell; and a depolarizer to insure continuity of electrolytic action. Steel subjected to the weather presents the necessary factors. The heterogeneity of surface, chemical or mechanical, furnishes the electrodes of dissimilar character; the moisture of the air, in its natural state or made more active because of dissolved carbon dioxide, sulphurous, or other gases, is the electrolyte; the electrical circuit is completed by the contact of the electrode spots through the body of the steel; the oxygen of the air reacts with the hydrogen liberated at the cathode surface and removes it by formation of water, thus effecting the necessary depolarization. Electrolytic action must proceed if all factors are present; it will cease if any one is withdrawn. At points where the iron forms the anodic electrode it will go into solution, be converted immediately into the hydrate, and be precipitated upon the surface as such, to subsequently undergo transition to the familiar hydrates and oxides, which are more commonly called rust.

ELECTROLYTIC THEORY UNSATISFACTORY.

One does not have to go far into the study of the corrosion problem to be forced to the conclusion that many of the actual facts observed in service tests are not satisfactorily accounted for by the usual interpretation of the electrolytic theory. For example, iron of highest purity should be most immune from rusting, and such rusting should be even in distribution, with absence of pitting. And yet pure iron does rust, and it does pit as severely as do impure products, especially in some service, as in water pipes.

The work of the Bureau of Mines during the past year has been devoted to the study of the surface influences, particularly of the influence of rust once formed on the progress of further rusting. The findings have received the general approval of authorities on corrosion as explaining many of the hitherto seemingly anomalous observations, and especially the differences observed in the corrosion of pipe as compared with that of iron exposed to the weather, and the more pronounced pitting common to iron pipe.

EFFECT AND KINDS OF RUST.

In brief, the investigation has shown that rust once formed is a factor in the progress of rusting at least equal in effect to those factors universally recognized and is more important than many factors that are subject to dispute because of being attended with
detrimental effects of considerable magnitude. It has been found that there is a reversal of polarity according as the rust is wet or dried. As regards rust freshly formed or wet, the underlying iron is electropositive to the surrounding metal, and consequently goes into solution; dried-out rust, on the other hand, assumes a negative polarity, which tends to reverse in time after the rust is thoroughly wet. This observation has a most vital bearing upon the differences observed in rusting under various conditions, and it accounts satisfactorily for the hitherto enigmatical pitting noticed in water pipes. A most important finding is that fresh wet rust does not act as an electrode, but as a semipermeable diaphragm which makes the underlying iron electropositive, and thus promotes its solution, and that the same effects may be obtained by colloidal or sedimentary substances. This fact is of importance in explaining many effects observed in iron pipe or in iron used under water.

Some interesting work has been done during the past year in the detection of steel scrap in wrought-iron pipe of supposedly genuine character. Methods for such detection have been devised and will be described in a forthcoming report, so that the information may be used by consumers of pipe.

SLAG INVESTIGATIONS.

On account of the growth and expansion of the iron and steel industry and of the industries which depend upon an abundant supply of iron and steel, there arose at the beginning the last century an urgent need for greater economy and output in the operation of the blast furnace. The raw materials for the manufacture of iron must needs remain iron ore and coal; and with the exhaustion of the higher grade ores the industry is becoming confronted with the problem of profitably working leaner ores or ores that present unusual operating difficulties.

In their preliminary survey of the field the metallurgists of the bureau chose as problems demanding scientific investigation the fluidity of blast-furnace slags and its relation to their chemical composition, and the mechanism and physical chemistry of the desulphurization process—two problems intimately associated with the realization of fuel economy and the production of high grade pig iron.

FLUIDITY OF BLAST-FURNACE SLAGS.

The first phase of these investigations, the fluidity of blast-furnace slags, has for many years been the subject of much speculation and theoretical deduction by operating men and scientists. Prior to the present investigations there had been no reliable conclusions drawn
because of the utter lack of experimental data relating to the problem.

The function of the slag in the blast furnace is the elimination of undesirable impurities from the iron ore in such a manner that the resulting mass may be easily flushed from the furnace without interrupting the smelting process. This requires that the slag be sufficiently fluid; that is, possess a low enough viscosity to flow readily from the furnace and that the composition of the slag be such that it can efficiently remove the last traces of impurity from the pig iron. If a slag is so refractory that the blast furnace has to be maintained at an abnormally high temperature, the result is a high consumption of fuel and the possibility of an off-grade product. In addition, the high temperature shortens the life of the furnace. At present the questions involved are answered mainly by rule-of-thumb methods and strict observance of previous practice. It is the aim of the bureau’s slag investigations to furnish metallurgists and furnacemen with reliable scientific data to guide them in their choice of operating factors and to make possible the broadening of present furnace practice to take care of the increasing need of working lean and complex ores.

Since the beginning of the investigation in November, 1915, the problem of slag viscosity has been successfully solved, so far as the method, apparatus, and technique of measurement are concerned, by the development of the Feild high-temperature viscosimeter. By means of this apparatus the viscosity of slags is accurately measured up to a temperature of 2,900° F., which is approximately 900° higher than had been reached by previous investigations. The viscosity-temperature relations of numerous typical commercial slags have already been investigated, and similar measurements of synthetic slags are under way to show the effect of the different constituents, particularly of magnesia, alumina, titanium oxide, manganese oxide, and sulphur. As soon as these investigations are completed the study of the desulphurization of pig iron and its relation to the viscosity and composition of slags is to be undertaken.

The electric furnace and apparatus used in these investigations is shown in Plate XIV, A. The furnace and its accessories were constructed in the instrument and machine shops of the bureau.

Numerous slag samples have been collected from blast-furnace plants throughout the country, and these are being investigated with the apparatus with a view to applying the laboratory results to operating practice.

A report on the methods of measurement, the apparatus, and the laboratory technique used in the viscosity investigations has been published by the Bureau of Mines as Technical Paper 157. The re-
sults of further research will be published from time to time as the experimental measurements accumulate.

It is earnestly hoped that the investigations designed to promote efficiency in the iron and steel industry, of which the present study of slags is the beginning, may be carried to their logical conclusion, and that the necessary funds and equipment may be made available for their continuance.

COOPERATIVE INVESTIGATIONS AT SALT LAKE CITY, UTAH.

An important feature of the bureau's work has been the close association in which it has worked with the universities and mining schools of the country. Nowhere is this better illustrated than in the activities of its Salt Lake City station. This city has of late years become an extremely important mining and metallurgical center. Some four years ago the Legislature of Utah granted an appropriation to the State university of $7,500 a year for metallurgical research especially looking to the improvement of methods for treating the low-grade and complex ores of the State, great deposits of which were then either lying idle and unworkable or were actually going to waste in the mining and treatment of the higher grade ore associated with them.

The university authorities sought the cooperation of the Bureau of Mines in the carrying out of this important research work, and it was finally decided to put one of the bureau's metallurgists in direct charge. A considerable part of the legislative appropriation mentioned above is each year expended on a number of fellowships, the recipients of which work on individual problems under the direction of the bureau's metallurgist. The remainder of the special fund is used for equipment, supplies, traveling expenses, etc. The station has its quarters in the university buildings and has the use of the university's general equipment, such as its library and laboratories. The present is the third year of the cooperation, and in that time the work has developed so favorably that the bureau now has seven representatives at the station as compared with the one originally there.

SUMMARY OF RESULTS.

The important results obtained in connection with the various investigations conducted by the station during the year were as follows.

BRINE-LEACHING PROCESS FOR LOW-GRADE AND COMPLEX ORES CONTAINING LEAD.

As stated above, one part of the work of the Salt Lake station is to devise processes for treating low-grade and complex nonferrous
A. ELECTRIC FURNACE AND APPARATUS FOR DETERMINING VISCOITY OF BLAST-FURNACE SLAGS.

B. PART OF APPARATUS USED FOR LABORATORY EXPERIMENTS ON SMELTER FUME.
es at a profit. As the values of the metals in the ores are relatively
hall, the processes must necessarily be simple and inexpensive.
or this reason, in devising hydrometallurgical processes, an attempt
as been made to use chemicals and such raw materials as are to be
und in the State, especially the salt in the Great Salt Lake, and the
phur gases emanating from the various smelters in the vicinity
Salt Lake City, which are not at present utilized. In attempt-
g to use such reagents it was found that a saturated brine, to
ich some sulphuric acid had been added, would dissolve the
ad from both the carbonate and the sulphate ores of that metal,
d that any silver present as the chloride would also be dissolved.
ead carbonate ores from all over the State, and from all over the
ed United States, have been tested and few of them are proved to
not amenable to the process. From the brine the lead can be
covered by precipitation with lime, or by the use of the electric cur-
t. The process has proved remarkably simple and the brine used
dissolving the lead from the ore and precipitating it in the metallic
has been reused time and again without deterioration. In fact,
e process is proving to be about as simple as any hydrometall-
gical process yet devised. It is being further tested with all avail-le samples of ores in order to determine its limitations.
If the process proves to be commercially applicable, great bodies of
at is now considered to be waste will soon be regarded as ore.
One great advantage of such a process is that by its use metal can
produced at the mine, which has never been done, except in the
iding of gold and silver ores, and to some extent in the leaching
copper ores. As can be readily understood, if the valuable metals
an ore can be extracted at the mine, the cost of hauling the ore to
smelter is eliminated. This of course means cutting down the ex-
se connected with the treatment of the ore, in turn making pos-
ole the profitable treatment of a lower grade of rock.
The application of such a process also means the avoidance of
ste, for at present ores that can not be treated as a profit are left
the mines, being generally used for filling stopes, and hence ulti-
ately lost.

**RECOVERY OF LEAD AND ZINC FROM MIXED SULPHIDES.**

As a rule, in treating ores containing a mixture of lead and zinc
phides for the recovery of their lead or their zinc, either the
ad or the zinc is lost. Moreover, the lead smelter penalizes the shipper
an ore if it contains zinc in excess of a certain stipulated per cent,
y 10 per cent, and the zinc smelter does the same if the ore contains
ad in excess of a certain stipulated per cent. Consequently the
paration of the two metals from each other as completely as pos-
sible is important. Much attention has been given to this problem by the metallurgists at the Salt Lake station, and as a result of their work they have devised a process whereby the mixed sulphides, plus a small per cent of common salt, are given a preliminary roast, which converts practically all of the lead to a form soluble in a saturated brine.

The zinc sulphide is untouched by the roast and can often be removed from the remaining iron sulphide by flotation. Certain zinc ores and zinc concentrates obtained as a result of ordinary gravity processes of concentration often contain a considerable amount of lead, for which as a rule nothing is paid, unless the lead-zinc ore is sold to manufacturers of pigment, or contains enough lead and silver to warrant sending the residue from the zinc plant to a lead smelter. Even then, only 60 per cent of the value of the silver in the residue will be paid for at the prevailing market price and only 60 per cent of the lead at 2 cents per pound, whereas the normal market price for metallic lead in pigs is about 4 to 5 cents a pound.

Thus we see that there is need of a process that will save the lead that is now lost altogether and will allow the miner to get a money return for the greater part of this lead. When tried in the laboratory the process described above satisfactorily extracted the lead from the mixed sulphides of lead and zinc.

APPLICATION OF OIL-FLotation PROCESS TO ORE SLIMES.

In the concentration of ores by ordinary gravity processes, heavy losses of the metal-bearing contents of the ore often occur, because the necessary crushing and grinding convert some of the minerals into fine slimes which are not recovered in the process of concentration. For this reason an investigation was undertaken that had for its object the recovery of these slimes by the oil-flotation process.

The investigation has shown that it is possible to apply the flotation process to the treatment of some of the lead carbonate ores not amenable to the brine-leaching processes previously described. If silver insoluble in brine is present in noteworthy amounts, the flotation process recovers both the lead and the silver in a high-grade concentrate, which can be sold to the smelters. Furthermore, ores of lead carbonate that contain too many acid-consuming minerals to permit brine leaching are amenable to the flotation process.

Thus it will be noted that as a result of the investigations carried on at the Salt Lake City station during the past year processes have been devised that permit the treatment of various carbonate ores of lead. Their importance as regards the treatment of low-grade lead carbonate ores can not be overestimated.
RECOVERY OF ZINC FROM LOW-GRADE OR COMPLEX ORES.

During the past two years many proposed processes for the treatment of the oxidized ores of zinc have been investigated at the Salt Lake City station. In the treatment of most ores the proposed hydrometallurgical processes have been found to present serious difficulties. On the other hand, zinc sulphide ores are at present being very successfully treated by such processes. Owing to the difficulties encountered in attempting to apply hydrometallurgical processes to oxidized ores of zinc, an igneous concentration process was tested, with encouraging results. The process consists in blowing a blast of air through a mixture of oxidized zinc ore, coke, and limestone. As a result the zinc oxide was drawn off as a fume, which could have been collected in a bag house, or by electrostatic precipitation. The ore from which the zinc has been volatilized forms a slag in the furnace and is tapped out in the usual manner. The commercial application of such a process is also important, as at present there is no process being used that permits the successful concentration of low-grade oxidized ores of zinc. Such ores have been accumulating in all of the important mining districts of the United States, especially in Utah, where there are large deposits of such ores.

SULPHUROUS ACID PROCESS FOR COPPER AND ZINC-LEAD ORES.

During the past fiscal year an investigation has been made to develop a method of utilizing the sulphur gases of the smelters, which are now not only wasted but at many smelters do damage to adjacent vegetation. The sulphur dioxide, which is the most important constituent of these gases, is an excellent solvent for the oxides of zinc and copper. However, in connection with the use of the gas as a leaching agent there are still problems to be solved, among which may be mentioned the obtaining of the gas from ordinary smelter gases in a sufficiently concentrated form and the subsequent precipitation of the metal from the sulphurous acid solution. Both of these problems have already occupied the attention of many investigators, and the former was studied at the Panama-Pacific Exposition laboratories of the bureau, as detailed elsewhere in this report. A commercial method has been worked out for obtaining copper from low-grade oxidized ores of copper by burning elemental sulphur for the production of sulphur gases. The investigation outlined will be continued.

PRODUCTION OF ZINC DUST FROM SOLUTIONS OF ZINC.

Since the advent of the European war zinc dust, which is used in connection with the cyanide process for the precipitation of gold and...
silver from cyanide solutions, has been hard to obtain. For this reason an investigation was undertaken which had for its object the preparation of zinc dust from solutions of zinc by an electrolytic method. Promising results were obtained. Moreover, the zinc dust obtained was of higher efficiency than the ordinary zinc dust of commerce.

CONTROL OF ORE SLIMES.

In the crushing and fine grinding of ores in concentration processes slimes are produced, and many of the tanks required for the settling of these slimes cover a large amount of floor space. Consequently any method by which these slimes could be quickly settled, so that the number of tanks or vats required would be decreased, would result in the saving of considerable floor space and cost of tanks and hence permit treating the ore at less cost. A study was undertaken with a view to developing such a method. Encouraging results were obtained. For instance, it was found that if certain mills should adopt the methods developed at the Salt Lake City station the cost of the slime-settling machinery could be reduced by about one-half.

WORK IN SOUTHWESTERN MISSOURI LEAD AND ZINC DISTRICT.

A detailed study of conditions in the lead and zinc mines and mills of the southwestern Missouri district, with especial reference to efficiency and losses in milling, was carried on during the past year. This work was undertaken in cooperation with the State School of Mines of Missouri, and the following features were studied: The character of the ore and gangue and the economic geology of the ore deposits; the efficiency of the milling methods; the possibilities of flotation as applied to the Joplin ores. This study was closely correlated with the work of the bureau's mining division in the district.

Some interesting and valuable data were obtained from the study of the efficiency in the milling practice and from the results of detailed mill tests. The mill tests showed especially where the losses were taking place in the mills and assisted greatly in determining what commercial improvements are possible. The information collected is to be published in a bulletin by the bureau.

COOPERATIVE METALLURGICAL EXHIBIT AND LABORATORY AT PANAMA-PACIFIC EXPOSITION.

Another good illustration of how the Bureau of Mines has endeavored in every way open to it to cooperate with the industry itself and take advantage of each special opportunity presented to bring the fruits of its work home to all the people who may be able to use them is found in the cooperative metallurgical exhibit and
laboratory (Pl. XV) maintained at the Panama-Pacific International Exposition.

The organization of the cooperative metallurgical exhibit resulted from a number of conferences held during the summer of 1914 between representatives of the exposition management and of the Bureau of Mines.

Plans were developed for a group of metallurgical laboratories where serious experimental work could be carried out. However, in view of the high educational mission of the exposition and the unusual opportunity offered by it of presenting to the nontechnical public a panoramic view, as it were, of the highly important but relatively unfamiliar metallurgical processes practiced in the West, a number of features of a general and popular character, such as charts, photographs, and operating models were included. In addition to the equipment for the experimental laboratories a number of full-sized pieces of metallurgical machinery were included in the exhibit.

Owing to the fact that the Government funds available were inadequate to make the project as broad and representative as possible it was decided to seek the cooperation of the mining and smelting companies and the manufacturers of metallurgical equipment, who gave the project hearty and generous support. The cooperation of the mining departments of the neighboring universities was also procured. A fund of about $15,000 was subscribed in addition to loans of apparatus and equipment representing an investment of at least $25,000.

The exhibit occupied approximately 7,000 square feet of floor space near the entrance of the Palace of Mines and Metallurgy. The attention of the visitor entering the building was usually arrested by the bright glow from the battery of assay furnaces situated near the railing surrounding the open laboratory space. Located conveniently near these furnaces was a group of crushing, grinding, sampling, and screening apparatus. Just back of the assay furnaces was a large roller agitator for solutions, and laboratory work benches. The equipment formed the so-called hydrometallurgical laboratory for the study of ore treatment by wet processes. During the period of the exposition several investigations were carried out in this laboratory, including studies of the cyanide treatment of complex silver minerals, the behavior of aluminum as a precipitant of gold and silver, and the comparative efficiencies of wet and of dry methods of screening. It will be noted that these investigations were all of a general nature, dealing with questions of fundamental importance to the industry. This same consideration was a fundamental criterion in the selection of problems for study in other sections of the laboratory.
HYDROMETALLURGICAL INVESTIGATIONS.

At this point it seems wise to outline the general character of the bureau’s hydrometallurgical investigations. These concern the treatment of ores of the precious and base metals by wet methods, as distinguished from pyrometallurgical practice, or the recovery of metals by igneous fusion. The object of the investigations is to lead to a clearer and better understanding of the processes, in order that their operation may be under better control. There are two lines of possible improvement in all such processes, or, for that matter, in any recovery process, either metallurgical or chemical—the percentage of recovery may be improved, or the cost of making a given recovery may be lowered. Either makes possible the economical treatment of lower grade ores—material that remains waste until such a time as it can be profitably treated.

The settling of finely divided suspensions in water, or in solvents that may be used, is of considerable moment in hydrometallurgical work. Such material is referred to in mill parlance as “slime.” As there was no sound laboratory method known for ascertaining the settling capacity necessary for a mill handling a particular ore, the development of such a method was taken up. Work upon this problem was carried out both at the exposition and in the field, a considerable number of mining companies cooperating in furnishing data of actual operation. The results of mill operation were found to check reasonably close with those obtained by the laboratory method.

STUDY OF BEHAVIOR OF ALUMINUM IN CYANIDE SOLUTIONS.

The behavior of aluminum in cyanide solutions was investigated, as metallic aluminum is used as a precipitant, replacing zinc in certain cases, and furthermore, aluminum in a soluble form occurs in certain gold and silver ores. On account of the fact that there was little specific knowledge regarding the behavior of aluminum in cyanide solutions, the reactions occurring between metallic aluminum and the caustic alkalies were investigated, and a particular study was made of the ore and pulp from the Goldfield Consolidated mine, Goldfield, Nev., as that ore is one of the best examples of the occurrence of soluble aluminum salts in a precious-metal ore. The aluminum occurs as sulphate, and is the result of the decomposition of various minerals containing aluminum.

This work has been completed, and the chemical reactions taking place under the conditions of mill operation have been established. Space is not available for recording a complete outline of the results, but the more important conclusions reached were that there are two aluminates of calcium formed, namely, a primary aluminate when alumina predominates, and a secondary aluminate when lime is in excess.
PART OF COOPERATIVE METALLURGICAL EXHIBIT AND LABORATORY AT PANAMA-PACIFIC EXPOSITION.
The primary aluminate is soluble, whereas the secondary aluminate is not; therefore, in mill operation, if troublesome insoluble aluminum compounds in the precipitate are to be avoided, the amount of lime used in milling must be restricted to no more than that necessary to form the soluble aluminate. It might be explained that lime is universally used as a source of alkali in cyanide work, and also as an aid in the settling of slime; hence, if aluminum is present, it is important to know the behavior of the calcium aluminates formed in the humid way. Upon the addition of lime during cyanide treatment, first the primary and then the secondary aluminate is formed. Presence of aluminum accounts for the rather high lime consumption in treating such ores. It was found that, contrary to popular supposition, precipitated aluminum salts did not cause cyanide wastes by carrying down with them adsorbed cyanide when the sulphates were present. On the other hand, during precipitation of cyanide solutions with metallic aluminum, under certain circumstances when an aluminum salt is precipitated, cyanide is lost through adsorption. In connection with this investigation, it was found that too long contact of the solution with the precipitant, whether aluminum or zinc, caused a loss of cyanide, probably through decomposition by the nascent hydrogen evolved.

EFFICIENCY OF CRUSHING MACHINES.

In ascertaining the efficiency of crushing machines, as well as in the study and control of all hydrometallurgical processes, small-scale screen-sizing tests are of the greatest value. In order that the work of one mill may be compared with that of another, it is necessary that a uniform screen scale be used by all operators, and, furthermore, that a uniform method of making the sizing test be employed. Unfortunately, in the past much confusion has existed, both as regards the screen scale and the method of making the test, therefore it is often not possible to compare directly the results of different mills. It was with the end in view of establishing a standard method of performing sizing tests, as well as for the purpose of ascertaining the limitation of such a method, that this subject was taken up. In brief, the work so far done demonstrates that satisfactory sizing tests may be made either by hand or with a machine.

It must be emphasized, however, that certain precautions must be observed if consistent results are to be obtained, and, furthermore, it must be expected that considerable time will be consumed in making sizing tests by hand. In the sizing of crushed ores it is essential to remove the finely divided amorphous material by washing prior to screen sizing. If this is done, concordant results can be obtained, but if sizing of the original material without such washing is at-
tempted, the time necessary for the operation is increased by reason of the clogging of the finer screens by the fine material, and, furthermore, the proportion of the coarser sizes is greater, by reason of the fact that the fine clay particles adhere to the coarse sizes. The only way to insure their removal is by preliminary washing, as previously pointed out.

CYANIDATION OF SILVER ORES.

Silver occurs in a great variety of combinations with other elements, so that rather complex and obscure reactions and frequent irregularities happen when silver ores are treated by the cyanide process. Hence, the investigation of the cyanidation of silver ores has been undertaken and considerable progress has been made. The first step has been to study the behavior of various synthetic ores prepared from pure silver minerals. The work so far has been confined to argentite (sulphide of silver), polybasite (sulpho-antimonite of silver and copper), and to pyrrargyrite (sulpho-antimonite of silver). These are the more commonly occurring silver minerals.

The work has not proceeded sufficiently far to warrant definite conclusions regarding all the points involved, but it is being continued and detailed reports will later be made. In general it has been found the polybasite is greatly benefited by the presence of a lead salt, as is also argentite. The definite results so far obtained tend to show that the opposite is true as regards pyrrargyrite. This is of particular interest, as the addition of a small amount of lead acetate to cyanidic liquors is a common practice in mills but is based almost entirely on rule-of-thumb data.

ASSAYING EXHIBIT.

The assaying work conducted in connection with the investigations mentioned above attracted much interest at the exposition, and by means of a graphic chart placed next to the aisle visitors were able to follow the many mysterious and seemingly intricate operations of the “fire assay.”

COPPER AND LEAD SMELTING LABORATORY.

Beyond the hydrometallurgical laboratory was a section devoted to the study of problems arising in the smelting of copper and lead ores. The equipment of this laboratory included a multiple-hearth roasting furnace of special design, a tilting furnace, cooling and scrubbing towers for gases, apparatus for cleansing gases of dust and fume by the process of electrical precipitation, and equipment such as pyrometers and draft gages. The investigations in this laboratory which centered around the smelter-fume problem included the distillation of sulphur from pyritic ores in roasting practice and
a critical study of the Thiogen process of sulphur recovery. A detailed discussion of these problems may be found on a later page on smelter-flume problems.

**BALANCE ROOM AND MISCELLANEOUS EXHIBITS.**

Adjoining this laboratory was the glass-inclosed balance room where the delicate weighing operations involved in assaying and analytical work were carried out. Next to this on the west side of the block was the general display room containing several colored charts illustrating present metallurgical practice in the treatment of copper and lead ores, working models of metallurgical equipment, and photographs and samples of ore and metallurgical products. Adjoining this was a room used as a general office in which was a fairly complete collection of chemical and metallurgical handbooks, as well as files of scientific journals. These books were open to the public for reference at all times and were used by many.

The remainder of the western half of the block was occupied by the metallographic and chemical laboratories which, owing to the delicate nature of the apparatus employed, were surrounded by glass partitions. In these laboratories chemical and microscopic studies supplementing the work in the metallurgical laboratories were made. Original investigations were also conducted there, including a study of the reactions between the sulphides of iron and water vapor, sulphur dioxide, and other gases at elevated temperature; the form in which metal losses occur in slag from copper smelting; and the behavior of chemical absorbents for sulphur dioxide from smelter gases.

On the east side of the block was a group of the standard machinery used for the extraction of gold and silver by the cyanide process, covering nearly every step of practical operation.

At the northeast corner of the block was a model sampling mill.

**POPULARITY AND VALUE OF EXHIBIT AS A WHOLE.**

The exhibit proved popular, and in addition to gratifying the casual interest of visitors, it was unquestionably of great educational value. Classes from neighboring high schools, normal schools, and universities were conducted through the exhibit by members of the staff, who explained the work in progress in the various laboratories, also the general metallurgical process with which the investigations were concerned. The laboratories were open at all times to visitors who desired an intimate view of the experimental work. In the demonstration work the guiding thought was, first, to set forth the latest developments in metallurgical practice and, second, to show how, in line with the modern trend in all industries, exact and highly
specialized laboratory investigations are leading the way to increased efficiency and economy and, therefore, to a great conservation of both our material and human resources.

One of the most significant things about the exhibit was the broad spirit of cooperation shown by the many collaborators. In organizing the exhibit an earnest effort was made to invite the cooperation of all the important companies in the smelting industry. Naturally, some companies found themselves unable to participate, but all who expressed a desire to do so were included in the plans. It is felt that the precedent established by the cooperation between industrial organizations, universities, and a governmental bureau for a broad public purpose such as that represented by the exposition will prove of much value in the years to come. The occasion of the exposition supplied, as it were, the psychological time for undertaking such a project, and it is indeed gratifying that in addition to much valuable work accomplished at the exposition further results may be expected from the continuation of the work at the two neighboring universities, as told more in detail elsewhere.

In carrying through a project of this sort many difficulties had to be overcome, and the closest sort of cooperation between the officials of the Bureau of Mines and the officials of the exposition was absolutely essential. The success attained bears excellent witness of the effectiveness of this cooperation, and the members of the bureau's staff appreciate highly the cordial spirit encountered in all their dealings with the exposition authorities.

**SMELTER-FUME INVESTIGATIONS.**

As stated previously, the bureau's work on metallurgy practically commenced with a study of smelter fume, and this subject has continued to receive considerable attention up to the present time.

The attention of a visitor at one of the large copper or lead ore reduction works is often arrested by the tremendous quantity of molten slag that is continually being discharged from trains of slag cars and which, flowing down the sides of the slag dump, suggests lava flowing down the mountain side from a miniature volcano. The tailings from the concentrating mill form an even greater mass of waste material which, accumulating year after year, frequently builds up artificial mounds more than 100 feet high and covering many acres.

Gazing on these huge accumulations of waste material one is prompted to inquire whether they do not still contain material of value, and in passing it may be mentioned that the great improvements made in metallurgical processes in the last few years have made it possible to profitably rework this material at several plants.
The huge fume cloud emitted by the main stack of the smelter, although presenting a striking spectacle as it stretches for miles across the country, is not likely to suggest to the visitor the same possibilities of potential value as the enormous accumulations of waste mentioned. It is hard to realize that the weight of the gases leaving the smelter stack is frequently more than ten times as great as that of the slag that the plant produces, and perhaps three or four times as great as that of the tailings discharged from the concentrating plant.

Although the major part of this gas is air from which the oxygen has been partly removed in the various processes through which it has passed, the gas stream often contains other material that, if it could be collected in serviceable condition, would be worth a veritable king's ransom. The substances in the gas stream may be divided into two classes, namely, minute suspended particles of solid and liquid matter, the so-called dust and fume, which render the stack discharge visible to the eye, and the truly gaseous material which is by itself invisible. The suspended matter is composed of minute particles of ore and other substances from the furnace charge, which are mechanically carried out by the rapidly moving gases, and also of material that has been volatilized by the intense heat of the furnaces and subsequently condensed in the form of liquid or solid particles when the gases have somewhat cooled, just as atmospheric moisture in a warm moist wind from the south condenses into fog when striking colder currents from the north.

As previously indicated, the gaseous part of the stack discharge consists mainly of the gases of the atmosphere with which are mixed water vapor and carbon dioxide from the combustion of fuel in the furnaces, and also sulphur dioxide arising from the burning of the sulphur in the ore by oxygen from the air.

The suspended material in the gas stream from a copper smelter will contain in general not only copper but also lead, zinc, gold, silver, and many other substances associated with the copper in the ore. The value of these metallic constituents discharged with the gases by a large smelting plant may amount to several thousand dollars per day, and it is only within recent years that methods have been developed by which a part if not all of the suspended material can be removed from the gas stream and subjected to special processes for the recovery of the valuable metals.

During the past few years the Bureau of Mines has been able to assist the smelting interests in effecting a recovery of this material formerly wasted. As an illustration may be mentioned the work of the Anaconda Smelter Commission, with which the bureau has been closely associated. This work is designed to improve smoke conditions at the Anaconda smelter in Montana.
THE SULPHUR PROBLEM OF THE SMELTERS.

Although the problem of recovering the valuable solid material from smelter-stack discharge has attracted some public notice, the smelter-fume problem has come to the attention of the public chiefly in connection with the questions of nuisance and damage. Although formerly the suspended dust and fume in the smelter gases were frequently the cause of complaint from the community, this situation has been largely relieved by the developments referred to above, and at the present time the sulphur dioxide in the gases is the principal cause of complaint. Trouble due to this cause has become rather acute in certain districts where agricultural areas lie close to the smelting plants and where prevailing weather conditions are such that sulphur dioxide gas from the smelter in sufficient concentration to injure vegetation frequently comes in contact with the orchards and growing crops.

The tremendous tonnage of sulphide ores of lead, zinc, and copper now smelted in this country makes the absorption and utilization of sulphur from the smelter fume a particularly difficult problem.

Thus far the most generally applicable method of using the sulphur has been the manufacture of sulphuric acid. The two chief limits to its commercial applicability are (1) lack of a local market for the acid, coupled with the difficulty and expense of its transportation to great distances; (2) the great dilution of the sulphur dioxide with air and other gases in most smelters.

The greatest single use for sulphuric acid to-day is in the manufacture of phosphate fertilizer. The proximity of phosphate rock on the one hand, and of a market for the finished superphosphate fertilizer on the other, are usually determining conditions in this matter.

When it is considered that there are many smelters in the country, most of them in the West, each of which daily burns off 250 to 1,000 tons of sulphur from its ores into the atmosphere, and that each ton of sulphur will make 3 tons of concentrated sulphuric acid and 6 of superphosphate fertilizer, the industrial problem of disposing of the sulphur can be better appreciated.

The discovery in Idaho and Montana, within the past few years, of what are probably the most extensive phosphate-rock beds yet found the world over, is likely to have a very important bearing on the problem in the future; but even so, the freight rates on the finished fertilizer to the southern and eastern markets are still practically prohibitive, and the demand for fertilizer on our virgin soils of the West is developing very slowly. A few days' output of the sulphur from a single one of our large western smelters would supply sufficient acid for the present yearly fertilizer demands of the whole Pacific coast. However, the consumption of fertilizer in the West
has more than tripled in the past five years, and eventually the demand for fertilizer will undoubtedly come to be a factor in smelter-smoke treatment.

There is also the chance of so modifying present smelting practice itself that, with the expenditure of little or no extra fuel, part of the sulphur now being burnt up in the furnaces would be distilled off and collected in the unburnt form. Some of the modern developments in smelting practice during the last few years seem to point strongly in this direction, although here again the possible improvements are probably limited to certain branches or departments only of the work, and part of the sulphur would have still to be taken care of by such other methods as already mentioned.

The problem arising from the objections raised by a community or agricultural district to the operation of a smelter in its vicinity, aside from its more distinctly personal aspect, is essentially one of economics. Any factor that tends to make living conditions unpleasant or unhealthful or to decrease the productivity of soil in any district may be regarded as a source of economic loss to a community. On the other hand, a large metallurgical plant employing several thousand workmen is sure to be an important if not the principal factor in the development of the district in which it is situated, and a partial or complete shutdown must invariably result in a loss to a community.

In undertaking to solve this problem on a broad economic basis accurate information is necessary not only as regards the prevalence of smelter gases in the so-called "smoke zone" but also as to the possible injurious effect of these gases upon vegetation of various sorts. During the years of 1913 and 1914, through cooperation with the Selby Smelter Commission, of which Dr. J. A. Holmes, former director of the Bureau of Mines, was, until his death, chairman, the bureau was able to assist in the investigation and adjustment of questions occasioned by the operation of the smelting plant of the Selby Smelting & Lead Co. at Selby, Cal.

WORK OF THE SELBY SMELTER COMMISSION.

The report of the Selby Smelter Commission, which has been published by the Bureau of Mines, describes the extensive investigation made of conditions in the "smoke zone" and adjoining country. This included such work as a study of soil conditions, with especial reference to the presence of material emanating from the smelter and its possible effect on plant growth, a survey of the prevalent plant diseases and of many other factors affecting plant and animal culture. A thorough study of the distribution of smelter gases in the atmosphere of the region, for which it was necessary to develop simple and
accurate methods for the determination of minute quantities of sulphur dioxide in the air, formed an important part of the work. This report also contains the record of an extensive series of experiments to determine both the nature and the economic consequence of the action of dilute sulphur dioxide gas upon growing vegetation.

Still another phase of the work dealt with a study of the metallurgical processes within the plant in the course of which the smelter gases were produced, the purpose being to ascertain what changes in operation could be made to reduce the quantity of fume evolved should the field work show that this was necessary.

As a result of this investigation the protracted litigation between the Selby Smelting & Lead Co. and the citizens of Solano County, Cal., was brought to a close and conditions were outlined by the commission, by the observance of which the smelting company might continue operations without violation of the court decree. In this connection it is interesting to note that the plan adopted by the Selby Commission of basing their findings upon the results of investigations by a corps of skilled experts has come to be generally recognized as the common sense method of approaching the problem. This is evidenced by the fact that the methods of the Selby Commission have since been adopted at several places, notably in the vicinity of Salt Lake City, where one of the large smelting companies is conducting an extensive investigation of the fume situation in the area surrounding the plant.

STUDY OF SULPHUR-RECOVERY PROCESSES.

As previously mentioned in the general discussion of the sulphur problem, several methods have been suggested for the recovery of solid sulphur as a by-product from smelting operations. Although considerable time and effort has been expended in developing some of these processes and in certain cases experimentation undertaken on a large scale and at heavy expense has shown comparatively little progress. The lack of success can be traced to insufficient knowledge concerning the fundamental physical and chemical principles underlying the process used. The mistake has frequently been made of assuming that because a certain qualitative chemical change is known to take place it can without question be made the basis of an industrial process. Thus, one observing year after year the almost ceaseless motion of the ocean waves and the tremendous force which they exert at times is unavoidably impressed by the energy contained in the moving water. The observation of this fact does not, however, show that this energy can be profitably utilized for it may turn out that the cost of contracting and operating apparatus suitable for the conversion of the energy of the
waves into electrical energy, let us say, will be out of all proportion to the value of the electric current generated.

Therefore, in order to determine whether any of the processes already proposed can be successfully operated and be used as the foundation for the development of new processes, much experimental work is necessary. A special laboratory (Pl. XIV, B) has been equipped by the bureau for work upon this phase of the smelter-fume problem. Here a sample of ore, the exact chemical composition of which has been determined by careful analysis, can be submitted to a chemical process the conditions of which can be accurately controlled and measured by the operator. These experiments can frequently be made with a few grams (1 ounce equals 28.3 grams) of material, and more useful information can be obtained than if the experiment is carried out with tons of material on an industrial scale involving the expenditure of vastly more time and money.

Other experiments are made with larger quantities of material and with larger equipment, such as a roasting furnace of special design in which 100 to 200 kilos (1 kilo = 2.2 pounds) of ore may be treated in 24 hours.

LABORATORY INVESTIGATION OF SULPHUR RECOVERY.

The objects of the experimental work conducted during the past year in this special laboratory were as follows:

1. The direct production of solid sulphur by the modification of smelting operations in common use.

2. The reduction of sulphur dioxide to solid sulphur by the use of solid, liquid, or gaseous fuel.

3. The production of concentrated sulphur dioxide from dilute smelter gases.

As an illustration of the type of problem falling under group 1, the following may be mentioned:

Processes for the treatment of sulphide ores, involving the use of steam to facilitate the recovery of a part of the sulphur in the solid state, have from time to time been proposed and patented. The advantage claimed for the use of steam is based in practically every patent on the assumption that certain chemical reactions take place between the ore and the steam or water vapor. Therefore, in order to judge the possibility of success of any of these processes it is necessary to determine the degree of chemical reaction when water vapor comes in contact with ore within a furnace. If only a slight reaction occurs under the various conditions that can be produced in a furnace, it is obvious that the presence of water vapor is not likely to affect materially the changes taking place in the furnace, and the production of any important quantity of sulphur through its agency
is not to be expected. An accurate knowledge of the nature and extent of the reactions taking place at various temperatures between water vapor and the metallic sulphides in the ore is therefore essential, and this is one of the things that is being carefully studied by the Bureau of Mines.

As part of the work of the Bureau of Mines’ laboratory at the Panama-Pacific International Exposition, it was arranged to cooperate with the Thiogen Company in a critical study of a process that it had developed for the recovery of sulphur from smelter gases. This work falls under group 2 given above. A thorough study has been made of the various steps involved in the “wet Thiogen process,” and the results of the investigation are now in process of publication as a Bureau of Mines’ bulletin.

From work done upon a laboratory scale it is of course impossible to do more than make a preliminary rough estimate of the cost of using the process on an industrial scale. It was possible, however, to demonstrate that there are no insuperable technical difficulties in the way of the successful operation of the process and that under favorable conditions as regards fuel cost, cold-water supply, market for sulphur, etc., it would probably prove commercial.

These illustrations will serve to indicate the type of work which the Bureau of Mines is doing in its efforts to assist in the solution of the sulphur end of the smelter-fume problem. As previously mentioned, no one process can be hoped to afford a complete general solution of this problem. Alteration in economic conditions as well as the extensive changes and improvements in metallurgical practice and the development of new chemical industries will from time to time make it possible to increase the utilization of by-product sulphur from smelting operations. The Bureau of Mines is giving close attention to this subject in order that it may assist such developments in every way possible.

FLOTATION OF ORES.

One of the most striking developments in metallurgical processes in the past few years has been the successful results obtained with oil-flotation methods of recovering metals from their ores, linked with the installation of extensive equipment for utilizing the process. Accordingly, it has seemed fitting to present a short account of the history, significance, and present status of the process.

HISTORY OF FLOTATION.

The flotation of minerals dates back to the accounts of Agricola, who tells us of the virgins who dipped greasy feathers into the stream and drew forth gold. Strangely enough, gold and other minerals of metallic luster tend to stick to a greased surface, whereas
the worthless gangue minerals that accompany them do not. This property of preferential oiling of metallic minerals has been utilized in many ways and has resulted in the modern flotation process.

The earliest account of the use of a flotation method in the United States is that of John Turnbridge, of Newark, N. J. It appears in patent specification No. 207695, granted to him on September 3, 1879. It is a method for recovering precious metals from the jeweler’s wash waters and consists in plunging the water through a bath of oil, which collected the mineral particles.

The person who is credited with being the mother of modern ore flotation is Mrs. Carrie Everson, of Chicago, Denver, and California, successively. However, her flotation patents are antedated by not less than nine other patents involving the flotative principle. She proposed to treat ores by pulverizing them and mixing with water and with oil amounting to 5 to 17 per cent of the weight of the ore. The valuable minerals were collected by the oil and skimmed off of the pulp. Since then literally hundreds of United States patents have been granted for various flotation proposals, but the fact remains that a woman was the first person to attempt commercial recovery of valuable minerals from low-grade ores by this process. Since that time various modifications of the process have been made.

In 1906 Sulman and Pickard took out a patent in which they claim the production of an air froth. A slight amount of oil, amounting to 1 pound per ton of ore, was used, being agitated with about 4 tons of water. The oil caused the water to froth and the finely divided particles of valuable mineral were concentrated in the froth floating on top of the pulp. Some previous investigators had proposed air bubbles to assist bulk oil flotation of the minerals but they claimed that their froth consisted almost entirely of air and films of water slightly contaminated with the frothing oil.

This is the basis of modern froth flotation, and it is the only type now considered of much practical importance.

The owners of the Sulman and Pickard patent, the Minerals Separation Co., Limited, are now engaged in litigation with individuals who feel that the patent was antedated by previous knowledge.

America was late in adopting the process and we owe the first successful commercial development of flotation to the various companies operating at Broken Hill, New South Wales, Australia.

However, when American engineers do take up a process, its use spreads rapidly. This is true as regards the flotation process, and as a result practically every mining company in this country which subjects its ores to a preliminary ore-dressing process before shipment, and which has had trouble recovering all the valuable metals in its ore, has experimented with this process in hopes of procuring better extractions.
The first successful application of flotation in the United States that was of any commercial importance was probably that at the plant of the Butte & Superior Copper Co., Butte, Mont., in 1912. At the present time there are probably as many as 200 concentrating mills in the United States using flotation.

VALUE OF THE PROCESS.

The flotation machines used in these mills are of many diverse types and the developments during the past year have been largely improvement of machinery for accomplishing the same effect with less power.

The reason why the flotation process has proven to be such a valuable addition to the former milling and ore-dressing processes is due to the fact that it is adapted to the treatment of finely ground ore pulps; in fact, before this process was developed, the ore slimes formed during crushing in a concentrating mill were a source of serious losses because no machinery had been devised that could save a high proportion of the valuable metals in such fine material.

On this account the practice previous to the introduction of the flotation process was to crush the ore so as to prevent, as far as possible, the production of fine material. However, more or less of the metal contained in all ores subjected to an ore-dressing process was lost during the treatment of the ore, and for that reason nearly every concentrating mill in this country, of any size, has adopted flotation during the past year or two in order to treat its slimes.

WHERE THE PROCESS IS APPLICABLE.

It is not to be inferred that the flotation process can be successfully applied at every mill where values are being lost. As a rule, the process can be successfully applied if the values being lost in the tailings from such processes are in the form of sulphides. However, the values lost in the tailings from such processes are not always sulphides, but many of them constitute oxides. These are not recovered by the ordinary flotation process. For this reason the Bureau of Mines has done much experimental work in connection with this process with a view to devising modifications of the process by the addition of such reagents as will permit the saving of the metals present not only as sulphides but as oxides as well. It has been very successful in its work along this line and has found that the process can be successfully applied to the treatment of oxidized minerals that usually do not have a metallic luster. In this way the effectiveness of the process for the prevention of mineral waste, one of the main objects of all the bureau's work, has been greatly increased.

The flotation process, besides preventing mineral waste at mills using ordinary gravity concentrating processes, can also be applied
to the recovery of metals contained in tailings from former mill treatment of ores, if the tailings have been adequately preserved by impounding, or otherwise.

In this connection it may be stated that the bureau is endeavoring to emphasize the obligation the mining industry owes to the Nation of storing for future treatment those ores and mill products containing metals that can not be successfully recovered at the present time, for, as as time goes on, organized study of metallurgical processes will make possible the commercial use of leaner and leaner ores, and thus extend indefinitely the life of our mineral resources.

The flotation process also offers a method of treating ores that could not heretofore be successfully concentrated, owing to the fact that the valuable minerals contained in them are in such small particles that the ore must be ground as fine as flour before the valuable minerals can be liberated, so that when ordinary gravity concentrating processes are used the valuable particles of the ore are lost.

**SUMMARY.**

In summary it may be said that the flotation process has been successfully applied to the treatment of:

1. Tailings from ordinary gravity concentrating processes, in which the valuable metals previously lost are in the form of sulphides.

2. Tailings in which the valuable minerals are oxidized, the use of sulphidizing reagents being generally necessary in order to superficially convert the metallic particles into sulphides.

3. The concentration of ores that contain the valuable minerals in such form as to make recovery by ordinary gravity processes impracticable.

Probably no other ore-dressing or metallurgical process devised in recent years has so materially aided in the prevention of mineral waste as has the flotation process. It is safe to predict that in time the scope of the process will be greatly extended and that methods will be developed for treating all types of ores by it.
TECHNICAL-SERVICE WORK AT PITTSBURGH EXPERIMENT STATION.

Closely related to practically all the activities of the Bureau of Mines is the technical-service work done at the bureau's Pittsburgh experiment station. This comprises the computing and compiling of experimental data, the drafting and designing of experimental equipment, and the preparation of photographs and motion pictures relating to the bureau's investigations. This service aids in the interpretation and presentation of the results of the bureau's investigations, thus performing a necessary fundamental part in the study of problems relating to the mineral industry. During the past year the technical-service work included:

1. Computing the results of field and laboratory tests and making reports therefrom; determining physical and chemical laws from observations made and expressing them in the form of mathematical equations; and compiling conversion tables and making land surveys.

2. Designing apparatus and equipment for experimental work; making mine-disaster maps; engrossing mine-rescue and first-aid certificates; and making illustrations for bulletins and reports.

3. Taking photographs to show: Details and results of tests, details of apparatus, progress of buildings, approved first-aid methods and bandages; making lantern slides and enlargements.

4. Producing new motion pictures; repairing and replacing worn film; duplicating films when desirable, in order to supply the demand; loaning motion pictures and other negatives for the purpose of supplying duplicate pictures to mining companies for educational work; revising films in order to improve and get them up to date. Four reels, in duplicate, illustrating the work of the bureau, have been made and assembled. About 63,000 feet of film is now available for exhibition by bureau employees, an increase during the current year of 25,000 feet. The difficulties encountered by the photographer in making mine-safety pictures underground are shown in Plate XVI, in which the photographer is seen in one of the large copper mines in Arizona at work, with his equipment, including arc lights sufficient to give 40,000 candlepower.

Heretofore the work of the bureau has been considerably interfered with by the necessity for having individual investigators show parties of visitors their work. This difficulty has been obviated by having an engineer familiar with the work of the Pittsburgh station act as an official guide. He shows the visitors the routine work of the station, without interrupting it, usually ending his demonstration with the motion picture "The Work of the Bureau."
BUREAU OF MINES OPERATOR TAKING MOTION PICTURES IN ARIZONA MINE.
NEW OFFICE BUILDINGS AT PITTSBURGH.

The new offices and laboratories for the bureau’s Pittsburgh experiment station, contract for which was let in the spring of 1915, have been partly completed and the main offices are now occupied.

These buildings stand on land acquired by the Government, an admirable site adjacent to the grounds of the Carnegie Institute of Technology and near the Carnegie Institute, the Carnegie Library, and the University of Pittsburgh. The tract fronts to the north on Forbes Street, and is immediately east of the Forbes Street Bridge over the deep cut of the Pittsburgh Junction Railroad, which bounds the property on the west.

The main building is three stories high, has a frontage of 332 feet, and is flanked at either end with two-story wings extending back from Forbes Street 211 feet.

The central part of the building, which is 56 feet by 210 feet, will contain quarters for the administration offices and the mining-engineering division and also a lecture room seating 300 persons. The west wing, 48 by 211 feet, will house the mechanical laboratory. The east wing, of the same size, will accommodate the chemical laboratory. In general the interior finish is substantial but severely plain.

In the rear of the main building will be the power plant and the metallurgical and fuel-testing laboratories in a building 55 feet by 220 feet, built of reinforced concrete and placed on a lower level, so as to be invisible from Forbes Street. In this building are an engine house 55 feet by 110 feet, a fuel-testing laboratory 55 feet by 70 feet, and a metallurgical testing laboratory 55 feet by 70 feet. An extension of this building is contemplated to provide a boiler house 55 feet by 110 feet and a 50-foot extension to the fuel-testing laboratory. The general appearance of the buildings is shown in figure 9.
BUREAU OF MINES EXHIBIT ON GOVERNMENT SAFETY-FIRST TRAIN.

During the months of May to August, 1916, a traveling exhibit showing apparatus, devices, and methods recommended by the Government for preserving the health and safety of the people of the United States, visited 87 cities and towns in 16 different States, covering territory all the way from Philadelphia, Pa., to Denver, Colo. The train was organized by the Federal departments and bureaus concerned in the work mentioned, and the 12 steel cars comprising the train were furnished through the cooperation of Mr. Daniel Willard, president of the Baltimore & Ohio Railroad. The train was furnished transportation by the Baltimore & Ohio system, the Missouri, Kansas & Texas system, and the Union Pacific system.

The traveling exhibit was an effort to give the public a clear idea of the humanitarian work being accomplished by the Government. Such an exhibit has never before been witnessed by the people. Those who have been fortunate enough to be able to visit Washington and spend a few days in learning about the Government's activities have been privileged to see a number of these exhibits at various times, but never before has practically the entire safety-first work of the Government been assembled as on this train. That the people were surprised at the extent of the Government's interest in their behalf was manifest every day the train was on its itinerary. It became a common expression that no one before had had an adequate idea of the practical work the Federal Government was doing along these lines.

The Government issues millions of publications each year on the subjects depicted by the train, but these unfortunately do not lend themselves to such graphic presentation as the actual apparatus used in these endeavors. It is a safe assumption that many of the visitors left the train better American citizens and with a much clearer view of the helpfulness of the Federal Government to the people.

The Hon. Franklin K. Lane, Secretary of the Interior, was the originator of the plan of having a railway train take to the doorsteps of the people an exhibit of the work of the Government. Secretary Lane not only started the movement but organized the necessary machinery for the actual accomplishment. The details of bringing the various departments and bureaus together were assigned to Mr. Van H. Manning, director of the Bureau of Mines, who was designated as the executive officer in charge of the train.

With few exceptions all of the material exhibited by the Bureau of Mines on the safety-first train had seen actual service. In the car
devoted to the work of the Bureau of Mines the exhibit which attracted the most attention represented five men equipped with different types of oxygen-breathing rescue apparatus used by the bureau's rescue crews at disasters following explosions.

Much interest was manifested in the cage of life-saving canary birds. The canary is very sensitive to a deadly gas (carbon monoxide) found in mines after fires and explosions, and for this reason is used by rescue crews and miners in testing mine air. When the bird shows signs of distress the men know that it is time to put on their rescue apparatus. The rescuers carry with them an inclosed cage and a supply of oxygen. The asphyxiated bird is placed in this cage and the oxygen turned on, with the result that the bird generally recovers.

Another exhibit was a portable mine-rescue telephone for men wearing oxygen-breathing rescue apparatus and consequently unable to talk distinctly. This telephone has a transmitter that is strapped over the vocal cords and enables a rescuer wearing breathing apparatus to maintain communication with the fresh-air base for a distance of about one-quarter of a mile.

In reviving a person overcome by mine gases, it is sometimes advantageous to administer pure oxygen. The device used by the bureau for this purpose, consisting of an oxygen tank, a reducing valve for regulating the flow of oxygen, tubes, and a face mask, with an outlet valve for the breath, was shown.

Photographs of the rock-dust barriers devised by bureau engineers for checking explosions in coal mines were displayed, and a working model of the trough rock-dust barrier was shown.

A device for sampling mine air for rock dust, used by bureau engineers in investigating the effects of siliceous dust in causing pulmonary disease among miners, was shown.

A photograph of an explosion-proof motor approved by the bureau as permissible for use in gaseous mines was exhibited.

Permissible electric safety lamps and permissible flame safety lamps were shown. One exhibit was a box for testing safety lamps before taking them into a mine, the lamp being tested by filling the box with an explosive gas and then thrusting the lighted lamp into it.

Devices exhibited to insure the safety of miners in handling explosives consisted of a 5-pound powder jack or metal waterproof box for carrying powder into a mine, and a safety box for carrying the detonators used in blasting. In this box each detonator is held separately and only one can be removed conveniently at a time. The detonators cannot fall out if the box should be overturned.

There was also exhibited an apparatus to insure safety in firing shots by electricity in mines.
PUBLICATIONS ISSUED BY THE BUREAU OF MINES.

The Bureau of Mines publishes three classes of reports—bulletins, technical papers, and miners' circulars. In addition it issues various lists and schedules, a monthly statement of fatalities in coal mines, and the annual report of the director.

Most of the bulletins present in detail the results of technical and scientific investigations, and therefore are of interest chiefly to engineers, chemists, mine officials, and other persons familiar with the subjects discussed. The technical papers are shorter and less formal than the bulletins and contain preliminary statements of the results of the larger investigations or describe the shorter investigations incidental to a larger one. The miners' circulars deal with topics relating to accident prevention and rescue and first-aid methods, the safeguarding of health, and other matters that directly concern the workers in mines, mills, and metallurgical plants. These circulars are written in simple, nontechnical English, and are printed in much larger editions than are the bulletins and technical papers.

The bureau has already published approximately 100 bulletins, 150 technical papers, and 20 miners' circulars. The following classification gives an idea of the investigations so far represented in the publications of the bureau:

- Publications on the utilization of coal and lignite.
- Publications on the composition of coal.
- Publications on the technology of petroleum and natural gas.
- Publications relating to mining laws.
- Publications on mineral technology.
- Publications on metallurgy.
- Publications on coal mining.
- Publications on metal mining.
- Publications on accident statistics.
- Publications on investigations of mine electrical equipment.
- Publications on investigations of explosives.

The bureau issues a complete list of all its publications, showing those available for free distribution on application to the director and those obtainable from the Superintendent of Documents, Governing Printing Office, on payment of the cost of printing. Interested persons should apply to the Director, Bureau of Mines, Washington, D. C., for a copy of the latest list.
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