ACCIDENTS FROM EXPLOSIVES
AT METAL AND
NONMETALLIC MINES

Metal- and Nonmetallic-Mine Accident-Prevention
Course—Section 4
(Revised July 1956)
ACCIDENTS FROM EXPLOSIVES
AT METAL AND
NONMETALLIC MINES

Metal- and Nonmetallic-Mine Accident-Prevention
Course—Section 4
(Revised July 1956)
CONTENTS

Purpose and scope .................................................................................. 1
Acknowledgments .................................................................................. 2
Use of explosives in mining ..................................................................... 2
  History of explosives in mines ............................................................... 2
  Consumption of explosives ................................................................. 3
  Nature and hazards of explosives ......................................................... 3
Explosives injury statistics ....................................................................... 3
Causes of explosives accidents ................................................................ 7
  Examples of explosives accidents ......................................................... 7
  Underlying causes of accidents and injuries from explosives ............ 10
    Flying material from blast ............................................................... 11
    Premature shots ............................................................................. 12
    Missed holes ............................................................................... 12
    Asphyxiation from noxious gas ....................................................... 12
Injuries to children from explosives ..................................................... 13
Selection of explosives ........................................................................... 14
  Strength ......................................................................................... 14
  Velocity ......................................................................................... 15
  Resistance to moisture ..................................................................... 15
  Density ......................................................................................... 15
  Fumes produced ............................................................................. 15
  Stability in variable temperatures ...................................................... 16
Storage ................................................................................................. 16
  Explosives and detonators ................................................................. 16
  Fuse .............................................................................................. 17
  Construction of magazines ................................................................. 18
    Permanent magazines for explosives .............................................. 18
    Construction of permanent magazines ......................................... 18
    Marking premises ......................................................................... 20
    Box-type magazines for explosives .............................................. 20
    Construction of box-type magazines ............................................ 20
    Marking magazines ...................................................................... 20
    Detonator magazines .................................................................... 20
  Location ........................................................................................... 20
    Surface magazines ....................................................................... 20
    Underground magazines ............................................................... 25
  Precautions in operating magazines ................................................. 31
  Auxiliary magazines ........................................................................ 32
  Storing explosives in working places ................................................. 32
Transportation of explosives, detonators, and fuse .............................. 33
  Requirements for vehicles carrying explosives .................................. 33
  Handling explosives ......................................................................... 35
  Transportation underground ................................................................ 38
  Transportation for opencut and quarry work .................................... 41
Use of explosives and detonators ........................................................ 41
  Principles of safe blasting ................................................................ 41
  When and by whom shots are fired ................................................... 42
  Electric versus fuse blasting ............................................................. 43
  Electric-blasting switch assemblies .................................................. 45
  Blasting accessories ........................................................................ 50
    Sources of information .................................................................. 50
    Cap crimpers .............................................................................. 50
    Blasting machines ...................................................................... 50
    Blasting galvanometer ................................................................. 51
Use of explosives and detonators—Continued

Sources of power for electric blasting .................................................. 51
Sources of power .................................................................................. 51
Ohm's law ......................................................................................... 51
Methods of connecting blasting circuits ............................................... 51
Series circuits .................................................................................. 52
Parallel circuits ............................................................................... 52
Combination circuits ....................................................................... 53
Calculation of power for electric blasting ........................................... 54
Series circuits .................................................................................. 55
Parallel circuits ............................................................................... 56
Safety precautions in electric blasting ............................................... 57
Safety practices ............................................................................... 57
Stray currents ................................................................................. 64
Static electricity ............................................................................... 64
Radio-frequency energy .................................................................. 65
Galvanic action ............................................................................... 65
Precautions in using fuse ................................................................. 65
Position of detonator in primer ........................................................... 66
Requirements for primers ................................................................. 66
Safety primers ................................................................................ 70
Position of primer in blast hole ........................................................... 70
Loading holes ................................................................................ 71
Hazards of excessive force in loading ............................................... 71
Pneumatic loading devices ............................................................... 73
Stemming holes ............................................................................... 75
Blasting warnings and signals ............................................................ 76
Blockholing and mudcapping ............................................................. 76
Chute blasting ................................................................................ 77
Firing large rounds ........................................................................ 78
Long-hole drilling and blasting ........................................................ 79
Handling misfires ........................................................................... 81
Gases from explosives ..................................................................... 82
Liquid oxygen ................................................................................ 86
Permissible explosives .................................................................... 87
Opencut blasting ............................................................................ 88
Detonating fuse .............................................................................. 94
Disposal of deteriorated explosives and detonators ....................... 97
Safe practices for explosives and blasting .......................................... 100
Magazine—surface .......................................................................... 100
Magazine—underground ................................................................ 101
Surface transportation of explosives ............................................... 101
Underground transportation of explosives ....................................... 102
General use of explosives ................................................................ 102
Fuse blasting .................................................................................. 103
Electric blasting ............................................................................ 103
Small drill-hole blasting ................................................................. 104
Large drill-hole blasting ................................................................. 105
Gopher-hole blasting ..................................................................... 106
Tunnel or coyote-hole blasting ....................................................... 106
Conclusions .................................................................................... 106
Suggested reading—explosives and blasting .................................... 107
List of miners' circulars .................................................................. 109

ILLUSTRATIONS

Fig. Page
1. Injury-frequency trend from explosives at underground metal and nonmetallic mines, 1932-54 ................................................................. 5
2. Injury-frequency trend from explosives at opencut metal and nonmetallic mines, 1932-54 ................................................................. 6
3. Permanent storage magazine—brick construction ....................... 19
4. Underground detonator magazine ................................................. 21
5. Barricaded explosives magazine—concrete and sand-filled construction 22
CONTENTS

6. Barricaded explosives magazine—cinder-block construction ........................................ 23
7. Barricaded explosives magazine—steel construction ....................................................... 23
8. Main explosives-storage magazine at opencut mine—sheet-steel, sectional-type, "Flintkote"-lined .................................................. 25
9. Portable explosives-storage magazines at opencut mine .............................................. 26
10. Explosives magazine—excavation in rock requiring support; vaporproof-type electric fixtures ........................................... 27
11. Explosives magazine—entire excavation in rock between shaft and ore body; no timber required .............................................. 27
12. Explosives magazine—entire excavation in rock; vaporproof lighting fixtures .............. 28
13. Explosives magazine—vaporproof-type lights; switches outside .................................. 28
14. Explosives magazine—excavation in slate, which requires timbering; vaporproof-type fixtures; electric conductors in conduit ......................... 29
15. Explosives magazine—all workings shown are in ore formation requiring heavy timbering; vaporproof lights; wiring in conduit .................. 30
16. Panel truck for transporting explosives to blasting site ............................................... 34
17. Insulated car and truck for handling explosives underground ...................................... 36
18. Explosives car—capacity, 2,500 pounds ........................................................................ 37
19. Mine truck for bringing explosives to level magazine .................................................... 38
20. Plastic container for carrying electric detonators ......................................................... 39
21. Capped-fuse carrying case ............................................................................................. 40
22. Fuse-capping room ....................................................................................................... 42
23. Switch and wiring diagram, Company A ........................................................................ 45
24. Details of switches, Company A ..................................................................................... 46
25. Switch and wiring diagram, Company B ......................................................................... 47
26. Details of switches, Company B ..................................................................................... 48
27. Automatic-warning blasting switch ............................................................................. 49
28. Electric blasting—series connection ............................................................................. 52
29. Electric blasting—parallel connection .......................................................................... 53
30. Electric blasting—series-in-parallel connection .............................................................. 53
31. Electric blasting—parallel-in-series connection ............................................................. 54
32. Electric blasting—connecting lead-wires to bus-wires .................................................. 59
33. Removing short circuit from terminals of lead wires when connecting to blasting circuit ......................................................................................... 60
34. Electric blasting—connecting lead-wire plug into blasting circuit .................................. 61
35. Electric blasting—miner closing switch of stope circuit to connect it to main blasting circuit .............................................................................. 62
36. Electric blasting—miners remove checks from section board as they leave area ............ 62
37. Electric blasting—after all men are out foreman closes main blasting switch .................. 63
38. Methods of making primers with safety fuse and blasting caps .................................... 67
39. Methods of making primers with electric blasting caps ............................................... 68
40. Blowing out holes with compressed air ........................................................................... 73
41. Preparing primers and loading holes ............................................................................. 74
42. Drift round of holes ready for blasting .......................................................................... 74
43. Diagram of pneumatic device for loading drill holes ..................................................... 75
44. Long-hole drilling and blasting in Michigan iron-ore mine .......................................... 80
45. Starting fan after blasting to clear smoke and gases from working place ...................... 83
46. Water curtain in heading to settle dust and absorb gas after blasting ............................. 85
47. Misting nozzles at outlet of exhaust-pipe to settle dust and absorb gas after blasting .......... 86
48. Methods of preparing primers with caps and fuse and with electric detonators ............. 89
49. Methods of preparing primers with detonating fuse ..................................................... 90
50. Blasting a round in an open-cut iron-ore mine ............................................................. 91
51. Lowering 50-pound cartridge of explosives in 9-inch churn-drill hole by means of tripod ............................................................................ 92
52. Connecting blast holes with detonating fuse .................................................................. 92
53. Portable steel shelter for men in open-cut blasting ........................................................ 93
54. Electric blasting caps properly placed and taped to Primacord ...................................... 95
55. Blasting with Primacord ................................................................................................. 96
56. A, Primacord trunkline spliced with square knot; B, right-angle connection from trunkline to branchline ......................................................... 97
57. Cutting Primacord from reel after lowering primer into blast hole .................................. 98
VI
ACCIDENTS FROM EXPLOSIVES AT METAL MINES

TABLES

1. Principal causes of injuries at metal and nonmetallic mines, 1932-54
   Page 4
2. Frequency rates of injuries from explosives at underground metal and nonmetallic mines, 1932-51 and 1952-54
   Page 6
3. Frequency rates of injuries from explosives at opencut metal and nonmetallic mines, 1932-51 and 1952-54
   Page 7
4. Selected explosives accidents, 1940-44
   Page 11
5. Injuries from explosives at metal and nonmetal mines, reported to National Safety Competition, 1933-54
   Page 11
6. American table of distances for storage of explosives
   Page 24
7. Resistance of copper and aluminum wire
   Page 55
8. Resistance of electric blasting caps, ohms per cap
   Page 55
ACCIDENTS FROM EXPLOSIVES AT METAL AND NONMETALLIC MINES

Metal- and Nonmetallic-Mine Accident-Prevention Course—Section 4

Revised by Frank E. Cash

PURPOSE AND SCOPE

The first metal-mine accident-prevention course was prepared and published in 1942–45 as a series of seven miners’ circulars (Nos. 51–57). The scope of the course has been broadened, revised, and brought up to date, and it is being published as a similar series of seven miners’ circulars on accident prevention in metal and nonmetallic mines. These circulars are:

1. Accident Statistics (Miners’ Circular 51), dealing with general statistics on accidents and injuries at metal and nonmetallic mines, including causes, costs, and the uses of investigations and reports of all accidents.

2. Falls of Rock or Ore (Miners’ Circular 52), discussing the selection of mining methods to minimize the hazards of falling and sliding ground, the use of various types of support, and the protection of employees from falls of ground.

3. Hoisting and Haulage (Miners’ Circular 53), presenting the hazards of hoisting and haulage in metal and nonmetallic mines and means of preventing accidents.

4. Explosives (Miners’ Circular 54), giving information on accidents and injuries due to storing, handling, and using explosives in metal and nonmetallic mines and precautions for preventing them.

5. Fires, Gases, and Ventilation (Miners’ Circular 55), explaining the causes of fires in metal and nonmetallic mines and the measures used to prevent, control, and extinguish them; describing gases found in mines and methods of detection and personal protection; and discussing necessity for and standards of proper ventilation.

6. Electrical and Mechanical Hazards (Miners’ Circular 56), covering accidents and injuries from electricity and machinery and their prevention and injuries from falls of persons.

7. Health and Miscellaneous Hazards (Miners’ Circular 57), including data on dust hazards, means of protection and sampling devices, protective clothing and equipment; and illumination, supervision, discipline, and safety training for employees in metal and nonmetallic mines.

These seven circulars do not contain all the material that may be desired on every phase of accident prevention at metal and nonmetallic mines, but they will serve as basic discussion. To them may be added supplementary material of particular interest in the field where the

---

1 Work on manuscript completed July 1956.
2 Mining engineer, Bureau of Mines.
course is utilized. This accident-prevention course, offered to the mining industry by the Bureau of Mines, has been compiled from studies by the Bureau and experience and knowledge gained by its engineers, to which is added information on safe mining practices made available by mining companies and their officials.

This is the fourth section of the revised series of circulars that cover various phases of accident prevention in metal and nonmetallic mines; it gives information on accidents and injuries from storing, handling, and using explosives in metal and nonmetallic mines and discusses the precautions by which they can be prevented. The practical basis for these precautions is afforded by the examples of actual accidents and by their relationship to efficient blasting.

ACKNOWLEDGMENTS

Much of the original text is retained in the revised course on Accident Prevention in Metal and Nonmetallic Mines.

The revision was made under the general supervision of James Westfield, Assistant Director—Health and Safety; William J. Fene, chief, Division of Safety; and Simon H. Ash, former chief, Safety Branch, Bureau of Mines.

Frank E. Cash revised this miners' circular; supplemental material was supplied by the following Bureau engineers:

Arthur M. Evans, Dallas, Tex.  Louis H. McGuire, Seattle, Wash.
Emil W. Felegy, San Francisco, Calif.  Lester L. Naus, Salt Lake City, Utah
Lester D. Knill, Salt Lake City, Utah  Douglas H. Platt, Albany, N. Y.
Milton C. McCull, Birmingham, Ala.  Roy G. Stott, Duluth, Minn.

The manuscript was reviewed by Catharine S. Hower, Lester L. Naus, Douglas H. Platt, and Roy G. Stott.

Many of the illustrations were supplied by mining and manufacturing companies and taken from Bureau of Mines publications.

USE OF EXPLOSIVES IN MINING

HISTORY OF EXPLOSIVES IN MINES

There are few industrial projects in which explosives are not used for one purpose or another, from removing tree stumps to tunneling through rock. Mining in all its forms makes a larger use of explosives than any other industry. It is said that gunpowder was first employed in 1627 for blasting rock in the mines of Austria, and by 1689 the practice had spread to Cornwall, England. Electric firing was first used in 1823 and was followed by the invention of safety fuse in 1831. About 1862 the successful manufacture of guncotton provided the first alternative for black blasting powder. This was followed by the introduction of dynamite in 1867 and the use of mercury fulminate in detonators about the same year. Later it was discovered that guncotton and nitroglycerin could be combined to form gelatin dynamite, and many specialized forms of explosives have been perfected.
CONSUMPTION OF EXPLOSIVES

In 1952 metal mines in the United States used approximately 7 tons of black blasting powder, 31 tons of permissibles, and 75,574 tons of high explosives; quarries and nonmetallic mines consumed approximately 553 tons of black blasting powder, 381 tons of permissibles, and 82,793 tons (including 37 tons of LOX) of high explosives. Metal mines, nonmetallic mines, and quarries used about 10.6 percent of the black blasting powder and 42.1 percent of the high explosives (including permissible and LOX explosives) used during 1952. In metal mines, 99.9 percent of the explosives used were high explosives other than permissibles.  

NATURE AND HAZARDS OF EXPLOSIVES

Explosives are substances (or mixtures of substances) that have the property of rapid and violent change to gaseous form upon the application of shock or high temperature. Except for black blasting powder, commercial explosives have been modified and improved over past years to a degree that makes possible their handling, storage, and use with reasonable safety as long as the utmost care is used at all times. The relative safety that can be maintained by careful observance of simple precautions is borne out by the infrequency of accidents during the storage and transportation of explosives and by the use of great quantities of explosives under properly controlled conditions without accident. The inescapable necessity for constant care to maintain safe conditions in utilizing explosives is plainly evident in the histories of those types of explosives accidents that regularly occur.

EXPLOSIVES INJURY STATISTICS

Explosives accidents have been and still are a major cause of fatalities in metal and nonmetallic mines. Falls and slides of rock or ore, hoisting and haulage, and falls of persons have caused greater numbers of fatal injuries, but explosives accidents still rank with these as one of the serious hazards of mining. The relative percentages of fatal and nonfatal injuries from these and other principal causes for 1932–54 are shown in table 1 in the order of the frequency of the total (fatal and nonfatal) injuries.

The injuries attributed to explosives at metal and nonmetallic mines (underground and opencut) constitute 9.9 percent of the fatal and 0.8 percent of the nonfatal injuries from all causes. At underground mines these injuries make up 10.1 percent of the fatal and 0.8 percent of the nonfatal injuries. At opencut mines they are 7.6 percent of the fatal and 1.3 percent of the nonfatal injuries.

---

A review of injuries from explosives in the iron-ore mines of Lake Superior for 1944-54 revealed that there were 9 fatal and 59 nonfatal injuries (total, 68), which is approximately 0.7 percent of the total injuries from all causes. These 68 injuries resulted in a time charge of 66,998 days, which is 3.8 percent of the total days charged to injuries from all causes. The 9 fatal and 58 of the nonfatal

A review of injuries from explosives in the iron-ore mines of Lake Superior for 1944–54 revealed that there were 9 fatal and 59 nonfatal injuries (total, 68), which is approximately 0.7 percent of the total injuries from all causes. These 68 injuries resulted in a time charge of 66,998 days, which is 3.8 percent of the total days charged to injuries from all causes. The 9 fatal and 58 of the nonfatal

<table>
<thead>
<tr>
<th>Cause</th>
<th>Fatal</th>
<th>Nonfatal</th>
<th>Fatal and nonfatal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Falls and slides of rock or ore:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Underground mines</td>
<td>1,043</td>
<td>35,076</td>
<td>36,119</td>
</tr>
<tr>
<td>Opencut mines</td>
<td>92</td>
<td>3,858</td>
<td>3,950</td>
</tr>
<tr>
<td>All mines</td>
<td>1,135</td>
<td>38,934</td>
<td>39,069</td>
</tr>
<tr>
<td>Handling materials:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Underground mines</td>
<td>51</td>
<td>29,902</td>
<td>29,953</td>
</tr>
<tr>
<td>Opencut mines</td>
<td>1</td>
<td>1,988</td>
<td>1,993</td>
</tr>
<tr>
<td>All mines</td>
<td>56</td>
<td>31,890</td>
<td>31,946</td>
</tr>
<tr>
<td>Hoisting and haulage:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hoisting, underground mines</td>
<td>222</td>
<td>3,558</td>
<td>3,780</td>
</tr>
<tr>
<td>Haulage, underground mines</td>
<td>283</td>
<td>22,365</td>
<td>22,648</td>
</tr>
<tr>
<td>Haulage, opencut mines</td>
<td>83</td>
<td>1,677</td>
<td>1,760</td>
</tr>
<tr>
<td>All mines</td>
<td>588</td>
<td>27,320</td>
<td>27,908</td>
</tr>
<tr>
<td>Falls of persons:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Underground mines</td>
<td>494</td>
<td>16,616</td>
<td>17,110</td>
</tr>
<tr>
<td>Opencut mines</td>
<td>29</td>
<td>2,559</td>
<td>2,588</td>
</tr>
<tr>
<td>All mines</td>
<td>523</td>
<td>19,155</td>
<td>19,678</td>
</tr>
<tr>
<td>Machinery</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Underground mines</td>
<td>92</td>
<td>11,367</td>
<td>11,380</td>
</tr>
<tr>
<td>Opencut mines</td>
<td>34</td>
<td>2,278</td>
<td>2,312</td>
</tr>
<tr>
<td>All mines</td>
<td>126</td>
<td>13,645</td>
<td>13,711</td>
</tr>
<tr>
<td>Explosives</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Underground mines</td>
<td>300</td>
<td>1,699</td>
<td>1,709</td>
</tr>
<tr>
<td>Opencut mines</td>
<td>31</td>
<td>1,162</td>
<td>1,193</td>
</tr>
<tr>
<td>All mines</td>
<td>331</td>
<td>2,861</td>
<td>2,892</td>
</tr>
<tr>
<td>Electricity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Underground mines</td>
<td>89</td>
<td>1,090</td>
<td>1,179</td>
</tr>
<tr>
<td>Opencut mines</td>
<td>32</td>
<td>202</td>
<td>234</td>
</tr>
<tr>
<td>All mines</td>
<td>121</td>
<td>1,292</td>
<td>1,413</td>
</tr>
<tr>
<td>All other causes:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Underground mines</td>
<td>477</td>
<td>96,334</td>
<td>96,811</td>
</tr>
<tr>
<td>Opencut mines</td>
<td>48</td>
<td>6,533</td>
<td>6,581</td>
</tr>
<tr>
<td>All mines</td>
<td>525</td>
<td>102,867</td>
<td>103,392</td>
</tr>
<tr>
<td>Total, all causes:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Underground mines</td>
<td>3,051</td>
<td>207,509</td>
<td>207,560</td>
</tr>
<tr>
<td>Opencut mines</td>
<td>34</td>
<td>18,593</td>
<td>19,247</td>
</tr>
<tr>
<td>All mines</td>
<td>3,405</td>
<td>226,102</td>
<td>226,355</td>
</tr>
</tbody>
</table>


Injuries occurred in underground mines, where approximately 55 percent of the men were employed.

Table 2 gives the man-hours worked, the total fatal and nonfatal injuries, and those caused from explosions, with the percentage of the total and the frequency rates of each, at underground mines. These injury rates are shown graphically in figure 1.

The injury-frequency trend from explosives at underground mines (fig. 1) was downward, with a decrease of 48.7 percent during 1932-54. During the 23-year period there were 300 fatal and 1,669 nonfatal injuries (total, 1,969), or 0.9 percent of the total injuries from all causes.

During 1950-54 the trend was upward, with an increase of 7.3 percent. During the 5-year period there were 39 fatal and 289 nonfatal injuries (total, 328), or 0.9 percent of the total injuries from all causes (see table 2).

Table 3 gives the man-hours worked, the total fatal and nonfatal injuries, and those caused from explosives, with the percentage of the total and the frequency rates of each, at opencut metal and nonmetallic mines. These injury rates are shown graphically in figure 2.

The injury-frequency trend from explosives at opencut mines (fig. 2), was downward, with a decrease of 23 percent during 1932-54. During the 23-year period there were 31 fatal and 234 nonfatal injuries (total, 265), or 1.4 percent of the total injuries from all causes.

During 1950-54 the trend was also downward, with a decrease of 50.8 percent. During the 5-year period there were 11 fatal and 45 nonfatal injuries (total, 56), or 1.2 percent of the total injuries from all causes (see table 3).
### Table 2.—Frequency rates of injuries from explosives at underground metal and nonmetallic mines, 1932-51 and 1952-54
(Prepared by the Branch of Accident Analysis, Division of Safety)

<table>
<thead>
<tr>
<th>Year</th>
<th>Man-hours (million)</th>
<th>Fatal</th>
<th>Nonfatal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total, all causes</td>
<td>Explosives</td>
<td>Percent of total</td>
</tr>
<tr>
<td>1932</td>
<td>83.5</td>
<td>105</td>
<td>19</td>
</tr>
<tr>
<td>1933</td>
<td>81.8</td>
<td>90</td>
<td>7</td>
</tr>
<tr>
<td>1934</td>
<td>101.1</td>
<td>101</td>
<td>11</td>
</tr>
<tr>
<td>1935</td>
<td>141.1</td>
<td>154</td>
<td>23</td>
</tr>
<tr>
<td>1936</td>
<td>177.7</td>
<td>185</td>
<td>23</td>
</tr>
<tr>
<td>1937</td>
<td>210.3</td>
<td>207</td>
<td>35</td>
</tr>
<tr>
<td>1938</td>
<td>185.8</td>
<td>143</td>
<td>6</td>
</tr>
<tr>
<td>1939</td>
<td>181.0</td>
<td>157</td>
<td>16</td>
</tr>
<tr>
<td>1940</td>
<td>201.6</td>
<td>200</td>
<td>26</td>
</tr>
<tr>
<td>1941</td>
<td>207.0</td>
<td>201</td>
<td>16</td>
</tr>
<tr>
<td>1942</td>
<td>1,552.4</td>
<td>1,545</td>
<td>182</td>
</tr>
<tr>
<td>1943</td>
<td>195.2</td>
<td>155</td>
<td>18</td>
</tr>
<tr>
<td>1944</td>
<td>198.8</td>
<td>206</td>
<td>15</td>
</tr>
<tr>
<td>1945</td>
<td>153.8</td>
<td>189</td>
<td>9</td>
</tr>
<tr>
<td>1946</td>
<td>146.9</td>
<td>127</td>
<td>12</td>
</tr>
<tr>
<td>1947</td>
<td>126.5</td>
<td>101</td>
<td>10</td>
</tr>
<tr>
<td>1948</td>
<td>121.7</td>
<td>101</td>
<td>11</td>
</tr>
<tr>
<td>1949</td>
<td>139.9</td>
<td>128</td>
<td>6</td>
</tr>
<tr>
<td>1950</td>
<td>142.3</td>
<td>99</td>
<td>7</td>
</tr>
<tr>
<td>1951</td>
<td>128.6</td>
<td>73</td>
<td>9</td>
</tr>
<tr>
<td>1952</td>
<td>139.9</td>
<td>101</td>
<td>8</td>
</tr>
<tr>
<td>1953</td>
<td>134.7</td>
<td>94</td>
<td>10</td>
</tr>
<tr>
<td>1954</td>
<td>1,452.1</td>
<td>1,219</td>
<td>97</td>
</tr>
<tr>
<td>1955</td>
<td>146.3</td>
<td>122</td>
<td>10</td>
</tr>
<tr>
<td>1956</td>
<td>133.9</td>
<td>115</td>
<td>4</td>
</tr>
<tr>
<td>1957</td>
<td>128.9</td>
<td>98</td>
<td>13</td>
</tr>
<tr>
<td>1958</td>
<td>112.9</td>
<td>74</td>
<td>4</td>
</tr>
</tbody>
</table>

1 Per million man-hours.
CAUSES OF EXPLOSIVES ACCIDENTS

Because accidental detonation of explosives can occur in so many ways and under such unexpected circumstances, constant care and precaution in their storage, handling, and use are essential. Men should be selected for blasting crews who are known to be careful and willing to follow instructions; they should be instructed and trained in the safe handling of explosives in accordance with the safety rules established by the explosives-manufacturing companies or the safety codes of industrial organizations. Close supervision of men working with explosives will eliminate much of the common thoughtlessness that has been the greatest cause of accidents and injuries.

EXAMPLES OF EXPLOSIVES ACCIDENTS

During the period 1869 to 1954 there were at least 30 explosive disasters (5 or more fatalities) at metal and nonmetallic mines. These occurred at 15 metal mines (11 underground and 4 opencut) and at 13 quarries. These disasters resulted in 195 fatal injuries at mines and 141 at quarries. They occurred in Alaska, California, Colorado, Michigan, Minnesota, Montana, Nevada, North Carolina, Pennsylvania, Tennessee, Utah, and West Virginia.

Three of these disasters are described.

CAUSES OF EXPLOSIVES ACCIDENTS

Because accidental detonation of explosives can occur in so many ways and under such unexpected circumstances, constant care and precaution in their storage, handling, and use are essential. Men should be selected for blasting crews who are known to be careful and willing to follow instructions; they should be instructed and trained in the safe handling of explosives in accordance with the safety rules established by the explosives-manufacturing companies or the safety codes of industrial organizations. Close supervision of men working with explosives will eliminate much of the common thoughtlessness that has been the greatest cause of accidents and injuries.

EXAMPLES OF EXPLOSIVES ACCIDENTS

During the period 1869 to 1954 there were at least 30 explosive disasters (5 or more fatalities) at metal and nonmetallic mines. These occurred at 15 metal mines (11 underground and 4 opencut) and at 13 quarries. These disasters resulted in 195 fatal injuries at mines and 141 at quarries. They occurred in Alaska, California, Colorado, Michigan, Minnesota, Montana, Nevada, North Carolina, Pennsylvania, Tennessee, Utah, and West Virginia.

Three of these disasters are described.
ACCIDENTS FROM EXPLOSIVES AT METAL MINES

Eureka (Open-cut). Nev., July 7, 1912—10 Killed

While loading a surface drill hole, 10 men were killed by a premature explosion. The cause was not determined, because all evidence was destroyed by the explosion. The known facts were as follows: A group of men was engaged in charging the hole, which was in the capping. Holes of this type held a relatively large quantity of explosives and were usually loaded by 5 or 6 men, who dropped the explosives into the hole. In this case, Trojan powder had been first charged; and there remained, it is believed, 5 boxes of Hercules Special reported to contain 20 percent nitroglycerin and 20 percent ammonium nitrate. Two boxes were unexploded. The reason for believing that 3 boxes exploded is that 3 craters were blown out in the ground; but it might have happened that the boxes were piled on another, in which case each crater would represent more than 1 box. What actually caused the dynamite to explode remains unknown.

Limestone Quarry, Pa., April 18, 1920—6 Killed

A premature explosion occurred in a limestone quarry during charging of six 5%-inch blast holes in a single row preparatory to blasting. A line of Cordeau detonating fuse was placed in hole No. 2, but electric detonators were also used in the hole. After 12 or 13 cases of loose 40-percent nitrostarch powder had been poured into the hole, it was found that a space of 17 feet remained for stemming. It was then decided that space for an additional case of powder might be obtained by tamping the charge. Accordingly, tamping was done with a plunger weighing 30 or 40 pounds, about 3 inches in diameter and 10 inches long. The plunger was made of lead with an iron core; it had an iron eye in the top to which a 3/4-inch rope was attached. This weight was ordinarily used for sinking explosives in wet holes, but not for tamping. It is estimated that the tamping had continued at least 10 minutes. The quarry superintendent went a considerable distance for a box of powder, returned, and reached a point about 10 feet from the hole when the charge exploded, instantly killing the man who was tamping and injuring the superintendent and the shovel runner, who was also near by. The flying rock killed 5 and injured 1 in another group, who were cleaning holes on the lower ledge. The explosion apparently was caused by hard tamping with the heavy metal plunger.

Boyd Mine, Tenn., January 5, 1943—9 Killed

A sulfide-dust explosion occurred in this underground mine where instantaneous and 1 to 10 delay detonators were used for blasting. A dust cloud was created by the blasting of the first shots and ignited with the subsequent shots in a round of 35 holes in the 10 North No. 1 stope. The main ventilation fan on the surface was stopped by the explosion, and the air currents in the mine reversed themselves. Forty-two men were in the mine at the time of the explosion, 25 of whom were in the vicinity of the stope. Owing to reversal of the air currents, 8 men were killed and 17 injured by fumes on the level below the stope where normally fresh air entered this section of the mine. One of the injured men died several days later, making a total of 9 killed. The 17 men who worked some distance from the 10 North No. 1 stope were able to save themselves by stopping a blower fan and opening a compressed-air line near the face of the crosscut in which they were working. These men were rescued by crews working in fresh air after the mine ventilation was restored.

The following examples of the most frequent unsafe practices in blasting and misuse of explosives have been taken from the reports of accidents from explosives that were investigated by the Bureau of Mines or State mine inspectors.

In a number of accidents that caused permanent disabling injuries, detonators exploded when the fuse was forced into the detonator barrel by pressure and twisting. The detonators had been carried or stored loose, and foreign matter had probably lodged in the barrel. In these examples the detonators were improperly stored and transported before use.

A miner attempted to force a primer cartridge to the bottom of a drill hole after it had become wedged in the hole. Pressure with a wooden tamping stick caused the primer to explode. Unless a detonator is well centered in the car-
tridge, the end may be forced against the rock in the hole and exploded by hard tamping, even with a wooden stick.

A blaster was springing some drill holes with single sticks of dynamite and detonators with fuse 2 to 3 feet long. A premature shot permanently crippled the blaster, who either had cut the fuse too short or had held the primer too long before dropping it into the hole. Test pieces from the same roll of fuse revealed a uniform burning rate. Using short fuse is dangerous; the fuse should be long enough to extend at least 1 foot outside the hole when the primer is in place.

A yard crew was blasting slag, using mudapped shots. The man lighting the shot was killed and two others were injured when a premature shot occurred. The fuse lengths used were 10 to 15 inches, and it was said that the blaster had believed this length would give plenty of time to reach a safe place. Use of less than 30 to 33 inches of fuse under any circumstances should be considered dangerous.

Two men were killed in blasting a round in a shaft bottom when they overstayed the burning time of the 6-foot fuse. The round consisted of 19 holes, and on this day the miners had trouble in lighting the fuse and delayed even after an urgent warning from the foreman. The use of fuse in shaftwork is inadvisable, and 6-foot lengths are too short in such places. These men also believed that fuse burned at the rate of 1 foot a minute.

A miner was killed and another permanently disabled when they remained too long in lighting a round of 29 holes in a drift. Four men were available, but one man lit the fuse while another split them. The original length of the fuse was 7 feet, and 2 to 18 inches was trimmed to time the holes. The place was wet, and 2 fuse lighters were used in succession. The holes began to go off as the spitting was completed. This was unsafe blasting practice by experienced miners who were not given necessary instructions or supervision to cope with abnormal conditions.

A miner was fatally injured when he returned to a crosscut face in which two holes were being blasted. Some other holes were being blasted nearby; and although this man had helped prepare the shots, he confused the reports and returned through smoke to the face just as those shots went off. In this case company rules against returning before a safe interval were violated.

While reopening some old workings, a shift boss connected the leg wires of a loaded slabbing hole to a firing line and caused an explosion that killed him and injured another miner. A battery that the foreman had attached to the wire circuit to use it for signaling had not been removed. The shift boss failed to follow the usual precautions in connecting electric blasting circuits.

Three miners were killed by the explosion of 140 sticks of dynamite in a sack from which a round of 24 holes was to be loaded. One of the three men was preparing primers, and the explosion occurred when one of the capped fuse lengths was accidentally ignited by a carbide light. Similar accidents have occurred so frequently that there is serious doubt as to the safety of preparing primers in the close vicinity of other explosives, especially when carbide cap lamps are worn.

Two miners were permanently disabled when they drilled into a "bootleg" containing explosives. In this instance the hole was started near but not in the bootleg. In another mine a miner was killed and his helper partly blinded and disfigured when they started a hole in a bootleg which proved to contain unexploded dynamite. These accidents could be multiplied at length from those due to this cause reported in 2 or 3 years' time. Failure to find and detonate explosives in missed holes or bootlegs is a prolific source of fatal and serious accidents.

A contract miner was killed and his partner seriously injured when two explosives storage boxes exploded near a manway raise during the blasting of a heading about 74 feet away. The two contract miners in the vicinity had
explosives storage boxes (200-pound capacity) side by side on the floor of a rock sublevel drift about 6 to 10 feet north of the ladderway. There was a fuse storage cabinet on the opposite side of the drift 11 feet away from the explosives. On the day of the accident the 2 miners had loaded 22 holes in their heading; before firing the round they called the 2 miners in the adjacent contract out of their place and instructed them to take positions on the track below to keep anyone from entering the blasting area. After lighting the fuses the two miners took their positions near the ladderway on the sublevel above and below the blast. When the shots went off a loud, crashing report was heard or felt throughout that portion of the mine. An immediate hunt found one miner dead, the other seriously injured, and the ladderway seriously damaged by the exploded storage boxes. Removal of the dynamite and fuse from a place in the direct line of the blast had been overlooked by supervisors and men.

A miner and his helper attempted to free a draw chute by using a "bomb" made of several cartridges of 60-percent dynamite tied to the end of a long pole. They ignited the fuse and pushed the bomb up under the large boulder well up in the chute and started retreating along the scraper drift to get to a safe location. The miner turned and noticed that the fuse was spitting near the drift, so he and his helper rushed back to again push the bomb into the draw hole. While they were attempting to push the bomb back, the dynamite exploded, killing the miner instantly; his helper was severely injured and lost his eyesight. Careful investigation indicated that the fuse had been cut 1½ feet in length, in violation of company rules, which required a minimum fuse length of at least 4 feet.

A bomb on a blasting pole was placed in a raise over a grizzly to blast down the hungup muck. The bomb and pole fell through the grizzly to an empty chute below, where the bomb exploded, killing a miner stationed there to guard the chute during the blast. This man did not stand in a safe place, as he should not have been in front of the chute from which an open raise led directly to the blast.

A grizzlyman returned to a grizzly chamber, where he had prepared some shots to break large boulders and had connected them to the section firing line. He was killed when others put in the switch to shoot the blasts prepared in the section. The victim had failed to notify others of his return after having told them he was leaving, and the others failed to make sure that no men were in the places to be blasted.

Two instances of disastrous explosions in large-diameter blast holes occurred during loading. In one, 60-percent gelatin dynamite had coated the ragged sides of the hole when cutup cartridges were dropped in to fill the cavity made by springing. Detonation occurred when a metal weight was lowered into the hole to measure the height of the charge. In the other accident a large cartridge of 75-percent gelatin dynamite stuck in a ragged hole and was detonated when pounded with a wooden tamping block.

UNDERLYING CAUSES OF ACCIDENTS AND INJURIES FROM EXPLOSIVES

The pertinent facts of 106 explosives accidents on which reports were received by the Bureau of Mines during 1940–44 are summarized in table 4. This table includes the reported explosives accidents from all types of mines (except coal mines), from quarries, and from construction and other miscellaneous activities. The reports received were from all parts of the country and should be representative of explosives accidents in metal and nonmetallic mines and related activities. As a result of these accidents, there were 114 fatal and 230

---

nonfatal injuries. In other words, approximately 33 percent of the injuries were fatal.

The injuries from explosives reported to the National Safety Competition, 1933-54, are shown in table 5. This classification shows the prevalence of different kinds of explosives accidents at metal and nonmetallic mines for a 23-year period. Approximately 52 percent of the injuries were at opencut mines.

**FLYING MATERIAL FROM BLAST**

The most frequent type of accident, as indicated by these summaries, is that in which persons are killed or injured by blasted material. Approximately 51 percent of the injuries listed in table 5 were of this type, and about the same proportion of those listed in table 4 appear to be of this nature. A great number of such accidents occurred when blasting was done in opencut mines without having everyone in a safe location. Some factors that cause injuries from flying blasted material are:

1. Staying too long at the face when spitting fuse.
2. Unguarded shots, improper warning methods, and not going to a safe place.
3. Returning too soon before all shots have fired.
4. Short fusing.

**TABLE 4.—Selected explosives accidents, 1940-44**

<table>
<thead>
<tr>
<th>Type of operation</th>
<th>Location</th>
<th>Explosives in-</th>
<th>Cause of accident</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Underground</td>
<td>Surface</td>
<td>Storage</td>
<td>Transportation</td>
</tr>
<tr>
<td>Underground mines</td>
<td>47</td>
<td>3</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Opencut mines and quarries</td>
<td>36</td>
<td>1</td>
<td>2</td>
<td>33</td>
</tr>
<tr>
<td>Construction and miscellaneous</td>
<td>20</td>
<td>1</td>
<td>2</td>
<td>17</td>
</tr>
<tr>
<td>Total</td>
<td>47</td>
<td>56</td>
<td>5</td>
<td>96</td>
</tr>
</tbody>
</table>

**TABLE 5.—Injuries from explosives at metal and nonmetallic mines, reported to National Safety Competition, 1933-54**

<table>
<thead>
<tr>
<th>Agency</th>
<th>Number of injuries</th>
<th>Underground</th>
<th>Opencut</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hit by blasted material</td>
<td>114</td>
<td>279</td>
<td>393</td>
<td></td>
</tr>
<tr>
<td>Premature shots</td>
<td>78</td>
<td>101</td>
<td>179</td>
<td></td>
</tr>
<tr>
<td>Missed holes or delayed shots</td>
<td>34</td>
<td>14</td>
<td>48</td>
<td></td>
</tr>
<tr>
<td>Asphyxiation</td>
<td>36</td>
<td>36</td>
<td>72</td>
<td></td>
</tr>
<tr>
<td>Handling, storing, destroying, or transporting explosives or detonators</td>
<td>9</td>
<td>12</td>
<td>21</td>
<td></td>
</tr>
<tr>
<td>Explosion of explosives or detonators outside drill hole</td>
<td>5</td>
<td>3</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>Undetermined</td>
<td>86</td>
<td>24</td>
<td>110</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>362</td>
<td>433</td>
<td>795</td>
<td></td>
</tr>
</tbody>
</table>
ACCIDENTS FROM EXPLOSIVES AT METAL MINES

PREMATURE SHOTS

The second greatest class of accidents in blasting was premature shots, which caused approximately 22 percent of the injuries listed in table 5 and probably a greater proportion of those in table 4. The usual factors producing accidents of this type are:

1. Detonation of charge while loading hole due to impact of tamping rod or friction of metal on tamping rod.
2. In electric blasting premature detonation of charged holes may be caused by making connection to electrically charged lines, by application of current while men are at the working face, by accidental contact of shooting wires with charged conductors, by stray currents, or by other unsafe use of shooting wires.
3. Short fusing.
4. Premature shots may result from electrical storms.

MISSED HOLES

Detonation of missed holes was nearly three times as frequent underground as in surface mining in the accidents of table 5; the proportion is even greater in those of table 4. Although the cause of the detonation of misfired holes is not known in a number of instances, the majority of such accidents is due to the dangerous practices of picking or drilling in bootlegs or close to missed holes.

ASPHYXIATION FROM NOXIOUS GAS

Asphyxiation from fumes of explosives in underground mines occurred when men returned too soon after blasting or (through some mishap) were overcome by powder smoke before reaching a place in good ventilation. In the injuries listed for 1933-54, 36 of the 362 underground injuries (9.9 percent) were from this cause; in the list for 1940-44 only 4 of 47 underground accidents (8.5 percent) were due to fumes. The lists in the two tables do not permit any but general comparisons; therefore, it can only be stated that some improvement is indicated, perhaps through use of more suitable explosives and better ventilating practices.

These summaries fully support the generally accepted opinion that few accidents happen in the storage or transportation of explosives. In the list of table 4, only 1 injury in 49 occurred under these conditions; of those in table 5, the proportion was about 1 in 10. At mining operations (table 5), 4 accidents were associated with storage and 3 with transportation. About 95 percent of the accidents in each of the tables were in connection with the use or attempted use of explosives and detonators.

The most common unsafe practices in the use of explosives were: Forcing or pounding charges in boreholes; overstaying the time for lighting fuse; accidental contact of flame or heat with detonators, fuse, or explosives; drilling into missed holes; and returning too soon after blasting, resulting in injuries or asphyxiation. Several fatal injuries in electric blasting were caused by thoughtlessly connecting leg wires of electric detonators to charged circuits or by failing to make sure that all persons were in the clear before firing.

The accidents at underground mines listed in table 5 resulted in 48 fatalities, while those at opencut mines and quarries caused 81 deaths. Blasting in the course of construction work was also hazardous, causing 26 deaths.
The most prevalent types and causes of explosives accidents are clearly indicated by the foregoing summaries. From similar reviews of the actual unsafe conditions or practices that have caused repeated accidents there have been formulated standard practices and rules to prevent continued death, injury, and destruction. In arriving at these conclusions it is necessary to survey the circumstances of enough mishaps to obtain reliable information. In many explosives accidents determination of the cause is difficult, since the evidence of the origin is destroyed by the blast, and frequently those involved are killed. Survivors are often of little help, as the accident occurs so suddenly they cannot tell what happened, or they may prefer not to divulge whatever information they have. In most explosives accidents the cause is a thoughtless, misjudged, or foolhardy act of an individual; such an act often results from improper training and supervision in the handling and use of explosives.

INJURIES TO CHILDREN FROM EXPLOSIVES

Every year many children are injured from tampering with blasting caps or playing with explosives. There are two methods of lessening the number of such injuries:

1. The users of explosives must see that they are not left where children can have access to them.
2. Children must be taught to recognize these detonators and explosives, to leave them alone, and to notify an adult if they should be encountered while playing.

In spite of all warnings, some people still leave explosives and detonators where children can get them. If explosives and detonators not required for the day's work were always accounted for and removed to locked storage magazines, these injuries would not occur—certainly not in their present numbers. Those who cache a few caps under a boulder or lay them away in a building or put them in their pockets where they may be forgotten needlessly contribute to this toll of injuries and loss of life.

When explosives and (more especially) detonators come into the hands of children they are usually detonated in some manner and frequently cause injuries to two or more. Among 28 accidents listed by the Institute of Makers of Explosives for the first quarter of 1954 there were 42 injuries to children 3 to 16 years of age. Typical examples follow:

Two 8-year-old boys received injuries of abdomen, chest, and legs when they threw a blasting cap in a fire.

Two boys 11 and 12 years old were injured when they pried a cap with a nail. One lost two fingers, and the other suffered minor powder burns.

Two 12-year-old boys playing with a blasting cap received eye, arm, chest, and leg injuries.

A boy 15 years old lighted a capped fuse with a match and lost 3 fingers of his right hand.

A girl 12 years old lighted a capped fuse with a match and lost a thumb and forefinger on the right hand.

An 11-year-old boy struck a cap with a rock and was injured about his hands and face.
Two boys (10 and 6 years) and a girl (3 years) were injured while playing with an electric detonator connected to a battery.

**SELECTION OF EXPLOSIVES**

The choice of an explosive of suitable type for the work it is to do has real importance, not only in the blasting results achieved but in the effect on the health and safety of those who use it. Some ores are harder to break than others, and an explosive that works well at one mine may not do so at another where the formation is different. Moreover, the amount and type of gases produced must be considered in selecting an explosive for use in confined underground workings.

Because of the numerous types and brands of explosives on the market, selection of an explosive for the job in hand may necessarily result from trial and experience. Successful use of a certain kind of explosive at one mine may be a favorable guide to its possible use at a similar operation, but the technical representatives of explosives manufacturers will advise and assist in introducing and perfecting the use of an explosive that will give the best results.

In general terms, a good blasting explosive should be stable at normal temperatures, not detonated by mechanical shock, easily handled, not injurious to health, and have enough disruptive power for the work required of it.

In metal and nonmetal mining blasting is generally done by the use of high explosives—that is, detonating explosives fired by shock from an intermediate agent called a detonator as compared to black blasting powder, which acts by rapid burning initiated by an igniting agency. Detonating explosives decompose almost instantaneously, while “low explosives” burn progressively from the point of ignition over a very brief but sustained period. High explosives used in commercial work are the dynamites, of which various types, grades, and strengths are made, such as straight nitroglycerin dynamite, and permissible explosives. Dynamites are usually prepared in stick or cartridge form, but some low-velocity types are also made in granular form, known as free-running dynamite or “blasting powder”; in this form they have been used in place of black powder in opencut or quarry work.

In selecting high explosives, especially for underground work, the principal factors to be considered are strength, velocity or shattering effect, water resistance, density, fumes, temperature of freezing, and stability in hot climates. From the standpoint of safety, the most critical factors are the stability in changing temperatures and moisture, the volume of poisonous gases evolved when the explosive is detonated or burns rather than detonates, and the freezing properties.

**STRENGTH**

Strength is the force developed by the explosive. The straight dynamosites are rated on the percentage, by weight, of nitroglycerin that they contain. The percent-strength grading of any other kind of dynamite means that it will release as much force as the same grade of straight dynamite measured by weight. Although 60-percent straight dynamite contains 3 times as much nitroglycerin as a
20-percent straight dynamite, the other ingredients are correspondingly less; since all of them enter into the explosion, 60-percent dynamite is approximately 1 1/2 times as strong as 20-percent, rather than 3 times as strong.

Two dynamites of the same strength may not necessarily produce the same blasting action owing to the fact that other properties, particularly density and velocity, also influence performance.

VELOCITY

The rate of exploding or detonation is called the velocity of an explosive. Explosives of greater speed of action generally have more shattering effect than those of lower velocity, but strength and density also influence the shattering power of an explosive. The three qualities should be considered together in selecting a suitable explosive to secure desired fragmentation.

RESISTANCE TO MOISTURE

Water-resisting qualities of high explosives vary greatly and are important where blasting is done in wet ground. If blasts are fired soon after loading in wet holes, an explosive having moderate resistance to water can be used; where the explosive may be left under water for a length of time, a gelatin or semigelatin dynamite or one of similar high water resistance should be used. The permissibles and the low-density ammonia dynamites have relatively little resistance to water.

DENSITY

The density of high explosives may be indicated by the number of 1 3/4 by 8-inch cartridges to 50 pounds. In very hard ore and rock it is desirable to concentrate the explosive force in the bottom of the hole, and a high-density explosive is required. In large-diameter holes, high-density gelatin is often used in the bottom of the hole and a bulkier explosive with less density above to bring the charge up enough in the hole to break the top rock, or the hole may be sprung, and a large quantity of explosive may be used of a density suitable to the material. Bulky, low-density explosives may be used to distribute the charge along the length of a drill hole in material that is easily broken.

FUMES PRODUCED

Varying amounts of gas or fumes are given off when explosives are fired, depending on the kind of explosive, the completeness of the detonation, and the kind of material being blasted. For surface work the nature of these fumes is not so important, but for underground work an explosive that produces large amounts of objectionable or dangerous fumes is unsafe. Ordinarily, gelatin dynamite gives off the least quantity of poisonous fumes, although certain other types of explosives may be of the same order. Burning dynamite produces the most poisonous fumes, and incompletely detonated dynamite follows closely. Complete detonation is obtained ordinarily from an explosive that is in good condition and that is thoroughly confined by elimination of air spaces in the charge and by tight tamping of the
hole and through the use of a strong detonator pointing toward the bulk of the charge.

**STABILITY IN VARIABLE TEMPERATURES**

High explosives now made are low freezing, except when ordered to the contrary. Ordinarily they will not freeze under exposure to such normal atmospheric temperatures as occur in the United States. This important development in explosives manufacture in recent years makes blasting possible in all seasons, with little or no need for the hazardous process of thawing explosives.

The explosive should be of such composition that it does not become unreliable or oversensitive through necessary exposure to extreme changes in temperature or from moist to dry atmospheres. Such alterations in the composition of an explosive will affect its efficiency, the fumes produced, and the safety of handling.

All gelatin dynamites stiffen appreciably in cold, and either they or any granular dynamite containing ammonium nitrate may become “set” as a result of moisture pickup and temperature changes. Such stiffness or hardness at times occasions the suspicion that the dynamite may be frozen. The question may be settled very quickly by means of the “pin test.” A common pin will not penetrate frozen dynamite, but it can be pushed readily into cartridges that are merely stiff or hard.

**STORAGE**

**EXPLOSIVES AND DETONATORS**

The storage of explosives has a much deeper relationship to safety in their use than is commonly realized. Improper storage of explosives and detonators leads directly to misfires, to incomplete detonation, and to the burning of charges in the borehole.

The handling of misfires and the existence of undiscovered misfires are two chief sources of accidents from explosives. Incomplete detonation often leaves unexploded dynamite in the drill holes or scattered through the blasted material; numerous accidents, most of which cause serious injuries, are directly due to such unexploded dynamite. Explosives and detonators that have deteriorated to some extent because of improper storage or other cause may detonate and partly burn, producing an excess of noxious gases and inefficient results; such conditions may cause fatal accidents from the dangerous gases given off. For these reasons it is imperative to prevent deterioration of explosives and detonators by storing them in dry, well-ventilated, cool magazines. This is essential to safety in the use of explosives.

A leak in the roof, wet floors in a magazine, or any condition of storage that exposes ammonium nitrate explosives or blasting caps to moisture is likely to result in some or all of these troubles.

Inadequate ventilation of magazines may also lead to misfires, incomplete detonation, or burning charges; for, unless air circulates freely through a magazine, the atmosphere may become hot and humid, and long exposure to such atmosphere has essentially the same

---

final effect as dampness upon ammonia explosives and blasting caps. Heat and humidity may affect nitroglycerin explosives by causing separation of the nitroglycerin from the other ingredients or a leakiness that makes the explosive much more sensitive and dangerous to handle.

Cases and other containers of explosives should not be stacked against the walls of the magazine so as to stop or reduce ventilation. Stacks of explosives cases should be separated to allow access to all parts of the magazine, and ordinarily stacks should not be more than six cases in height.

A steel magazine without some protection from the direct rays of the sun will absorb so much heat—at least in some climates—that the explosives inside may become insensitive. This is particularly likely to occur in a climate where the days are hot and the nights cold and the explosives are subjected successively to extremes of high and low temperatures. A number of misfires and partial detonations due to this cause are on record. A steel magazine exposed to direct rays of the sun should be insulated or protected by a wooden or other nonconducting roof supported on posts, with enough clearance to permit free circulation of air between it and the magazine, and the magazine should be covered with a coat of aluminum paint. Tests by the Du Pont Powder Co. showed that certain magazines coated with aluminum paint were 14° cooler than magazines painted black.

Explosives and detonators should be stored so that the oldest stocks will be used first, avoiding accumulations of old and possibly deteriorated supplies. Cases of high explosives should be stored so that cartridges are lying flat and not standing on end. Explosives retained for extended periods should be turned over at intervals of 3 months to counteract the possible concentration of nitroglycerin in one part of the cartridges or case. No loose cartridges or detonators should be left lying around; they should be kept in a separate closed container.

Explosives should be stored apart from all other material, especially detonators, electric detonators, carbide, and flammable materials. Accidental ignition of detonators might detonate explosives; and tools and materials other than explosives should be kept out of magazines to minimize the need for access to magazines by more persons than necessary, as well as to permit proper explosives storage without the complications and probable occurrence of accidents due to handling tools within magazines.

**FUSE**

Safety fuse, detonating fuse, or blasting supplies may be stored with either explosives or detonators. Fuse should be stored in a dry, cool place; the ideal storage temperature is 45° to 70° F. Fuse stored in a damp place is likely to absorb enough moisture to delay its burning speed or even to prevent its burning. If the fuse is dried before using the normal burning speed may be slowed and, worst of all, become irregular; irregularity obviously tends to increase the chances of misfires and the spoiling of rounds due to charges exploding out of the intended order. This latter condition may result in cutting off the drill holes, leaving unexploded dynamite in the bottoms of the holes and possibly in the muckpile.
If fuse is stored in a hot place, the waterproofing may become soft and sticky and may penetrate the powder train, slowing the burning speed and making the fuse irregular or even damaging the powder so that it will not burn at all. On the other hand, too much heat may dry the waterproofing so that it will crack and render the fuse useless for damp or wet work. Cracked fuse may also result in side flashing as the fuse burns, causing misfires or premature shots through ignition of the dynamite.

The arrangement of stored fuse should facilitate the use of old stocks ahead of new stocks, thus avoiding accumulations of extremely old fuse as the waterproofing coats tend to lose their elasticity and become brittle with age. Such conditions are almost certain to have an adverse effect on the efficiency of the fuse when used.

If fuse is allowed to come into contact with oils, paints, kerosine, gasoline, distillates, or similar solvents these substances may penetrate the powder train and cause it to fail completely or to burn with irregular speed.

CONSTRUCTION OF MAGAZINES

The Bureau of Mines has approved certain types of storage magazines and has recommended standards of construction, location, and operation of magazines that fulfill the requirements affecting accident prevention.

PERMANENT MAGAZINES FOR EXPLOSIVES

All high explosives in amounts exceeding 125 pounds should be stored in permanent magazines that are theft-, fire-, and bullet-resistant.

CONSTRUCTION OF PERMANENT MAGAZINES

Permanent magazines should be of a building type, an igloo or Army type, a portable type, or a tunnel or dugout type, whether on or exposed to the surface or underground. Walls of building-type magazines should be substantially constructed of theft- and bullet-resistant materials and should meet the following standards or be constructed of other materials in a manner that will make them at least equally theft- and bullet-resistant:

1. Solid construction, not less than 6 inches in thickness, of such materials as concrete, masonry, medium-soft brick (fig. 3), or wood.
2. Filled construction, such as concrete blocks with the cells filled with screened sand, weak concrete, cement mortar, or other effective bullet-resistant filler; or exterior and interior wooden walls not less than 6 inches apart, with the space between filled with screened sand, weak concrete, cement mortar, or other effective bullet-resistant fillers and the exterior walls covered with sheet iron not lighter than No. 26 gage, or other fire-resistant material.
3. Lined construction, such as steel not lighter than No. 14 gage, lined with weak concrete, cement mortar, brick, or screened sand not less than 6 inches thick or with hardwood not less than 2 inches thick or with softwood not less than 3 inches thick.

The same standards should govern the construction of any artificial enclosing wall for tunnel- or dugout-type magazines on or exposed to the surface of the ground. Any artificial enclosing wall for permanent underground magazines should be substantially constructed of wood not less than 2 inches thick or of other material of equivalent or greater strength.
Foundations of building-type magazines should be substantially constructed, and any space between the floor and the ground should be enclosed in such a manner as to prevent the entrance of persons, animals, sparks, and firebrands.

Figure 3.—Permanent Storage Magazine—Brick Construction.

Roofs of building-type magazines should be fire-resistant and substantially constructed to resist theft, as for example, 3/4-inch sheathing covered with sheet iron or slate. Roofs not made of fireproof material should be covered with sheet iron not lighter than No. 26 gage or with other fire-resistant material. The roofs of magazines so located that it is possible to fire bullets directly through the roof into the explosives should be made bullet-resistant by material of construction or by a ceiling that forms a tray containing not less than a 4-inch layer of sand or other effective bullet-resistant filler erected in the interior of the magazine, or by other methods.

Doors of magazines on or exposed to the surface of the ground should be constructed of 3/8-inch steel plate lined with a 2-inch thickness of wood; or of a thinner steel plate with a greater thickness of wood, at the rate of 1 additional inch of wood for each 1/8-inch decrease in the thickness of the steel plate; or of wooden walls at least 4 inches apart and filled with screened sand or other effective bullet-resistant filler, the exterior being covered with sheet iron not lighter than No. 26 gage or with other fire-resistant material; or of wood not less than 6 inches thick; or of reinforced concrete not less than 4 inches thick. Doors of underground magazines should be substantially constructed of wood not less than 2 inches thick or of other material of equivalent or greater strength.

Doors of permanent magazines should be equipped with mortise locks, with padlocks fastened in strong hasps and staples, or with three-point locks. Padlocks and mortise locks should be the equivalent of five-tumbler jarproof locks. Doors should be provided with strong hinges, hasps, and staples attached by weld, by rivets, or by bolts fitted with lockwashers and nuts on the inside of the magazine and so installed that the fastening cannot be removed when the magazine is locked.

Magazines should have no openings, except for entrance and ventilation. Foundation vents should be of offset-type construction, and all
vents should be effectively protected with metal screening or otherwise constructed to prevent the entrance of persons, animals, sparks, or firebrands or direct penetration of bullets that can detonate the explosives.

**MARKING PREMISES**

The premises on which a permanent magazine is established should be conspicuously marked by signs containing the words "Explosives—Keep Off." No signs should be placed on the surface of magazines or be so located that a bullet passing directly through the face of a sign will strike the magazine.

**BOX-TYPE MAGAZINES FOR EXPLOSIVES**

High explosives in amounts of 125 pounds or less should be stored in permanent magazines or in box-type magazines that are theft-resistant.

**CONSTRUCTION OF BOX-TYPE MAGAZINES**

Box-type magazines should be strongly constructed of 2-inch hardwood, 3-inch softwood, or other equally theft-resistant material. Metal magazines should be lined with nonsparking material. Doors or lids should be provided with strong hinges, hasps, and staples attached by welds, rivets, or bolts fitted with lockwashers and nuts on the interior of the magazine and installed in such a manner that the fastening cannot be removed when the magazine is locked. Box-type magazines should be equipped with a lock equivalent to a five-tumbler jar-proof lock.

**MARKING MAGAZINES**

Box-type magazines should be painted a distinctive color and clearly and conspicuously marked "Explosives."

**DETONATOR MAGAZINES**

1. All detonators numbering 1,000,000 or more should be stored in permanent magazines complying with the standards given.
2. All detonators numbering over 5,000 but less than 1,000,000 should be stored in permanent magazines complying with the standards set forth, except that magazines need not be bullet-resistant. Any metal magazine should be lined with a nonsparking material.
3. All detonators numbering 5,000 or less may be stored in permanent magazines; if not so stored, such detonators should be stored in box-type magazines complying with the standards for magazines of this type.
4. No detonators should be stored in any magazines containing high or low explosives or blasting-device heaters.

An underground magazine for storing detonators is shown in figure 4.

**LOCATION**

**SURFACE MAGAZINES**

Accessibility in location of a magazine is desirable to permit transfer of explosives to the place where they are used, but it is even more important that a magazine be far enough away from other buildings or valuable structures that the least possible damage will be done to buildings or to persons in the surrounding area if an explosion occurs within the magazine. Damage from a magazine explosion is
caused by the resulting air blast, by shock waves in the air and in the ground, and by flying missiles.\textsuperscript{8} Direct effects of the moving air blasts are severe at the point of the blast but fade rapidly with distance. The shock waves create a sharp pressure push away from the explosion, immediately followed by a slower, but equally strong, pressure push or suction wave in the opposite direction. These pressure waves cause no appreciable movements of the air itself but move objects and cause windows, walls, and roofs to collapse or shatter. Flying and burning fragments thrown from the exploded magazine

may do severe damage at great distances. Explosions of magazines containing approximately 10 tons of high explosives have caused serious damage at distances of 1,500 to 2,000 feet; explosions of amounts approximating 100 tons have caused severe damage as much as 1 mile away. The areas in which minor damage from missiles and broken windows results are much more extended.

Some States and cities have laws or regulations specifying the locations of magazines; where such laws do not contain more particular specifications, it is recommended that surface magazines be placed in conformity with the American Table of Distances when practicable (table 6). This table specifies the distances that magazines containing explosives should be from inhabited buildings, highways, and railroads.

The Bureau of Mines recommends that surface magazines be detached from other buildings in conformity with the distances in table 6 and that they be not nearer than 200 feet from any powerplant, mill, or other vital structure or from the surface opening of any mine. The topography or other physical conditions may prevent locating a proposed magazine at the distance recommended in the table; under these circumstances it may be possible to construct the magazine behind natural or builtup barricades or divide the necessary maximum amount stored between two magazines a safe distance from each other (figs. 5, 6, and 7).

Figure 5.—Barricaded Explosives Magazine—Concrete and Sand-Filled Construction.

Permanent magazines should be at least 200 feet from each other, except a detonator magazine; and magazines where over 25,000 pounds of explosives are stored should have an increase, over 200 feet, of $\frac{2}{73}$ feet for each 1,000 pounds of explosives over 25,000 pounds stored therein, provided that these distances may be disregarded where the total quantity stored in these magazines, considered as a whole, complies with the amended American Table of Distances; under no cir-
circumstances should a detonator magazine be less than 100 feet (not barricaded) or 50 feet (barricaded) from a magazine containing explosives. The distance between magazines containing explosives may be reduced one-half where an effectual artificial or natural barricade exists between the magazines.

Box-type magazines, when outside a building, should be anchored securely. No magazine should be placed in a building containing oil, grease, gasoline, waste paper, or other highly flammable materials;
moreover, a magazine should not be placed less than 20 feet from a stove or furnace or open fire or flame, or less than 5 feet from other sources of external heat.  

Surface magazines should not be installed underneath electrical transmission lines or so near that there may be danger of contact if they should break or be blown down.

Table 6.—American Table of Distances for storage of explosives

<table>
<thead>
<tr>
<th>Explosives</th>
<th>Distances when storage is barricated, feet</th>
<th>Explosives</th>
<th>Distances when storage is barricated, feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pounds over</td>
<td>Pounds not over</td>
<td>Inhabited buildings</td>
<td>Passenger railways</td>
</tr>
<tr>
<td>2</td>
<td>5</td>
<td>70</td>
<td>30</td>
</tr>
<tr>
<td>3</td>
<td>10</td>
<td>90</td>
<td>45</td>
</tr>
<tr>
<td>5</td>
<td>20</td>
<td>110</td>
<td>60</td>
</tr>
<tr>
<td>7</td>
<td>30</td>
<td>125</td>
<td>80</td>
</tr>
<tr>
<td>10</td>
<td>40</td>
<td>140</td>
<td>100</td>
</tr>
<tr>
<td>15</td>
<td>50</td>
<td>150</td>
<td>120</td>
</tr>
<tr>
<td>20</td>
<td>60</td>
<td>160</td>
<td>140</td>
</tr>
<tr>
<td>30</td>
<td>75</td>
<td>180</td>
<td>160</td>
</tr>
<tr>
<td>40</td>
<td>90</td>
<td>200</td>
<td>180</td>
</tr>
</tbody>
</table>

1 E. L. du Pont de Nemours & Co., Inc., Explosives Department, American Table of Distances for Storage of Explosives, as revised and approved by Institute of Makers of Explosives January 30, 1953: Blasters’ Handbook 1932, pp. 126-127.

Note 1—“Explosive” means any chemical compound, mixture, or device, the primary or common purpose of which is to function by explosion, that is, with substantially instantaneous release of gas and heat, unless such compound, mixture, or device is otherwise specifically classified by the Interstate Commerce Commission.

Note 2—“Magazine” means any building or structure, other than an explosives-manufacturing building, used for the storage of explosives.

Note 3—“Natural barricade” means natural features of the ground, such as hills, or timber of sufficient density that the surrounding exposures which require protection cannot be seen from the magazine when the trees are bare of leaves.

Note 4—“Artificial barricade” means an artificial mound or revetted wall of earth of a minimum thickness of 0.5 feet.

Note 5—“Barricated” means that a building containing explosives is effectively screened from a magazine, building, railway, or highway, either by a natural barricade, or by an artificial barricade of such height that

Many of the explosives-storage magazines at opencut mines and quarries are substantial, sheet-steel, sectional-type, portable magazines sold by explosives manufacturers. These magazines range in size from 6 feet wide, 6 feet long, and 7 feet high and a recommended capacity of about 6,000 pounds of explosives to 10 feet wide, 20 feet long, and 9 feet high and a recommended capacity of about 40,000 pounds, (figs. 8 and 9).  

![Figure 8](image-url)

**UNDERGROUND MAGAZINES**

Storage magazines in underground mines should be at least 200 feet from any main shaft, slope, or active mine working. They should be at least 25 feet from all haulageways or other travelways and prefer-

a straight line from the top of any sidewall of the building containing explosives to the cave line of any magazine, or building, or to a point 12 feet above the center of a railway or highway, will pass through such intervening natural or artificial barricade.

**Note 6**—When a building containing explosives is not barricaded, the distances shown in the table should be doubled.

**Note 7**—"Inhabited building" means a building regularly occupied in whole or in part as a habitation for human beings, or any church, schoolhouse, railroad station, store, or other structure where people are accustomed to assemble, except any building or structure occupied in connection with the manufacture, transportation, storage, or use of explosives.

**Note 8**—"Railway" means any steam, electric, or other railroad or railway which carries passengers for hire.

**Note 9**—"Highway" means any public street or public road.

**Note 10**—When 2 or more storage magazines are located on the same property, each magazine must comply with the minimum distances specified from inhabited buildings, railways, and highways, and in addition they should be separated from each other by not less than the distances shown for "Separation of Magazines," except that the quantity of explosives contained in cap magazines shall govern in regard to the spacing of said cap magazines from magazines containing other explosives. If any 2 or more magazines are separated from each other by less than the specified "Separation of Magazines" distances, then such 2 or more magazines, as a group, must be considered as 1 magazine, and the total quantity of explosives stored in such group must be treated as if stored in a single magazine located on the site of any magazine of the group, and must comply with the minimum distances specified from other magazines, inhabited buildings, railways, and highways.

**Note 11**—The Institute of Makers of Explosives does not approve the permanent storage of more than 300,000 pounds of commercial explosives in 1 magazine or in a group of magazines which is considered as 1 magazine.

**Note 12**—This table applies only to the manufacture and permanent storage of commercial explosives. It is not applicable to transportation of explosives, or any handling or temporary storage necessary or incident thereto. It is not intended to apply to bombs, projectiles, or other heavily encased explosives.

---

Portable Explosives-Storage Magazines at Opencut Mine.

ably in a section of the mine remote from active workings. Such a magazine should be in a separate drift or chamber and preferably offset from the entrance; magazines should be separated by at least 25 feet of solid ground. Main magazines underground that may contain rather large amounts of explosives can usually be located and constructed, according to plan, at a place where an explosion would not wreck active shafts or haulageways and kill or trap men underground. Ventilation should be so arranged that fumes from a fire or explosion would not be carried through active parts of the mine or endanger men leaving the mine. In mines of any size, where explosives are kept in underground magazines, they should be at locations where an explosion would not block entry to or exit from the mine.

In the Lake Superior iron-ore mines \(^{11}\) underground magazines are planned consistent with future mine development; located a safe distance from shafts, working places, haulageways, travelways, and electrical conductors; ventilated on return air; and with a barricade consisting of not less than 25 feet of rock or ore (in place) between the explosive and detonator magazine. Care is taken to provide one or more right-angle turns between magazines and places where men travel or work.

The location and arrangement of some of these magazines are pictured in figures 10, 11, 12, 13, 14, and 15.

In figure 10 the magazine is 450 feet from the shaft in a timbered drift in a slate formation at a right angle to the main haulage drift. The fuse- and detonator-storage and explosives-storage magazines are, respectively, 12 and 50 feet from the haulage drift. Each magazine is at a right angle to, and on an opposite side of, the crosscut. They are floored and lined with plank, and each is provided with a 2-inch wood door. The magazines are ventilated by a blower fan in the haulage drift and 3-inch pipe. The electric conductors for lighting are in conduit, vaporproof-type fixtures are provided, and the control switch

---

Explosives storage. Timbered room lined with plank wooden floor
Ventilated by blower through flexible tubing

Fuse and detonator storage. Timbered room lined with plank wooden floor

Main haulage drift 450' to shaft

Figure 10.—Explosives Magazine—Excavation in Rock Requiring Support; Vapor-proof-Type Electric Fixtures.

Explosives storage. Cinder-block lined; concrete floor, covered with wooden slats. Ceiling made of 8" concrete slabs reinforced with railroad rails
Ventilated by blower on haulage and flexible tubing to magazine

Figure 11.—Explosives Magazine—Entire Excavation in Rock Between Shaft and Ore Body; No Timber Required.
Figures 12 and 13 illustrate the layout of an explosives magazine. Figure 12 shows the entire excavation in rock, including vaporproof lighting fixtures and arrangements for storage of explosives, fuse, and detonator. Figure 13 focuses on the magazine's vaporproof-type lights and switches outside. The diagrams depict the structure's layout, dimensions, and storage areas, emphasizing safety and accessibility.
is at the turn of the main haulage drift. The explosives are carried from the main haulage drift to the magazine.

In figure 11 the magazine is 500 feet from the hoisting shaft and 1,800 feet from the nearest working place in an untimbered, abandoned rock crosscut at a right angle to the main haulage drift. The detonator and the explosives magazine are, respectively, 30 and 126 feet from the haulage drift. Each storage is at a right angle to and on an opposite side of the crosscut. The entire crosscut and the magazines have concrete floors, and each magazine has a steel door and a reinforced-concrete ceiling. The walls in the detonator magazine are of concrete, and those in the explosives magazines are of cinder block. The crosscut is bulkheaded inside the explosives magazines, and the bulkhead contains a steel door for emergency travel. The crosscut is ventilated by a blower fan in the haulage drift through flexible tubing which discharges air just outside the explosives magazine. The light wiring is in conduit, vaporproof-type fixtures are provided, and the control switch is between the detonator magazine and the haulage drift. The explosives are carried into the magazine and stored on a platform.

In figure 12 the magazine is in an untimbered rock drift 275 feet from the hoisting shaft and 130 feet from the ore body. The drift is at a right angle with the main haulage crosscut. Both magazines have concrete floors. The detonator and the explosives magazines are, respectively, 20 and 86 (99 through drift) feet from the haulage crosscut. Explosives are transported from the explosives car in the crosscut to the magazine on a flat wood truck equipped with rubber-tired
FIGURE 15.—Explosives Magazine—All Workings Shown Are in Ore Formation, Requiring Heavy Timbering; Vaporproof Lights; Wiring in Conduit.

wheels and stored on wooden platforms. The light wiring is in conduit, vaporproof-type light fixtures are installed, and the control switch is in the main-haulage crosscut.

In figure 13 the magazines shown are in right-angle offsets from a projection of the main haulage drift, on the side of the shaft away from the ore body. The detonator magazine is 105 feet from the shaft, and the explosives magazine is 25 feet beyond that. Both magazines are timbered and lined with plank. The explosives are stored in one end of a T drift 48 feet in length. If stored explosives are accidentally detonated the other end of the T drift would serve as an expansion chamber to absorb some of the concussive forces generated and thereby materially lessen the otherwise devastating effect along the drift and at the hoisting shaft. There is no trolley-wire installation in the drift on the explosives-storage side of the shaft. A steel track is installed to within 20 feet of the detonator magazine, and a wooden track extends to the magazines. Explosives are lowered to the magazine level in a car on the cage, and the car is pushed by hand to the explosives magazine and unloaded. Light wiring is in
conduit, vaporproof-type light fixtures are installed, and the control switches are in the drift outside of the detonator magazine.

Figure 14 pictures a magazine arrangement that has 2 advantages over that shown in figure 13; 1 is that an additional right-angle turn is provided, and the other is the increased distance from the hoisting shaft. The drift and the magazines are timbered and lined with wood and have wood floors. The light wiring is the conduit; vaporproof-type light fixtures are provided; and the control switch is at the turn from the shaft tail-track drift. The explosives are carried from this tail-track drift into the magazine.

In figure 15 the magazine is approximately 400 feet from the shaft and 300 feet from the nearest working place. The T drift, which is at a right angle with the haulage drift, is in the ore formation, is closely timbered, and has a wooden floor. The detonator and explosives magazines are, respectively, 30 and 65 feet from the haulage drift. Both magazines are lined with wood and have wood floors. The expansion chamber shown would lessen the destructive effect of the forces released in case of an explosion in the magazine. The magazines are lighted with vaporproof-type fixtures, conductors are in conduit, and the switches are in the drift a short distance from the detonator magazine.

PRECAUTIONS IN OPERATING MAGAZINES

Magazines should have natural light or be lighted by portable, electric, storage-battery lamps, by protected electric systems with the switch outside, or by flood lighting from the outside. The floors should be of wood or other nonsparking material and have no metal exposed. Any explosive material that might be on the floor or on the outside of a case would be likely to detonate if struck or scraped in handling the cases. Magazines of steel or covered with sheet metal should be grounded. Other precautions against fire are keeping the magazine clean and removing waste paper, sawdust, and used empty boxes so that they do not accumulate in or around any magazine. An area of at least 25 feet around surface magazines should be kept free of rubbish, dry grass or brush, or other easily combustible material. Smoking or carrying open lights or other flame into or around any magazine should not be allowed.

Storage magazines should not be heated.

Magazine floors should be swept frequently and the sweepings removed and destroyed. If magazine floors become stained with nitroglycerin, they should be scrubbed well with a stiff broom, hard brush, or mop, using a solution composed of 1½ quarts of water, 3½ quarts of denatured alcohol, 1 quart of acetone, and 1 pound of sodium sulfide (60 percent commercial). The liquid should be used freely to decompose the nitroglycerin thoroughly. If the magazine floor is covered with rubberoid or any material impervious to nitroglycerin, this portion of the floor should be swept thoroughly with dry sawdust and the sweepings taken to a safe distance from the magazine and destroyed.

---

The main storage magazine for a mine may be on the surface or underground, but in either instance one or more distributing magazines may be accessible to active workings. The main magazine for a small mine often is used as a distributing point. The mining law in certain States prohibits storage of more than 1 day’s supply of explosives in a mine. Where underground storage magazines are not at a safe distance from active workings and where poisonous gases from a fire or explosion in these magazines would endanger persons in the mine, the quantity stored should be strictly limited.

Magazines used for distributing explosives and detonators should be constructed to meet the minimum standards of storage magazines. The supply kept in strictly distributing magazines should be limited to approximately 1 day’s requirements. The same general provisions as to location, fire hazards, and order in the storage arrangements as are applicable to storage magazines should be observed in operating distributing magazines.

It may sometimes be advisable to heat distributing magazines in extremely cold climates where the place would otherwise be damp and cold. The source of heat should be outside the magazine, and the heat should be circulated through pipes or coils, or as warmed air. The system should be regulated to maintain a mild, evenly distributed temperature.

The safest implements for opening wooden cases of explosives are a hardwood wedge and a mallet. One approved method of opening the case is to drive the wedge against the edge of the lid to loosen it and then to drive it under the lid. Another method is to split the sides of the box with the wedge on a corner at the third dovetail from the top. Any kind of metal tool used in opening a case of explosives may strike a spark from the nails that could cause the dynamite to explode. True, many cases of dynamite are opened with metal tools without accident; but the hazard is always present, and the person using a metal tool is unnecessarily exposing himself to possible death or injury. A metallic slitter may be used safely for opening fiberboard cases provided it does not come in contact with the metallic fasteners of the case, but it would be preferable to use one made of plastic or some other nonmetallic substance. Most miners open explosives cartons simply by inserting their fingers under a section of the stapled lid and pulling. The staples yield readily to a positive pull.

Whether explosives in any quantity are stored near the working place or are brought from distributing magazines immediately before blasting time usually will depend on variable conditions, such as distance to the working place and the regularity and sequence of the work; in some instances established custom decides the practice. Explosives should remain in the working place no longer than is absolutely necessary. Thus, if mining conditions permit, the explosives should be obtained just before they are needed for charging or blasting. In many mines blasting is done at irregular periods, and the time required for transporting explosives from a central maga-
TRANSPORTATION OF EXPLOSIVES, DETONATORS, AND FUSE

zine makes this impractical. Under other conditions it may be necessary to have a working supply of explosives near the working place. Keeping explosives in the working place at some point selected by a miner is undesirable, and a safe storage place should be provided. Separate boxes should be supplied for explosives and detonators; these boxes should be strongly constructed and kept locked. They should be in a crosscut or opening off the travelway wherever possible, and in any instance should not be in direct line with the blast or less than 10 feet from the track and 25 feet from any trolley or powerline. Detonators should be stored far enough from explosives to preclude handling them over an open box of explosives. Explosives and detonators should be separated until they must be brought together, usually at the place and time when the primers are made up; it is not safe to do this close to stored explosives. Although a day's supply of detonators may be kept in a separate compartment of a storage box without undue risk if a partition of 4 inches of wood is between them and any explosives, handling of these detonators into and out of the open box is likely to be unsafe.

Explosives, detonators, or capped fuse left over at the end of a shift should not be left in a working place or lying around in the mine. If they will be needed by the next shift they may be kept properly in local storage boxes to avoid impractical and unnecessary handling and transportation. If leftover explosives and detonators are not expected to be used on following shifts or storage boxes are not provided, the excess supply should be returned to the magazines from which they were distributed.

Explosives, detonators, and fuse left in the mine are likely to absorb moisture and become unreliable; they are also hazards if left lying around.

TRANSPORTATION OF EXPLOSIVES, DETONATORS, AND FUSE

When a shipment of explosives is unloaded from a freight car or truck and placed in a storage magazine or when a supply is taken from a magazine for use, certain precautions should be observed. Any sparks, fire, or friction that would cause intense heat might start an explosion; therefore, sparks or flames must be excluded from the vicinity; men should never smoke or carry matches or smoking materials while handling explosives or working near them. Cases of explosives should always be lifted and set down carefully and never be slid over each other or dropped from one position to another.

REQUIREMENTS FOR VEHICLES CARRYING EXPLOSIVES

Automobile trucks used for transporting explosives should be strong enough for the proposed load and in good repair; the brakes and steering mechanism should be in effective working condition; there should be no accumulation of oil or grease; the fuel line and tank should have no leaks; the electric wiring should be well-insulated; and two suitable fire extinguishers should be provided.

The floors of such vehicles should be tight, and any exposed metal on the inside of the body that might touch any package of explosives
should be covered with wood or other nonsparking material. Covered vehicles are preferable; if open bodies are used the cases should not be piled higher than the covered sides, and a fire-resisting tarpaulin should be placed over the load.

No metal tools, carbide, oil, matches, firearms, electric storage batteries, or any flammable substances, acids, or oxidizing compounds should be carried with explosives.

Vehicles transporting explosives should be conspicuously marked on the sides and ends with the word "Explosives" or display a red flag clearly lettered "Explosives" or "Danger" (fig. 16).

Explosives should not be transported in any pole-type trailer; no such trailer should be attached to a vehicle hauling explosives.

Vehicles transporting explosives should be driven only by authorized, reliable persons; no unauthorized persons should be allowed on them. Such vehicles should be kept under full control and no unnecessary stops made; they should be not taken inside a garage for repairs or other purposes.

Vehicles transporting explosives should not be left unattended at any time except while actual deliveries are made. Motors should be stopped before explosives are loaded or unloaded.

The transportation of explosives over public highways is regulated by the Interstate Commerce Commission, whose regulations include many of the foregoing.

Dangerous emergencies arise if vehicles by which explosives are transported are not maintained and operated according to the regulations given. A truck operated by an explosives dealer was carrying a full load on a main highway when the driver discovered that it was on fire. He was able to turn off on a side road and into the middle of a large field without delay. Jumping from the cab, he found the
fire too large to combat with an extinguisher and realized that his duty was to keep spectators and volunteer assistants at a safe distance. Fortunately, this effort was successful, and when the truck exploded a few minutes later no one was injured. The fire was thought to have started in the gasoline line from the tank to the engine.

In another State, two trucks loaded with explosives were traveling close together when the driver of the leading truck noticed that the other truck was on fire. He stopped quickly to warn the other driver of the fire, and a collision occurred. The second truck left the road, turned over, and exploded; the driver and his relief man on this truck were killed.

HANDLING EXPLOSIVES

The transportation of explosives from the storage magazine to the places where they will be used either on the surface or underground should follow the same general principles to be observed in all phases of handling and keeping explosives. Briefly stated, these principles are: 13

Explosives and detonators should be kept apart until the charge is loaded. When working conditions permit, they should be transported in separate conveyances or carried by different men; in any instance, they should be placed in separate insulated containers.

High explosives and detonators should be handled carefully at all times to avoid shock and friction.

Explosives and detonators should be protected from flame, sparks, or extreme heat. They should also be protected from moisture.

Wires of electric detonators should be kept short-circuited and should be kept from contact with stray electricity or electrically charged surfaces.

In connecting detonator wires to leading wires the ends of wires should be cleaned. 14 The detonator or connecting wire should be wrapped tightly around the end of the leading wire about 1 inch from the end. Then the end of the leading wire should be bent back sharply and a turn or two of the detonator wire be taken around the loop. The last loop is simply to make a stronger connection.

The bare joints in the wires of a blasting circuit should never be allowed to touch the ground or breast, to lie in pools of water, or to rest on rails, pipes, or any other electrical conductor. They should be held up on chucks or blocks so that only the insulated parts of the wire touch the ground and supports. Taped joints are recommended where they are covered by stemming, where they cannot be held out of the water on props, or where blasting must be done during a rainstorm.

TRANSPORTATION UNDERGROUND

Two factors influence the quantity of explosives that should be taken underground at any one time: (1) In most instances, the quantity stored in the mine should be as small as possible; and (2) the time spent in transporting the explosives and the number of trips should be reduced to a minimum.

In shaft operations explosives in the original containers usually are lowered at a suitable time when there will be the least conflict with the movement of other materials or supplies and very few men will be in the vicinity of the shaft or stations. Some mines set aside

a specific time for lowering explosives, during which all hoisting of rock is discontinued; this rule applies to both 2- and 3-compartment shafts. Men do not ride with explosives; loading at the surface and unloading below are done by different men. Supplies of explosives left at shaft collars or level stations should be moved as soon as possible; previous notice of such deliveries should always be given.

Where explosives are taken into the mine in a car, a covered (preferably insulated) explosives car should be provided. The car body should be so constructed that no metal will be exposed on the inside, and it should be lined with wood, rubber, or other insulating material. Figure 17 shows an insulated explosives car and truck for handling explosives underground. The details of the car are shown in figure 18.

Explosives and detonators should be hauled on separate trips and if by electric locomotive there should be an insulated coupling between the locomotive and explosives cars.\(^5\) If explosives and detonators are hauled together, the detonators should be in an insulated container safely separated from the explosives; at least one empty car should be between the explosives car and the locomotive. Trips containing explosives should be pulled and never pushed.

If explosives are hand-trammed over main haulage tracks, the movement of the car should be protected by a block or dispatcher system, or men should precede and follow the explosives car at distances of 75 feet or more to warn approaching motors and/or trammed vehicles. Explosives cars should never be attached to a man-trip, and explosives or detonators should not be transported on a man-trip. A trip with explosives should not follow a man-trip closely but should move at a time when men are not congregating on haulways or at shaft stations. Some mines reserve a definite time for moving explosives, and the route used is cleared of other trains or cars. Explosives should be taken from one magazine to any other with as little delay and handling as possible. A truck with sideboards and used for bringing explosives to a level magazine is shown in figure 19.

Steel construction; interior, tops, sides, and ends lined with %-inch plywood; bottom of 1½-inch plywood; plywood fastened to angles with countersunk bolts.

Figure 18—Explosives Car. Capacity, 2,500 Pounds.
Where explosives or detonators are not transported in the original containers they should be brought into a mine or taken to working places in separate insulated containers. Canvas bags are widely used for carrying loose explosives to working places, and where conditions do not favor the use of rigid containers, specially constructed strong bags with straps or handles may be suitable for this purpose. A plastic container for carrying electric detonators to the face is shown in figure 20. Capped fuse should be carried in insulated containers separate from those containing explosives. Carrying fuse and detonators in canvas bags is much better than simply in an unprotected roll but less safe than in a rigid container (fig. 21).

TRANSPORTATION FOR OPENCUT AND QUARRY WORK

Most recommendations given for transporting explosives to a magazine apply in surface work to their transfer from the magazine to the
Detailed regulations for quarry blasting have been adopted by representatives of cement and quarry industries, explosives manufacturers, and the Bureau of Mines, which cover safety in opencut blasting rather completely. The following important provisions of these standards relate to handling explosives supplied in loading boreholes: 16

Explosives and detonators should be brought to working places in the original containers or in separate insulated containers and kept there until removed for placement in drill holes.

Capped fuse should be carried in covered insulated containers separate from those containing explosives, but single containers may be used if detonators and explosives are separated by a substantial partition.

Explosives should not be transported on the quarry property, handled, or used immediately before or during an electrical storm.

Blasting caps and electric blasting caps should be kept separate and apart from other explosives until ready to be used.

It is recommended that primers be made up just before placing in a hole.

Detonators or other explosive materials that are not to be used in the blast should not be either in or near the loading area.

When drill holes are to be loaded for blasting, the explosives containers should be stacked in piles at least 25 feet, and preferably 50 feet, from the nearest hole to be loaded. For a given total amount of explosives in the loading area it is preferable to have a few piles each containing relatively large quantities of explosives rather than to have a large number of piles each containing small quantities. The containers should be opened some distance from the piles as needed and the opened explosives cases carried one at a time to the loading station. This station should be at least 6 feet from the hole to be loaded or from any unstemmed loaded hole and at least 25 feet from the main pile. The quantity of explosives at this point should not exceed 125 pounds. From this station the explosives should be passed one cartridge or unit at a time for loading into the hole. Empty cases and lining paper should be removed to a waste pile immediately.

Excessively large amounts of explosives should not be delivered to the loading area at one time. If explosives are delivered by truck the quantity permitted at or near the loading operations should be limited to one truckload. Other trucks loaded with explosives should wait or be unloaded in separate safe places away from the loading operations.

When explosives for a blast cannot be delivered to the loading area by truck or railroad and must be carried to the holes by men, the same care should be taken to avoid having excessively large quantities of explosives in one area.

Explosives should be delivered to the holes farthest from the truck first to avoid driving or walking among piles of explosives.

Some serious blasting disasters in quarries or similar operations in recent years have been caused by neglect or violation of these standard procedures, and one explosion from other causes was made much worse by having piles of explosives too close to danger points.

An open box of primed cartridges was being carried from hole to hole by a blaster in an open-cut mine; the blaster was killed and a helper injured by the explosion of this dynamite. Leg wires of the electric detonators were not short circuited and were left trailing outside the box; these wires may have come in contact with an electric charge, some object may have fallen into the open box, or a wire may have been jerked. Similar accidents occurred where fuse was used in making the primers.

* * *
A quarry disaster in which 31 men were killed was due to detonation of approximately 20 tons of dynamite by premature explosion of a hole. The dynamite for charging each hole had been placed about the tops of the holes, which were only 12 feet apart.

USE OF EXPLOSIVES AND DETONATORS

A review of reports of explosives accidents, summarized in tables 4 and 5, shows that accidents during storage and transportation are relatively infrequent, indicating that the hazard is small or that it has been customary to follow safe methods, perhaps both.

The actual use of explosives is a different matter, as the annual records show a large number of accidents from this source year after year, with many accidents from the same clearly unsafe practices. The unsafe acts responsible for most explosives accidents are committed either through lack of knowledge of the dangers involved or through the thoughtlessness or poor judgment of those doing the blasting.

PRINCIPLES OF SAFE BLASTING

Three fundamental principles underlie safe practice at any blasting operations: (1) The risks of accidents should be reduced by having as few men as possible handle explosives, (2) men employed in blasting should be careful and should have training and experience in the work they are to do, and (3) safety regulations must be observed.

The number of men engaged in blasting can be curtailed by assigning certain men to those duties and systematizing the operations. At a magazine one man should be in charge and receive and issue all explosives and detonators. At most mines it has been found advisable to have one man cut, cap, and prepare capped fuse for use; the same man usually issues capped fuse and detonators to miners; the central fuse-capping room where this work is done at a large iron mine is shown in figure 22. In large blasting operations, as in quarries, tunnels, or long-hole blasting of stopes where crews of men work together, men or groups of men should be given the tasks of bringing explosives, opening boxes, loading, priming, tamping, connecting blasting circuits, and firing. Each man in a crew should know the duties of the others, as well as his own, and the procedure to be followed to prevent confusion and interference on any task by persons not assigned those duties. No unnecessary men should be on any part of the work, and persons not of the loading crew should be excluded from the vicinity. In mining and other operations where blasting at a particular place is done by a crew of only 2 or 3 men, the same principles apply.

Men who handle explosives should be those who will act with caution and good judgment. They should know the use of explosives, know safe from dangerous practices, and follow those that are safe. Where crews are used in blasting, supervisors and those designated to skilled duties should have the necessary qualifications. A “green” man should be instructed carefully in the necessary safety regulations before he is allowed to handle explosives; then he should work under the direction of an experienced, careful man until he has proved his fitness. Men experienced in the use of explosives who, through lack of knowledge, thoughtlessness, or recklessness, follow unsafe practices should be trained in safe methods; those who cannot or will not adopt such teaching should not continue to handle or use explosives.
Training methods that have been used successfully are: Posting safety regulations and clearly understandable illustrations of safe methods, distribution of similar material in bulletin form, holding classes or schools, and discussion among the men themselves with instruction of men at work by their immediate supervisors.

The enforcement of safety regulations is of primary importance in preventing explosives accidents because an experience that would prove the wisdom of one or more safety regulations usually comes too late to do a victim any good; another reason for supervising and enforcing regulations in blasting is the ease with which omissions and short cuts are adopted. Close supervision must be coupled with the fostering of a sense not only of individual but also of group responsibility for careful observance of safe blasting practices.

WHEN AND BY WHOM SHOTS ARE FIRED

Where room-and-pillar mining of flat-lying ore bodies is conducted in sections under close supervision, specialized loading and blasting crews are effectively employed to increase the safety of handling explosives and in blasting.

Blasting in shafts and development drifts is usually done at the end of a drilling shift, and blasting in stopes is usually done at the end of a working shift by the respective crews. Depending upon the type of development, secondary blasting in draw points, on grizzlies, and in chutes is done as frequently as conditions warrant.
Signal systems have been devised to warn employees of impending blasts. Warning-signal control points are usually placed on haulage levels, in scraper drifts, at grizzlies, and at draw points. Basic training for those engaged at any of these locations includes instructions on operation of the warning-signal system, the location of signal controls, and the places to which workers should retreat in the various work areas when a blasting warning signal is sounded.

Development and mining crews usually perform complete work cycles in the respective work places; each crew may be as small as 1 man and rarely include more than 5 or 6. Each knows the characteristics of the ground to be blasted; much of this knowledge is acquired while the rounds are being drilled. They therefore know the type and quantity of explosives necessary to break the ground satisfactorily.

Where blasting is done electrically, for example, lead wires from all rounds in one inclined stope may be extended from the various work places to a trunk blasting circuit, there to be connected first by the crew from the farthest removed working place and successively by the next crew when the first crew reaches the tie-in point of the second. This method is followed until all crews have left the stope. Each crew then proceeds to the final interrupter switch, where it must remove its tag or lock from the inside connection of the final break before the blasting switch is released. When all have been removed, connection can be made to the blasting switch where either the foreman or designated crew member fires all blasts. In development raises and drifts each crew makes its own connections, leg wires to lead wires, to blasting circuit through one or more interrupter switches, thence to the blasting switch and (depending upon whether other crews work in the area) shots are fired when all have left the working places and are accounted for at the blasting switch. Usually separate blasting switches are provided for shaft, development, and stope blasting.

Where locks have been provided for each crew the responsibility for all crew members is delegated to a crew leader. Locks are affixed to the door or handle of the blasting switch as each crew enters a work area, and each must be removed before the blasting switch can be operated. Some mines have adopted a system of tagging the switch; while not affording the positive protection of the locks, apparently this procedure has proved just as effective because its function is not so much to police as to remind.

**ELECTRIC VERSUS FUSE BLASTING**

Detonators are used to explode dynamites or other high explosives by the energy liberated as a combination of concussion and heat when fired. Commercial detonators have been developed in later years to be less sensitive and more efficient than the older capsules of mercury fulminate. A blasting cap for use with fuse consists of a metal casing closed at one end. The pressed charge of initiating explosive in the closed end is exploded when the safety fuse inserted in the open end burns down to the charge. The explosive in modern detonators consists of layers of different explosive mixtures or charges; there

---


386914 0—57——4
may be first a base charge at the end, next a priming charge, and at
the top an initiating charge. Manufacturers use various explosive
materials to make these charges.

Electric blasting caps have largely the same fundamental constitu-
ents as fuse detonators, with an electrical heating unit for igniting
the explosive charge. A short length of fine electric-filament wire is
in contact with the igniting portion of the charge, and the whole de-
tonator is sealed to make it impervious to moisture. The fine wire
filament or bridgewire is generally an alloy of platinum and other
metals or nickel, chromium, and iron. The bridgewire is made in-
candescent immediately by application of a small electric current,
which causes the ignition charge to burn and, in turn, to detonate the
priming and base charges. Movement of the terminals of the leg-
wires in the detonator may ignite the charge by friction, therefore
the legwires should not be jerked or worked loose.

Delay electric blasting caps are similar to electric blasting caps,
except that a delay element is inserted between the electrical firing
element and the detonating charges. They are used to detonate
charges of dynamite in rotation, and their advantages over caps and
fuse for this purpose are greater safety and more accurate timing.
Rotation firing has the general advantage that complete rounds can
be fired without returning to the breast.

Delay electric blasting caps are of two types—the regular and milli-
second. The regular are manufactured in 10 standard delay periods.
The time interval of delay for the first period is approximately 1 sec-
don, and the time intervals increase gradually up to approximately
2½ seconds between the 9th and 10th periods. The millisecond-delay
electric blasting cap differs from the regular type in that the delay
periods are very short. They are furnished in 14 periods, whose num-
bbers indicate the firing time in thousandths of a second (25/1,000 to
500/1,000 second).

Electric blasting is used widely in shaft sinking and driving long
raises and is general practice in wet places. The number of mines
in which it is used for all classes of work is increasing. The advan-
tages of electric blasting are:

- All persons can be in a place of safety before firing is done.
- Misfires are reduced, and delayed shots largely eliminated.
- Heavy smoke and gases from burning fuse are eliminated.
- More efficient blasting can be done in wet places.

The dangers or disadvantages of electric blasting are:

- Current may be applied prematurely to the blasting circuit.
- Stray currents may be encountered.

For blasting with fuse the advantages are:

- Less equipment is needed.
- The cost of supplies in ordinary blasting is slightly lower; where long fuse
  lengths are used the difference in cost is negligible.
- Blasting may be done safely where stray currents cannot be eliminated easily.

Disadvantages of fuse are:

- Men may overstay the time limit in attempting to light fuse.
- There are more chances of misfires and hangfires.
- Premature shorts are more frequent.
- More smoke and fumes are produced.
- There is greater danger of fire, unless special fuse lighters are used in place
  of matches or open lights.
Rubber-jacketed 2-conductor No. 12 jumper cable, equipped with special plugs. Removed after blasting and carried by person supervising charging and blasting.

Caution:
1. Do not remove short circuits from detonator leg wires until ready to connect to lead wires or bus wires.
2. Keys to blasting switch must be in possession of person supervising charging and wiring.
3. Short-circuits must not be removed from bus wires and lead wires until men are leaving preparatory to blasting.
4. All electrical connections must be carefully made.
5. Cross-bonding of rails and pipe lines to be not more than 100' from face. Tugger frames to be electrically bonded. Should be tested for voltage differentials when bonds are moved forward.

Power switch—25A-250V.—2P. Deion circuit breaker with receptacle for jumper cable with spring return to "open" position.

Blasting switch—60A—250V.—2P.—S.T. non-fuse safety switch. Remodeled to provide 2 extra clips mounted on an insulating support so that the blades will transfer automatically into these clips when the handle is released. These clips to be short-circuited by a jumper. Operating mechanism to be held in "open" or short-circuited position by means of a spring return added to switch. Switch also to be locked in "open" position.

Safety switch—Single-pole, normally closed switch with spring mechanism to hold switch in closed position. Hole in shaft of handle for pin to hold in "open" position when men go to blast. Switch may also be locked in "closed" position.

Blasting line—Not less than #12 2-conductor or 2 single-conductor, rubber-jacketed cable suspended on insulators on opposite side of drift from light and power lines.

Lead wires—Not less then #14 single conductor, rubber covered.

Bus wires—Not less than #16 (not ordinarily required, but may be necessary when blasting large rounds.)

Figure 23.—Switch and Wiring Diagram, Company A.
The advantages are with electric blasting; and it is probable therefore that this method gradually will supersede further the use of fuse. This conclusion is substantiated by the experience of the Miami Copper Co., where over 95 percent of the blasting is done with permanent electric blasting circuits.  

**ELECTRIC-BLASTING SWITCH ASSEMBLIES**

There are now commercially available a few electric-blasting switches. This was not true in 1945, when a survey of the electric-blasting practices was made in the Lake Superior district.  

This survey revealed that the blasting procedures and equipment in use, although similar, are not standard, even in mines operated by the same company. One factor contributing to this condition was that suitable electrical switches were not being manufactured at that time and that each electrical department was forced to remodel and assemble existent switches or build its own switches to fit its requirements.  

A summary comparison of the six electric-blasting switch assemblies described in the report reveals their similarities, advantages, and disadvantages.

Each assembly is composed of three main parts: (1) A device for protecting the power source against overcurrents; (2) a blasting switch, usually mounted near such device and incorporating a break or gap in the blasting circuit; and (3) a “safety switch,” installed in the blasting circuit at a point a safe distance from the blast. Five assemblies provide protection of the source of power against overcurrents by means of a fused switch, and one employs a circuit breaker.

Probably the most controversial point in connection with electric blasting is grounding. In general, ground connections are eliminated or avoided beyond the switch from which the blast is fired. It is especially important to avoid grounding the short circuits across the lead wires. Another point frequently overlooked in practice is proper insulation of the lead wires, especially at joints or splices; this is of paramount importance in protection against stray currents.

Two wiring diagrams and switch-assembly details are shown in figures 23, 24, 25, and 26.

The blasting switch assembly shown in figure 27 is used in all secondary blasting in block-caving operations at the asbestos mines at Thetford Mines, Quebec, Canada. It was designed by the safety engineer of Kenneth B. S. Roberson, Ltd., and has been used since 1940. Reportedly it has materially reduced explosives accidents at grizzlies and in scraper drifts.

Each installation illustrated serves two grizzly or slusher drifts, and to complete the electrical circuit after a blast or series of blasts is prepared crossovers must be plugged in at all crosscuts leading from adjacent similar working places. The crossover in each case is placed waisthigh and thus acts as a physical warning that blasting is about to take place.
Sprtrg to return switch to shortcircuited position

Figure 24—Details of Switches, Company A.
A, Power and blasting-switch unit; B, blasting switch (open); C, safety switch.
The positive warning system also includes protection to haulage crews on the level below in the form of blowing a siren in a timed cycle of 8 seconds on and 3 seconds off, with the blast timed at the end of the third "on" period.

The blasting circuit is shunted and grounded at all times. After a blast has been prepared the leading circuit is completed and plugged.
To manual blasting switch!

Details of Switches, Company B.

A. Main switch; B, manual blasting switch; C, magnetic blasting switch.

Figure 29—Details of Switches, Company B.
into the shunted switchbox. A starting button is then pressed to actuate the automatic switch. Through various relays and timing devices incorporated in the assembly the switch blows the warning siren on the haulage level the required number of times, and at the end of the 30-second interval lifts the shunt-and-ground to energize the blasting circuit for 3 seconds. After the blast is fired the shunt-and-ground conditions are restored automatically, and the line is blocked out.

Du Pont manufactures a blasting-switch assembly consisting of a blasting and sectioning switch. The blasting switch is quick-make, quick-break, spring-actuated, and oil-immersed. The design embodies two main principles—spring return to the “Off” or normal position upon release of the operating handle and automatic short circuiting of the firing lines when in the “Off” position by gravity.

The sectioning switch is an oil-immersed switch intended specifically for sectioning power-firing circuits between the blasting switch and the shot area or areas. When this switch is in the “Shunt” position it breaks both of the individual firing lines and provides a positive short circuit across them. When it is in the “Fire” position the short circuit is broken and the individual lines are joined. The switch should be in the “Fire” position before the blasting switch is thrown.

SOURCES OF INFORMATION

Information may be procured from the following firms and organizations:

- American Cyanamid Co., New York, N. Y.
- Atlas Powder Co., Wilmington, Del.
- Austin Powder Co., Cleveland, Ohio
- Columbia Powder Co., Tacoma, Wash.
- E. I. du Pont de Nemours & Co., Wilmington, Del.
- Ensign Bickford Co., Simsbury, Conn.
- Hercules Powder Co., Wilmington, Del.
- Illinois Powder Co., St. Louis, Mo.
- Institute of Makers of Explosives, 250 East 43rd Street, New York 17, N. Y.

These organizations and other explosives manufacturers maintain technically trained staffs to serve users of explosives. The Institute of Makers of Explosives or explosives manufacturers should be consulted on special problems in blasting.

CAP CRIMPERS

For both safety and efficiency, blasting caps must be fastened securely to safety fuse. Cap crimpers are specially designed to accomplish this, and no other device should be used for the purpose. There are two types of cap crimpers—the hand type and the bench type.

BLASTING MACHINES

Blasting machines supply current for firing blasts by electricity. There are two general types, the condenser-discharge type and the generator type. Generator machines are of the twist or pushdown type and have been the conventional equipment in use for many years. They are so designed that no current flows from them until the twist or rack bar reaches the end of the stroke, when the current is released to the firing line at close to peak amperage and voltage. Generator-type machines are intended to be used for firing in straight series; they can be employed under certain conditions for firing in parallel series but never for firing caps in straight parallel. Condenser-type blasting machines utilize dry-cell batteries to charge a bank of condensers; the condensers then can supply a high-voltage current of short duration to electrical firing devices.

The condenser-discharge blasting machines developed by Du Pont have a series of batteries for charging a bank of condensers, with appropriate switches, resistors, and wiring. According to the manufacturer they are characterized by: (1) Extremely high capacity for their weight and size, (2) absence of moving parts, (3) elimination of the human element of the mechanical type machines, (4) a test pilot light, and (5) a wiring and switching system embodying important safety features. In addition, the large machines can be used for firing blasting caps connected in parallel.

---

BLASTING GALVANOMETER

The galvanometer is of utmost importance wherever electric blasting is practiced. It permits a blaster to test individual blasting caps; to determine whether or not a blasting circuit is closed and in proper condition for firing; to locate broken wires, faulty connections, grounds, and short circuits; and to find the approximate resistance of a circuit. Use of this instrument not only saves time in electric blasting but, in addition, increases the safety of the operation by reducing the possibility of misfires.

SOURCES OF POWER FOR ELECTRIC BLASTING

SOURCES OF POWER

In electric blasting the usual sources of current are power circuits, blasting machines, or storage batteries. Power circuits may be alternating or direct current and include mechanically driven portable generators. The capacity of the power source, in volts and amperes, may determine the method of connecting the shots to be fired. The type of power available may also limit the number of shots that can be fired at one time by a particular power connection.

The characteristics of electric blasting caps make it necessary to supply current above a minimum strength (0.5 ampere) to assure the firing of all shots. A strong electric current will heat the bridgewire of an electric blasting cap to the temperature necessary to fire it almost instantaneously, while a weak current will take longer. With extremely weak current the time might be several minutes. As all electric blasting caps vary slightly in sensitiveness, one of the more sensitive caps may fire enough in advance of the others to break the circuit before the rest of the caps have received enough current to fire them. This trouble may occur when too many detonators are connected in the same circuit but is eliminated by allowing for a strong enough current to reach each cap to compensate for any slight variation in sensitiveness. The wiring circuit should be planned so that all caps will receive a generous excess of current.

OHM'S LAW

The current that will flow in any electric circuit will equal the potential of the power supply divided by the resistance of the circuit. This is Ohm's law, which is expressed by the equation,

$$ I = \frac{E}{R} $$

$I =$ current, in amperes;
$E =$ potential of the power supply, in volts;
$R =$ circuit resistance, in ohms.

METHODS OF CONNECTING BLASTING CIRCUITS

The two primary methods of connecting blasting circuits are series and parallel. Combinations of both may be used for large groups of shots or under special circumstances, but consideration of these combinations is not needed for ordinary blasting.
SERIES CIRCUITS

A series circuit is one in which the legwires of the caps are connected to each other in a continuous circuit and the two free end wires are connected to the lead wires from the firing circuit. In this type of connection each cap receives the same circuit, since there is only one path for the current through every cap in the series (fig. 28).

![Series Connection Diagram](image)

Twelve electric blasting caps connected in "series" and fired by a blasting machine.

This method has the advantages that less wire is needed for making connections, that broken wires of connections can be readily detected with a circuit tester, and that the resistance of the circuit can easily be computed. Disadvantages that may arise are that some caps might fail to fire if the current supplied is too weak for that circuit or if current leaks from uninsulated joints of legwires, so that only part of the current reaches the bridge of some caps.

PARALLEL CIRCUITS

A parallel circuit is one in which 1 legwire from each cap is connected to 1 side of the blasting circuit and the other legwire of each cap is connected to the other side of the circuit. In this kind of connection each cap offers a path for the current that will divide equally through each cap if the resistance is the same in each (fig. 29).

One advantage of a parallel connection is that each cap is independent of the other caps in the circuit, and variations in sensitiveness will not affect the success of a round. Tracing wires from hole to hole is not necessary as in checking a series connection; counting the wires connected to each buswire will give a check on the holes connected. Joints do not need to be insulated, as with series connections, but no direct short circuits can be allowed, as too little current would reach the bridgewires to fire the caps. Disadvantages of a parallel circuit are: A high-amperage current is necessary, the entire circuit cannot be tested with a circuit tester although each cap can be tested during loading, and more wire may be required than with series connections.

The parallel method reduces the probability of misfires and is preferable where practical.
Twelve electric blasting caps connected in "parallel" and fired from a power circuit.

**COMBINATION CIRCUITS**

Various combinations of series and parallel connections can be made which are used to accommodate the requirements of the blast to the power supply available. By using a suitable combination, such as the parallel-series connection, it is possible to fire more than 50 caps at one time with a single application of the current by a power circuit (and with certain limitations by a blasting machine (figs. 30 and 31).

Graded parallel-series circuits are made by placing any number of caps in a first series and increasing the number progressively in each...
Thirty electric blasting caps connected \textit{“parallel-in-series”} and fired by a powerline. In the above layout there are 10 caps in each parallel circuit and 3 parallel circuits-in-series. These circuits are connected in parallel to the source of power. This method supplies much stronger current to the first series of caps, because of its lower resistance, than to the second series and more to the second than to the third. Thus the different series will fire progressively if application of the current is continued. The time interval between the firing of the several series is negligible as a rotation factor. Use of the method is controlled by patent.

\section*{CALCULATION OF POWER FOR ELECTRIC BLASTING}

With knowledge of Ohm's law and also of the amount of current necessary to insure virtually instantaneous detonation of an electric blasting cap of a number of electric blasting caps in the circuit selected, it is possible to lay out a blasting circuit in such a manner that all caps will receive a current supply adequate to insure a successful blast. The circuit selected depends upon a number of factors, the most important of which are: (1) The nature and source of current available, (2) the number of caps to be fired, and (3) the total circuit resistance.

Following are examples of methods of connecting blasts using series and parallel circuits. These examples are for power circuits with 220-volt alternating current and for instantaneous electric blasting caps with copper legwires 20 feet in length. All lead and buswires are also copper.\footnote{E. I. du Pont de Nemours & Co. Inc., Explosives Department, Blasters' Handbook: 1952, pp. 201-208 and tables XIII and XIV.} In calculations of this kind it is necessary to have available the information on resistance given in tables 7 and 8.
TABLE 8.—Resistance of electric blasting caps, ohms per cap

<table>
<thead>
<tr>
<th>Length of wire, feet</th>
<th>Copper wire</th>
<th>Iron wire</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Instantaneous caps</td>
<td>Regular and “MS” delay caps</td>
</tr>
<tr>
<td>4</td>
<td>0.94</td>
<td>1.50</td>
</tr>
<tr>
<td>6</td>
<td>1.00</td>
<td>1.56</td>
</tr>
<tr>
<td>8</td>
<td>1.04</td>
<td>1.60</td>
</tr>
<tr>
<td>9</td>
<td>1.07</td>
<td>1.63</td>
</tr>
<tr>
<td>10</td>
<td>1.10</td>
<td>1.66</td>
</tr>
<tr>
<td>12</td>
<td>1.13</td>
<td>1.69</td>
</tr>
<tr>
<td>16</td>
<td>1.20</td>
<td>1.76</td>
</tr>
<tr>
<td>20</td>
<td>1.32</td>
<td>1.89</td>
</tr>
<tr>
<td>24</td>
<td>1.45</td>
<td>2.01</td>
</tr>
<tr>
<td>30</td>
<td>1.58</td>
<td>2.14</td>
</tr>
<tr>
<td>40</td>
<td>1.62</td>
<td>2.18</td>
</tr>
<tr>
<td>50</td>
<td>1.82</td>
<td>2.38</td>
</tr>
<tr>
<td>60</td>
<td>2.02</td>
<td>2.58</td>
</tr>
<tr>
<td>80</td>
<td>2.43</td>
<td>2.99</td>
</tr>
<tr>
<td>100</td>
<td>2.83</td>
<td>3.39</td>
</tr>
<tr>
<td>150</td>
<td>3.64</td>
<td>4.49</td>
</tr>
<tr>
<td>200</td>
<td>4.85</td>
<td>5.41</td>
</tr>
<tr>
<td>250</td>
<td>5.36</td>
<td>6.42</td>
</tr>
</tbody>
</table>

SERIES CIRCUITS

An advantage of the series connection (fig. 28) is that it can be tested readily with a blasting galvanometer, and it is possible to tell at any time before firing whether or not there is a break or poor connection anywhere in the circuit.

The following calculation of a series circuit involves 30 delay electric blasting caps with 8-foot copper legwires, connected to two 1,000-foot, No. 14, single lead wires.24

With a series connection the current supply should be at least 1.5 amperes. The voltage required for any given series can be found by calculating the total resistance in ohms and multiplying this by 1.5 amperes. The total resistance of the circuit under discussion equals the combined resistance of the 30 blasting caps plus the resistance of twice 1,000 or 2,000 feet of No. 14 leading wire.

\[
\begin{align*}
(a) & \quad 30 \times 1.63 = 48.90 \text{ ohms.} \\
(b) & \quad 1,000 \times 2 \times 2.58 + 1,000 = 5.16 \text{ ohms.} \\
(c) & \quad 48.90 + 5.16 = 54.06 \text{ ohms.}
\end{align*}
\]

The voltage required is equal to the total resistance multiplied by 1.5 amperes, or

\[(d) \quad 54.06 \times 1.5 = 81.09 \text{ volts.}\]

Since this figure represents the voltage drop through the blasting circuit, it is evident that these caps can be fired with a 110-volt power circuit or generator, or a 30-cap blasting machine.

The theoretical power required for this blast is the square of the current multiplied by the resistance \( (I^2R) \), or

\[(c) \quad (1.5)^2 \times 54.06 = 121.63 \text{ watts.}\]

The above example is applicable to series circuits containing either delay or instantaneous electric blasting caps alone. The resistance for instantaneous blasting caps is less than for delay caps. Series containing both instantaneous and delay caps are known as mixed series and are not recommended by the Bureau of Mines.

Experience has shown that, in primary or other important blasting, it is best practice to limit the number of electric blasting caps to a maximum of 50 caps per series, irrespective of the source of power. If more than 50 caps are involved in such blasts it is recommended that parallel-series circuits be used.

When firing is to be done with a blasting machine the total resistance of the circuit must not exceed the capacity of the machine. A blasting machine is a portable device of definite limits and is rated according to the number of 30-foot copper-wire delay electric blasting caps for which it will produce ample current for a straight series connection, and firing more than the rated number of caps should not be attempted.

**PARALLEL CIRCUITS**

The multiple path through which the current travels in a parallel circuit (fig. 29) calls for a much higher amperage requirement than in a series connection, which has but one path (fig. 30); each path in a parallel connection must be provided with enough current to cause the detonator in it to fire. The current in the leading wires must be increased in direct proportion to the number of caps.

The following example illustrates the method of calculating a straight parallel blasting circuit consisting of 75 instantaneous electric blasting caps with 20-foot copper leg wires connected to 400 feet of No. 14 buswire and two No. 12 lead wires, each 1,000 feet long.\[25\] In the straight parallel circuit it is good practice to allow 0.5 ampere per cap.

Seventy-five caps at 0.5 ampere per cap require a total current of

\[(a) \quad 75 \times 0.5 = 37.5 \text{ amperes.}\]

When electric blasting caps are connected in parallel, their total resistance equals the resistance of the single cap divided by the number of caps, or, in this case,

\[(b) \quad 1.45 + 75 = 0.0193 \text{ ohm.}\]

It will be noted that the calculated resistance of the caps is very small; and, as is usually the case, it is satisfactory to disregard this figure in making calculations and to consider only the resistance of the bus and leading wires as the total resistance of the circuit. Further-

---

more, in assigning a value of resistance of the buswire it is customary to consider only one-half of its total length, which in this instance would be $400 \div 2 = 200$ feet.

(e) $200 \times 2.58 \div 1,000 = 0.52$ ohm.

The resistance of the lead wire is then

(d) $2,000 \times 1.62 \div 1,000 = 3.24$ ohms.

The total resistance is then

(e) $0.52 \times 3.24 = 3.76$ ohms.

The voltage required is the product of the resistance and the current, namely

(f) $3.76 \times 37.5 = 141.0$ volts.

The theoretical power input for this blast is

(g) $(37.5)^2 \times 3.76 = 5,287.5$ watts.

Firing of this blast should not be attempted with a 110-volt source of power under the above conditions. The use of heavier wire would reduce the resistance of the circuit and make possible the use of a 110-volt source of power.

Either direct or alternating current can be used in firing electric detonators, but with alternating current misfires may occur if less than 25 cycles is employed, and 60 is recommended. Where alternating current is used measurements on which computations are based should be taken at the point where the blasting line is connected to the powerline. Any voltage can be used with either type of current, provided it is sufficient to deliver the required amperage. Voltages above 440 introduce problems of insulation that make them difficult to work with from an electrical standpoint.

SAFETY PRECAUTIONS IN ELECTRIC BLASTING

SAFETY PRACTICES

Variations in the resistance of the bridgewires in electric detonators of different types or from different manufacturers are not overcome by normal firing methods; current sufficient to heat the wire in one cap to a temperature that will ignite the charge may be insufficient for another type of detonator, causing a misfire or improper firing. Consequently, electric detonators of different types or from different manufacturers should never be mixed when a round is fired.

In a number of mines some difficulty has been experienced in using instantaneous electric blasting caps with delays. Investigations by mining companies showed that, under certain conditions, instantaneous caps may detonate before the delay bridges are fused, resulting in misfires of the delays. This difficulty was noted in blasts where several circuits of varying size were fired simultaneously. Explosives manufacturers advise that, although instantaneous electric blasting caps can be fired in the same series with delay electric blasting caps, it is preferable to put the instantaneous caps in one series and each period of delays in a separate series and to connect the series in parallel.

Troubles with electric blasting may be due to a poorly installed blasting circuit, insufficient current, poor connections at the face, use of wrong delays or wrong blasting order, and overloading of blasting machines. Misfires should be much less frequent with a properly installed electric blasting system than with fuse; for this reason, electric blasting properly done is likely to be safer and often more economical. Experience has shown that the kind of man commonly spoken of as the average miner can be trained to use electric blasting.

Perhaps the chief dangers in electric blasting are from premature shots caused by making connections to charged lines, accidental contact of exposed wires with charged surfaces, or stray currents.

Safeguards against these dangers, as practiced in a carefully planned system of electric blasting at a large metal mine in the West, are illustrated in photographs of vital steps in the method. In figure 32 the legwires of detonators in a round of holes are being connected to 2 buswires suspended from wooden pegs, which are placed in short holes drilled for the purpose. The terminals of lead wires are kept short circuited until ready to be connected to the firing circuit, as in figure 33. After connection to the firing circuit is made with a plug, as in figure 34, the miner closes a switch at a central point to connect the stope circuit to the main blasting circuit, as shown in figure 35. The miners remove their check numbers from a section board (fig. 36) to show that they are out of the area, and the actual blasting is done by a foreman by means of a firing switch on the main circuit (fig. 37) after he has checked to see that all men in the area are out.

The metal frames of power switches used in blasting should be grounded to a low-resistance ground for the operator's protection and to minimize the hazard of lightning. Blasting switches, plugin receptacles, and shunting switches in the blasting circuit should never be grounded, and preferably they should be insulated from ground or other possible sources of stray currents.

Permanent blasting wires should end a safe distance from the working place, and from this point to the face lead wires should be used. These lead wires on a roll should be taken into the face by the miners at blasting time; after connecting to the legwires or connecting wires, miners should unroll the lead wire as they retreat from the face, supporting it on nonconductors, and make the connection to the permanent line. Under no consideration should anyone string lead wires on his way to the face to be blasted, as this enhances the dangers from stray currents. Miners should also inspect blasting switches and interrupter gaps to see that they are locked in the off position before entering the face to blast.

All wiring installations pertinent to electric blasting should be installed carefully and inspected at frequent intervals.

**Stray Currents**

Electricity as used about a mine always will attempt to return to its source, which may be a battery, a generator, a motor-generator set, a rotary converter, or a transformer; it will return to that source over the paths having the least resistance. With the large amount of electrically operated equipment in mines it is not strange that occasionally electric currents travel back to their sources through the ground or by
way of wet timber, air and water lines, and the armored covering of transmission cables. Generally these return currents are so weak that they can do no damage; occasionally, however, they are strong enough to detonate a blasting cap and are distinct hazards. None of these currents should be picked up by the lead wires, as a premature explosion can occur when the miner connects the lead wires to the detonators. To pick up such a current and cause the explosion, it is only necessary for one of the blasting wires to come in contact with the object carrying the current, such as a pipeline, while the other is in contact with the ground.
The hazard of stray currents in electric blasting can be very greatly reduced, if not eliminated, in most mines (1) by reducing or preventing the stray currents and (2) by safeguarding blasting circuits so that stray currents will not reach the detonators. The first can be accomplished by secure bonding of the rails used by trolley locomotives and by grounding electric equipment, such as fans and hoists, as well as pipelines, armored cables, and other possible conductors. Lead wires and detonator legwires should be short-circuited up to the time of connecting the detonator and lead wires. Testing the lead wires with a meter or with an electric igniter without a cap will give assurance against danger from stray currents, except that of a possible
surge occurring while the connection is being made. Lead wires should be thoroughly insulated and as a further precaution should be divided into sections by switches or removable lengths of wire. The ends of such sections should be short-circuited.

Explosives manufacturers have perfected instruments by means of which stray currents can be detected before final hookup to the blasting switch is made.

One of the mines on the Vermilion range in the Lake Superior iron district uses all the safeguards that have been mentioned and also has an air-operated relay switch installed close to the face to be blasted. This switch is open while the legwires are being connected and closed.
FIGURE 35.—Electric Blasting—Miner Closing Switch of Stope Circuit to Connect It to Main Blasting Circuit.

FIGURE 36.—Electric Blasting—Miners Remove Checks From Section Board as They Leave Area.
by the miner on his way from the face by means of an air valve a safe distance from the face.27

Mines of the Tennessee Copper Co. are in ore of a heavy sulfur and iron content, and ignitions of sulfide dust had occurred during blasting with caps and safety fuse.

Electric blasting was installed in these mines in 1940.28 The change had been made primarily to permit the blast rounds to be fired from a safe distance.

In this system the current for blasting is taken from 220-volt alternating-current lines or from the 250-volt direct-current trolley wire. Blasting machines are used where these currents are not available. The installation is safeguarded by the available known means of eliminating stray currents and, in turn, premature detonation of explosives.

Tests throughout the Boyd mine showed the existence of fluctuating stray direct currents ranging from 0.1 volt to 26 volts. The minimum current necessary to explode an ordinary electric blasting cap is approximately 0.35 ampere, and the minimum voltage required is 0.75 volt. Tests on the alternating-current circuits indicated that the insulation was effective in preventing dangerous stray currents from this source, but high voltages were found when drifting from one ore body to another through a rock section.

The Tennessee Copper Co., realizing that stray currents could cause premature explosions and that the ore itself was almost a perfect electric conductor, requested the Bureau of Mines to assist it in a study of these stray-current conditions. The result of this investigation was that it would be difficult, if not impossible, to eliminate dangerous stray currents from direct-current sources as long as trolley haulage was employed.

Since electric blasting was a necessary part of the operation, other types of locomotives were investigated. As a result, storage-battery locomotives were put into service during 1945. After 3 years of service the storage-battery locomotives have reduced stray currents to a minimum and otherwise are operating safely and efficiently.

In a northeastern United States magnetite mine electric blasting is not used because of the ever-present possibility of stray currents. As the result of Bureau of Mines recommendations and subsequent experiments all development drift and raise rounds are fired by means of Ignitacord.

Other methods that may be used to reduce the dangers of stray currents are substitution of diesel locomotives for trolley-locomotive haulage or installation of large return conductors bonded at frequent intervals to the rails, pipelines, and current-conducting ore bodies.

**STATIC ELECTRICITY**

In addition to stray currents from leaking power circuits, static electricity must be considered a possible hazard in electric blasting. One form that is not man-made and cannot be controlled is that caused by lightning. The only protection against such currents where electric blasting is being used at surface operations, or in mines where conductors extend from the blasting lines to the surface, is to refrain from loading holes or attempting to blast during thunderstorms. In such circumstances, if holes are already loaded, men should be withdrawn from the vicinity until the danger from lightning is past.

An example of the disasters that may be caused by the detonation of explosives charges by lightning occurred in 1918 at an opencut iron mine in the Lake Superior district. Coyote holes and connecting drifts in a 40-foot bank had been loaded with black blasting powder and dynamite, and electric detonators were used. While a crew was placing stemming in the coyote holes, an electrical storm and heavy rain passed over the mine. Lightning struck somewhere, setting off several charges; the blast caused the bank to cave, killing and burying 18 of the 19 men in the crew.

In 1937 a similar accident happened in a deep shaft mine, where a crew of 17 men was preparing a number of holes for electric blasting. Lightning struck near the headframe on the surface, and an electric charge passed through a bell line to the working place 4,000 feet below. Eleven holes were detonated, killing 8 and injuring 4 of the crew.

In some circumstances machinery will build up static charges when in operation, but if an effective grounding system is provided, these static charges will be released before they become dangerous.

USE OF EXPLOSIVES AND DETONATORS

RADIO-FREQUENCY ENERGY

Radio transmitters can cause premature firing of electric blasting caps, even though there is no physical connection between them. The chance is extremely remote, however, because it requires a combination of circumstances that is very unlikely to occur in actual practice. The most important factors involved are the transmitter power, the transmitter frequency, the position of the transmitter antenna and circuit, and the position of the cap in the circuit.

With comparable power, high-frequency stations are less likely to fire caps than low-frequency, because the conditions for maximum energy transfer are much more critical.

Current induction is at its peak when the cap circuit is parallel to and in the same plane with the antenna. Horizontal antennas are therefore potentially more hazardous than vertical, because most cap circuits are laid out on the ground. Similarly, the most dangerous condition is when the cap circuit parallels rather than is at right angles to the horizontal antenna and is also in its zone of maximum radiation.

A simple test procedure to determine whether or not blasting in areas where radio transmitting equipment is used is hazardous has been developed. In surveying an area or testing a transmitter it is obvious that conditions should deliberately be made as hazardous as they ever conceivably could be. The test circuit, therefore, should consist of a straight piece of wire of exactly half the radio wavelength (or a multiple thereof) with a No. 47 radio pilot lamp (or its equivalent) in the center of the wire. This should be held off the ground, parallel to the transmitting antenna and as close to it as any blasting would ever be done. If any glow is observed electric blasting is not advised. The half wavelength can be computed in feet by dividing 500,000 by the frequency of the transmitter, in kilocycles.

GALVANIC ACTION

An aluminum loading pole designed to replace the heavier wooden loading pole in seismic shooting experienced a short career in the field. Not long after the new pole was adopted a seismograph crew had two premature detonations that were definitely traced to the battery effect developed by the aluminum loading pole, the steel casing in the shot hole, and the alkaline drilling mud. Laboratory measurements indicated a working potential of approximately 1.25 volts (theoretical value = 1.26 volts) for an aluminum-iron cell containing a slightly alkaline electrolyte. In subsequent field tests duplicating the accident conditions, electric blasting caps were fired repeatedly.

It is obvious, therefore, that only wooden or other nonmetallic loading poles should be used.

PRECAUTIONS IN USING FUSE

If the precautions in storing fuse that have been discussed are followed fuse should reach the distributing station in good condition. Care must be exercised to prevent damage to fuse through all stages of

---

blasting to reduce the chances of misfires, delayed shots, or even premature detonations. Any kinking of fuse while it is being brought to the working place or during loading may cause a break in the powder train that will cause a misfire or a delay in firing; cracking of the covering of the fuse may admit moisture or allow side spitting, which can ignite the explosive charge. This latter condition may explain some of the reported accidents from "fast fuse." If the end of a length of fuse is wet, frayed in cutting, or not cut straight across before being inserted in a detonator, a misfire is likely.

Fuse should not be uncoiled while cold, as it may crack and admit moisture. Oils such as gasoline or kerosine, grease containing light oils, turpentine, or linseed oil should not be allowed to come in contact with the fuse, as these oils may penetrate to the powder and cause misfires.

When a new spool or reel of safety fuse is unpacked in the fuse-capping room a piece of exact length (3 feet) should be cut from a section beginning 2 to 5 feet from its end to which a cap should be crimped. It should be placed inside a section of pipe or other protected place, spit, and its burning rate accurately determined. Any appreciable variation from the burning rate of 1 foot in 40 seconds should be made known to all who use capped fuse. Where coiled fuse is used, a section should be tested for each coil.

The burning rate of the most commonly used fuse is about 40 seconds to the foot. Short fusing should not be tolerated, and no fuse under 30 inches in length should be used in blasting. A minimum length of fuse should be adopted for each class of work, and fuse should always project at least 1 foot out of the hole. A standard practice should be adopted by each operation for trimming fuse to insure proper rotation of shots and to avoid cutting any fuse too short for safety. The use of master fuse lighters and igniter cord or the practice of "bunch spitting" helps to decrease the time consumed in lighting rounds. Some timing device should be provided to insure against overstaying the safe limit of time while spitting; hot-wire spitters are being widely used for this purpose, but the advantage of their use is lost if men do not leave when the spitter is burned out. When all the holes cannot be safely lit with 1 spitter, 2 men can divide the work if their spitters are lighted at the same time. There should be the fewest number of men possible at the face during spitting, as unnecessary men only increase the exposure and may confuse or distract the miner doing the spitting; where one man spits all the holes another should be present to give any needed assistance in spitting or supplying a light.

Tools, excess explosives, or other materials should be taken from the face to be blasted, and all necessary work should be completed before spitting. Air or spray valves should be so arranged that no time is lost in opening them on the way out.

**POSITION OF DETONATOR IN PRIMER**

**REQUIREMENTS FOR PRIMERS**

A primer is a cartridge of explosives containing the detonating device for setting off an explosive charge. It is placed in the borehole...
so that the remainder of the charge is detonated when the primer is fired. Primers should be made carefully to meet the following requirements for safety and reliability of results: 38

The primer should be assembled so it can be loaded safely, easily, and in the preferred position in the charge (figs. 38 and 39).

The detonator should be secured so that it cannot be pulled out of the primer cartridge without some effort. The fuse should not be subjected to sharp bends or the wires of electric detonators to tight knots.

The cartridge should not be slit, as the whole cartridge is necessary to hold the detonator properly and to protect it from abrasion, friction, impact, and pressure during loading.

In preparing primers maximum protection is afforded the detonator when it is put in the exact center, parallel with the long axis of the cartridge; however, this arrangement may present difficulties in loading, and modifications may be made accordingly. Holes for inserting detonators in cartridges may be punched with a pointed punch of wood (fig. 40) or nonsparking material, such as the handle of a cap crimper. The hole should be longer than the detonator and big enough so the detonator can be inserted without use of pressure. In the method generally recommended the hole for the detonators is made in the end of the cartridge so that when the detonator is inserted it will be approximately in the center, entirely surrounded by the explosive, and protected from impact, friction, and contact with the walls of the blasthole. Another method is to punch a slanting hole in the side of the cartridge and near the middle so that when the detonator is placed it will be approximately in the center of the

---

cartridge; this method has some hazards and disadvantages. When capped fuse is used it should be tied to the cartridge with string to prevent the detonator from being pulled out in handling.

Any hole not in the center of the cartridge is unsatisfactory, as the detonator will not be in proper position for efficient work and may result in accidental detonation upon impact when handling or loading. Fuse should not be laced through a cartridge, because the bending may result in cracking the protective covering of the fuse, making it pos-
sible for moisture to enter and cause a misfire; besides, there is an added chance of side spits igniting the charge.

In a method of making primers that has been generally used in some sections of the Southwest, the capped end of the fuse is inserted centrally in one end of the cartridge; the primer is placed near the bottom of the hole, with the end containing the detonator in that direction and the fuse turned back along the cartridge. This method has the advantages that the primers can be easily made and quickly loaded, the detonator and fuse are not easily pulled out in loading or by the firing of other holes, the charge can be tamped, and the detonator is pointed toward the bulk of the charge. The disadvantage of the sharp turn of the fuse around the end of the cartridge is that the fuse may be pinched, cutting off the train of fire, or moisture may enter through cracks at this point. This type of primer has been successful only in dry holes, with good grade of fuse at warm temperatures, and is not recommended by explosives manufacturers.

Primers with electric blasting caps can be made safely with either of the methods described for detonators and fuse. Manufacturers of explosives recommend making primers with electric blasting caps by punching a hole from the center of one end of the cartridge in a slanting direction to come out at the side 2 or 3 inches from the end, doubling over the legwires of the electric blasting cap and pushing them through the hole and looping them around the cartridge, punching another hole in the same end straight down, and inserting the cap so that it is well covered by explosive and takes up the slack on the wires. In this method the wires do not cross each other, and the detonator is correctly placed in the cartridge. A satisfactory primer is made by one hole punched axially in the end and another horizontally through the cartridge. The cap wires are doubled over and threaded through the horizontal hole; then they are separated and looped around the cartridge. The cap is inserted in the end hole and the wires pulled tight. The primer may be used without regard to the direction toward which the cap is painted, but it obviously requires more time to prepare than the half-hitched type.

Another method of priming with an electric detonator that can be used with less difficulty for small-diameter cartridges and will enable the primer to be used either near the top or the bottom of the borehole consists in punching a hole transversely through the cartridge, running the cap through this, and then punching another hole in the top of the cartridge for the cap. This avoids crossing the wires and places the cap in the proper position pointing toward the bulk of the charge. Such a primer does not hang vertically from the wires and hence is not so convenient for loading in vertical as in horizontal or slanting holes.

A girth hitch or double half hitch, made with the detonator legwires around the explosive cartridge, will prevent tension upon and movement of legwires between the hitch and the detonator, thus eliminating one cause of dislodging the detonator during loading.

In priming with delay electric detonators it may be difficult to punch a hole long and large enough in a cartridge to take the longer delays, and forcing the detonator into hard or tightly packed cartridges is likely to ruin it. In such instances it is better to cut the cartridge lengthwise down one side, place the detonator inside, then close the halves tightly about the detonator and tie them securely.
Sheathed primers are made up with cardboard or paper tubes closed at one end. They may be used with either electric blasting caps or safety fuse and caps. The sheath, when slipped over small-diameter assemblies, prevents the cap from coming out of the primer, adds rigidity, and minimizes abuse to the primer cartridge during loading. It has particular merit in rough holes but does, however, increase the noxious fumes somewhat.

**SAFETY PRIMERS**

Safety primers of wood or fiber have been tried at a number of mines and tunnel projects. These are plugs with holes for the detonators and wires in which the live ends of the detonators are flush with the ends of the plugs. The primer is placed in the bottom of the hole, with the detonator pointing back toward the collar. The advantages are that explosives are not left in the bottom of the hole, the detonator is held parallel to the charge, explosives at the bottom of the hole can be strongly tamped without danger of accidental discharge, and live primers thrown out in the muck pile are less dangerous.

The use of safety primers has not become general, probably because they must be placed in the bottom of the hole (which may not be favorable to full efficiency of the blast), the volume of carbon monoxide produced is increased, and there is a small extra cost. It is also probable that one reason for slow acceptance of such a device is the inertia brought about by established practices. Bureau of Mines tests with wooden and cardboard safety primers at the Mount Weather (Va.) Testing Adit indicated that about twice the volume of carbon monoxide is produced when these safety primers are used in firing an average 4-foot round; the proportion would be decreased in firing rounds of greater length. In well-ventilated places the disadvantage of the increased carbon monoxide should be weighed against the benefits derived from the greater safety in handling and loading wooden safety primers.

**POSITION OF PRIMER IN BLAST HOLE**

The position of the primer in the blast hole affects the efficiency of the explosives charge and the possibilities of misfires. Detonation of the primer has greater force in the direction in which the base of the detonator is pointing. Where one or more holes are blasted simultaneously it may be advantageous to place the primer near the outer end of the charge; the base of the detonator should then be pointed toward the bulk of the charge. Where stemming is used one cartridge should be placed between the primer and the stemming to protect the primer from damage and prevent accidental detonation during tamping. Instantaneous detonation of all block holes at a given location will lessen misfires caused by cutting or pulling out legwires.

The primer itself should never be tamped. In raises or wherever holes inclined upward are loaded the primer and the following cartridge should be put into the hole at the same time. When this is done enough pressure may be applied with the tamping stick to insure that the primer will stay in place.

In rounds loaded with the primer second from the back of the holes those with electric detonators can be safely placed so that the detonators point toward the bulk of the charge. If fuse is used it must
be bent around the end of the primer cartridge, in order to point toward the bulk of the charge. In wet ground the concussion of blasting may force moisture into the fuse at such bends, causing misfires; to avoid this risk the primers of lifters may be placed near the outer end of the charge with the detonator pointing inward, as there is less danger of the fuse of such holes being cut off.

In hard rock the explosive must be compacted in the drill hole to have as great a loading density as may be obtained by ordinary methods to secure the maximum effect of the explosive and to make sure that the detonation will not be halted by any gas in the charge. Except for the primer, the charges should be tamped to completely fill the section of the drill hole, and to do this it has been general practice to slit the paper of the cartridges, which allows them to spread when pressure is put on them with the tamping stick. A type of cartridge has been developed with a perforated-paper wrapping so that slitting is unnecessary. The space in the drill hole is usually incompletely filled unless the explosive used is of a plastic nature; unless the hole is firm rock gaps may be caused by loose material between the cartridges or irregularities in the sides of the hole. If the loading stick does not have a square-cut end nearly the diameter of the drill hole, a cup-shaped cavity may be formed in the end of each stick of explosive as it is tamped. If the explosives in a hole are not closely compacted or if they become separated by the pressure changes caused by blasting other holes, part of the charge may not detonate and will be found in a bootleg or in the muck pile. In long holes loaded with long columns of dynamite, including well-drill holes, a primer may be placed near each end of the column, or Primacord may be used. Primers may be placed in the middle of a charge of explosives of a less sensitive type; in loading sprung holes primers usually are placed in the center of the charge.

The initial impulse imparted to a primer by explosion of the detonator should increase to the normal rate of detonation of the explosive under favorable conditions. The explosive wave is then propagated throughout the charge by the explosive itself and under favorable conditions will continue at the normal rate for that explosive. The intensity with which the detonation is carried through the charge depends upon the sensitiveness of the explosive, the diameter of the cartridges, the manner of loading, and probably other factors. With certain types of explosives having low sensitivity, propagation cannot be depended upon, and use of multiple detonators or Primacord is advisable.

LOADING HOLES

HAZARDS OF EXCESSIVE FORCE IN LOADING

A big proportion of the premature explosions reported during the period covered by table 5 occurred in loading blast holes. These accidents resulted from failure to protect the primers and explosives from impact, grinding, friction, sparks and flame. In loading small-diameter blast holes cartridges of suitable size usually can be pushed to the back of the hole without opening them or cutting them into small pieces; the cartridges may be slit to aid in compacting the charge, but the paper should not be removed. With large-diameter, vertical blast holes, if the holes are straight and smooth the cartridge
can usually be dropped free to the bottom of the hole. This is common practice and is considered safe in shallow holes or in smooth, deep holes in which the cartridges fit tightly enough for air pressure beneath them to retard their fall. In rough holes or those where the cartridge might fall too rapidly the charge should be lowered with a rope. Straight nitroglycerin dynamite should not be dropped. If a blast hole is so ragged that explosives cannot be lowered, cartridges may have to be cut into pieces, which are dropped a few at a time. Gelatin dynamite and ammonia-type granular explosives are preferred for work of this type.

The Institute of Makers of Explosives does not recommend straight nitroglycerin dynamite for large-diameter vertical holes under any circumstances, because it is too sensitive for safety in this kind of work.

Whenever the explosive blocks the hole it is hazardous to drop a heavy tamping block on it or to hammer it with a tamping bar. Such pounding, used either as an attempt to move explosive stuck in a hole or merely to pack the charge more tightly, caused about one-fifth of the serious explosives accidents in mines listed in table 5; more accidents were ascribed to this cause than to any other.

The Institute of Makers of Explosives states that explosive stuck in large-diameter holes may sometimes be freed by punching a hole in it with a light, thin pole or a pointed tamping block but warns that there are times when the hazard is so great that it would be wiser to let it alone and either load on top of it or detonate it. In large-diameter, vertical blast holes very little or no tamping is necessary; in smaller diameter holes it may be desirable to tamp the explosive in the bottom of the hole, but violent use of the tamping block must be avoided.

The same principles apply to loading the smaller diameter blast holes used in mining, at whatever angle they are drilled. It is always dangerous to force a cartridge into a blast hole of any diameter. Cartridges should be of a size to slide easily into the hole, and the holes should be drilled as nearly uniform and even as the nature of the material will allow.

The tamping stick should be a wooden rod with a square-cut end and should have no metal parts. The principal source of danger in tamping holes is from grit, hence holes should be made as clean as possible with a scraper or blowpipe (figs. 40 and 41) before starting to load. If tamping is done so violently that the rod penetrates the cartridges of explosives, some of the explosives may be smeared on the rod and on the sides of the hole. Grinding of the rod against the grit and walls of the hole may strike a spark, which may explode the smeared dynamite and detonate the charge; or heavy impact of the rod against irregularities in the hole may explode such smeared explosive, especially if there is metal in the rod. A short, firm stroke is recommended. Figure 42 shows a drift round of holes loaded and ready for blasting.

Plastic pipe of proper diameter and length, with either a wooden or plastic plug in one end, is being used at a number of mines for loading long, small-diameter blast holes. This has proved an effective and convenient tamping tool.
The employment of air loaders to place loose bag powder in sprung vertical and horizontal drill holes in quarries met little success. Use of these machines to charge horizontal holes has resulted in a number of premature explosions in which the explosion occurred in the loader or in the hole or in both.

Mining Engineering\(^3\)\(^4\) describes a pneumatic device that enabled the Malmberget mines of Sweden to increase their loading density materially per foot of drill hole.

The following is a practical example of the charge per foot obtained in 36-mm. drill holes:

1. Loading normal cartridges with wooden stick, 0.34 pound of dynamite per foot of drill hole;
2. loading 5-foot-long cartridges of larger diameter, 0.58 pound of

dynamite per foot of drill hole; and (3) loading by means of the pneumatic device, 0.81 pound of dynamite per foot of drill hole.

The pneumatic charging apparatus manufactured by the Nitroglycerin AB in Stockholm, is shown in figure 43 and is described as follows:

The charging pipe is equipped with a back piece which can be opened and closed and through which the cartridges of explosives can be inserted. The diameter of the cartridges must be 1 to 2 mm. smaller than the internal diameter of the pipe so a current of air can pass between the cartridge and the wall of the pipe. Compressed air is supplied through a hose connected to the back piece. A choke flange in the air intake limits the amount of air admitted so the cartridge will not exceed a maximum speed of 33 feet per second.

The pipe is equipped with a nozzle in the front end, the internal diameter of which is the same as the diameter of the cartridge. When the compressed air is turned on, the current of air draws the cartridge with it until the front end reaches the nozzle. The air is thereby hindered from streaming out. The pressure in the pipe rises, and the cartridge is forced out into the drill hole, whereupon three steel edges on the inside of the nozzle cut up the paper casing of the cartridge with lengthwise cuts. The split cartridge can easily be packed together with the help of the charging pipe so that the dynamite fills the hole completely. The pipe is then drawn out, and the next cartridge is pressed forward and packed in the same manner.

Figure 41.—Preparing Primers and Loading Holes.
Confining the charge in the hole with suitable stemming material contributes both to the safety and efficiency of blasting. The principal advantages are that the charge is protected from ignition except through the fuse, the charge is protected from the effects of the explosion of preceding holes, the amount of poisonous gases produced is decreased, and the efficiency of the explosive is increased appreciably.

Tests at the Mount Weather (Va.) Testing Adit of the Bureau of Mines led to the following conclusions in regard to blasting with and without stemming:

Blasting a number of rounds with no stemming proved only 72 percent as efficient as when 2 cartridges of sand stemming per hole were used with 40-percent ammonia gelatin dynamite.

Blasting a number of rounds with no stemming proved only 77 percent as efficient as when clay or sand stemming was used with 60-percent ammonia gelatin dynamite.

The volume of poisonous gases produced was increased when rounds did not break efficiently. The reduction in the quantity of dynamite required when stemming was used resulted in a corresponding decrease in the amount of gases produced; this decrease was greatest when the use of stemming confined the explosive so that it was as completely detonated as is practically possible.

Where combustible materials were used for stemming, such as wooden, rubber, or cotton plugs, there was a considerable increase in the carbon monoxide produced.

Besides the saving in the amount of explosives necessary to break a round which frequently results from the use of stemming, there is added safety in that the stemming can be tamped more solidly without danger of accident than the explosives themselves.

BLASTING WARNINGS AND SIGNALS

In every kind of blasting ample warning must be given before firing, and all persons in the vicinity must go to places of safety and remain there until the blast is completed. Failure to heed blasting warnings and failure of the person doing the firing to make sure that the warnings have been understood and heeded have been responsible for numerous accidents in both surface and underground blasting.

In surface blasting, where "springing" shots and secondary blasting are frequent, portable iron shelterhouses often are used to afford safe refuge for men relatively near the blast, thus avoiding the necessity of longer retreats over broken material. Strong timber shelters may serve the same purpose. All approaches to the blasting area should, of course, be guarded. A code of blasting signals should be used and all employees familiarized with it.

In underground mines where blasting is necessary during the shift warning signals should be established, and satisfactory signaling devices should be provided. A warning should be sounded before each blast is fired, and all possible approaches to the location where the shots are about to be fired should be guarded.

Signals used in areas of frequent blasting may be given with electric lights and/or electric sirens or air whistles. The signals should be put on before the fuse is lighted or the blasting switch is connected to the firing line and remain on until after the charge has detonated. Men hearing or seeing these signals should warn others in the vicinity, and all should retire to a safe place. They should not return to the blasting area before a "Clear" signal is given. The blasting schedules of crews in working places that approach each other as they are advanced should be prearranged and controlled by supervision when the places are 30 feet or less apart.

BLOCKHOLING AND MUDCAPPING

Secondary blasting is necessary when rock has broken into boulders too large to handle by the regular means of loading and transportation. In general, two methods are used for breaking up the rock—
one called “blockholing” and the other “mudcapping,” “bulldozing,” or “doby ng.”

The most economical method of using high explosives is to confine them in a drill hole well tamped with a stemming material; this method should be used in secondary blasting wherever possible. Because less dynamite is used and the blast is better controlled, blockholing is preferable to mudcapping. In blockholing a hole is drilled in the boulder and charged with a small amount of explosive, which is shot by either fuse and cap or electric detonator. Stemming is recommended.

In mudcapping the explosive is placed on the surface of the rock, covered with a cap of thick mud, and fired with a detonator. The mudcap should be several inches thick and should not contain pebbles or stones that will be thrown by the blast. Several times as much explosive is needed to break a rock by this method as by blockholing, and with most kinds of rock the cost of drilling the hole is less than that of the extra dynamite. Under certain conditions mudcapping may be an advantage, and if conducted with due regard for safety it is a practical method.

Bureau of Mines tests showed clearly the greater efficiency of the blockhole method. On uniform blocks of the same type of rock a charge of 2 cartridges of 35-percent dynamite without capping produced only a slight crack; an equal charge partly confined by a mudcapping broke another block into many pieces; and a charge of 2 ounces of dynamite confined by stemming in a hole 12 inches deep also broke a similar block.

**CHUTE BLASTING**

Ore broken in stopes frequently is dumped or scraped into chutes or raises, through which it passes by gravity to haulage levels. Broken ore may hang up in a chute because sticky material packs or boulders wedge. Where there is no manway alongside the chute from which the blocked material can be worked loose with a bar or hammer, blasting may be necessary to bring down the ore. Sometimes the ore can be started by running water into the top of the chute, but this has its disadvantages. Chute blasting generally consists of detonating a bundle of cartridges of explosives under the obstruction. The concussion of a bomb of explosives below the hanging ore frequently starts it running, even if the bomb is not in contact with the ore; however, contact gives better results. The cartridges for a bomb are tied together with stout twine, and a detonator is inserted in a middle cartridge. The bundle is lashed to the end of a stick (usually 10 to 12 feet long) and pushed up the raise through the loading gate. If one length of stick is not enough others are spliced end-to-end until the obstruction is reached.

Many accidents have happened with this method of blasting in chutes, particularly where fuse and detonators are employed for detonating the bombs. The bombs have fallen or have been knocked from the blasting sticks down the raises and have exploded on the levels, injuring or killing men. The charge may fall off the stick because it

---

has been insecurely tied, or it may be knocked off by lumps of ore falling down and breaking the blasting stick. The explosive cannot be placed to best advantage when it contains a lighted fuse of short length, for under such conditions the blaster is more or less nervous, and his main thought is to get out of danger. Once the fuse is lighted there is no way of preventing the bomb from exploding if the explosive is displaced. Electric blasting is a safer method because the bomb can be fired at will.

Although electric detonators and blasting wires are slightly more expensive than fuse and blasting caps, the added safety of electric blasting and the more efficient use of the explosive makes that method preferable, and it may be more economical as a regular practice.

With electric blasting time can be taken to make sure that the bomb is properly placed and that everyone is safe before the charge is detonated. In some circumstances less explosives may be used because the bomb can be expected to be placed where it is wanted and no allowance need be made for extra cartridges against the chance that a favorable placement will not be achieved.

Burning fuse makes a large part of the smoke that is connected with fuse blasting, and smoke from fuse used in blasting hungup chutes during the working shift may be a distinct disadvantage.

Safety rules for blasting hanging ore in chutes in some mines of the Lake Superior district are:

1. Tie the powder to the end of the staff with small rope. Never use the firing fuse to tie the bundle.
2. Do not make any tight knots in the fuse.
3. After preparing the powder, but before lighting the fuse, lift the staff into the exact position desired for the blast, and block it into that position. Then lower the staff, spit the fuse, and replace it in the same position.
4. If the dirt is hung up too high to be reached with a staff, the pit boss shall decide what is to be done.

**FIRING LARGE ROUNDS**

When numerous holes are to be blasted as one round additional precautions are necessary in using fuse. The number of holes that one man can light safely and the length of fuse to be used naturally will depend on local conditions, such as the distance to be traveled to reach a place of safety, the wetness of the face, ease of movement, and possibly other circumstances. The maximum number of holes that 1 man may spit may be 12 at 1 mine and 20 or more elsewhere. The smoke made in spitting a large number of holes may make it difficult to see at the face before spitting is finished; for this and other reasons two or more men should work together, and they should have good lights. A boss should always be present to keep an accurate check on the time, so that men will not remain too long. The use of master fuse lighters or of “bunch blasting” will reduce the time required to light the fuse.

At the Knob Hill mine, Washington, as many as 50 blast holes are fired in a stope at one time by igniting the pilot (Thermalite) fuse at the foot of the manway on the level below. Other mines use Spittercord for the same purpose.

For rounds of 50 or more holes, electric blasting is far superior to fuse from both the economic as well as the safety standpoint; in some
USE OF EXPLOSIVES AND DETONATORS

Circumstances this may be true for rounds of even fewer holes. The hindrance and hazard from the smoke of burning fuse are eliminated, and all holes can be blasted simultaneously where this is desired. The wiring and checking of connections would be a necessary labor, but the hazards of electric blasting are not greatly increased by increasing the size of rounds. Men must be checked out, and the usual precautions must be taken to prevent detonations, as in all electric blasting.

LONG-HOLE DRILLING AND BLASTING

Diamond- and pneumatic-percussion-drill blast holes are used in various types of stoping and sometimes in development work. The usual length of pneumatic-percussion drill holes is 12 to 50 feet. Diamond-drill holes used for blasting are sometimes over 100 feet long. Except in very hard ore, the holes are charged with 40-percent gelatin dynamite or similar explosives. Where long holes must be loaded from mine workings that will not admit loading sticks to be employed long enough for the depth of the hole, loading and tamping have been accomplished with jointed sticks, hose, or pipes. Jointed sticks have been made in sections 4 or 5 feet long, joined with leather straps or rubber or plastic couplings; in another method the sections are wooden rods hollowed and strung on sashcord or rubber-covered wire. The cord is attached to the end section and can be pulled tight to make a firm rod of the sections in the hole. Where plastic or rubber pipe is used the tamping end is plugged with wood, rubber, or plastic.

Primacord is placed the length of the holes to secure complete detonation, and 2 or 3 feet of clay stemming is used at several mines. Long-hole blasting is particularly adapted to the mining of ore bodies or parts of ore bodies that cannot be mined safely by other methods, such as ore overlying open stopes and pillars in broken or caved ground. A great deal of preliminary development work is generally avoided, and drilling is done from a safe location. Blasting is also safer than when shorter holes are used, as the shots are fired when men are out of the mine and it is unnecessary to enter the blasted area. There is also a material decrease in the dust thrown into the air when diamond drilling is done.

The method of mining was changed in a Michigan iron-ore mine from sublevel caving and sublevel stoping to an open-stope system to permit long blast holes to be diamond-drilled (fig. 44). The preliminary development and drilling plan are described in Information Circular 7317.\textsuperscript{37}

Long-hole drilling in some Washington mines is described as follows: Long-hole percussion-type drills have largely replaced diamond drills because a 50-percent saving is realized in drilling. Blasting is safer than in the use of shorter holes, as the shots are fired electrically when men are out of the mine and it is unnecessary to enter the blasted area. Usually the blast-hole ring is loaded from a slot-shaped mine opening where the work can be performed safely. Short, vertical raise connections can be loaded at the top and blasted in 5-foot sections, beginning at the bottom, by drilling a long, 3-inch hole in the center which is not loaded and then drilling a pattern of long holes that are

loaded and fired in 5-foot sections. Long-hole drilling made it possible to drive vertical raises safely without using ladders and working from below.

In the northeastern United States the advantages of long-hole drilling and blasting are summarized as follows: Where long-hole drilling is employed as the principal means of mining an ore body, the back and walls of work areas are accessible for inspection and scaling. Vertical ring drilling usually is done from the floor of sublevels where adequate storage for supplies and equipment is provided, as well as access to a raise removed from the stope; it is considered the safest system. Long, horizontal holes drilled radially from drifts or cross-
cuts also afford a safe system. When they are drilled from a raise less storage and work space is available. Final raise-pillar recovery presents rock-fall but not necessarily blasting hazards. In the Lake Superior district the advantages of long-hole drilling and blasting are summarized by one authority as follows:

1. The hazards of ore and rock falls are reduced because miners drill, load, and fire their blasts from under a safe protective back.
2. Fewer men are required to produce a given tonnage of ore. Barmen and pipemen are not required to be in daily attendance. Steel handling, scraping, mucking, and timbering are reduced. Less development is required.
3. It is generally reported there is a lower consumption of explosives per ton of ore broken.
4. Trained loading and blasting crews may be used to advantage, thereby reducing the number of men required to handle explosives.
5. Better ventilation and dust control are possible because men are not required to enter the stopes.

HANDLING MISFIRES

Misfires or delayed shots cause numerous accidents in blasting, both on the surface and underground. Many accidents occur when persons return too soon after a blast has been fired and are injured or killed by the explosion of a hole that has delayed firing; or, more frequently, a missed hole is exploded by some work done after blasting.

The best method of reducing the hazard is to reduce the number of misfires by proper storage and by correct methods of priming, loading, stemming, and firing the explosives.

No one should return to the face after a blast until the smoke, dust, and fumes have been cleared away. If there is reason to suspect a missed hole, the return should not be made until a safe interval has elapsed; where electric detonators are used a wait of at least 15 minutes is advised; where fuse and detonators are used the interval should be as long as possible, preferably until the next day. Records of misfires show that charges have exploded several hours after the fuse was lighted. Misfires should be reported to a designated person, and subsequent steps should be taken by him or under his direction.

When a misfire is found or suspected no other work should be done except that necessary to remove the hazard, and only those persons necessary to the work of removal should remain in the danger zone. If the missed hole does not have more than 2 feet of stemming over the charge a new primer can be inserted against the stemming and the hole fired. The stemming can be removed by washing it out with water under pressure from a hose. This is probably the safest method of removing stemming from a borehole and the one most strongly recommended. No picking or digging should be done about a missed hole unless with wooden tools and then only with extreme care under supervision.

All places that have been blasted should be examined carefully for missed holes, and any bootlegs should be inspected for the presence of explosives. If explosives are found they should be treated as missed holes. Some companies require that bootlegs must be loaded and shot before any other work is undertaken in the place where they are found.

Under no circumstances should an attempt be made to remove stemming or explosives from a misfired hole with a metal spoon, compressed-air blowpipe, or water hose with metal nozzle. Drilling should not be undertaken in the vicinity of a missed hole.

**GASES FROM EXPLOSIVES**

All explosives emit toxic gases when fired. These gases may be produced in deadly amounts or be relatively harmless, depending on the type and quantity of explosive used, the degree to which the explosive charges are detonated rather than burned, the conditions of confinement, and the composition of the material being blasted. Dynamites used in underground metal and nonmetallic mining usually are chosen for their favorable fume properties, but the detonation of rounds involving one or more cases of explosives usually will produce enough toxic gases or may so reduce the oxygen content of the air that it is dangerous to breathe. The quantities of gases produced normally require a moderately strong ventilating current to dilute and remove them if the return of men to the face is not delayed for several hours. In the absence of adequate ventilation a lapse of several hours may still find dangerous quantities of gases in the working face and in the broken muckpile. A blower fan installed for clearing out blasting fumes from an advancing face is shown in figure 45. Blowing with a compressed-air hose may clear only a small space, even in 1 or 2 hours. The results of field tests of the fumes produced by various types of explosives were published by the Bureau in Bulletin 287 and Technical Paper 482 and contained the following conclusions:

When an explosive is properly detonated in inert country rock the only toxic gas produced in dangerous quantities is carbon monoxide. Some sulfur dioxide and oxides of nitrogen were frequently produced under these conditions, but the quantities were harmless. Blasts in massive sulfides produced dangerous quantities of hydrogen sulfide and sulfur dioxide.

The oxygen balance of the explosive appears to be most important as regards the amount of carbon monoxide produced. The condition of the explosive also affects the gases from blasting. Deteriorated, insensitive explosives give more carbon monoxide than fresh. Although less toxic gas is made by some explosives than by others, with all the explosives tested efficient ventilation is required to remove the gases that follow blasting from the mine workings before men return to work.

The composition of the gases from blasting the various holes of a round is not uniform, and no definite relationships were found to explain the variations. However, in hard rock the use of stemming reduces the volume of carbon monoxide.

Sprinkling muckpiles removes most of the sulfur dioxide, hydrocyanic acid, and oxides of nitrogen in the trapped gas. It has no appreciable effect on the carbon monoxide, which is only slightly soluble in water.

Fuse equivalent in amount to that used in blasting an average round was burned. The amount of carbon monoxide given off was too small to have any appreciable effect. The smoke was dense and sickening, but poisonous gases were not present in large enough quantities to be noticed.

When a charge of dynamite burns, oxides of nitrogen are formed and give the characteristic burned-powder odor. The oxides of nitrogen can be detected by smell; they corrode the respiratory passages, and the breathing of relatively small amounts may cause death. Their effect is unlike carbon monoxide poisoning in that a patient may apparently recover and then suddenly die several days later. One-hundredth of 1 percent may cause dangerous illness if breathed for a short time, but 0.07 percent is fatal if breathed for 20 minutes.
FIGURE 45.—Starting Fan After Blasting to Clear Smoke and Gases From Working Place.

Descriptions of two accidents follow:

A typical accident due to fumes from blasting occurred when 2 miners were suffocated in a drift being started from the bottom of a 250-foot winze. A round in the drift face had been blasted at 4 p.m., when the day shift left the mine, and blasting on the level above broke the compressed-air line. When the miners went to the drift at 7 p.m. they found heavy "powder" smoke but left because the mucking machine would not operate. At 11 p.m. the men were notified that the air line had been repaired and returned to the drift face. They found the air clear, but their carbide lights would hardly burn. Before they could disconnect the air hose to obtain relief they collapsed. One recovered after they were rescued.

A recent accident from explosives fumes has been described: A miner, age 36, with 4 years' experience was overcome when he entered a drift blocked by a muckpile after blasting. A raise was being driven from the end of a small drift, and two cuts had been made before the accident. When the miner entered the drift he found that a pile of ore from the blast made during the previous shift (4
hours before) had blocked the end of the drift below the raise. He shoveled an opening large enough to permit him to crawl through and hang a block at the breast of the drift. He then felt himself losing consciousness. His partner called for help, and he was rushed to the surface, where an inhalator was used. When the doctor arrived the man was breathing normally; the doctor stated that the prompt use of the inhalator undoubtedly saved the miner's life.

* * *

The Mine Safety Orders of California contain the following provisions:

Each case containing explosives for underground use shall be clearly marked with the class that indicates the amount of poisonous gas produced per 1 1/4-by 8-inch cartridge.

For the purposes of this order, the poisonous gas-producing properties of an explosive shall be the volume of carbon monoxide plus hydrogen sulfide emitted by 1 1/4-by 8-inch cartridges, as shown by tests in the Bichel gage according to the standard procedure of the U. S. Bureau of Mines, provided the resulting gases do not contain more oxygen than is sufficient to burn the combustible gases to their maximum oxidizable state.

No explosive shall be used underground if the gases emitted in test in the Bichel gage, according to the standard procedure of the U. S. Bureau of Mines, show more oxygen than is sufficient to burn the combustible gases to their maximum oxidizable state.

Cases containing explosives for use underground will be marked to comply with the following classification:

Cubic feet of carbon monoxide plus hydrogen sulfide per 1 1/4-by 8-inch cartridge when tested according to the second paragraph:

<table>
<thead>
<tr>
<th>Fume Class 1 Less than 0.16</th>
<th>Fume Class 2 0.16 to 0.33</th>
<th>Fume Class 3 0.33 to 0.67</th>
</tr>
</thead>
</table>

Explosives in cartridge sizes smaller than 1 1/4-by 8-inch shall not emit more poisonous gases per cartridge than are emitted by 1 1/4-by 8-inch cartridges as defined above.

No explosive shall be used underground in the presence of combustible gases and/or combustible dusts unless specific application is made by the operator to, and the use approved by, the commission.

All explosives packed in cartridges must be loaded in the original cartridge without alteration of the quantity of the wrapper.

Explosives manufacturers publish recommendations regarding the use of different types of explosives underground in conformity with the foregoing standards, which were established through consultation with the Institute of Makers of Explosives. The manufacturer will advise a purchaser regarding the characteristics of a particular explosive and its appropriateness for the use intended.

No published information is available as to the amounts of poisonous gases given off by modern metal-mine explosives, but the following general characteristics are stated in manufacturers' handbooks.

<table>
<thead>
<tr>
<th>Type</th>
<th>Fumes</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Straight dynamite</td>
<td>Poor</td>
<td>Underground use not advised.</td>
</tr>
<tr>
<td>Ammonia dynamite</td>
<td>do</td>
<td>Do</td>
</tr>
<tr>
<td>Special ammonia dynamite</td>
<td>Fair</td>
<td>Types especially manufactured for purpose.</td>
</tr>
<tr>
<td>Low-density gelatins</td>
<td>Poor</td>
<td>Underground use not advised.</td>
</tr>
<tr>
<td>High-density gelatins</td>
<td>Good</td>
<td>Underground use advised, except in higher strengths.</td>
</tr>
<tr>
<td>Ammonia gelatin dynamite</td>
<td>do</td>
<td>Recommended for underground use.</td>
</tr>
</tbody>
</table>

The foregoing classification is on the basis of fumes produced and does not consider other important characteristics that affect its performance. A manufacturer may also modify a less favorable type to give it a more suitable fume status.
Low-density explosives with objectionable fumes have been found acceptable in some mining districts where blasting is done off shift and there is a considerable time interval between shifts. Even then adequate ventilation must be provided to remove carbon monoxide and replace depleted oxygen.

In underground blasting working conditions may be improved by spraying the face and broken rock with water. The use of a spray attachment connected to the air and water lines, followed by sprinkling with a water hose, has been found effective, because the spray can be turned on at the time of blasting and left in operation until the next shift comes on. Water so applied helps to allay the smoke and dust, thus improving visibility and reducing air contamination. It also dissolves certain toxic gases rapidly, and if enough water is used it diffuses the fumes in the rockpile so that they are swept out more readily by the ventilation.

The use of air-and-water or mist sprays introduced into development raises and headings after blasting and placed at muckpiles during loading and scraping operations has materially reduced dust and concentrations of noxious and objectionable gases that are released after blasting.

Specifications for shop construction of a compressed-air-water spray have been published.39

At least two types of water-curtain or misting nozzles are used in the Lake Superior district to settle or collect dust and gas after blasting (figs 46 and 47). Each nozzle uses about 2 gallons of water per hour. They are usually turned on just before blasting.

The Institute of Makers of Explosives makes the following suggestions for minimizing poisonous gas hazards from use of explosives: 40

1. Use the largest diameter cartridge of explosive which is consistent with the work to be done. Preferably explosives of not less than 1 3/4 inches in diameter should be used.

---

39 Mining Engineering, Practical Dust Control: January 1950, p. 86.
FIGURE 47.—Misting Nozzles at Outlet of Exhaust Pipe to Settle Dust and Absorb Gas After Blasting

2. Avoid the use of explosives which have obviously deteriorated.
3. Explosives should be shot in the wrappers supplied; do not remove wrappers from an explosive or add paper or other combustible material to the charge.
4. Do not overcharge. Explosives used in excess of needs cause increased proportions of poisonous gases.
5. Avoid all conditions which may cause burning rather than detonation of the explosives; as for example, breaks in the explosive column, separation of primer from the remainder of the charge, a poorly crimped cap which permits the fuse to be pulled out of the cap, or the use of explosives or caps which have deteriorated. Detonators should be kept as dry as possible before use.
6. In wet work always use an explosive having adequate water resistance and fire the blast as soon after loading as practicable.
7. In wet work use properly waterproofed cap and fuse assembly or electric blasting caps of adequate water resistance.
8. Confine the charge properly with noncombustible stemming, preferably moist sand, and clay, or other suitable stemming material.
9. Provide adequate ventilation and make sure that the air is directed to the working places.
10. Make frequent tests to be sure that the air used for ventilation, which from fans or compressors, is free from carbon monoxide or other noxious gases.
11. Spray the muck pile with water.
12. Allow the maximum practicable time between blasting and mucking operations.

LIQUID OXYGEN

Liquid-oxygen explosives are ordinarily made from a carbonaceous absorbent soaked with liquid oxygen of high purity. These explosives have a limited field of usefulness in opencut mining; the Bureau of Mines does not recommend their use underground or in confined spaces.\(^4\) The principal advantages are low cost, high execution value, and safety from misfires through evaporation of the oxygen within a short period. The chief disadvantages are high sensitivity to impact, limited explosive life, and formation of large quantities of carbon monoxide and carbon dioxide.

USE OF EXPLOSIVES AND DETONATORS

Bureau of Mines investigations have been instrumental in improving the safety qualities of liquid-oxygen explosives in two respects: (1) The sensitivity to impact has been greatly reduced by the use of pure carbonaceous absorbents with a 20-percent moisture content. (2) Risk of premature detonation through accidental ignition has been lessened by treating the cartridge with fire retardants.

Although the accident record of liquid-oxygen explosives is reasonably good, there are records of serious accidents in the necessary oxygen plants, in the transportation of cartridges in soaking boxes, and in charging boreholes. All these accidents were due, as far as could be determined, to neglect of one or another and sometimes several of the following known safety precautions:

All persons authorized to handle and use liquid-oxygen explosives should be instructed in their properties and characteristics to enable them to comprehend the necessity for strict observance of safety regulations.

On account of the nature of liquid oxygen, it should be protected at all times from open flames, electric arcs, or glowing and incandescent particles that might burst into flame in an atmosphere enriched by oxygen.

Only regularly assigned employees should be permitted in the liquid-oxygen plant; these employees should wear special clothing and carry no matches or smoking materials.

Soaking boxes should be clean, and cartridges placed in them should be free from grease, oil, or grit; no metal instrument should be used in this operation.

Persons handling soaking boxes or cartridges should carry no matches or smoking materials; they should wear clean gloves free from grease, oil, or other foreign material.

Vehicles transporting soaking boxes should not carry detonators or other materials with the explosives; such vehicles must be driven with care and only on a prescribed route.

Only authorized employees should open soaking boxes in the field or handle cartridges; cartridges should be handled only with nonsparking implements.

Cartridges should never be thrown or dropped; they should be lowered into the hole with a rope.

Cartridges should never be forced into a hole; if they become lodged they should not be punched out until after a period of 6 to 40 hours, depending on the size of the charge and the condition of confinement.

Punching or forcing should be done only with nonsparking implements.

Holes should be stemmed only with fine dust or sand and never should be tamped.

When holes are blasted in confined the atmosphere should be tested before returning to the shot.

An investigation, in cooperation with the Linde Air Products Co., to evaluate the hazards associated with the use of liquid-oxygen explosives and to determine the conditions under which such explosives may be used with safety is detailed in Report of Investigations 4667.42

PERMISSIBLE EXPLOSIVES

A permissible explosive gives a relatively shorter flame and generates less heat compared with dynamite or black powder. These explosives are prepared particularly for coal mines to minimize the hazard of the ignition of explosive gas or coal dust, such ignition being fairly easy with black powder or dynamite. If explosive gas is encountered in metal mines or tunnels, permissible explosives have definite

advantages. Likewise, under certain conditions permissibles may be advantageous for blasting where a considerable amount of timber is used.

**OPENCUT BLASTING**

Many blasting practices previously discussed for underground mines apply equally to opencut blasting. There will be some repetition; but this discussion is confined, as far as is practicable, to opencut and quarry blasting.

Blasting in opencut mining is usually 1 of 4 general methods—churn drilling, benching, toeholing, or tunneling. Sometimes a combination of churn drilling and toeholing, or benching and toeholing is employed.

The drilling machines are: (1) Standard caterpillar-mounted rotary or churn drills and jet-piercing machines for vertical blast holes 4 to 10 inches in diameter; (2) wagon drills for 2- to 3½-inch-diameter blast holes at any angle from vertical to horizontal; and (3) jackhammer-type drills for blockholing and secondary drilling.

The types of explosives used in opencut mining, in order of quantities, are: (1) Semigelatin dynamite, (2) ammonia dynamite, (3) gelatin dynamite, and (4) a blasting agent (Nitramon and Nitramex).

Two grades of semigelatin dynamite (60 and 40-percent strength) are generally used. The cartridges range in size and weight from 7½ by 24 inches (weighing 50 pounds each) used in 9-inch-diameter blast holes, to 1½ by 8-inches (weighing about ½ pound each) for secondary and miscellaneous blasting.

Ammonia dynamite in cartridges and bags is used. The grades and cartridge sizes are similar to those of semigelatin dynamite. The ammonia-b-g dynamite is generally packed in bags ranging in size from 7½ by 24 inches and weighing 50 pounds to 5 by 14 inches and weighing 12½ pounds. This type of explosive has low water resistance and is used primarily in dry holes too ragged for satisfactory loading with cartridges or in holes that are sprung or chambered. It is a powerful but slow-acting explosive.

Gelatin dynamite is used principally in very wet holes. Two grades of gelatin dynamite are used—25- and 40-percent strength in 5- by 16-inch and 3- by 10-inch cartridges for primary blasting and 40-percent strength in 1¼ by 8-inch cartridges for secondary and miscellaneous blasting.

A blasting agent and its primer in 5½ by 24-inch sealed metal cans is used at a number of opencut mines and quarries for blasting in vertical and coyote holes.

Generally, detonating fuse (reinforced) in the blast holes and plain for surface trunklines is used for blasting. Safety fuse and blasting caps are used in about 30 percent of the mines to initiate the detonating fuse or in secondary blasting; and electric detonators are used at about 60 percent of the mines. To fire wagon-drill rounds, many mines use detonating fuse and millisecond-delay electric blasting caps.

Figures 48 and 49 show methods of preparing primers for opencut blasting, and figure 50 shows a blast in an opencut iron mine.
Drilling and blasting methods in the opencut mines of the Lake Superior district are described in Bureau of Mines Information Circular 7552.\textsuperscript{43}

Drilling and blasting methods in quarries are described in Bulletin 473.\textsuperscript{44}

At most mines the cartridges of explosives are dropped into the holes, but at a few the explosives cartridges are lowered into the holes (fig. 51).


A. One threading with a slip knot in detonating fuse.

B. Two threadings with a plain knot in detonating fuse.

C. One threading with a plain knot in detonating fuse.

D. Four threadings without knot in detonating fuse.

E. Two threadings without knot in detonating fuse.

**FIGURE 49.—Methods of Preparing Primers With Detonating Fuse.**

For stemming materials fine ore or drill cuttings are shoveled into the drill holes and seldom tamped. The holes usually are stemmed to their collars. The blast holes are connected with detonating fuse (fig. 52), the blasting warnings and signals are sounded, and the round is detonated from a safe distance. A steel shelter is often provided for men during a blast in opencut mines when it is not feasible for all of them to go a considerable distance from the blast location (fig. 53).

In the northeastern United States large-diameter drill holes are loaded with large-diameter explosives and fired with detonating fuse (Primacord). Millisecond-delay electric blasting caps are used to fire smaller diameter wagon-drill holes.
At a large opencut copper mine 10-inch drill holes are put down to a depth of 50 to 60 feet. The upper 8 feet of hole is usually supported by 10-inch casing. The explosive (8-by-18-inch 40-percent special gelatin) is brought from the magazine to the blasting area in trucks with wooden bodies. The boxes are opened 30 feet from the hole and the cartridges carried to the hole one at a time. One or two men do the loading, lowering the explosive with rope from a reel set over the hole. Primacord is attached to the first cartridge and lowered with it into the hole. The 50-pound weight of the explosive is held by the rope, not by the Primacord. About 6 feet of Primacord is left above the top of the hole. From 8 to 12 cartridges are placed in a hole, and no attempt is made to compact the charge. After the charge is loaded in the hole other men in the crew gather all waste paper and empty boxes. Holes are stemmed with screened sand, which is shoveled into the hole by still other men in the crew. After all holes are loaded and stemmed to the collar the main or trunk line of Primacord is strung over the hole, and the leads of each hole are tied to it. An electric detonator on the end of the Primacord is fired by a plunger-type blasting machine. Warning signals are sounded 5 minutes before the blast, and flagmen move out from the blasting area, clearing all persons from the danger zone. After word has been relayed from all guards that the area is clear, the signal to blast is given.

At another opencut mine, 6-inch drill holes are drilled on 50-foot benches to a depth of 5 feet below grade. The holes are sprung 2 or 3 times with 40- and 60-percent gelatin dynamite, using 20 pounds in each charge. Toeholes, 20 feet in depth and 1½ inches in diameter, are drilled and sprung 3 times, using 18 pounds of 40- and 60-percent gelatin dynamite. Water is poured in both types of holes as stemming.
Figure 51.—Lowering 50-Pound Cartridge of Explosives in 9-inch Churn-Drill Hole by Means of Tripod.

Figure 52.—Connecting Blast Holes With Detonating Fuse.
when spring charges are shot. Detonation is by electric detonators and battery. The interval between the blasting of spring charges and reloading ranges between 30 minutes and several hours. The main blast in churn-drill holes consists of 185 pounds of 30-percent ammonia bag powder and 40- and 60-percent gelatin dynamite. Toeholes are loaded with 40- and 60-percent gelatin dynamite. The charges in the drill holes are tamped with a wooden dolly, which is raised and dropped about 3 feet. Screenings are used for stemming in the churn-drill holes but not in the toe holes. Two electric detonators and detonating fuse are placed in the drill holes, and toeholes are shot with two electric detonators.

Tunnel blasting is practiced by a rock quarry in the Northwest at which large tonnages are broken at one time. One blast consisted of 123,750 pounds of 60-percent semigelatin and 40-percent high-ammonia bag powder in 5- by 16-inch cartridges. Five tunnel openings with about 3- by 4-foot lateral wings were driven in the quarry face. The explosives were delivered by truck to the tunnel openings, where the cases were opened with wooden mallets and wedges. The dynamite cartridges were taken on hand trucks into the wings of the tunnel, where they were stacked as compactly as possible in 50 prepared pockets. Each charge was primed with two No. 6 electric blasting caps. The legwires were securely taped to the lead wires and tested several times with a galvanometer. The rubber-insulated leading
wires were supported on pegs in the tunnel walls. A line of Primacord throughout the tunnels supplemented the electric detonators. The two separate detonating agencies were used to minimize the possibilities of misfires. They operated independently, and either was sufficient to detonate all the charges. The spaces between the charges and all of the main tunnels were backfilled with screenings from the crushing plant, tamped tightly from floor to roof. All debris and trash were removed by a part of the crew assigned to that duty. The blast was fired by power from a 250-volt direct-current circuit applied simultaneously to both detonating lines.

DETONATING FUSE

The detonating fuse now in general use is known as Primacord and consists of a high-explosive core within a weatherproof sheath, overlaid by reinforcing covers. It is available in five types with tensile strengths of 110 to 250 pounds. Primacord is light in weight, flexible, and easily manipulated. It is quite insensitive and is not detonated by fire, friction, or ordinary shock but should be stored and handled in the same manner as other explosives. Primacord is detonated by 1 or preferably 2 blasting or electric blasting caps tightly taped beside it with closed ends of the caps pointing in the direction in which the detonation is to advance (fig. 54). Failure to attach the caps properly is probably the most frequent cause for misfires.

In instantaneous firing with a Primacord trunkline it is of prime importance to design the layout so that the blast holes fire in proper sequence with respect to the open face or the most logical direction of movement of the blast.\textsuperscript{45} This is to make certain that the charges nearest the point of initiation do not “cut off” any of the later firing holes by ground movement.

Figure 55 shows typical layouts for 1, 2, and 3 rows of blast holes detonated with Primacord and electric blasting caps or caps and fuse. The blasting caps are attached at points Z, and right-angle connections are made at points X. The double trunkline is recommended to provide a second means of detonating each hole in case of an accidental break in the main trunkline. In multiple-row blasts the trunkline should make one or more complete loops, with crossties between loops.

Connections from a mainline or trunkline to a branchline at a blast hole are made with a right-angle connection, as shown in figure 56, B. A trunkline splice (fig. 56, A), should be made only with a square knot pulled tight. There should be no Primacord splices in the blast holes. All connections in trunk and branch lines should be kept dry.

Delay firing is occasionally used for primary blasting underground and frequently for secondary blasting in quarries. Short-interval delay firing of Primacord blasts is accomplished by initiating the branchlines or parallel trunklines on the surface in the desired order.

In priming large-diameter blast holes with detonating fuse it should be lowered to the bottom of the hole by attaching it to the first cartridge. It should then be cut from the reel and the reel moved away before other explosives are loaded (fig. 57). The detonating fuse should be drawn tight and made secure. It should be checked to see

that it has not been broken before stemming material is put in the blast hole.

Bureau of Mines records indicate that accidents can happen with Primacord, even though its use is considered relatively safer than other methods for detonating a charge of explosives. As an instance, a man was holding a Primacord feeder line at the top of a drill hole to prevent its being dragged into the hole by the cartridges forming the balance of the charge. A premature explosion originating in the hole resulted in serious injury to both of his hands. In this instance the explosives detonated the Primacord. A better practice is to fasten the Primacord rather than hold it, so there is one less person at the hole being charged.

In another instance, a quarry was employing delayed blasting, and it is believed that two missed holes resulted from the use of Primacord. The round consisted of three rows of holes so arranged that it was necessary to blast each row in proper sequence. To accomplish this the Primacord trunkline to the first row of holes was attached to an instantaneous electric detonator; a No. 1 delay detonator was attached to the Primacord trunkline of the second row and a No. 2 delay detonator to the Primacord trunkline of the third row. Apparently when
the charges in the first row of holes exploded, backbreak at the collars of these holes resulted in cutting two feeder lines of Primacord in the second row of holes. The Primacord feeder lines were therefore cut before the delay detonator exploded and resulted in the two missed holes.

When it is necessary to blast rows of holes in sequence and Primacord is to be used, each row should be loaded and blasted separately. In blasting with delay electric detonators, backbreak may damage or even cut the legwires of the delays, but the current will already have passed through the wires and the bridgewires will have fused so that the hole should not misfire.
DISPOSAL OF DETERIORATED EXPLOSIVES AND DETONATORS

Explosives, detonators, or fuse that have been damaged or have deteriorated, or for which there is no immediate use or storage space, should be destroyed. The longer such explosives are left exposed or stored the more hazardous it may be to handle them, aside from the continuous danger of accidental detonation of unreliable explosives. The following information and suggestions concerning the disposal of unusable explosives have been prepared by the Bureau of Mines and manufacturers of explosives.

Deteriorated explosives frequently are much more hazardous than those in good condition and hence require care in handling and disposal. When a considerable quantity of explosives must be destroyed and experienced or competent men are not available or if there is any question about the safety of the undertaking, advice or assistance should be obtained from the Bureau of Mines or from the manufacturer of the explosives. Small amounts of dynamite can be destroyed by exploding them in a safe place, but this is seldom practical where larger quantities are involved.

The preferred method of destroying dynamite and detonating fuse is by burning. There is always a possibility of an explosion when either material is burned; consequently, the burning should be done at a location chosen to eliminate the possibility of injury to persons or damage to property should an explosion occur. In destroying explosives or blasting supplies only one type should be destroyed at a
time. Any attempt to burn explosives in which detonators are included is almost certain to result in an explosion. Therefore, care should be exercised to see that no detonators are included.

Dynamite that shows obvious signs of deterioration, such as hardness, discoloration, excessive softness, or leakiness, should be destroyed. If the leaking has gone so far that the sawdust in which the dynamite is packed is saturated or the wood cases are stained, the dynamite should not be handled, except under the supervision of an authorized representative of the Bureau of Mines or an explosives manufacturer. Dynamite that has become unfit for use through wetting, overheating, or other damage should be destroyed.

Dynamite can be burned with relative safety if certain precautions are taken. It is advisable to limit the quantity of dynamite burned at any one time to 100 pounds or even less, depending on local conditions. Permissible gelatins are prone to detonate on burning, so not
more than 10 pounds should be burned at one time. Dynamite should never be burned in cases or deep piles where detonation is to be avoided. Dynamites become more sensitive as their temperatures are increased, reaching a particularly dangerous state between 350° to 450° F. Sensitivity and proneness to detonation also are increased greatly by any confinement of the explosives; where explosives are heated and confined, even by being covered by other cartridges or boxes of explosives, the process of burning may easily be changed to detonation by a slight shock, such as the fall of any part of the burning material from the top to the bottom of the pile. For these reasons burning must be done in a manner to keep the unburned portion of the explosives at a relatively low heat and to avoid rolling or falling of the explosives as they are being consumed.

The cases should be opened carefully with wooden implements; the cartridges should be removed and spread in a layer not over 2 to 3 inches thick, preferably with a mat of loose paper or excelsior underneath, as some dynamites are difficult to ignite. If the dynamite does not burn readily it may be necessary to saturate it with kerosine. Gasoline should not be used. The pile should be ignited by a small pilot fire of paper or kindling material arranged so that the operator will have ample time to reach a place of safety before the fire reaches the explosive. All persons should remain in a safe place until the dynamite is completely consumed. When more than 100 pounds of dynamite or 10 pounds of permissible gelatin is to be destroyed it is unsafe to place a second lot of dynamite on the hot ground of the preceding burning; a new space should be selected unless the ground is cooled, and as soon as all dynamite has been destroyed the ground where the material was burned should be plowed, as the residue from burning dynamite contains salts that may be eaten by cattle with serious results.

Primacord should not be burned on the spool but should be strung out in parallel lines on top of paper or other quick-burning material. Black powder may be destroyed by pouring it into water. Where this procedure is not advisable it may be burned by pouring it on the ground in a trail about 2 inches wide, keeping any parallel parts of the trail at least 10 feet apart.

Blasting caps, electric blasting caps, and delay electric blasting caps that have deteriorated from age or improper storage should be destroyed. These devices should also be destroyed if they have been under water. When the shells of caps that have been wet and then dried show signs of corrosion the caps may be dangerous to handle, and they should not be handled until a representative of the manufacturer has been consulted. Generally, detonators can be destroyed safely and conveniently by exploding them under some confinement; they should not be thrown into small bodies of water from which they may be recovered later. Ordinary blasting caps to be used with fuse should be left in the original containers with the covers removed; if loose, they should be placed in a bag or small box. The caps to be destroyed should be placed in a hole in the ground and primed with one cartridge of dynamite and a good electric blasting cap or ordinary cap and fuse. The charge should be covered with paper and then dry sand or fine dirt and fired. Not more than 100 caps should be fired at one time, and the same hole should not be used for successive shots.
Before electric or delay electric blasting caps are destroyed it is necessary to cut off the wires about 1 inch from the top of the cap; tin snips or similar tools should be used in cutting to avoid pulling the wires. No attempt should be made to cut the wires from more than one cap at a time. They should then be destroyed in the same manner as has been described for ordinary blasting caps.

Safety fuse may be disposed of by burning in a bonfire.

Other methods of destroying explosives and blasting supplies used by manufacturers should be employed only under the direction of the manufacturer's representative.

Serious and fatal injuries often result from attempts to dispose of unusable detonators by placing them with a charge in a borehole or a mudcap shot.

One such accident occurred when a chute blaster placed a "spoiled" detonator in a mudcap shot with another good detonator and, by error, lit the 6-Inch fuse on the spoiled detonator instead of the 30-Inch fuse on the good one. Though injured, he recovered and was able to explain the cause of the premature blast.

Two disasters have occurred in recent years through attempts to dispose of quantities of deteriorated detonators in well-drill holes. In one a charged hole exploded prematurely when some electric delay detonators that were unfit for use were being dropped in with the charge. The explosion of the hole detonated a quantity of explosives stacked on the ground to be loaded in other holes. All of the loading crew were killed. The other disaster occurred when several hundred deteriorated blasting caps in their original metal containers were dropped into a well-drill hole loaded with dynamite to within 10 feet of the top. The blasting caps exploded and detonated the charge, killing three men of the loading crew.

SAFE PRACTICES FOR EXPLOSIVES AND BLASTING

1. Surface explosives-storage magazines should be:
   (a) Constructed of incombustible material or covered with fire-resistant material and be reasonably bulletproof.
   (b) Placed in accordance with the American Table of Distances as feasible and be not less than 200 feet from any mine opening or vital structure.
   (c) Provided with suitable danger signs nearby.
   (d) Provided with proper ventilators, effectively screened.
   (e) Provided with proper doors.
   (f) Kept locked securely at all times when not in use.
   (g) Unheated, except in a manner approved by the Bureau of Mines or other competent authority, to suit extreme cold-weather conditions.

2. The interior of magazines should be kept clean and dry at all times.

3. The floors of explosives magazines should be of nonsparking material, preferably of wood, with no exposed metal.

4. If an explosives magazine is illuminated electrically, the lamps should have explosion-proof globes, the switch should be outside the building, and wiring should be enclosed in rigid conduits.

5. The area surrounding the magazine for not less than 25 feet (preferably 50 feet) in all directions should be kept free of rubbish, dry grass, or other combustible material; preferably this area should be covered with some material to prevent the growth of grass, brush, and weeds.

6. Explosives should be stored in such manner as to insure issuance of the oldest stock first. Cases of explosives should be stored with the topside up, except when periodic turning of cases of explosives is required as recommended by the manufacturers. Cases should not be stored in such a manner that the cartridges stand on end.

7. Deteriorated or damaged explosives and detonators should be destroyed. Explosives and detonators should be destroyed only by a person who is experienced in this work, preferably a technical representative of a manufacturer of explosives.

8. Detonators should be stored in a separate magazine of incombustible material or covered with fire-resistant material and located not less than 100 feet, unbarricaded, or 50 feet, barricaded, from a magazine containing explosives.

9. Detonators, tools, and materials other than explosives should not be stored in an explosives magazine; however, this does not prevent the storing of safety fuse or detonating fuse in any explosives or detonator magazine.

10. Fuse should be stored in a cool, dry place and should never be allowed to become overheated.

11. Fuse should not be allowed to come in contact with oils, paints, kerosine, gasoline, distillates, or similar solvents. (These substances may penetrate the powder train and cause it to fail completely or to burn at an irregular speed.)

12. The older fuse should be used first, before new stock. (Old fuse sometimes becomes brittle.)

13. Unauthorized persons should not be permitted access to any magazine.

MAGAZINE—UNDERGROUND

14. Underground explosives-storage magazines should be:
   (a) In an area removed from fire hazards.
   (b) At least 200 feet from main shaft or active working.
   (c) In a separate offset, preferably in an abandoned section.
   (d) At least 25 feet from haulageways or travelways, if feasible.
   (e) Provided with signs plainly marked EXPLOSIVES—DANGER at the entrance to the drift in which the magazine is situated and on the magazine itself.
   (f) Provided with proper ventilators, well-screened.
   (g) Kept locked at all times except when attendant is present.

15. Magazines should be kept dry and should be properly drained.

16. Lighting should be indirect, or by means of permissible electric storage-battery lamps, or by some other electrical system approved by the Bureau of Mines.

17. Detonator magazines should not be situated nearer than 25 feet from any explosives magazine.

18. The detonator magazine may be used as a fuse-cutting station, when situated in a safe place.

19. Hardwood or plastic tools should be used to open wood cases of explosives. Steel or iron tools should never be used.

20. Waste paper, sawdust, used empty boxes or other containers, or packing material should not be allowed to accumulate in or near storage or distributing magazines.

21. Smoking should be prohibited in or around magazines.

22. Open lights or other flames should not be permitted in or around magazines.

23. Blasting should not be permitted within 200 feet of an underground magazine.

24. Explosives or detonators (preferably not over 1 day's supply) may be stored in separate, locked, box-type magazines a safe distance from working faces.

SURFACE TRANSPORTATION OF EXPLOSIVES

25. Vehicles used in surface transportation of explosives should be constructed substantially, have tight bodies with no internally exposed metal, and be kept in good working order. Open vehicles should be provided with tarpaulins. The ends and sides of the vehicles should be high enough to prevent containers from falling off.

26. Vehicles should not carry blasting caps or detonators while carrying explosives.

27. Vehicles carrying explosives should not carry metal, metal tools, oils, matches, firearms, acids, or flammable materials of any description. This does not apply to truck repair tools carried in a proper receptacle.

28. Explosives should be transported on streets or highways only during daylight hours, if feasible. Streets with congested traffic should be avoided.

29. Motor vehicles used to transport explosives should be required to conform to the speed limits provided by the traffic laws.
30. State or other regulations as to marking vehicles used to transport explosives should be followed. If no laws or regulations are in effect, any such vehicle should be placarded on each side and the rear with the word EXPLOSIVES in letters not less than 3 inches high, or should display a red flag with the word DANGER in white letters not less than 6 inches high.

31. Unauthorized persons should not be permitted to ride on vehicles transporting explosives, and the driver and helper should neither smoke nor carry matches or lighters.

32. Vehicles carrying explosives should not be taken into a garage for repairs or for other purposes.

33. A vehicle containing explosives should never be left standing or unloaded without first stopping the motor and setting the brakes securely. Explosives cases should never be left immediately back of the exhaust, as a spark may start a fire or cause an explosion.

34. Explosives or detonators should never be left unattended except when they are placed in a magazine and the magazine is locked.

35. Containers of explosives or detonators should always be lifted and set down carefully, never slid over one another or dropped from one elevation to another.

UNDERGROUND TRANSPORTATION OF EXPLOSIVES

36. Explosives or detonators should not be transported on or with the man-trip.

37. Explosives should not be carried on an electric locomotive.

38. Explosives and detonators should be transported in separate insulated cars in those mines in which haulage is by trolley locomotive.

39. In other mines, explosives and detonators may be transported in ordinary mine cars when in the original unopened containers or in separate insulated carriers or compartments.

40. Cars transporting explosives should be pulled and not pushed by locomotives.

41. Only the attendants should be permitted to ride with explosives or detonators when being transported in a shaft, slope, or other underground workings.

42. Explosives should be taken into the mine when the regular shifts are out of the mine when this is feasible.

43. Explosives should be handled promptly, without undue delays while in transit.

44. Explosives and detonators, when carried by employees, should be placed in separate insulated carriers or containers.

45. Explosives should not be taken to a working place until drilling has been completed and all equipment has been moved a safe distance from the face.

GENERAL USE OF EXPLOSIVES

46. Explosives (fume class 2 and 3) that produce more than 0.16 cu. ft. of poisonous gases per 1½ by 8-inch stick should not be used underground. If explosives that produce more than 0.16 cu. ft. of poisonous gases per stick are used, special precautions should be taken to insure adequate ventilation.

47. Blasting crews should be composed only of careful, experienced men, who understand the hazards of explosives. The number of men used in loading operations should be kept at a minimum.

48. Blasting crews should be organized carefully, and each man should be assigned to definite tasks to prevent confusion.

49. When holes are being charged, no person other than those designated to load should be permitted to work where there is possible danger of a premature explosion.

50. Dynamite thought to be frozen should not be used.

51. Smoking should be prohibited while explosives are being handled.

52. Electric flashlights with insulated bodies or approved battery cap lights should be used in loading blasting holes.

53. If open-flame lamps are in use, they should be kept at a safe distance during loading of blasting holes.

54. Accurate daily records of explosives should be kept.

55. Primed cartridges (primers) for immediate use may be prepared and transported in separate insulated carriers, containers, or compartments. They should not be removed from the insulated carrier until ready for placement.
56. Primers should be prepared as recommended by the various explosives-manufacturing companies. The electric detonator or fuse and cap should be fastened securely to the primer cartridge.

57. Packages or containers of explosives should not be thrown or dropped while being loaded, unloaded, or otherwise handled, but should be carefully deposited and stored or placed in such a manner as to prevent the packages or containers from sliding, falling, or being otherwise displaced.

58. Only wooden tamping bars should be used, and tamping should be done by pressure on the bar. Do not "ram" the tamping bar. Metal tamping bars should not be used.

59. Stemming should be used in all drill holes. It is recommended that the stemming be in cartridge form before inserting it into the hole.

60. All unused explosives for blasting should be returned at once to the magazine.

61. All approaches to the vicinity of the blasting should be guarded by responsible employees so as to prevent anyone from walking into danger unknowingly.

62. Distinctive signals should be provided to give adequate warning before a blast. The All Clear signal should be given when it is safe to return.

63. Special precautions must be taken when two headings are about to connect. When the faces of the two headings are within 20 feet of each other, the men should be removed from both headings at the time of the blasting, and the approaches to both headings should be guarded.

64. When blasting several faces, as on a level, those farthest from the shaft should be blasted first. The others will be blasted in turn, and the face nearest the shaft will be the last.

FUSE BLASTING

65. At least two men should be present when spitting holes.

66. The minimum length of fuse should be designated by the company management, but no fuse should be less than 30 inches in length.

67. Burning rate of fuse should be tested frequently and should be posted on a bulletin board and at the fuse-cutting section.

68. The length of fuse for rounds should be that required by State law; or, in the absence of State law, it should be determined by the management. The following fuse lengths are recommended:

<table>
<thead>
<tr>
<th>Number of holes:</th>
<th>Burning rate: 40 seconds per foot</th>
<th>Burning time</th>
</tr>
</thead>
<tbody>
<tr>
<td>4-10</td>
<td>6 ft., 0 in.</td>
<td>4 min.</td>
</tr>
<tr>
<td>11-15</td>
<td>7 ft., 0 in.</td>
<td>4 min., 40 sec.</td>
</tr>
<tr>
<td>16-20</td>
<td>8 ft., 0 in.</td>
<td>5 min., 20 sec.</td>
</tr>
</tbody>
</table>

and correspondingly longer fuse for additional holes.

69. An effective type of lighter should be used to light fuses.

70. The number of holes that can be blasted at any one time should be determined by the management, and the rule should be strictly enforced. Normally, not over 15 fuses should be split by each blaster.

71. Lighting of fuse before placing the primer in a drill hole should be strictly prohibited.

72. Crimpers should be used for crimping caps. Never crimp caps with a knife or with the teeth.

73. In wet work, the cap crimp should be waterproofed.

74. Copper or wooden pins or skewers should be used for punching holes in the primer cartridges.

75. Blasting fuse should not be kinked sharply, bent, or handled roughly; such treatment may result in a missed hole.

ELECTRIC BLASTING

76. Drill holes in raises over 50 feet vertically above the level or side opening should be fired electrically.

77. Drill holes in shafts or winzes should be fired electrically.

78. The use of electric detonators for block holes is recommended when it is practicable to use them.

79. Electric power should be cut off equipment at or near a face before explosives are taken to such face, during charging, and between charging and firing of shots.
80. All electric detonators should be tested with a galvanometer before the
primers are made.
81. The legwires of the detonators should be kept short-circuited at all times
until ready to be connected for blasting.
82. Lead wires should be protected at all times from possible stray currents
or from other possible sources of electricity. The ends of the lead wires should
be kept short-circuited at all times until the shot is ready for blasting.
83. The correct procedure in firing blasts electrically is
   (a) Connect detonator wires.
   (b) Connect leadwires to the detonator wire.
   (c) Unreel the lead wire as the blaster retreats towards the safety switch.
   (d) Connect lead wire to the safety switch.
84. When large blasts are detonated with electric detonators, they should
   be fired from a power circuit of ample capacity.
85. When blasting is done from power circuits, a safety switch should be in-
   stalled a safe distance from the blast.
86. The safety switch and the blasting switch should be encased in boxes and
   arranged so that the covers cannot be closed with the switches in a closed
   position; switch boxes should be kept with the switches locked in an open posi-
   tion, except when about to blast.
87. Keys to the "master" switch should be entrusted only to the person desig-
   nated to fire the shot.
88. If the charge is to be fired with a blasting machine, the holes should be
   connected in series, as recommended by the manufacturers.
89. The number of detonators connected in series should not exceed the rated
capacity of the blasting machine.
90. Electric detonators of different makes should not be used in the same
round.

SMALL DRILL-HOLE BLASTING

91. New holes should not be started in the bottoms or "boots" of old holes.
92. Drill holes should be cleaned thoroughly with a scraper or blown out
with compressed air before charging.
93. Blockholing should be used in secondary blasting whenever possible. The
practice of mud capping is not recommended, except in an emergency or under
special circumstances.
94. Two mud caps or "dobles" should not be placed on one rock unless dete-
nated electrically.
95. The miner should be sure that the working place is free of gas before
entering after blasting. Compressed air or other ventilating equipment can be
used for ventilation.
96. The face should be inspected carefully for missed holes after each blast.
The face should be washed with a water spray as an aid in detecting missed
holes.
97. Misfires occurring at the end of a shift should be reported to company
officials and to miners who will work in that place during the next shift.
98. A misfire should not be returned to until at least 30 minutes have elapsed,
or such longer time as the State law requires.
99. If a misfire occurs when an electric detonator is used, the detonator
should be tested with a circuit tester, and if it shows a circuit, connect the wires
in the usual way and fire.
100. Employees should not be permitted to remove or attempt to remove
explosives from a missed hole. A missed hole should be handled under the
direction of the foreman or other person assigned to this task by company
officials.
101. The following suggested method of handling misfires applies only in
those States that do not have laws requiring a different method of reblasting
missed holes.
   (a) Do not use a scraper to remove stemming from a hole that has missed.
   (b) Missed holes having only 12 to 15 inches of stemming can sometimes
be detonated without removing the stemming by using a fresh primer in the
hole.
   (c) Wash enough stemming from the hole to place a fresh primer near the
unexploded charge. Use a stiff rubber hose and a fairly strong jet of water.
(This will ruin the explosives unless they are water-resistant.)
(d) Blow out the stemming with compressed air. Use a stiff rubber hose equipped with a regulator valve within reach of the operator; the regular steel blowpipe should not be used, even when tipped with rubber.

102. Drilling should be stopped in any working place where missed or cut-off holes are found, and drilling should not be resumed until the explosives are either blasted or washed out.

LARGE DRILL-HOLE BLASTING

103. The condition of each hole should be recorded and noted on the loading plan. The holes should be proved with a dolly before loading. A small mirror can be used for visual inspection of the hole.

104. Tamping equipment should be checked, and ropes should be inspected before being used. Dollies should not be permitted to become badly worn before being replaced with new ones.

105. Tamping dollies should be checked for exposed metal parts.

106. Detonating fuse is generally regarded as the safest method of detonating well-drill holes.

107. Great care should be taken to make the connections as recommended by the manufacturers.

108. Reels should be provided for reeling Cordeau or Primacord into the holes, or other suitable means should be made ready before loading is started.

109. If electric detonators are used in well-drill holes, precautions should be taken not to damage the insulation of the wires.

110. Enough stemming or tamping material should be screened and placed by each hole before delivery of any explosives.

111. Holes should never be loaded while coal-burning locomotives, shovels, or other equipment is working in the vicinity.

112. Explosives should never be transported, handled, or used during an electrical storm.

113. If explosives are delivered by truck, only one truckload should be permitted at or near the loading operations. Other loaded trucks should wait in a safe place away from the loading operations, or their time of arrival should be regulated to allow enough time to load the explosives from each truck into the holes before the next truck arrives.

114. Explosives should be distributed to the holes farthest from the truck road first, to avoid driving among piles of explosives. Trucks should remain a safe distance from holes that have been or are being loaded.

115. When explosives for a blast are delivered to the foot of a bank and are carried to the holes by men, the same care should be taken to avoid having excessively large amounts of explosives in one area.

116. No detonator, blasting caps, or other explosive material foreign to the proper loading and detonating of the blast should be allowed in the vicinity in which the loading is being done.

117. When a long line of holes is being loaded, a hole should be skipped at intervals, and the gaps should be filled in when loading is completed. The gaps will help prevent propagation of the entire shot in case of a premature explosion.

118. Large cartridges of dynamite, such as are commonly used in blasting well-drill holes, should not be dropped into a hole, unless the hole is free from obstructions for its entire length.

119. Large cartridges of dynamite that have wedged in a hole should not be tamped with a dolly. A spear-shaped tamping block, such as is recommended by the manufacturing companies, should be used to dislodge the cartridge.

120. A free-running powder or dynamite cut in small pieces should be used to load ragged holes or holes partly closed by an obstruction that cannot be removed.

121. Black powder or bag powder, when used in well-drill holes, should be poured from the container through a copper funnel having high sides and a closed top. An opening large enough for convenient handling of powder containers should be on one side. This gives protection from chance sparks that may come in contact with the explosives.

122. Stemming should be placed in each hole as soon as loading of the explosives has been completed, care being taken to protect the detonating fuse or lead wires from damage.

123. When the blasting signal is given, shelter should be taken immediately at a safe distance but under a suitable roof constructed of at least 2-inch oak boards.
Men should remain under the shelter until the signal has been given that blasting is over.

124. A misfired well-drill hole should be handled as recommended by the Institute of Makers of Explosives.

125. Drill holes that have been sprung or chambered should be allowed to cool before explosives are loaded; when large springing charges are fired, holes should be allowed to cool for 24 hours.

126. Powerlines adjacent to blasting operations should have the power cut off before blasting.

**GOPHER-HOLE BLASTING**

127. Explosives charges should be pushed to the back of the hole with a wood pole, care being taken not to block the hole.

128. The primer cartridge should be loaded after all other explosives have been placed in position.

129. Precaution should be taken when placing stemming in the hole, especially if loose explosives are on the bottom of the hole.

**TUNNEL OR COYOTE-HOLE BLASTING**

130. Employees should be prohibited from wearing shoes having steel plates or other metal that may cause a spark.

131. Precaution should be taken in transporting explosives to the loading operations:

   (a) If explosives containers are carried by men, the roadway should be kept free from obstructions that might be a stumbling hazard.

   (b) If explosives containers are passed from one man to the next, the men should be cautioned not to drop the explosives.

   (c) If explosives containers are slid (on board slides) to the loading operation inspection should be made for protruding nails.

   (d) Only copper or brass nails should be used in constructing the plank slide.

   (e) If wheelbarrows are used to carry explosives the wheels should be of nonsparking material.

   (f) If power trucks are used to carry explosives the wheels should be of nonsparking material.

132. Explosives should not be removed from the containers, and the containers should be piled compactly.

133. Employees should not be permitted to eat their lunches inside the blasting tunnel or in front of the area being loaded.

134. The following precautions should be taken when using detonating fuses:

   (a) The detonating fuse should be placed in slotted wooden boxes or troughs with wood tops fastened with copper or brass nails.

   (b) The detonating fuse should be taken from the wing entrance to the end of the blast and looped back through the units of the explosives charge.

135. The following precautions should be taken when blasting electrically:

   (a) When a box of dynamite is used as a primer, it should be prepared outside the tunnel and never at the loading site. The detonator wires should be brought outside the box through a notch in the side of the box, and the cover should be placed firmly on the box.

   (b) Lead wires should be installed before loading. The lead wires can be passed through ring pins in the roof or carried in slotted wood boxes or troughs with wood covers. Copper or brass nails should be used to fasten covers.

   (c) Circuits should be tested at least every 10 feet when stemming is placed in the crosscuts.

**CONCLUSIONS**

In mining either above or below ground only the safest and most suitable types of explosives should be used for the work at hand, which means that black blasting powder should be eliminated; no straight nitroglycerin dynamites should be used underground; electric blasting should in many places taken the place of fuse. Reasonable care
in handling and using explosives means that explosives magazines in metal and nonmetallic mines should be in cool, reasonably dry places several hundred feet from any shafts or stations where men pass or congregate; no person should be required or allowed to return to a blasted face or place until the smoke, gases, and dusts from the blast have been removed by ventilation or sprays.

Commercial explosives are destructive by nature, but they are necessary to mining and other work; the hazards of their handling and use must be regarded as potential penalties of misuse, carelessness, and misinformation rather than unavoidable risks of mining.

New types of explosives probably will be brought into use that will do away largely with hazards of premature detonation from shock or sparks, but that will be part of another chapter in industrial safety. The explosives now available for general use are reasonably reliable when their limitations are given proper consideration, but they are neither foolproof nor a protection for the untrained or thoughtless. The precautions to be followed to prevent accidents are known and should be made familiar to all who use explosives. Most accidents from explosives and blasting can be avoided by training mine workers in a few simple safety practices and by supervision to see that these practices are carried out.

From examples of the misuse of explosives and faulty blasting practices that have been cited in this circular, and others known to mining men, it is evident that the common hazards of explosives are largely man created. Blasting accidents are nearly always serious, resulting in death, dismemberment, or maiming of the careless individual and frequently of innocent bystanders. A determined training campaign in safe blasting practices is well worth while in any organization that uses explosives.

Some of the safety rules and recommended practices for handling, storing, and using explosives given in this circular conflict with current practices in certain mining and quarrying operations. Moreover, some of the managements of such operations have investigated the hazards of their contrary practices and have found no apparent undue hazards. The rules and safety practices thus brought into question have been established not by theory but as means to overcome actual causes of past accidents; a number of blasting practices may be carried on without accidents as long as they are controlled and supervised to prevent variations which cause serious accidents. Thus, "short fuse" can be used without accident as long as there is no delay in placing the fuse andprimer in the hole, or in the departure of the blaster from the vicinity of the blast, or if no explosive material that may be ignited by the burning fuse is adhering to the sides of the hole. Where all these circumstances are controlled and no accidents occur the hazard of the use of "short fuse" is not established, yet the practice most certainly should be condemned and should never be followed unless it can be shown clearly that that attendant hazards have been removed.

SUGGESTED READING—EXPLOSIVES AND BLASTING


**LIST OF MINERS’ CIRCULARS**

Note.—Circulars marked with a dagger (†) are out of print but may be consulted in many libraries. Others may be obtained from the Superintendent of Documents, Government Printing Office, Washington 25, D. C., at the price indicated. Stamps are not accepted in payment for such purchases.

†1. The Use and Care of Mine Rescue Breathing Apparatus, by J. W. Paul. 1911. 24 pp., 5 figs.
†7. The Use and Misure of Explosives in Coal Mining, by J. J. Rutledge. Rev. 1914. 51 pp., 8 figs.
†12. The Use and Care of Miners’ Safety Lamps, by J. W. Paul. Rev. 1915. 16 pp., 4 figs.
†19. The Prevention of Accidents From Explosives in Metal Mining, by Edwin Higgins. 1914. 16 pp., 11 figs.
†32. Use of a Type N Miners’ Gas Mask, by S. H. Katz and G. S. McCaa. 1929. 29 pp., 14 figs.
†37. Safety Education in Schools of Mining Districts, by F. S. Crawford, A. U. Miller, and C. W. Owings. 1938. 34 pp., 1 fig.