# CHAPTER 9
# UNITED STATES PROPELLANTS

**9-1. Introduction.** Selection of a propellant for an application is made on the basis of the requirements of that specific application. In general, guns are designed to meet specified performance standards and withstand a specific pressure in the barrel. With a knowledge of the properties of the constituents normally used for propellants, the propellant designer creates a formulation to satisfy the performance standards and limitations of the gun. When ignited, the propellant produces large quantities of hot, gaseous products. Complete combustion or deflagration of the propellant occurs in milliseconds in guns and the pressure produced accelerates the projectile down the barrel. Table 9-1 shows the approximate distribution of the energy content of the propellant.

*Table 9-1. Distribution of Propellant Energy*

| Energy absorbed | Percent of total |
|---|---|
| Motion of projectile | 32.0 |
| Frictional work | 2.0 |
| Translation of gases | 3.0 |
| Heat loss to gun and projectile | 20.0 |
| Sensible and latent heat loss in gases | 42.0 |
| Rotation of projectile and recoiling parts | 1.0 |

**9-2. Chemical Composition of Propellants.** Properties of the principal energetic ingredients of common gun propellants (nitrocellulose, nitroglycerin, and nitroguanidine) are discussed in Chapter 8. The composition and selected properties of various gun propellants are shown in table 9-2. The formulations arise from needs to maintain the flame temperature at certain levels, and from a desire to achieve the maximum energy content within that flame temperature limitation. Low flame temperatures, low levels of carbon monoxide, and hydrogen in the muzzle reduce the tendency of a gun to exhibit secondary flash. The main reason for seeking low flame temperatures is to reduce barrel erosion. In certain propellant systems, the need for flash reduction impacts on the flame temperature limit permitted. Usually, potassium salts are sufficiently effective in eliminating secondary flash. Also to be considered are the cost of ingredients and the physical properties of the final propellant.

*Table 9-2. Composition and Properties of Propellants*

| | M1 | M2 | M5 | M6 | M8 | M10 | M31 | M30 | IMR | M18 |
|---|---|---|---|---|---|---|---|---|---|---|
| Nitrocellulose (NC), % | 85.00 | 77.45 | 81.95 | 87.00 | 52.15 | 98.00 | 20.00 | 28.00 | 100.00 | 80.00 |
| % Nitrogen in NC | 13.15 | 13.25 | 13.25 | 13.15 | 13.25 | 13.15 | 12.60 | 12.60 | 13.15 | 13.15 |
| Nitroglycerin, % | - | 19.50 | 15.00 | - | 43.00 | - | 19.00 | 22.50 | - | 10.00 |
| Barium nitrate, % | - | 1.40 | 1.40 | - | - | - | - | - | - | - |
| Potassium nitrate, % | - | 0.75 | 0.75 | - | 1.25 | - | - | - | - | - |
| Potassium sulfate, % | - | - | - | - | - | 1.00[a] | - | - | 1.00[a] | - |
| Lead carbonate, % | - | - | - | - | - | - | - | - | - | - |
| Nitroguanidine, % | - | - | - | - | - | - | 54.70 | 47.70 | - | - |
| Dinitrotoluene, % | 10.00 | - | - | 10.00 | - | - | - | - | 8.00[b] | - |
| Dibutylphthalate, % | 5.00 | - | - | 3.00 | - | - | 4.50 | - | - | 9.00 |
| Diethylphthalate, % | - | - | - | - | 3.00 | - | - | - | - | |
| Diphenylamine, % | 1.00[a] | - | - | 1.00[a] | - | 1.00 | - | - | 0.70 | 1.00 |
| Ethyl centralite, % | - | 0.60 | 0.60 | - | 0.60 | - | 1.50 | 1.50 | - | - |
| Graphite, % | - | 0.30 | 0.30 | - | - | 0.10[b] | - | 0.10[b] | - | - |
| Cryolite, % | - | - | - | - | - | - | 0.30 | 0.30 | - | - |

*Table 9-2. Composition and Properties of Propellants (Cont)*

| | M1 | M2 | M5 | M6 | M8 | M10 | M31 | M30 | IMR | M18 |
|---|---|---|---|---|---|---|---|---|---|---|
| Ethyl alcohol (residual), % | 0.75 | 2.30 | 2.30 | 0.90 | 0.40 | 1.50 | 0.30 | 0.30 | 1.50 | 0.50 |
| Water (residual), % | 0.50 | 0.70 | 0.70 | 0.50 | 0 | 0.50 | 0 | 0 | 1.00 | 0 |
| Isochoric flame temp. $T_v$, K | 2,417 | 3,319 | 3,245 | 2,570 | 3,695 | 3,000 | 2,599 | 3,040 | 2,835 | 2,577 |
| Force, ft-lb/lbx$10^{-3}$, F | 305 | 360 | 355 | 317 | 382 | 339 | 334 | 364 | 331 | 319 |
| Unoxidized carbon, % | 8.6 | 0 | 0 | 6.8 | 0 | 4 | 8.7 | 3.2 | 2.7 | 6.8 |
| Combustibles, % | 65.3 | 47.2 | 47.4 | 62.4 | 37.2 | 54.5 | 49.8 | 41.0 | 59.2 | 66.6 |
| Heat of explosion, cal/g | 700 | 1,080 | 1,047 | 758 | 1,244 | 936 | 807 | 974 | 868 | 772 |
| Gas volume, moles/g | 0.04533 | 0.03900 | 0.03935 | 0.04432 | 0.03711 | 0.04068 | 0.04620 | 0.04308 | 0.04191 | 0.04457 |
| Ratio of specific heat | 1.2593 | 1.2238 | 1.2238 | 1.2543 | 1.2148 | 1.2342 | 1.2527 | 1.2385 | 1.2413 | 1.2523 |
| Covolume, in.$^3$/lb | 30.57 | 27.91 | 27.52 | 29.92 | 26.63 | 27.76 | 30.87 | 29.26 | 28.91 | 30.24 |
| Density, g/cm$^3$ | 1.57 | 1.65 | 1.65 | 1.58 | 1.62 | 1.67 | 1.64 | 1.66 | 1.62 | 1.62 |

[a] Added.

[b] Glaze added.

[c] Ball propellant.

a. The single-base propellants shown in table 9-2 are M1, M6, M10, and IMR. Nitrocellulose is the principal energetic material. These are low cost propellants that have a low flame temperature and low energy content. To reduce the flame temperature and barrel erosion, recent formulations of the IMR propellants do not use dinitrotoluene. Ethylene dimethacrylate and methyl centralite are among the replacement materials which produce much lower flame temperatures. IMR is considered a single-base propellant even though the formulation contains a small amount of nitroglycerin.

b. The double-base gun propellants shown in table 9-2 are M2, M5, M8 and M18. In these formulations the nitrocellulose is gelatinized by nitroglycerin. The presence of an active gelatinizer makes double-base propellants more energetic than single-base propellants. The ballistic potential is increased correspondingly. The flame temperature and resulting barrel erosion is also increased. Other aliphatic nitrate esters are also used to gelatinize the nitrocellulose. DEGN is the most widely used gelatinizer but DEGN has the undesirable property of being more volatile than nitroglycerin and so, makes the propellants less stable.

c. The triple-base gun propellants contain nitroguanidine as additional energizer which increases the energy content of the formulation without raising the flame temperature. This reduces gun barrel erosion with no sacrifice in performance. In addition, the triple-base propellants have a substantially reduced concentration of combustibles such as hydrogen and carbon monoxide in the product gas. This reduces the flash from the gun barrel.

d. Composite propellants, used in solid fuel rockets, contain a polymer binder, a fuel, and an oxidizer.

**9-3. Thermochemistry.** Thermochemical properties are prime considerations in formulating a propellant for a specific application. The thermochemical properties include the flame temperature of the gases produced by the propellant under certain standard conditions, their average molecular weight, and covolume. The commonly used equation of state used with the combustion products of gun propellants (for gun applications) is:

$$P(V-b)=nRT$$

where $P$ is the pressure, $V$ is the volume, $b$ is the covolume, $n$ is the number of moles of the gas per unit mass, $R$ is the universal gas constant, and $T$ is the temperature. The ideal gas equation of state is obtained in the case where $b$ equals zero. The covolume is a correction factor to take into account the extremely high pressures, 137,900 to 482,650 kilopascals (20,000 to 70,000 pounds per square inch), that exist in a gun barrel. Physically, the covolume is defined as the volume actually occupied by the gas molecules. Laboratories dealing with propellants have a variety of methods available, including computer programs, that are used routinely to estimate the thermochemical properties of propellants from basic chemical data. The simplest of these is the Hirschfelder-Sherman calculation in which the adiabatic, isochoric flame temperature $T_v$, heat of explosion $Q$, moles of gas per gram $n$, impetus (force)

$F=nRT_v$, ratio of specific heats, and covolume are calculated. An equilibrium computer program called the BLAKE code, formulated on the basis of a virial coefficient equation of state, has been devised for gun use. The usual input required for equilibrium propellant performance calculations consists of the chemical composition, the heat of formation ($H_f$ at 298°K), and the elemental formula of each ingredient. Several extensive compilations of heat of formation data are available.. Several techniques are available for estimating the heat of formation of compounds by addition of bond energies and/or group contribution where experimental data are lacking. A computer program has been developed for estimation of chemical thermodynamic data called "Chetah" (chemical, thermodynamic, and hazard appraisal). The estimated values obtained by these methods are usually for compounds in the ideal gaseous state. Therefore, the heat of vaporization and, sometimes, the heat of fusion must be taken into account to obtain the heat of formation of the compound in its normal state at 298°K. Experience indicates that the results of propellant performance calculations are not extremely sensitive to errors in the heat of formation of the ingredients. Recently, methods have been developed for calculating certain transport properties (for example, the thermal conductivity and viscosity) of the combustion product gases under specific conditions of temperature and pressure.

**9-4. Physical Properties.** Gun propellants must function reliably over a large ambient temperature range (for example, −54° to +74°C) and they must retain their performance characteristics during many years of storage. The propellant grains must retain their integrity in the face of a severe blast from the ignition system. This quality must be demonstrated particularly at low temperatures where the propellants tend to be brittle. The propellant grains must not soften excessively at high temperature because then they can be deformed by the ignition pulse. If this occurs, the propellant bed might be compressed so tightly that the ignition gases might not percolate satisfactorily through the bed. A number of physical properties of propellants are occasionally of interest to the ammunition designer. Among these properties are thermal expansion, thermal conductivity, specific heat, and thermal diffusivity. The following properties are of direct interest to the charge designer:

a. *Density.* Conventional single- and double-base propellants have values of approximately 1.60 grams per cubic centimeter, while triple-base (nitroguanidine) propellants are slightly higher. This is advantageous for tank ammunition where the maximum amount of propellant charge is required to meet the desired ballistic levels.

b. *Bulk Density.* This often is referred to by such terms as "gravimetric density" and "screen loading density" depending on the test utilized. The values reported are empirical and are greatly dependent on the specific gravity of the propellant, the grain geometry, surface characteristics, and the measuring technique. The term "bulk density" often is confused with loading density, a term that the ballistician uses for the ratio of the charge weight in a system to the chamber volume.

c. *Compressibility of Grains.* This is a measure of how much a propellant grain can be compressed before cracks appear. The usual required minimum value for gun propellants at 25°C is 30 percent. That value is based on historical experience.

**9-5. Manufacture.** The manufacturing methods for various types of propellants are given below.

a. *Single-Base Propellants.* The manufacture of nitrocellulose is discussed in chapter 8. Wet nitrocellulose from the manufacturing process is dehydrated after the moisture content has been reduced to approximately 28 percent by wringing. Dehydration is accomplished by pressing the nitrocellulose at low pressure so as to squeeze out some water, adding 95 percent ethanol, and pressing at about 24,133 kilopascals (3,500 pounds per square inch). A block containing 11.4 kilograms (25 pounds) of dry nitrocellulose and about one-third that much of 90 percent ethanol is obtained. The wet block is broken up into small lumps by means of a rotating drum containing iron prongs and a screen. The nitrocellulose is transferred to a water-cooled mixing machine of the dough-mixer type and, while this is in operation, ether equal to approximately two-thirds of the weight of dry nitrocellulose is added. Any plasticizing agents and stabilizers to be included in the composition are dissolved in or mixed with the ether prior to addition to the nitrocellulose. After addition of the ether is complete, materials such as potassium nitrate are added. Mixing of the ingredients is continued for about one hour. A partially colloided mixture which resembles dry oatmeal is produced. By pressing this at approximately 20,685 kilopascals (3,000 pounds per square inch) so as to form a block, the degree of colloiding is increased rapidly. This effect is further increased and uniformity of the mixture is improved by subjecting it to a pressure of about 24,133 kilopascals (3,500 pounds per square inch) in a macaroni press. Here the material is squeezed through a series of screens and perforated plates and emerges in a form resembling that of macaroni. This is pressed again to form a block of well colloided material. This is placed in a graining press and extruded through a carefully designed die by the application of pressure. The material emerges as a cord with one or more cylindrical perforations. The cord is cut into pieces of predetermined length. Removal of the volatile solvent, with shrinkage of the grains to their final dimensions, is accomplished by three operations. In the solvent recovery operation, the powder is placed in a large tank and warm air or other gas is passed through the mass. With careful control, so as to prevent surface hardening, the temperature of the air is gradually increased to not more than 65°C. The solvent recovery operation requires from 2 to 14 days, depending upon the size of the grain, and reduces the solvent content to approximately six percent. The water dry operation consists of placing the partially dried powder in water at about 25°C and gradually increasing the temperature to a maximum of 55°C. After a number of days, the residual solvent is reduced to 0.3 to 5 percent, depending upon the grain size. The powder now is air dried to remove surface moisture and screened to remove dust and grain clusters. The final operation before packing is to blend all the powder in a lot, which may vary from 22,700 to 227,000 kilograms depending on the type of powder. This is accomplished by transferring the powder from one conical bin to another by gravity flow. This blending improves uniformity of the lot with respect to composition and external moisture content.

b. *Double-Base Propellants.* Double-base propellants are manufactured by two methods. The solvent process is similar to that used for single-base powders except that a mixture of ethanol and acetone is used as the solvent and the solvent recovery procedure is omitted because of the hazard involved in recovering solvents containing nitroglycerin. The solventless process is used when the nitroglycerin and any other colloiding agents constitute approximately 40 percent of the composition. In this process the wet nitrocellulose is blended with the nitroglycerin in a tank filled with water. Ethyl centralite is mixed in and the bulk of the excess water is removed by centrifuging. The resulting paste is put in cotton bags and subjected to heated air currents to reduce the moisture content. The remaining constituents are then blended with the partly dried paste. Repeated rolling between heated steel rollers removes the rest of the water and completes colloiding of the nitrocellulose. The thickness of the sheet formed is controlled carefully and varies with use. If the sheet is to be cut into flakes for use in small arms or mortars, the thickness is between 0.08 and 0.32 millimeter (0.003 and 0.0125 inch). Sheets to be extruded in the form of large grains for use in rockets may be as thick as 3.18 millimeters (0.125 inch).

c. *Triple-Base Propellants.* The manufacturing process used for the nitroguanidine triple-base propellants in the United States has been uniformly solvent extrusion. The amount of solvent used is quite low so the propellant is very soft during extrusion. The soft strands may require partial drying before cutting in order not to deform the cross section at the cut. Removal of solvent from the triple-base propellant is rapid, possibly due to diffusion of solvent within the grain along the crystal-plastic interfaces. In order to make a good quality grain, lower drying temperature gradients are used in order to avoid steep solvent gradients resulting in distortion and cracking.

d. *Composite Propellants.* A composite propellant is manufactured by a simple mixing operation, cured, and molded into grains or poured directly into the rocket case and cured by heating in controlled ovens. Operational temperatures extend from −40° to +60°C. The high solid content requires great resin strength and good elastic properties to withstand low temperatures. Precise control of the oxidizer particle size is needed to control ballistic properties. Rockets up to 6.6 meters in diameter and weighing up to 45,400 kilograms have been fired successfully. The dense smoke produced by these propellants limits their use to long range systems where the signature of the rocket does not easily reveal the firing point.

e. *Ball Propellants.* Ball propellants are used for small arms. The nitrocellulose used to make the propellant is extracted from waste single-base propellant. To produce the propellant in ball form, water-wet nitrocellulose is mixed with ethyl acetate, colloided with animal glue, and agitated; excess water causes the propellant to precipitate in a ball. The animal glue is washed away using hot water. The propellant is screened to size and nitroglycerin is added in the presence of ethyl acetate. The nitroglycerin is absorbed by the ball propellant, the ethyl acetate is driven off, and the ball is carried to a roll mill to cause cracks, that serve as combustion sites, to form in the ball. The propellant is then dried and a deterrent coating such as dibutylphthalate is added. The deterrent reduces the burn rate of the propellant to an acceptable level.

**9-6. Propellant Grain Geometry.** The burning time of a propellant charge depends on two factors. One factor is the velocity at which the exothermic decomposition reaction occurs. This is called burning rate. The other factor is the total surface area of propellant exposed. In order to control the surface area available for reaction, propelling charges consist of numerous propellant grains. Propellant grains can have a variety of shapes as shown in figure 9-1. An additional grain geometry, the flake, is also used in mortars. The shape of the grain determines how much surface area is exposed as burning proceeds. For example, as a cord burns, the surface area of exposed propellant decreases. This is called a degressive grain. As a single perforated grain burns, the exposed surface area remains nearly constant because the outer surface area decreases as the inner surface area increases. This is called a neutral grain. In a progressive grain, for example the multi-perforated and rosette, the surface area increases during burning. The grain geometry and burning rate are interrelated. The burning time of a propelling charge that contains a propellant with a high burning rate and strongly digressive grain geometry could be equal to the burning time of a charge that contains a propellant with a low burning rate and strongly progressive grain geometry. European nations have favored the use of single perforation, strip, and cord propellants. The United States uses single perforation and multi-perforation propellants. The single perforation grains may be slotted or unslotted. The slotted grain has the desirable characteristic of venting gas during combustion. All countries use ball propellants for small arms. In a multi-perforation or rosette grain that consists of a propelling compound with a specific linear burning rate, the burn time can be varied by varying the web thickness. The web thickness, shown in figure 9-2, is the average dimension of the outer web and inner web. In general, the finer the web the shorter is the burning time of the propellant charge. The grain dimensions also influence the burning time. The finer the web the higher the pressure produced. A cannon is designed to operate with a maximum pressure. This pressure must be taken into account when designing the grain web. The same projectile velocity can be attained with a smaller amount of propellant with fine web and with a larger amount of propellant with a coarse web. However, the pressure with the former is considerably greater than the latter. In general, the heavier the projectile or the greater the prescribed velocity, the larger the powder grain and web used. As shown in figure 9-2, the burning of a seven perforation grain produces 12 unburned slivers or pieces of triangular cross section that represent approximately 15 percent of the total weight of the grain. These slivers burn digressively and usually are burned in the bore of the weapon; but if the tube is relatively short or a reduced charge of propellant is fired, incompletely burned slivers may be expelled from the muzzle. The rosette or Walsh grain (figure 9-1) with a scalloped outer periphery, reduces the number of slivers produced by a multi-perforation grain and therefore reduces or eliminates the amount of unburned powder ejected. In practice, there are certain general relationships between the dimensions of powder grains. These dimensions must remain within fairly narrow limits. Specification requirements for cannon powders include the relative dimensions which follow.

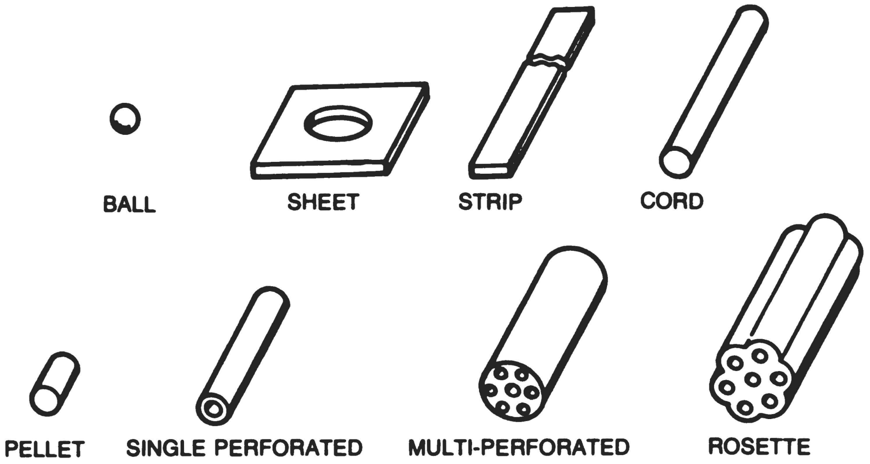


*Figure 9-1. Typical shapes of propellant grains.*

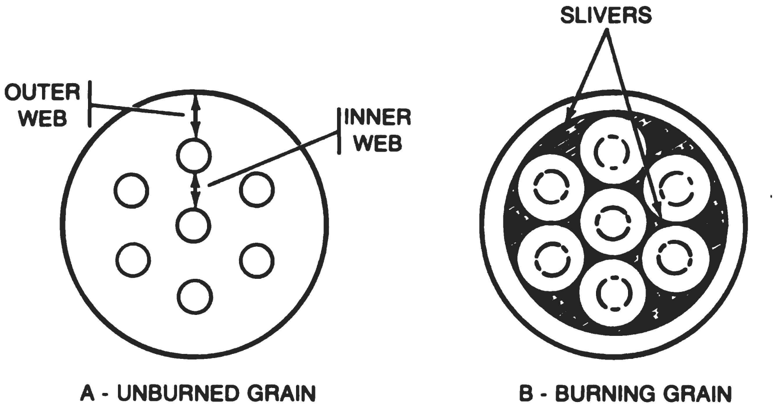


*Figure 9-2. Web thickness and direction of burning through a progressively burning grain.*

a. The ratio of average grain length (L) to average grain diameter (D) is 2.10 to 2.50 for multi-perforation grains and 3 to 6 for single perforation grains.

b. The ratio of average grain diameter (D) to the average diameter of perforations (d) is 5 to 15 for multi-perforation grains and approximately three for single perforation grains.

c. The difference between the average outer web thickness ($W_o$) and the average inner web thickness ($W_i$) of multi-perforation powder is not more than 15 percent of the average web thickness ($W_a$).

**9-7. Burning Rates.** Ballisticians view the propellant grains as burning in parallel layers, where the burning proceeds in a direction perpendicular to the surface. This universally accepted concept is known as Piobert's law and is supported by the experience of many investigators drawing their conclusions from many different approaches. The linear burning rate vs pressure behavior of a gun propellant (the rate at which burning proceeds normal to the surface) is a characteristic of the composition and is a required input for most interior ballistics calculations.

a. The burning rate is independent of grain geometry. Results of the two tests usually used to determine burning rates (the strand burner and closed bomb) are the same for cord, single perforation, and seven perforation grains. The closed bomb is used most commonly to determine relative force (*RF*) and relative quickness (*RQ*) of gun propellants. In this determination, a test propellant is fired in a closed bomb and the results are compared with those obtained with a reference propellant fired under identical conditions. *RF* is defined as

$$RF = \frac{P_{max} \text{ test propellant}}{P_{max} \text{ reference propellant}}$$

*RQ* is defined as

$$RQ = \frac{dP/dt \text{ test propellant}}{dP/dt \text{ reference propellant}}$$

where $dP/dt$ is the rate of change of pressure with time.

b. Burning rate vs pressure data commonly are fitted to an equation of the form

$$r = bP^n$$

known as de Saint Robert's equation. Plots of the log of the burning rate vs the log of the pressure of many propellants yield straight lines. Under that condition, $b$ and $n$ are constants. Table 9-3 gives values of $b$ and $n$ for several of the standard propellants. Using the values specified, the burning rate equation yields $r$ in inches per second when $P$ is in pounds per square inch.

*Table 9-3. Burning Rate Parameters for Several Standard Gun Propellants*

| Propellant | M1 | M2 | M6 | M10 | M30 |
|---|---|---|---|---|---|
| *b* | 0.002143 | 0.002432 | 0.002989 | 0.004004 | 0.00576 |
| *n* | 0.710 | 0.755 | 0.702 | 0.695 | 0.652 |

c. The burning rate of gun propellants generally increases with initial propellant temperature. The temperature coefficient of the burning rate is defined as the ratio of the change in burning rate and the change in temperature at constant pressure. Typical values for the temperature coefficient are 0.077 percent per degree centigrade at 206,850 kilopascals (30,000 pounds per square inch) for M10 and 0.05 percent for M30 under the same conditions.

d. The burning rate of conventional propellants increases with increasing flame temperature. Several empirical correlations have been developed which provide a means for estimating burning rates of different propellant formulations from the adiabatic flame temperature.

e. Propellants used in small arms usually have a deterrent impregnated into their surface which alters the chemical composition of the outer portion of the grains to slow the initial burning rate. Commonly used deterrents include dinitrotoluene and ethyl centralite. The deterrent has a moistureproofing effect and usually a melting point of less than 100°C. A coating of deterrent is applied by tumbling the propellant powder in a "sweetie" barrel in a water slurry with the deterrent at a temperature above the melting point of the deterrent.

f. The burning rate of solid propellants increases with increasing product gas velocity near the surface. This phenomenon is referred to as erosive burning. The extent of erosive burning depends on grain geometry and composition. Relatively "hot" propellants are apparently less subject to erosive burning than are "cool" ones. The inner surface of long tubes does not, apparently, burn in an even, uniform manner. The holes increase in size faster at the ends. Slotted tubes burn closely in conformance to Piobert's law.

g. The actual burning rate of solid propellants also deviates from the steady-state or expected value under rapid pressure excursions. That is, the instantaneous burning rate then will differ significantly from that expected for the corresponding instantaneous pressure. This phenomenon, called dynamic burning, has not been studied enough to present corrections to the burning rate equation.

**9-8. Ignitability.** Ignition of a propellant charge is accomplished by raising the temperature of the propellant surface to the ignition temperature. The simultaneous ignition of all the exposed surfaces is desirable for many gun applications. Black powder is used extensively for artillery and rocket propelling charge ignition. Black powder is a more efficient igniter than finely divided propellant, which is used in mortars, because it does not produce as much gas per unit weight as propellant, its use reduces ignition shock, it yields high initial pressures, and the hot particles in its combustion products assist in transferring heat to the propellant surface.

a. An increase in the nitrogen content of the nitrocellulose causes slight increase in ignitability.

b. The substitution of nitroglycerin for part of the nitrocellulose in a composition increases ignitability to a marked extent.

c. The inclusion of an inert, gelatinizing agent, such as dibutylphthalate or triacetin, in a propellant composition results in a decrease in ignitability.

d. The inclusion of TNT or dinitrotoluene in a composition causes measureable decrease in ignitability.

e. The inclusion of five percent or less of potassium nitrate in a composition causes a significant increase in ignitability.

f. The presence of a deterrent on a propellant causes retardation of ignition.

g. As the initial temperature of the propellant decreases, the ignitability decreases.

**9-9. Charge Design Considerations.** The selection of a propellant for a particular application is determined by cost, by the interior ballistics requirements, by propellant/weapon interface considerations, and by limitations with respect to muzzle effects. The propellant with the lowest cost formulation and the lowest flame temperature that still will meet the velocity and pressure requirements is generally used. Other important considerations are the effects on ballistic performance of various propellant grain shapes and the problem of matching the gas production rate from propellant burning to the rate of increase of volume in the gun behind the accelerating projectile. The shape of the grain also affects the amount that can be loaded in a given space and can control the generation of pressure waves in large caliber guns. The charge weight sometimes is restricted in large caliber guns by the momentum limit. The gas expelled from the muzzle adds to the total forward momentum. The propellant charge plays a major role in gun fouling and erosion. This field is receiving considerable attention at this time and in recent years, erosion often has been reduced dramatically by means of wear-reducing materials that are added to the propellant composition or to the charge as cartridge case liners. Efforts usually are made to minimize muzzle flash and smoke. Muzzle flash and smoke are related in a sense and have been investigated extensively. Two components contribute to muzzle flash: the primary flash and the secondary flash. The primary flash is caused by incandescent hot gases emerging from the muzzle or heated to incandescence by the shock following the projectile out of the gun. The secondary flash is caused by the burning of combustible muzzle gas when mixed with air and heated to ignition by the shock wave. Ignition of the gas cloud is also caused by the early, bright burning of tracers. This is a voluminous, relatively long lived event and is far more objectionable than the primary flash. In small caliber weapons, secondary muzzle flash is suppressed effectively in many weapons by means of mechanical devices attached to the muzzle. Various chemical additives, especially alkali metal salts, are very effective and widely used to suppress secondary flash. The salts may be incorporated into the compositions, or they may be loaded as separate components in the charge. Secondary flash is also reduced by reduction of the propellant composition flame temperature and by reduction of the proportion of combustible gases produced by the propellant. Gun smoke is due to particulate, usually inorganic, material emerging from the gun behind the projectile. Primer and igniter combustion products, barrel scrapings, and solid combustion products from the propellants are the major constituents of gun smoke. The visibility of the smoke or smoke density is due largely to the products from the alkali metal salt flash suppressant. These constituents also are responsible for the substantial increase of smoke density under humid conditions.

**9-10. Ballistic Effects.** The study of the combustion of a propellant in a confined volume, and the resultant rate of gas generation combined with its effect on the acceleration of a projectile, is called interior ballistics. Figure 9-3 shows a representative pressure travel curve for a projectile in a gun. The further the point of maximum pressure (points A, B, and C) is from the powder chamber, the greater the velocity acquired by the projectile. This is the reason the United States favors the use of multi-perforated grains.

a. There are four general equations which form the basis of interior ballistics.

(1) The burning rate equation is the first of the four. This equation has already been discussed.

(2) The equation of the form takes into account the propellant grain geometry. The web fraction, $W_f$, is defined by the equation:

$$W_f = \frac{2Rrdt}{W_0}$$

where $r$ is the burning rate, $R$ is the burning rate conversion factor, and $W_0$ is the original web thickness. The factor of two is present since the web is being burned from two opposite surfaces and $R$ is included to compensate for burning rate peculiarities. The amount of gas generated can be found as a function of $W_f$ by the following two equations:

$$\frac{G}{C} = f(W_f) = K_0 + K_1 W_f + K_2 W_f^3 = K_3 W_f^3 \text{ if } W_f \geq 0$$

$$\frac{G}{C} = f(W_f) = K_0 + K'_1 W_f = K'_2 W_f^2 + K'_3 W_f^3 \text{ if } W_f \leq 0.$$

where $G$ is the mass of gas generated, $C$ is the original charge mass, $K_0$-$K_3$ and $K'_1$-$K'_3$ are coefficients determined by the grains geometry and $W_f$ is the fraction of web remaining. The first equation is employed during non-splintered burning ($W_f \geq 0$) and the second is used after grain splintering has occurred ($W_f \leq 0$). Slivering is typical of multi-perforation grain types. In these grain types there is residual propellant when the web fraction is burned to zero. This remaining propellant is then burned as slivers. In simulations containing more than one grain type, each granulation is handled separately. The total gas generated is simply their sum.

(3) As propellants burn, the total energy available from a unit mass of propellant can be computed by the equation:

$$E = \frac{FG}{g - 1}$$

where $E$ is the energy liberated, $G$ is the ratio of specific heats of the propellant gas, $F$ is the propellant impetus

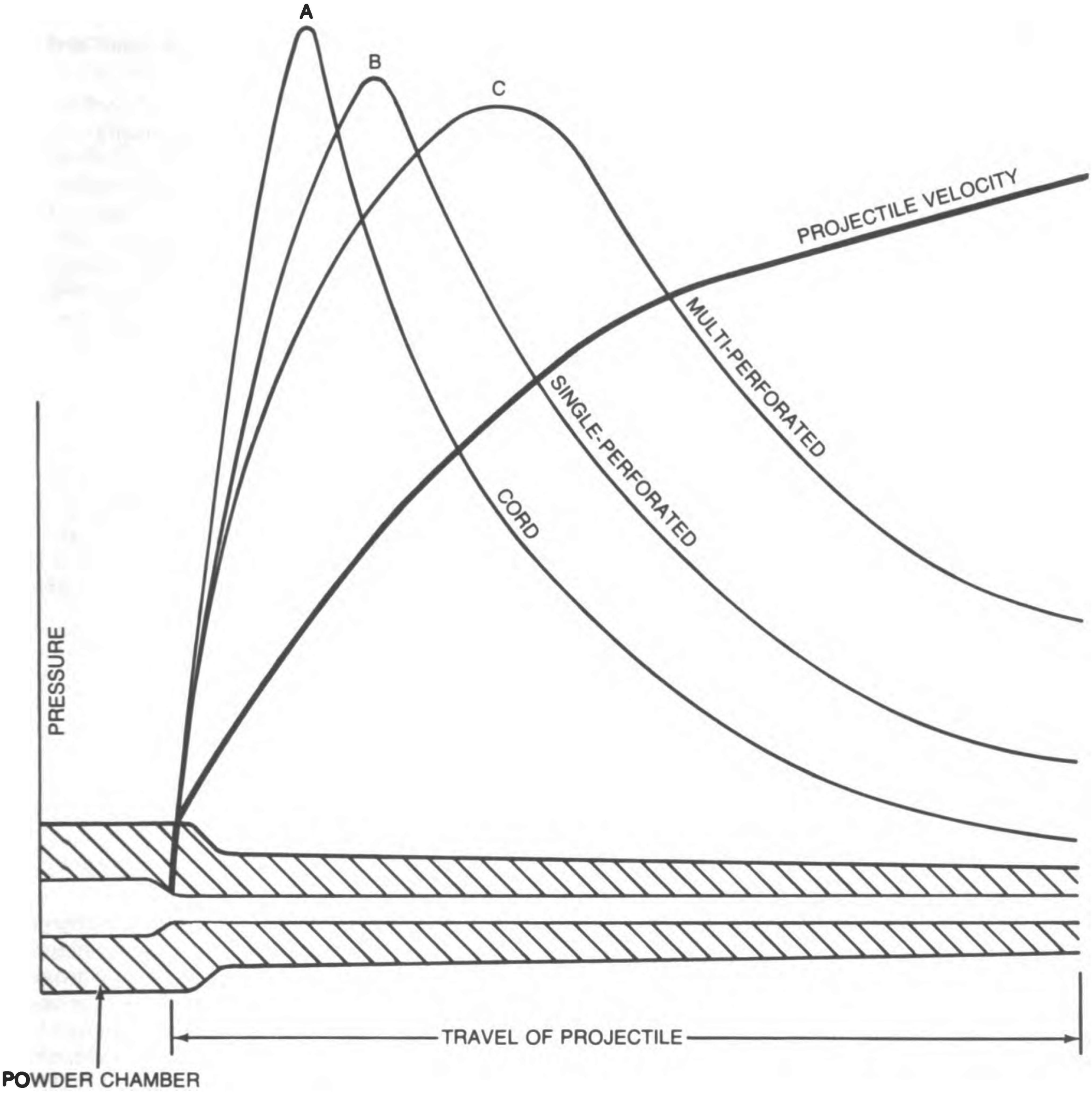


*Figure 9-3. Pressure travel curves for a projectile in a gun.*

(the amount of energy per unit mass). In cases where more than one grain type or more than one propellant type are used, the energy generated by each distinct granulation-propellant combination is calculated separately and summed to compute the total energy released. The energy released by the burning propellants is dissipated in several ways. The potential energy of the confined gas is increased (PV energy). Energy is spent accelerating the projectile and the gas itself (kinetic energy). Energy is lost through thermal and frictional processes which results in an increase of the gas temperature. The energy balance equation is

$$\frac{PE}{\gamma-2} = E - (0.5 M_{eff} V^2)(1 + B_f)$$

where $PE$ is the potential energy of the confined gas, $E$ is the total energy released by the propellants, $M_{eff}$ is the effective mass of the projectile and gases, $B_f$ is the energy loss coefficient, $V$ is the velocity of the projectile, and $\gamma$ is the specific heat ratio of the propellant gas. The effective mass used in this calculation is given by the equation:

$$M_{eff} = W_t . CF3 . M_p$$

where $W_t$ is a correction for projectile twisting, $CF3$ is a Piddock-Kent coefficient, and $M_p$ is the projectile mass. The factor $W_t$ is included since the projectile is undergoing rotational acceleration in addition to linear acceleration. $W_t$ is normally set at 1.02 which provides an excellent approximation.

(4) Projectile motion is determined by the application of Newton's third law

$$a = \frac{P_B A}{M_p}$$

where $a$ is the projectile's acceleration, $P_B$ is the base pressure, $A$ is the bore cross sectional area, and $M_p$ is the projectile's mass. The velocity and position may be obtained by integrating this expression one and two times, respectively with respect to time.

b. Several computer programs are used to perform interior ballistic calculations. One such program is the Interior Ballistic Interactive Simulation (IBIS) code. IBIS computes propellant charge weight, web dimensions, and grain dimensions from the pressure parameters of the cannon, projectile weight, muzzle velocity, bore cross sectional area, force of the propellant, and burning rate of the propellant.

**9-11. Sensitivity.** The colloidal structure of propellants reduces sensitivity to a point well below that of the individual ingredients, nitroglycerin and/or nitrocellulose. From a practical standpoint, the hazards associated with a propellant are mainly heat, spark, and very high energy impact.

a. To a great extent, the degree of confinement determines whether a propellant will deflagrate or detonate. Experiments have shown that the confinement afforded by the upper part of a column of propellant may be sufficient to cause explosion if the powder at the bottom of the pile is ignited. Various powder compositions were found to have correspondingly varying critical heights of column, the critical height varying inversely with the energy content of the composition. For the same composition, the critical height was found to vary directly with the average web of the powder. If the temperature of the powder is 50°C instead of 20°C, the critical height of a composition is only 30 to 50 percent as much as at the lower temperature. Propellants for small arms, chiefly nitrocellulose, were found to have critical height values of 38.1 to 50.8 centimeters. Single based cannon powders of larger grain sizes and containing moderants have critical height values of 76.2 centimeters or more. Propellants can be detonated by initiating compounds or booster explosives.

b. Propellants are sensitive to electric sparks only if the material is in the form of a dust. Some test results indicate the powder dust is much more ignitable by a static electricity spark than is nitrocellulose. Dry-house and blending-tower fires have occurred that were attributed to the primary ignition of powder dust by static electricity sparks. Atmospheric relative humidity above 60 percent prevents such spark discharges and ignitions. The humidity must be measured where the operation is going on.

c. Propellants can be ignited by the friction and impact of small arms bullets. Detonation or deflagration occurs according to confinement. Recently a great deal of attention has been placed on very high kinetic energy impacts such as the impact of a shaped charge jet spall. These concerns are obviously from the standpoint of practical application.

**9-12. Stability.** The stability of nitrocellulose, which was discussed in Chapter 8, is relatively poor. The stability of nitrocellulose based propellants is correspondingly poor. The degradation of nitrocellulose proceeds by two chemical reactions. In the first degradation reaction, nitrocellulose loses nitrogen oxides. The loss of nitrogen oxides is an intrinsic tendency of the nitrocellulose molecule. The reaction rate varies with the temperature, but even at low temperatures the loss of nitrogen oxides occurs. In the second degradation reaction, which occurs initially as a result of the first, the nitrogen oxides that are formed attack the nitrocellulose molecule. The reaction between the nitrocellulose and nitrogen oxides produces more nitrogen oxides. The increased number of nitrogen oxides and increased temperature cause the reaction rate to accellerate. After a few years the reaction rate in samples of sufficient size is so fast that the propellant self-heats above the flame point and will self-ignite. Nothing can be done to stop the first degradation reaction. The second degradation reaction is controlled by two means. The heat of reaction is dissipated by a suitable heat sink, for example the metal case of a cartridge is an excellent thermal conductor. This does not solve the problem totally, however, if the diameter of the cartridge case exceeds 3 inches. The second, and most effective, means of controlling the degradation reaction is to include a chemical stabilizer in the propellant composition. A stabilizer has a greater affinity for the nitrogen oxides than nitrocellulose, and so absorbs them before they can attack the nitrocellulose molecule. This reduces the rate of propellant decomposition to about that of the first degradation reaction. However, the stabilizer is consumed as it absorbs nitrogen oxides. Therefore the increase in time the propellant will remain stable is directly proportional to the amount of stabilizer added. Some propellants can be stabilized in this manner for 30 or 40 years. Three stabilizers are of interest for military applications in the United States; diphenylamine (DPA), ethyl centralite (EC), and the akardites (AK). DPA is used in single-base propellants but is incompatible with nitroglycerin and so cannot be used in double-base and triple-base compositions. EC or 2-NDPA is used for double- and triple-base propellants which use nitroglycerin as the gelatinizing agent for the nitrocellulose. Akardites are used in propellants that contain DEGN rather than nitroglycerin.

a. Diphenylamine, $(C_6H_5)_2NH$, is an ammonia derivative in which two of the hydrogens have been replaced by phenyl groups. Each phenyl ring has three hydrogens which can be replaced with nitro groups. Therefore, DPA can be nitrated to the hexanitrate by absorbing the nitrogen oxides produced during the decomposition of nitrocellulose. DPA is nitrated relatively easily and the reaction is not exothermic. During the decomposition of nitrocellulose, DPA nitrates to the following compounds in succession.

N-nitrosodiphenylamine
2-nitrodiphenylamine
4-nitrodiphenylamine
N-nitroso-2-nitrodiphenylamine
N-nitroso-4-nitrodiphenylamine
4,4', 2,4', 2,2', and 2,4-dinitrodiphenylamines
N-nitroso-4, 4'-dinitrodiphenylamine
N-nitroso-2, 4'-dinitrodiphenylamine
2, 4, 4' and 2, 2', 4-trinitrodiphenylamines
2,2', 4,4'-tetranitrodiphenylamine
2,2', 4,4', 6-pentanitrodiphenylamine
Hexanitrodiphenylamine

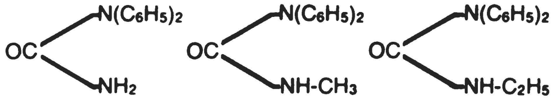
The propellant does not start to become unstable until most of the diphenylamine has been converted to hexanitrodiphenylamines. A very accurate test to measure the remaining safe storage life in a propellant lot is to analyze the distribution profile of the nitro DPAs. Only about one percent DPA can be added to a propellant because its nitrated products change the ballistic properties.

b. Centralite I (which is also called ethyl centralite or symmetrical diethyldiphenylurea), $OC[N-(C_2H_5)(C_6H_5)]_2$, was developed in Germany for use in double base propellants. The compound acts as a stabilizer, gelatinizer, and waterproofing agent. Unlike diphenylamine, centralite can be used in relatively large proportions and some propellant compositions contain as much as eight percent of this material. Like diphenylamine, centralite is nitrated by the products of nitrocellulose decomposition. The following compounds are formed successively, as many as four being present simultaneously, as deterioration of the powder proceeds.

4-nitrocentralite
4,4' dinitrocentralite
N-nitroso-N-ethylaniline
N-nitroso-N-ethyl-4-nitraniline
2,4, dinitro-N-ethyl-aniline

Centralite II (which is also called methyl centralite or symmetrical dimethyl diphenylurea), $OC[N(CH_3)(C_6H_5)]_2$, also has been used as a stabilizer but is not considered to be as effective as the ethyl analogue.

c. Three akardites, or acardites, are used to stabilize propellants. Their structure is shown in figure 9-4. Akardite II is often used in DEGN containing propellants.



AKARDITE I AKARDITE II AKARDITE III

*Figure 9-4. Akardites.*

# CHAPTER 10
# UNITED STATES PYROTECHNICS

## 10-1. Categories of Pyrotechnic Devices.

a. *General.* All pyrotechnic compositions contain oxidizers and fuels. Additional ingredients present in most compositions include binding agents, retardants, and waterproofing agents. Ingredients such as smoke dyes and color intensifiers are present in the appropriate types of compositions.

(1) Oxidizers are substances in which an oxidizing agent is liberated at the high temperatures of the chemical reaction involved. Two oxidizing agents, oxygen and fluorine, are currently used in pyrotechnic compositions. Oxygen is provided by the nitrates of barium, strontium, sodium, and potassium, the perchlorates of ammonium and potassium, or the peroxides of barium, strontium, and lead. Use of a specific oxidant is determined by the desired burning rate, luminosity, and color. Fluorine is usually provided by polytetrafluoroethylene or chlorotrifluoroethylene. Pyrotechnic compositions do not usually contain a stoichiometric proportion of oxidizer, the balance of the requirement for fuel oxidation is provided by atmospheric oxygen.

(2) Fuels include finely powdered aluminum, magnesium, metal hydrides, red phosphorus, sulfur, charcoal, boron, silicon, and silicides. The most frequently used are powdered aluminum and magnesium. Additional materials such as binding agents, waterproofing agents, and color intensifiers also act as fuels.

(3) Binding agents include resins, waxes, plastics, and oils. These materials make the finely divided particles adhere to each other when compressed into pyrotechnic items. They also prevent segregation and ensure a more uniformly blended composition. Binders also help to obtain maximum density and increased burning efficiency. In addition, they serve, in some cases, to reduce the sensitivity of compositions that otherwise would be unduly sensitive to shock and friction.

(4) Retardants are materials that are used to reduce the burning rate of the fuel-oxidizing agent mixture, with a minimum effect on the color intensity of the composition. Some retardants act only as inert diluents, while others take part in the combustion reaction at a much slower rate than the metallic fuels. Calcium carbonate, sodium oxalate, strontium resinate, titanium dioxide, polyvinyl chloride, ethyl cellulose, paraffin, linseed oil, castor oil, asphaltum, and sulfur are the most important retardants used. Certain of these serve other purposes as well. For example, sodium oxalate and polyvinyl chloride act also as color intensifiers, titanium dioxide is a source of incandescent solid particles in the flame produced by the composition, and the waxes and oils act as fuels, binding agents, and waterproofing agents as well as retardants.

(5) Waterproofing agents are necessary in many pyrotechnic compositions because of the susceptibility of metallic magnesium to reaction with moisture, the reactivity of metallic aluminum with certain compounds in the presence of moisture, and the hygroscopicity of nitrates and peroxides. Waterproofing agents are applied as a coating on metallic fuels, such as a coating of dried linseed oil on magnesium, or as an ingredient uniformly distributed throughout the rest of the composition. In some cases, the metallic fuel is given a coating by treatment with a solution of acidic or acidified potassium dichromate. Waxes, resinates of metals, and natural and synthetic resins are used for distribution throughout the composition. Many of these serve also as binding agents.

(6) Color intensifiers are highly chlorinated organic compounds such as hexachloroethane ($C_2Cl_6$), hexachlorobenzene ($C_6Cl_6$), polyvinyl chloride, and dechlorane ($C_{10}Cl_{12}$). These agents are effective because of their decomposition during combustion and the formation of metallic chlorides which produce characteristic color bands in the flame spectrum. The portion of the intensifier other than chlorine acts as a part of the fuel in the composition. Since they are less reactive than metallic fuels, color intensifiers act to some extent as retardants of combustion. Certain intensifiers such as polyvinyl chloride, because of their physical characteristics, can serve also as binding agents.

(7) Smoke dyes are azo and anthraquinone dyes. These dyes provide the color in smokes used for signaling, marking, and spotting.

b. *Flares and Signals.*

(1) The illumination provided by a flare is produced by both the thermal radiation from the product oxide particles and the spectral emission from excited metals. The human eye is more sensitive to the frequencies produced by sodium, so sodium nitrate is usually chosen as the oxidant. The composition of illuminating flares falls in the range of 53 to 58 percent magnesium, 36 to 40 percent sodium nitrate, and four to eight percent binder. Aluminum may also be used as a fuel. The three qualities which are useful in describing the performance of flares are intensity, illuminance, and light efficiency. The intensity ($I$), expressed in candelas is determined experimentally. The intensity of a flare is largely determined by the combustion temperature which depends on the stability of the products. 3000°K should be exceeded to accomodate the spectral sensitivity of the human eye. Illuminance ($E$), expressed in lumens per square meter, depends on the distance of the flare from the features that are to be illuminated. The approximate equation for illuminance is:

$$E = Ih(r^2 + h^2)^{3/2}$$

where $h$ is the height of the flare above the ground and $r$ is the radius of illumination. Light efficiency ($C$), expressed in lumens per watt, is the light output per unit energy in terms of the heat of reaction of the flare mixture burning in air. The approximate equation for lighting efficiency as a function of time is

$$C = 4It/Qm$$

where $Q$ is the heat of reaction, $m$ is the mass of the mixture, and $t$ is the time. The volumetric efficiency of a flare is the radiant energy per steradian per unit flare volume which is expressed in watt seconds per steradian cubic centimeter. A full description of a flare is given by the volumetric efficiency, burning time, and spectral distribution. Infrared flares are used with a scanning device such as a low light level television or image intensifier. These flares use metals with peak spectral emissions in the infrared rather than sodium. Table 10-1 lists the composition of some infrared flare mixtures as a function of the wave length of the light emitted. A special type of flare is a thermal decoy which has a strong infrared emission. One of the reactions utilized in decoys is the reaction between magnesium and a fluorocarbon such as polytetrafluorethylene. Hot carbon particles are formed which provide infrared emissions.

*Table 10-1. Infrared Flare Formulas*

| Component | Wavelength emitted in micrometers | | |
|---|---|---|---|
| | 0.76 | 0.79 | 0.8 - 0.9 |
| Silicon (%) | 10 | 10 | 16.3 |
| $KNO_3$ (%) | 70 | - | - |
| $CsNO_3$ (%) | - | - | 78.7 |
| $RbNO_3$ (%) | - | 60.8 | - |
| Hexamethylene tetramine, (%) | 16 | 23.2 | - |
| Epoxy resin, (%) | 4 | 6 | 5 |

(2) Signal flares are smaller and faster burning than illuminating flares. Various metals are added to these compositions to control the color of the flame. Combinations of metals may also be used to prevent enemy imitation of flare sequences. One example is the red-green flare. The composition is given in table 10-2.

*Table 10-2. Red-Green Flare System, Parts by Weight*

| | |
|---|---|
| Barium nitrate | 30 |
| Strontium nitrate | 13 |
| Potassium perchlorate | 9 |
| Magnesium | 30 |
| Dechlorane | 12 |
| Polyvinyl acetate resin | 4 |

The color of the flare is different when viewed through a filter than when viewed without a filter. Unfiltered, the green and red lights combine to form a yellow light which resembles the color of a pure yellow flare.

c. *Colored and White Smoke.*

(1) The pyrotechnic generation of smoke is almost exclusively a military device for screening and signaling. Screening smokes are generally white because black smokes are rarely sufficiently dense. Signal smokes, on the other hand, are colored so as to assure contrast and be distinct in the presence of clouds and ordinary smoke. Smoke has also been found to aid the daytime observance of tracer projectiles and also for tracking space vehicles during launch. Whereas smokes are often characterized by the mode of their formation, any concentrated suspension of particles ranging from 0.01 to about 5.0 micrometers can be considered a smoke. These particles, when suspended in air, reflect, scatter and absorb radiation. The following are pyrotechnic methods for smoke generation as opposed to mechanical methods such as atomization of fog oil, of titanium tetrachloride (FM smoke), or of sulfur trioxide.

(a) Venturi thermal generator type. The smoke producing material and the pyrotechnic fuel block required to volatilize the smoke material are in separate compartments. The smoke producing material is atomized and vaporized in the venturi nozzle by the hot gases formed by the burning of the fuel block. An example of this type smoke generator is the oil smoke pot which is powered by a slow burning, gassy pyrotechnic mixture such as ammonium nitrate and ammonium chloride with a small amount of carbonaceous fuel. The resulting gas jet pulls a stream of oil from a reservoir and injects it into a venturi where the formation of the aerosol takes place.

(b) Burning type. Burning type smoke compositions are intimate mixtures of chemicals. Smoke is produced from these mixtures by either of two methods. In the first method, a product of combustion forms the smoke or the product reacts with constituents of the atmosphere to form a smoke. In the second method, the heat of combustion of the pyrotechnic serves to volatilize a component of the mixture which then condenses to form the smoke. White phosphorus, either in bulk or in solution, is one example of the burning type of smoke generator. The resulting colloidal suspension of phosphorus pentoxide is quickly hydrolyzed by moisture to become phosphoric acid droplets which are the actual visible constituent of the smoke. Various other burning type smoke generators exist such as those used for signaling purposes and those which use red phosphorus, metallic phosphides, or phosphorus trichloride as the source of the particulate cloud. Another important burning type of smoke generator is the HC smoke mixture which has been prepared with a number of combinations of zinc with a chlorine carrier to form, on combustion, zinc chloride. For example,

$$2Al + C_2Cl_6 + 3ZnO \longrightarrow Al_2O_3 + 2C + 3ZnCl_2$$

(c) Explosive dissemination type. The smoke producing material is pulverized or atomized and then vaporized, or a preground solid is dispersed by the explosion of a bursting charge. The explosive dissemination smoke generator may contain metallic chlorides which upon dispersal, hydrolyze in air. Examples are titanium, silicon, and stannic tetrachloride. An effective smoke agent, whether mechanically dispersed from an aircraft spray tank or vaporized thermally, is a mixture of sulfur trioxide and chlorosulfonic acid (FS smoke agent) which upon hydrolysis forms sulfuric and hydrochloric acid dispersions. Of course, all such formulations are highly corrosive, and, if not outright toxic, then conducive to pulmonary edema. The so-called standard smoke is a smoke of such a density that a light of 25 candela intensity is just invisible when observed through a layer of approximately 30 meters. The amount of smoke agents required to produce one cubic meter of standard smoke is given in table 10-3.

*Table 10-3. Amount of Smoke Agent per Cubic Meter of Standard Smoke*

| Material | Grams per cubic meter |
|---|---|
| White phosphorus | 0.064 |
| Sulfur trioxide | 0.099 |
| FS agent | 0.116 |
| HC mixture | 0.127 |
| FM agent | 0.159 |
| Crude oil | 2.11 |

(2) The preferred method of dispersing colored smokes involves the vaporization and condensation of a colored organic volatile dye. The problem has always been one of selecting dyes which are thermally stable and which vaporize without decomposition at temperatures below 400°C. There are a very large number of dyes. The following are representative of dyes selected by the US as satisfactory agents for producing burning type colored smokes:

Yellow: Auramine hydrochloride
Green: 1,4-Di-p-toluidinoanthraquinone with auramine hydrochloride
Red: 1-Methylanthraquinone
Blue: Not suitable for signaling because of excessive light scatter.

These dyes are mixed to the extent of about 50 percent with a fuel such as lactose (20 percent) and an oxidizer (30 percent) for which potassium chlorate is preferred. If the mixtures should still burn too hot (and thereby destroy the dye), sodium or potassium bicarbonate are added as cooling agents. Colored smoke compositions are usually used in a compressed state without a binder. A major concern at present is the reported carcinogenic nature of organic dyes and elaborate programs have been initiated for their destruction. In addition to the smoke grenades which function by burning, others produce smoke by volatization of the dye from a separate dye compartment. These dyes should preferably have melting points below 150°C and be stable in the vapor phase. The following are currently used dyes:

Orange: 1-(4-Phenylazo)-2-naphthol
Yellow: N,N-Dimethyl-p-phenylazoaniline
Blue: 1,4-Diamylaminoanthraquinone

Mixtures of these dyes produce muddy colors of various hues. Lastly, dyes can be dispersed by explosive charges. These generate colored clouds (about 10×20m) which are formed instantaneously and which have a life expectancy, depending on environmental conditions, from 65 to 85 seconds, whereas aerial burning of the aforementioned burning type produces streamers about one meter across which last for about 57 to 120 seconds.

d. *Tracers and Fumers.* The principal small arms application of military pyrotechnics is in tracer munitions where they serve as incendiaries, spotters, and as fire control. Two types of tracers are used. The difference between the two types is the method of tracking. The more frequently used tracer uses the light produced by the burning tracer composition for tracking. Smoke tracers leave a trail of colored smoke for tracking. Red is the flame color most often employed in tracers. Red has a longer wavelength and so can penetrate haze, dust, and fog better than the other colors. A tracer may be directly ignited by the flame from a propellant charge or, as is the case in larger caliber shells, the ignition may be delayed to hide the position of a cannon. Table 10-4 lists several tracer and delay compositions.

*Table 10-4. Typical Formulas for Igniter and Tracer Compositions*

| Ingredient (%) | Delay action igniter I-136 | Dim igniter I-194 | Daylight (bright) igniter I-276 | Red tracer R-257 | Fumer R-284 |
|---|---|---|---|---|---|
| Strontium peroxide | 90 | - | - | - | - |
| Magnesium | - | 6 | 15 | 28 | 28 |
| I-136 Igniter | - | 94 | - | - | - |
| Calcium resinate | 10 | - | - | 4 | - |
| Barium peroxide | - | - | 83 | - | - |
| Zinc stearate | - | - | 1 | - | - |
| Toluidine red (identifier) | - | - | 1 | - | - |
| Strontium nitrate | - | - | - | 40 | 55 |
| Strontium oxalate | - | - | - | 8 | - |
| Potassium perchlorate | - | - | - | 20 | - |
| Polyvinyl chloride | - | - | - | - | 17 |

Compositions have also been developed for electro-optical devices. These compositions consist of calcium resinate, barium and strontium peroxides, and magnesium carbonate. The mechanism of tracer reactions is a complex one; the burning rate and brightness decrease with altitude but increase with increasing spin rate of the bullet. Smoke tracer compositions contain about 70 percent strontium peroxide, 10 percent calcium resinate, 10 percent catechol, and 10 percent smoke dye. Methylaminoanthraquinone is the dye used in red smoke and auramine is used for greenish-yellow smoke. A fumer, or gas generating tracer, uses the gaseous products of the burning tracer to fill the vacuum created behind the moving projectile. This increases range and decreases time of flight.

e. *Incendiaries.* Two types of incendiaries are commonly used. The traditional type is a bomb containing a flammable material. These materials include thermite (a mixture of aluminum and rust), phosphorus, and napalm. In addition, the case of the bomb may be constructed of a material such as magnesium that will bum at a high temperature once ignited. The buming material may be explosively scattered over a wide area. The more recently developed type of incendiary uses metals which produce pyrophoric, or burning, fragments. Three properties have been identified as important for metals which are suitable for use as incendiaries. The heat of formation of the oxide must be greater than 400 kilojoules per mole of oxygen consumed. The ratio of the oxide volume to metal volume must be greater than one. The metal must also have electrons in the conduction band. Formation of an intermetallic compound that reduces the number of electrons in the conduction band reduces the pyrophoricity of the compound. Table 10-5 lists the properties of metals considered suitable for incendiary use.

Table 10-5. *Properties of Pyrophoric Metals*

| Metal | Heat of oxide formation (per mole of oxygen) | Oxide volume/ metal volume | Electronic structure |
|---|---|---|---|
| U | −536 | 3.10 | $6d^1\ 7s^1$ |
| Th | −587 | 1.36 | $6d^2\ 7s^2$ |
| Zr | −512 | 1.55 | $4d^2\ 5s^2$ |
| Hf | −577 | 1.62 | $5d^2\ 6s^2$ |
| Ce | −486 | 1.23 | $5d^0\ 6s^2$ |
| La | −641 | 1.11 | $5d^1\ 6s^2$ |
| Pr | −621 | 1.12 | $5d^0\ 6s^2$ |
| Nd | −617 | 1.12 | $5d^0\ 6s^2$ |
| Sm | −431 | 1.06 | $5d^0\ 6s^2$ |
| Y | −427 | 1.44 | $4d^1\ 5s^2$ |
| Ti | −426 | 1.78 | $3d^2\ 4s^2$ |

For straight incendiary applications the sponge form of these metals is used because this form provides a large surface area. Metals which are used in this application include zirconium, titanium, and mischmetal. Polytetraflouroethylene can be used as an oxidizing agent. The heat of the reaction for several metals is shown in table 10-6. The numerical values given are strongly affected by the stoichiometry and the effective density of the reactants.

Table 10-6. *Maximum Volumetric Heats of Reaction for Metals Reacting with Fluorocarbons*

| Metal | Product | Kilojoules per cubic centimeter |
|---|---|---|
| Be | $BeF_2$ | −24.0 |
| La | $LaF_3$ | −21.0 |
| U | $UF_3$ | −19.8 |
| Mg | $MgF_2$ | −19.8 |
| Hf | $HfF_3$ | −19.0 |
| U | $UF_4$ | −18.9 |
| Zr | $ZrF_3$ | −18.6 |
| Zr | $ZrF_4$ | −18.6 |
| Hf | $HfF_4$ | −18.2 |
| Ti | $TiF_3$ | −17.0 |
| Ti | $FiF_4$ | −14.6 |

Depleted uranium is used extensively in pyrotechnics which have armor piercing capabilities. Depleted uranium deficient in the more radioactive isotope U235, is the waste product of the uranium enrichment process. The depleted uranium is formed into projectiles that can penetrate armor because of their high density and mechanical properties. The impact of the projectile causes the uranium to form many pyrophoric fragments which can ignite fuel and munition items.

f. *Delays and Fuses.* Delay compositions are mixtures of oxidants and powdered metals which produce very little gas during combustion. Work on delay systems continues because the existing delay mixtures do not store well and scale-up is not as flexible and as precise as is desired. A basic reason is that gasless delay mixtures are not truly gasless because gaseous reagents are present in the flame front or in the ignition mix. The gaseous reagents contribute to the pressure in the column so that the burn time is not strictly a linear function of the column length. This phenomenon has been called the anticipatory effect. Table 10-7 lists the most important delay compositions in use at the present time.

*Table 10-7. Delay Compositions*

| Mixture | Illustrative composition | | Burn time range centimeters per second | Temperature coefficient %/°K | Delay time change on storage in seconds per year per centimeter |
|---|---|---|---|---|---|
| D-16 | Mn | 29% | 0.8 - 5.4 (obturated) | 0.17 | 0.02 |
| | $PbCrO_4$ | 26% | | | |
| | $BaCrO_4$ | 45% | | | |
| T-10 | B | 3 - 15% | 0.23 - 0.32 (obturated) | 0.23 - 0.32 | 0.15 - 0.38 |
| | $BaCrO_4$ | 97 - 85% | | | |
| Zr-Ni Delays | Ni-Zr | 26% | 0.8 for 70/30 Zr-Ni, 4.6 for 30/70 Zr-Ni, 7.8 with $CeO_2$ (vented) | 0.16 | 0.06 |
| | $BaCrO_4$ | 60% | | | |
| | $KC10_4$ | 14% | | | |
| | Up to 10% | $CeO_2$ | | | |
| Tungsten-Viton | W | 30% | Approximately 0.8 - 6.2 (vented) | 0.1 | Not known, not suitable for storage in high humidity |
| | $BaCr0_4$ | 55% | | | |
| | $KC10_4$ | 10% | | | |
| | Diatomaceous earth | 4% | | | |
| | Viton | 1% | | | |
| UMNOL Tungsten Delay | W | 30% | 0.04 - 16 Up to 24 with $CaF_2$ (vented) | 0.1 | Sensitive to moisture |
| | $BaCr0_4$ | 55% | | | |
| | $KC10_4$ | 10% | | | |
| | Diatomatceous earth | 5% | | | |

The delay time change, or aging, is caused by the corrosion of the metallic fuels. The rate of corrosion is increased by the presence of moisture. In general the burn time of the delay is adjusted within stated limits by controlling the percentage of fuel in the composition. The chromate oxidizers may be carcinogenic.

g. *Photoflash Compositions.* Photoflash compositions are the single most hazardous class of pyrotechnic mixtures. The particle size of the ingredients is so small that burning resembles an explosion. The various photoflash devices are similar, differing principally in size and the amount of delay. When fired, each photoflash cartridge, after one, two, or four seconds, produces a flash having a peak intensity of approximately 50 million candela with a total output of five million candela seconds, whereas photoflash bombs generate above $5 \times 10^9$ candela. The most commonly used fuels include aluminum and magnesium. The most commonly used oxidizers include barium nitrate and potassium perchlorate. While atomized magnesium gives higher intensities in consolidated compositions, atomized aluminum performs better in loose compositions than do other fuels. Potassium perchlorate produces the highest heat of reaction with atomized aluminum. The output is highest for fuel rich compositions and alkaline earth nitrates which are far superior to alkali metal nitrates. Constant aluminum particle sizes of $22 \pm 8$ micrometers resulted in optimum efficiency at all altitudes. At high altitudes zirconium performs better. Photoflash compositions containing halfnium and potassium perchlorate possess greater luminous efficiency on a volume basis than do other formulations. Zirconium, for example, when burned in oxygen has an average color temperature of 4,883°K compared with 5,235°K for halfnium at peak intensity. In pyrotechnic flash units, substitution of aluminum with halfnium and titanium produced comparable peak output, but inferior output when zirconium and cesium were substituted.

h. *Igniters and Initiators.* Black powder is used extensively as an igniter for artillery propellant charges. Table 10-8 lists various black powder compositions used by the United States.

*Table 10-8. Black Powders Used in Pyrotechnics*

| Components (%) | Formulas | | |
|---|---|---|---|
| | 146 | 147 | 148 |
| Potassium nitrate | 74.0 | 70 | - |
| Sodium nitrate | - | - | 72 |
| Charcoal | 15.6 | - | 16 |
| Coal (semibituminous) | - | 14 | - |
| Sulfur | 10.4 | 16 | 12 |

A small amount of graphite is added as a glazing during the finishing process. The burning rate of black powder is dependent on the granulation of the ingredients and the grain size. The burning can be described as low order detonation. Coarse unpressed powders which are confined have approximate burning rates of 170 meters per second. Fine, unpressed, confined powders have burning rates of approximately 950 meters per second. A newer formulation of black powder called pyrodex consists of six percent sulfur, 10 percent charcoal, 83 percent potassium nitrate, and one percent calcium carbonate. This mixture has an ignition temperature above 260°C compared with 125°C for regular black powder. Other mixtures called either first fire, ignition mixtures, or starters are used. The names are somewhat misleading. The mixtures are intermediates between the primary igniter and main charge. Table 10-9 lists some of the numerous formulations of this type mixture.

*Table 10-9. Ignition Mixtures.*

| Components, % | Formulas | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 60 | 68 | 69 | 164 | 165 | 173 | 174 | 175 | 176 | 177 | 178 | 179 | 180 | 181 | 182 | 183 | 184 |
| Aluminum (powdered) | - | - | - | - | - | - | - | - | - | 40.0 | - | - | - | - | 35.0 | 20.0 | - |
| Ammonium dichromate | - | - | - | - | 10.5 | - | - | - | - | - | - | - | - | - | - | - | - |
| Asphaltum | - | - | - | - | - | 2.0 | - | - | - | - | - | - | - | - | - | - | - |
| Barium chromate | - | - | - | - | - | - | - | - | - | - | - | - | 90.0 | - | - | - | - |
| Barium peroxide | - | - | - | - | - | 78.0 | 80.5 | 4.0 | 79.0 | 31.0 | 91.0 | - | - | - | - | - | - |
| Boron (amorphous) | - | - | - | - | - | - | - | - | - | - | - | - | 10.0 | - | - | - | 23.7 |
| Calcium resinate | - | - | - | - | - | - | 2.0 | - | - | - | - | - | - | - | - | - | - |
| Charcoal | - | - | - | 6.0 | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Diatomaceous earth (See also superfloss) | 10 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| $Fe_2O_3$(Red) | 49 | - | - | - | 5.0 | - | - | - | - | - | - | 50.0 | - | 25.0 | - | - | - |
| $Fe_3O_4$(Black) | - | - | - | - | - | - | - | - | - | 29.0 | - | - | - | - | - | - | - |
| Potassium nitrate | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 70.7 |
| Potassium perchlorate | - | - | - | - | 74.0 | - | - | - | - | - | - | - | - | - | 64.0 | 63.0 | - |
| Laminac | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 5.6 |
| Magnesium (powdered) | - | - | - | - | - | - | - | - | - | - | 9.0 | - | - | - | - | - | - |
| Sodium nitrate | - | - | - | 47.0 | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Nitrocellulose | - | - | - | - | 10.5 | - | - | - | - | - | - | - | - | - | - | - | - |
| Parlon (chlorinated rubber) | - | - | - | - | - | - | - | - | 5.6 | - | - | - | - | - | - | - | - |
| $PbO_2$ | - | 80 | 60 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| $Pb_3O_4$ | - | - | - | - | - | 20.0 | 17.5 | 25.0 | 14.0 | - | - | - | - | - | - | - | - |
| Sr peroxide | - | - | - | - | - | - | - | 70.0 | - | - | - | - | - | - | - | - | - |
| Sugar | - | - | - | 47.0 | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Superfloss | - | - | - | - | - | - | - | - | - | - | - | - | - | 10.0 | - | - | - |
| Titanium | - | - | - | - | - | - | - | - | - | - | - | 32.5 | - | - | - | 13.0 | - |
| Toluidine red toner | - | - | - | - | - | - | - | - | 0.5 | - | - | - | - | - | - | - | - |
| Vegetable oil | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 1.0 | - | - |
| Vistanex (polyisobutylene) | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 4.0 | - |
| Zinc Stearate | - | - | - | - | - | - | - | 1.0 | 0.9 | - | - | - | - | - | - | - | - |
| Zirconium | 41 | 20 | 40 | - | - | - | - | - | - | - | - | 17.5 | - | 65.0 | - | - | - |

i. *Simulator Compositions.* Simulator compositions are used to simulate the functioning of ammunition items during training exercises. Simulators can harmlessly duplicate the effects of air bursts, booby-traps, ground bursts, gunflashes, and hand grenades. Simulators which must produce a loud noise may use black powder or such compositions as a mixture of aluminum powder, potassium perchlorate, and barium nitrate. These simulators also produce white smoke. Grey or black smoke can be produced by carbon rich compounds such as naphthalene which do not oxidize completely. Simulators can also contain colored smoke compositions for marking the positions of certain types of hits such as chemical or incendiary projectile impact. Some simulators contain a pyrotechnic whistle. Picric acid and such other organic acids as gallic, salicylic, and benzoic having the same characteristic odor, are the major ingredients in pyrotechnic whistles. Combinations of these acids with potassium chlorate, perchlorate, or nitrate, compressed in short tubes, emit a shrill whistling sound of varying pitch when ignited. Size, especially length of the tube in which the composition is pressed, determines pitch.

## 10-2. Manufacturing of Pyrotechnics.

a. *Storage.* Care must be exercised in the storage and handling of pyrotechnics and pyrotechnic ingredients. Small quantities of contaminants can cause changes in stability and burning rates which lead to inconsistency in performance.

b. *Grinding.* The particle size of the ingredients is extremely important in pyrotechnic compositions. Three methods are used to grind the particles to the proper size. One method is with a hammer mill. A hammer mill consists of a series of hammers which rotate at high speeds. The impact of the hammers grinds the material. Some heat sensitive material such as waxes or resins may be cooled with dry ice or liquid nitrogen before being processed by the hammer mill. Materials which cannot be ground safely in a hammer mill are ground in a ball mill. In the ball mill the sample is placed in a sealed drum with a large number of steel, brass, or ceramic balls. The drum is rotated. The tumbling of the balls grinds the material. The third method of grinding, an attrition mill, is used to further reduce the size of the particles of powder. In the attrition mill a stream of high velocity air is used to accellerate particles of the powder. The collisions of the particles with one another break them down further.

c. *Classification.* After grinding, the powders are classified by size. For powders above 44 microns, sieves are used. For powders below 44 microns, cyclones are used. Cyclones are funnel shaped chambers into which the powder is fed. An air current is maintained which centrifugially separates the powders by size. The coarser materials are forced to the wall of the container.

d. *Weighing.* To obtain the proper performance from a pyrotechnic composition accurate weighing is necessary.

e. *Blending.* Two methods are used for the blending of pyrotechnic compositions, dry and wet. The dry method is used for insensitive material. Passing the ingredients through sieves is used for small quantity production. A ball mill which uses rubber balls is used for larger quantities. Wet mixing is accomplished with the ingredients suspended in a liquid. This method is used to blend more sensitive materials.

f. *Granulation.* In order to ensure the pyrotechnic composition is sufficiently fluid after blending, the mixture is forced manually through a sieve. An alternate method is to press the composition into a cake and then granulate the cake.

g. *Loading.* Loading pyrotechnic compositions is accomplished by means of a press. Special tools support the element into which the composition is being loaded. Multiple layers of different types of composition are loaded by multiple pressing operations.

h. *Drying.* Drying is accomplished by subjecting the ingredients to 105° to 110°C for two to four hours. Vacuum drying may be necessary to further reduce moisture content.

i. *Assembly.* The pyrotechnic item is now ready for assembly into the end item. Care should be taken to prevent exposure to moisture and ensure the pyrotechnic item is properly supported for transportation.

**10-3. Testing.** The different types of tests used in the process of developing pyrotechnic ammunition are described in this paragraph.

a. *Kinds of Tests.*

(1) Development tests. Development tests are performed by the designing agency to ensure that component subassemblies or complete ammunition function in the manner for which they were designed. These tests evaluate the latest efforts of the designer and may be repeated until successful results are obtained. The ammunition is subjected to a series of tests that serve to determine that the device is safe and reliable, and to ascertain readiness for field testing and use. Part of the task of planning an ammunition development project is to specify the type of test, the order of execution, and other testing details. Development tests are usually made in the laboratory or developer's testing facility, and need not include all of the parts of the complete device.

(2) Evaluation. Evaluation tests are made to assess the usefulness of a pyrotechnic system. These tests expose the characteristics of the hardware to observation by personnel experienced with pyrotechnic applications. An evaluation of a flare launcher, for example, includes describing the launcher, evaluating projected altitude, illumination duration, effects of water soaking, day and night range functioning, ability to penetrate foliage, and comparing .38 and .45 caliber cartridges. Recommendations are made on the basis of these tests.

(3) Service tests. Service tests are intended to determine the suitability of hardware for use by the military under field conditions. They compare the hardware with requirements set down in the documents for the device being tested. The tests are always carried out on the complete device under field conditions. Acceptance tests are one form of service test.

(4) Surveillance tests. Surveillance tests are made on specific lots of ammunition taken from storage to determine if changes are needed in components to provide satisfactory operation as well as to determine the degree of deterioration of the original lot. Such tests should include adequate sampling of the lot to assure true representation and isolation of troublesome components, and adequate tests to assure satisfactory performance of renovated ammunition. Tests of this type will salvage lots of satisfactory ammunition whenever possible.

(5) Malfunction tests. Malfunction tests are carried out whenever failures have occurred. The rationale and planning for such tests is usually the responsibility of the investigator. Special tests are applied to pinpoint the cause of failure and recommend corrective action.

(6) NATO tests. NATO tests are prescribed for safety and environmental survival of all ammunition components planned for use by NATO countries. Engineering design tests are listed for airborne devices for both packaged and unpackaged stores.

b. *Light.*

(1) General. Light producers can be tested by use of human observers, simple electrical light detectors, or complex arrays of light detectors coupled to recording instruments and to computers for analysis of light intensity and spectal content as a function of time. Observers are used in many field situations that are difficult to assess by instrumentation systems and, therefore, play an important role in the ultimate testing of pyrotechnic light producers. Many test programs, for quality assurance of existing candles and the development of new types, are performed indoors at large military installations which have flare tunnels. A few instrumented outdoor sites are available to evaluate the light output of complete pyrotechnic ammunition under a semblance of field conditions.

(2) Laboratory tests. The candle of a pyrotechnic device is usually tested as a separate component in development, production, and quality control efforts. Candles with outputs of up to $10^6$ candelas are commonly tested in areas equipped to contain the burning candle safely and to measure the emitted light under controlled conditions. These areas consist of a fireplace or hearth and a light tunnel. These facilities are well suited for making comparative measurements of burning time and candlepower of flares, but caution is required in relating values obtained to those obtained in different tunnels, outdoor facilities, and actual end item conditions. Large variations can easily occur depending on the test system, test procedures, and the inherent variability of the flares. If the candle is tested with the burning surface upward, for instance, the reading will be greater than if the burning surface is pointed downward. This is due to the differences in flame shape and smoke pattern. The practical difficulties in measuring true candlepower of pyrotechnic flames makes reference to the specification under which the test was performed necessary when quoting the candela for a particular device. Nevertheless, measurements made under comparable conditions are valuable to rate light output and to maintain quality standards. The light output of small arms tracer projectiles is measured in a spinner that is capable of rotating the projectile at up to 130,000 rpm's. Light intensity measurements in tunnels are affected by the following variables.

(a) Usually, large volumes of smoke issue from the test flare. The smoke can reflect light or obscure the flame depending upon the motion of the smoke. Blowers and dampers are used to adjust the wind velocity to maintain control of this variable.

(b) Power density radiated by the flare is a variable. The flare is not truly an isoentropic source, as assumed in calculations, because flux is not radiated uniformly over the entire burning surface. Radiation from the cylindrical sides may be twice that from end on. Measurements in tunnels are usually made from the side of the flare.

(c) The area of the flare in the field of the photocell is a variable. Intensity readings will be incorrect if the field of the optical system includes only a portion of the flame produced by the flare. The entire flame produced by the flare should be in the field of view of the photocell, and any light reflected from the smoke in the vicinity of the burning flare should be kept to a minimum.

(d) The reflectivity of the background is a variable. Background reflections can produce particularly large errors in measurements of light output. Apparent increases of 40 percent have occurred because of reflections from the tunnel floor. This condition is corrected by restricting the view of the measuring instrument to that portion of the flare producing the light.

(e) The accuracy of the spectral correlation and intensity calibration is a variable. Spectral correction conforming to the response of the International Commission of Illumination and intensity calibration with standard sources for the test equipment are required.

(3) Field tests. The flame size and volume of smoke produced by some flares is too great for indoor tests. Such flares are tested outdoors at test sites that are relatively flat, open areas approximately 120 meters (400 feet) in diameter and that have a means of suspending the flare at least 24 meters (80 feet) above the center of a plane containing the photocells. Often the most practical method of evaluating light effects is visual observation supplemented with photography. This is particularly true of small arms tracers.

(4) Color measurement. The color of light-producing illuminants is assessed by visual observation of flare burning or by the use of instruments that can dissect the light into characteristic colors or wavelengths. Quantitative spectral data allows the engineer to observe dilution of a desired color by unwanted colors, thus enabling corrections to be made. These procedures may also be used for quality control during production. A flare radiometer consists of a number (10 is used in the Picatinny Arsenal apparatus) of interface filters, which cover the visible spectral region. The filters are chosen to have a uniform spectral response at a precisely chosen peak wavelength. Photocells and associated circuits are positioned behind the filters. The output of the photocells can be digitized and interfaced directly with a computer. Correction for human eye response can be made automatically. Candlepower can be computed by integration of the luminous intensity over the wavelength range of interest. Dominant wavelength and purity are determined by multiplying the radiant energy distribution by the three color distributions of the International Commission of Illumination, wavelength by wavelength. Chromaticity coordinates are calculated from the integrals under the three product curves and plotted in a chromaticity diagram to determine dominant wavelength and purity.

c. *Smoke.*

(1) General. In early stages of development, when gross effects are sought, much is gained by simple visual observation of the smoke produced. Visual observation is usually followed by still and motion photography to make better estimates of volume and color. In the case of screening smokes, quantitative measurements of the obscuring power can be made by the attenuation of light by the smoke. Signalling smokes have four properties of importance to the military: color, visibility, duration, and volume. Since instability is one of the main features of the smoke cloud, the ability to persist is usually judged by comparison with smoke from a control that is being burned simultaneously within close proximity of the test smoke generator. Care must be taken to observe that the two independent plumes are observed under similar atmospheric conditions.

(2) Laboratory tests. The test volume of the equipment used to measure smoke production may vary from a few cubic feet to several thousand cubic feet. The test chambers usually provide a means of physically manipulating the sample under test including parts or fittings for air, smoke, and exhaust; and an optical system for obscuration measurements. The screening values of smokes are determined by a figure of merit known as the total obscuring power (*TOP*) which is the area in square feet that can be obscured by a pound of smoke formulation. *TOP* can be measured directly by positioning a target in a smoke chamber until the target is just obscured. *TOP* can also be determined by measuring the attenuation of a light beam through a fixed distance of smoke. The intensity of the light as a function of incident intensity is given by the equation:

$$I = I_0 \exp(eCL) \qquad (10\text{-}1)$$

where $I$ is the observed light intensity, $I_0$ is the intensity with no smoke present, $C$ is the concentration of the smoke in pounds per cubic foot, $L$ is the path length in feet, and $e$ is the scattering or extinction coefficient in feet squared per pound. *TOP* is defined by the equation:

$$TOP = \frac{I}{C_t L_t}$$

where $C_t$ is the concentration of smoke required for obscuration in pounds per cubic feet and $L_t$ is the fixed distance between the lamp and photocell in feet. The concentration of smoke, $C$, from equation 10-1 is related to the concentration in equation 10-2 by the relationship:

$$C = YC_t \qquad (10\text{-}3)$$

where $Y$ is the yield or the ratio of the weight of aerosol produced to the unit weight of the smoke producing composition. Combining equations 10-1, 10-2, and 10-3 yields:

$$TOP = \frac{Y}{\ln(I_t/I_0)} \qquad (10\text{-}4)$$

where $I_t$ is the transmitted light intensity under obscuration. The value of 0.0125 has been adopted by some researchers for the ratio $I_t/I_0$ based on physiological studies of the discriminating capacity of human vision. Equation 10-4 yields:

$$TOP = \frac{\ln(I_t/I_0)}{(\ln 0.0125)CL_t} \qquad (10\text{-}5)$$

For fixed chambers and weights of smoke producing compounds equation 10-5 becomes:

$$TOP = K \log(I_t/I_0) \qquad (10\text{-}6)$$

Equation 10-6 is valid if the smoke is dilute so that particle coalescence is minimal.

(3) Field tests. In the field, observers are often used in the assessment of smoke producing ammunition. A number of observers are commonly used in order to obtain statistically significant results. Any person with serious visual defects is eliminated, usually by tests made immediately before the observation. Color blindness is of particular concern when testing colored smokes. Observers are sometimes supplied with binoculars during smoke tests. They compare performance with controls having well known characteristics. Wind tends to produce both good and bad effects in smoke production and use. In outdoor tests, wind speed and direction are normally recorded. Wind may aid in distributing the smoke for screening purposes. If the smoke is produced continuously, wind often helps to pinpoint a marked area by observing the origin of the plume. On the other hand, the wind may scatter the smoke. In testing field ready smoke producers, each sample is numbered. The ignition time and burning time of each sample is recorded. Comments concerning out of the ordinary conditions, such as excessive sparking on ignition, flame-ups while burning, and fuze failures are also recorded.

(4) Photographic techniques. Smoke plumes can be studied with time exposure photography. Exposure times of several minutes can be used to study the diffusion of smoke into the atmosphere. Time exposure during the daylight requires either an extremely slow film, a very small aperature, or the use of very dense filters. If these conditions cannot be attained, the dispersion photographs can be made under twilight conditions.

d. *Heat.* Incendiary devices are normally evaluated in terms of their ability to inflict specific damage against specifically defined targets such as burning a hole through a metal plate. The burning time is another of the parameters that is commonly measured. Several techniques, such as photography and the use of spectrometers and radiometers, have been tried to improve these testing methods. Photography with infrared film with appropriate filters can provide an effective means of evaluating the temperature distribution over the surface of a large flame, provided the fuel is relatively homogeneous and the observation path is relatively homogeneous. The film should be calibrated with a black body source of infrared and the calibration film and recording film should be processed identically. Small arms incendiary rounds can be evaluated by firing against an aluminum plate and recording the flash photographically. The photographs are compared to photographs of acceptable rounds. The following factors should be measured or assessed qualitatively in tests of flame producers. Quantitative methods have not been devised to measure all the factors:

(1) Fuel dissemination in terms of "blob" size, spectral and spacial distribution.

(2) Percentage of the fuel that ignited.

(3) The adhesiveness of fuel "blobs" to different surfaces as a function of the type of surface, "blob" velocity, and altitude.

(a) To test for $ClO_3$, add one milliliter of the test solution to one milliliter of a solution that was prepared from 20 grams of aniline hydrochloride and 50 milliliters of hydrochloric acid. The presence of the ion is indicated by a pink violet or dark blue color.

(b) To test for $NO_3$, add two milliliters of the test solution to two milliliters of a solution that was prepared from 25 grams of $FeSO_4$ in 100 milliliters of distilled water and 25 milliliters of concentrated sulfuric acid. Hold the test tube at a slight angle and add one milliliter of concentrated sulfuric acid to the wall of the test tube. Manipulate the test tube to cause the drop to slide down the wall and into the solution. The drop of sulfuric acid will sink to the bottom. A brown color at the interface between the sulfuric acid and water indicates the presence of the nitrate.

(c) To test for $ClO_4$, first prepare a solution of 40 milliliters of 10 percent aqueous $CuSO_4$, 19 milliliters pyridine, and 50 milliliters of distilled water. This solution must be stored in a tightly stoppered bottle to avoid breathing the pyridine vapors. Add two milliliters of this solution to 3 milliliters of the solution under test. A precipitate of blue or white crystals indicates the presence of the perchlorate ion. If no precipitation forms in a few minutes, scratch the bottom of the test tube with a glass rod to try to induce crystallization.

(d) To determine the amount of the chlorate quantitatively, add an excess of $NaHSO_3$, and then precipitate AgCl by adding an excess of silver nitrate solution. Filter and weigh the precipitate. One gram of precipitate corresponds to 0.855 grams of $KClO_2$ in the mixture.

(e) To determine the amount of the perchlorate quantitatively, use tetraphenylphosphonium chloride to precipitate the tetraphenylphosphonium salt.

(f) To determine the amount of $NO_3$, the chlorate and perchlorate must be removed from the solution. Then nitron is used to form a precipitate. Nitron is a standard reagent with the formula $C_{20}H_{16}N_4$ and a molecular weight of 312.38.

(3) In the original test mixture the materials which did not dissolve in water are most likely either metals, sulfur, or charcoal. Magnesium will cause the evolution of bubbles of hydrogen gas if five percent acetic acid is added. Aluminum will not. Aluminum will evolve hydrogen in five percent hydrochloric acid or five percent sodium hydroxide. To test for iron, dissolve in dilute hydrochloric acid or nitric acid and add potassium ferrocyanide. A blue color indicates iron. To test for sulfur, dissolve in carbon disulfide or pyridine and dry the solvent. The characteristic yellow color indicates sulfur. Charcoal will produce an orange flame in the flame test.

**10-5. Sensitivity.**

a. *Impact.* This test is performed on any of the various impact sensitivity devices.

b. *Friction.* This test is performed on the pendulum friction device.

c. *Hygroscopicity.* In this test a weighed sample of the material is subjected to air at a specified temperature and relative humidity. The weight gain is noted.

d. *Sensitivity to Heat.* Three methods are used to measure sensitivity to heat.

(1) In the first method, a sample of the material is contained in a blasting cap and immersed in molten metal bath. The temperature of the bath is controlled so that a reaction occurs in five seconds.

(2) In the second method, isothermal heating, a sample of the material is subjected to a preselected temperature for an extended period. This method determines the induction period of the material at a specified temperature.

(3) In the third method, adiabatic heating, a sample is placed in an oven or furnace and heated at a slow rate. A thermocouple monitors the temperature at the sample. When an exothermic reaction starts, the temperature of the furnace is adjusted so no heat is gained or lost by the sample. The temperature at which the reaction accelerates to deflagration is called the autoignition or deflagration temperature.

e. *Electrostatic Discharge.* The standard electrostatic discharge sensitivity device described in Chapter 5 is used for this test.

f. *Compatibility.* This test is performed by mixing a sample of the pyrotechnic composite with another material and subjecting the mixture to the 120°C vacuum stability test for 40 hours.

# CHAPTER 11

# FOREIGN ENERGETIC MATERIALS

**11-1. Introduction.** This chapter reflects the currently available, unclassified information on foreign energetic materials. Security restrictions may, in some cases, date the material presented. Generally, foreign energetic materials are the same as those used by the United States although the composition of some of the composites varies.

**11-2. French Energetic Materials.** No information is presented on priming compositions or initiating explosives. The French for fulminating explosives such as mercury fulminate is explosifs fulminants. Table 11-1 lists some of the secondary explosives used by the French.

*Table 11-1. French Secondary Explosives*

| English | French |
|---|---|
| TNT | Trotyl |
| Pyroxylin | Pyroxyline, collodion |
| Pyrocellulose | Coton-Poudre (CP) |
| Guncotton | Coton-Poudre (CP) |
| Nitroglycerin | Nitroglycerine |
| Nitrostarch | Nitrate d' amidon |
| PETN | Penthrite |
| TEGN | Dinitrate de triethyleneglycol |
| HMX | Octogene, cyclotetramethylenetetrnitramin |
| RDX | Hexogene, T4, cyclotrimethylene-trinitramine |
| Picric acid | Melinite |

The following explosives are also used by the French:

a. *Explosif Amylace.* These are the amide explosives. An inorganic amide explosive, also called ammonobase, is a compound in which one hydrogen is replaced by a metal. Metallic amides are prepared by precipitation from liquid ammonia solutions by the action of potassium amide, $KNH_2$. Potassium amide is also referred to as potassamide. An organic amide contains the monovalent radical $-CO.NH_2$. Organic amides are nonexplosive unless nitrated and are not considered here. The metallic amides include:

(1) Auric imidoamide, $Au(:NH)NH_2$ or $HN:Au.NH_2$, is an extremely explosive and sensitive powder. The compound does not explode when wet and so is stored under water. Storage at 100°C for several hours causes auric imidoamide to become so sensitive that handling without an explosion is virtually impossible.

(2) Cadmium amide, $Cd(NH_3)$, is a white powder which explodes upon rapid heating. The salt can be prepared by treating cadmium iodide or KCd cyanide with a solution of potassamide in liquid ammonia. When heated to 180°C in vacuo, cadmium amide loses ammonia leaving cadmium nitride, $Cd_3N_2$, a black, amorphous powder that explodes when brought in contact with water.

(3) Potassium amide, $KNH_2$, is not used as an explosive but is used as an intermediate in the preparation of other explosive amides. The normal method of preparation is to add a small amount of platinum black to a solution of liquid ammonia and metallic potassium. Without the platinum, the reaction takes weeks or months.

(4) Silver amide, $AgNH_2$, is a white precipitate which darkens and shrinks in volume on exposure to air. The compound can be prepared by mixing a solution of potassamide with silver nitrate or iodide in liquid NH followed by washing by decantation and careful drying. This compound is extremely sensitive and can shatter test tubes and tear holes in several layers of towels wrapped around the tube for the protection of the operator.

(5) Sodium amide, $NaNH_2$, consists of white crystals with a melting point of 206.4°C. The compound dissolves in liquid $NH_3$ and is vigorously hydrolyzed by water. Preparation is by means of metallic sodium dissolved in ammonia, the reaction is catalyzed by iron wire.

b. *Explosifs Antigrisouteux.* These are French industrial explosives used in coal mines. Under prescribed conditions these do not ignite mixtures of methane, air, and coal dust. Some standard compositions are:

| Components | N no 7 | N no 9 | N no 62 |
|---|---|---|---|
| Ammonium nitrate (%) | 76.0 | 48.2 | 12.0 |
| Dinitronaphthalene (%) | 7.0 | - | - |
| TNT (%) | - | 9.15 | - |
| PETN (%) | - | - | 23.0 |
| Wood flour (%) | 2.0 | 1.65 | - |
| Sodium chloride (%) | 15.0 | 41.0 | 65.0 |

c. *Explosifs Chlorates.* These explosives are also known as chlorate cheddites or chlorate streetites. The chlorate cheddites may be subdivided into nongelatin and gelatin types. The nongelatin type cheddites are in the form of soft grains which are white or yellow in color unless they have been artifically colored with an oil soluble dye in order to distinguish one type from another. They are readily compressible and, in order to obtain the full explosive power, their density should be carefully controlled. If the density is low, the maximum power is not developed but if the density is very high detonation is difficult. These explosives are relatively insensitive to shock and friction at room temperature and, when unconfined, burn more or less rapidly without any tendency to explode even when fired in large masses. Heating at 120°C for an appreciable period causes no decomposition. But at 200°C the oil in cheddite decomposes, part of the nitrocompound volatilizes, and the whole mass darkens. Heating of cheddites in small quantities to 250° to 265°C causes deflagration. Densities of compressed materials average 1.3 to 1.4, power (by Trauzl test) is slightly less than that of TNT, but brisance is only 30 to 50 percent of TNT due to the low detonation velocity, 2,300 to 3,200 meters per second. The rate of detonation depends not only on composition but also on density. The rate of detonation increases as the density increases up to a certain optimum density, but then the rate decreases very rapidly. For example, one of the cheddites developed the rate 2,283 meters per second at a density of 1.07 grams per cubic centimeter which increased to 2,901 meters per second at a density of 1.17 grams per cubic centimeter but dropped to 2,451 meters per second at a density of 1.14 grams per cubic centimeter and failed to detonate at density of 1.5 grams per cubic centimeter. None of the chlorate cheddites can contain any ammonium salt because double decomposition might take place with the formation of dangerous ammonium chloride. Cheddites containing potassium or sodium perchlorates are more stable and less reactive than those containing potassium or sodium chlorate. Ammonium perchlorate may also be used, provided chlorates are absent. Sodium chlorate is more hygroscopic than potassium chlorate, but is more economical and contains more oxygen per unit weight. The gelatin type cheddites are plastic type explosives which do not harden in storage. These explosives are not very powerful but their brisance is superior to any ammonium nitrate explosive. Tables 11-2 and 11-3 give the composition of some of the most current French cheddites.

*Table 11-2. French Chlorate Cheddites*

| Composition and some properties | 55 -CSE -1948 | 58 -CSE -1948 | gelatin cheddite n° 18 |
|---|---|---|---|
| Sodium chlorate (%) | 74 | 74 | 74.0 |
| DNT (liquid) (%) | 23 | 23 | 19.0 |
| Sawdust (%) | - | 3 | - |
| Cork flour (%) | 3 | - | - |
| NG (%) | - | - | 5.5 |
| Collodion cotton (%) | - | - | 1.5 |
| Density, grams per centimeter | - | - | 2.0 |
| Power (picric acid 100%) | 93 | 89 | 83 |

*Table 11-3. French Perchlorate Cheddites*

| Composition | I | II | III | Sevranites | |
|---|---|---|---|---|---|
| | | | | n°1 | n°2 |
| Ammonium perchlorate (%) | 82 | 50 | 88 - 9 | 31 | 42 |
| Sodium nitrate (%) | - | 30 | - | - | - |
| DNT (%) | 13 | 15 | - | - | - |
| Castor oil (%) | 5 | 5 | - | - | - |
| Paraffin (%) | - | - | 12 - 10 | - | - |
| Collodion cotton (%) | - | - | - | - | - |
| PETN (%) | - | - | - | 48 | 42 |
| Plasticizer (%) | - | - | - | 18 | 16 |
| Aluminum powder (%) | - | - | - | 3 | - |

d. *Explosifs Couche.* These are explosives with temperatures of explosion of below 1,500°C which are permitted for use in coal layers of fiery coal mines. For example, Grisou naphthalite couche contains 95 percent ammonium nitrate and 5 percent trinitronaphthalene, while Grisou dynamite couche contains 12 percent nitroglycerin, 0.5 percent collodion cotton, and 87.5 percent ammonium nitrate. Sodium chloride is also used in couche to reduce the explosion temperature.

e. *Explosifs CSE.* These are a series of explosives developed at the laboratory of the Commission des Substances Explosives (CSE). The explosifs chlorates are actually CSE explosives. Other examples include: 63-CSE-1949 which contains 67 percent ammonium nitrate, 12 percent 20/80 pentolite, and 21 percent aluminum powder; 68-CSE-1949 which contains 20 percent ammonium nitrate, 20 percent PETN, 1.5 percent dinitronapthalene, and 58.5 percent sodium chloride; 123-CSE-1948 which contains 17 percent ammonium nitrate, 23 percent PETN, and 60 percent sodium chloride; and 133-CSE-1948 which contains 22 percent ammonium nitrate, 20 percent PETN, 3 percent TNT, and 55 percent sodium chloride. These are used in fiery coal mines. Table 11-4 shows some of the silicon CSE explosives.

*Table 11-4. CSE Silicon Explosives*

| Composition and properties | Designation of explosive | | | |
|---|---|---|---|---|
| | n°78 CSE-1950 | n°88 CSE-1950 | Nn°O | Nn°31 |
| Ammonium nitrate (%) | 79.0 | 82.0 | 78.7 | 78.5 |
| Silicon (pulverized) (%) | 5.5 | 7.4 | - | - |
| Aluminum (granular) (%) | - | - | - | 9.2 |
| TNT (%) | - | 10.6 | 21.3 | - |
| Pentolite (20/80) (%) | 15.5 | - | - | 12.3 |
| Density, grams per centimeter | 1.40 | 1.24 | 1.40 | 1.40 |
| Velocity of detonation meters/second | 4,700 | 4,000 | 4,460 | 4,150 |

Some of the following plastic explosives were developed by the CSE. 33-CSE-1951 contains 75 percent RDX, 21 percent nitroglycerin, and 4 percent nitropolystyrene. 34-CSE-1951 contains 88 percent ammonium nitrate and 12 percent RDX. 36-CSE-1951 contains 82 percent RDX and a solution of 40 percent polystyrene in liquid DNT. This explosive has a velocity of detonation of 7,520 meters per second. 37-CSE-1951 contains 85 percent ammonium nitrate and 15 percent nitropolystyrene. 38-CSE-1951 contains 72.25 percent ammonium nitrate, 12.75 percent nitropolystyrene, and 15 percent sodium chloride.

f. *Explosif D.* This explosive contains 85 percent RDX and 15 percent TNT.

g. *Explosifs et Poudres.* These explosives and propellants include mixtures of combustibles such as nitroguanidine, hexanitrodiphenylamine (HNDPhA), and 9-oxo-2,4,5,7-tetranitrothiodiphenylamine with oxidizers such as nitrates, chlorates, or perchlorates. A mixture of 53 percent nitroguanidine and 47 percent ammonium perchlorate and a mixture of 56 percent nitroguanidine and 44 percent potassium nitrate possess high temperatures of deflagration and are suitable for use in weapons operating at high temperatures or for oil seismic prospecting at great depth.

h. *Explosifs Roche.* These explosives, with temperatures of explosion between 1,500°C and 1,900°C, are permitted for use in rock layers of fiery coal mines. Grisou dynamite roche contains 29 percent nitroglycerin, 1 percent collodion cotton, and 70 percent ammonium nitrate. Grisou dynamite roche salpetree contains 29 percent nitroglycerin, 1 percent collodion cotton, 5 percent potassium nitrate and 65 percent ammonium nitrate.

**11-3. German Energetic Materials.** Table 11-5 lists some of the secondary explosives used by the Germans.

*Table 11-5. German Secondary Explosives*

| English | German |
|---|---|
| DEGN | Diathylenglykol-dinitrat |
| Pyroxylin | Kollodiumwolle |
| Pyrocellulose | Schiessbaumwolle |
| Guncotton | Schiessbaumwolle, schiesswolle |
| Nitroglycerin | Nitroglyzerin |
| Nitrostarch | Nitrostaerke, staerkenitrat |
| PETN | Peutrit, niperyth, nitropenta (NP) |
| TEGN | Triglykoldinitrat |
| EDDN | Diamin |
| Nitroguanidine | Gudol |
| TNT | Fp 02 |

**11-4. Italian Energetic Materials.** Italian explosives are listed in table 11-6.

*Table 11-6. Italian Explosives*

| English | Italian |
|---|---|
| Lead azide | Azotidrato di piombo, acido di piombo |
| Lead styphnate | Stifnato di piombo |
| Mercury fulminate | Fulminato-di mercurio |
| Tetracene | Guanilnitrosoammina, tetrazene |
| DEGN | Nitrodiglicole, nitroeterolo, dinitrodietilenglicol |
| Collodion cotton (11.2 to 12.3% N) | Cotone collodio |
| Pyrocellulose (12.5 to 12.7% N) | Pirocollodio |
| Guncotton (13.2 to 13.4% N) | Fulmicotoneo cotone fulminante |
| Nitroglycerin | Nitroglicerina |
| PETN | Pentrite, tetranitrato di penaeritrite |
| TMETN | Metriolo (nitrometriolo), nitropentaglicerina |
| HMX | Ciclotetrametilentetranitroammia, octogene, HMX |
| RDX | Ciclonite, ciclotrimetilentrinitroammia |
| Nitroguanidine | Nitroguanidina |
| Tetryl | Tetrile |
| Ammonium picrate | Picrato ammonico, picrato di ammonio |
| TNT | Tritolo |

The following explosives are used by the Italians:

a. *Afocite.* Afocite is a blasting explosive composition in two formulations. One formulation is 58 percent to 62 percent ammonium nitrate, 28 percent to 31 percent potassium nitrate, 7 percent to 9 percent carbon, and 2 to 3 percent sulfur. The other formulation is 58 to 62 percent ammonium nitrate, 31 percent to 38 percent potassium nitrate, 3.5 percent to 4.5 percent charcoal, 2 percent to 3 percent sulfur, and 1.5 percent moisture.

b. *Amatolo.* These are the amatols. The most popular mixture is tipo 60/40, which has 60 percent ammonium nitrate and 40 percent TNT. Other compositions used are tipo 80/20 and tipo 90/10.

c. *Ammonaftite.* This is a mining explosive containing 76.7 percent ammonium nitrate, 15 percent nitroglycerin, 0.3 percent collodion cotton, 0.3 percent grain flour, and 0.5 percent yellow ocher.

d. *Ammonal.* These are mixtures containing various percentages of ammonium nitrate, aluminum, and TNT.

e. *Ammonite No. 1.* This is a blasting explosive consisting of 88 percent ammonium nitrate, 3 percent DNT, 3 percent nitroglycerin, 5 percent vegetable flour, and 1 percent diphenylamine.

f. *Antigrison.* These are permissible explosives. Autigrison N.O contains 80.57 percent ammonium nitrate, 6.36 percent dinitronaphthalene, and 13.02 percent ammonium chloride. Autigrison N.2 contains 81.49 percent ammonium nitrate, 11.11 percent dinitronaphthalene, and 7.4 percent ammonium chloride. Autigrison N.3 contains 82 percent ammonium nitrate, 5 percent trinitronaphthalene, and 13 percent ammonium chloride.

g. *Autonile.* There are two explosive mixtures of ammonium nitrate and TNT. In one, used in quarries, the oxygen content is 5.9 percent. The other, used in tunnels, has an oxygen content of 3.08 percent.

h. *BM.* These are a series of mining explosives.

(1) BM.1. per galleria is a grey powder consisting of TNT, ammonium nitrate, and thermite.

(2) BM.as. per uso a cielo aperto is a reddish powder consisting of ammonium nitrate, cyclic aliphatic compounds, and metallic powders.

(3) BM.ac. per uso a cielo aperto is a brownish yellow powder containing ammonium nitrate and TNT.

(4) BM.57. per uso a cielo aperto is a greyish black powder based on ammonium nitrate.

(5) Super BM. per galleria is a green powder which is slightly plastic. The powder contains aromatic nitrocompounds with organic nitrates and plasticizers.

(6) BM.a2 is a brown powder containing ammonium nitrate, TNT, and thermite.

(7) Super BM. cava is a grey powder.

(8) BM.2. per galleria is a grey powder containing an inorganic nitrate, organic nitrocompounds, and aluminum powder.

(9) Carlsoniti are perchlorate based explosives such as one formulation that contains 85 percent $KClO_4$ and 15 percent vaseline and another that contains 88 percent $KClO_4$ and 12 percent dinitrobenzene.

i. *Italian Dynamites.* Italian dynamites are divided into two groups, those with inert bases and those with active bases.

(1) The inert base dynamites are:

(a) Tipo I which consists of 70 to 75 percent nitroglycerin and 25 to 30 percent kieselguhr.

(b) Tipo II which consists of 50 percent nitroglycerin and kieselguhr.

(c) Dinamite nera (black dynamite) which consists of 45 to 55 percent nitroglycerin and 45 to 55 percent coke.

(d) Dinamite al carbonie di legno (charcoal dynamite) which consists of 90 percent nitroglycerin and 10 percent charcoal.

(e) Dinamite rossa (red dynamite) contains 68 percent nitroglycerin and 32 percent tripoli.

(f) Wetter-dinamite (permissible dynamite) contains 35 to 40 percent nitroglycerin, 10 to 14 percent kieselguhr, and 32 to 50 percent magnesium sulfate.

(2) The active base dynamites are:

(a) Gelatina gomma (or gelatina esplodente) which is a blasting gelatin with the composition of 92 to 93 percent nitroglycerin and 7 to 8 percent collodion cotton.

(b) Gelatina esplosiva da guerra which is a military blasting gelatin with the composition 86.4 percent nitroglycerin, 9.6 percent collodion cotton, and 4 percent camphor.

(c) Gelatina dinamite is a gelatin dynamite containing 67 to 86 percent nitroglycerin, 3 to 5.5 percent collodion cotton, 5 to 25 percent potassium nitrate, and 2 to 10 percent woodflour.

(d) Ammon dinamite (gelatina 65 percent) contains 63 percent nitroglycerin, 2 percent collodion cotton, 30 percent ammonium nitrate, and 5 percent woodflour.

(e) Gelatina dinamite incongelabile o antigelo, a nonfreezing gelatin dynamite, contains 20 to 25 percent nitroglycerin, 1 to 2 percent collodion cotton, 8 to 12 percent nitrotoluenes, 25 to 60 percent of a mixture that contains sodium nitrate and ammonium nitrate, and 1 to 8 percent cereal flour.

(f) Gelatina 40 percent contains 40 percent nitroglycerin, 10 percent drip oil, 44 percent sodium nitrate, and 6 percent cereal flour. The drip oil contains liquid DNT's and is a biproduct of TNT manufacture.

(g) Ammon-gelatina I contains 40 percent nitroglycerin which has been gelatinized with collodion cotton, 45 percent ammonium nitrate, 5 percent sodium nitrate, and 10 percent woodflour.

(h) Ammon-gelatina II contains 20 percent nitroglycerin gelatinized with collodion cotton, 75 percent ammonium nitrate, and 5 percent woodflour.

(i) Dinamite No. 1, non-gelatinizzate contains 70 to 74 percent nitroglycerin and 30 to 26 percent woodflour.

(j) Dinamite No. 2, non-gelatinizzate contains 35 to 48 percent sodium nitrate and/or lead nitrate (52 to 39 percent) with 12 to 17 percent cereal flour.

(k) Table 11-7 lists the composition of some more nitroglycerin based dynamites. GDI, GDII, CD2, GDM, GEO, gomma A, and gomma B are the most frequently used.

j. *Diamon.* This is an explosive which consists of 69 percent ammonium nitrate, 8 percent $KClO_4$, 20 percent TNT, and 3 percent aluminum.

k. *Diamon 1B.* This is a mining explosive containing ammonium nitrate, TNT, woodmeal, 3 to 6 percent nitroglycerin, and some other ingredients.

l. *Esplosivi Da Mina.* Mining explosives are listed in tables 11-8 and 11-9.

*Table 11-7. Esplosivi Da Mina Gelatinosi Con Nitroglicerina (Mining Explosives with Nitroglycerin)*

| Composition (%) and some properties | 1 GDII | 2 GD2 | 3 | 4 GDI | 5 GDIM | 6 GEOM | 7 | 8 | 9 GEO | Gomma | | GDM |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | B | A | |
| Nitroglycerin | 43.2 | 48.3 | 7.0 | 60.0 | 38.0 | 57.0 | 71.0 | 40.75 | 77.5 | 82.5 | 92 | 38.0 |
| Collodion cotton | 2.3 | 2.7 | 0.8 | 3.5 | 2.3 | 3.5 | 5.0 | 1.5 | 5.0 | 5.5 | 8 | 2.3 |
| Ammonium nitrate | - | - | - | - | 50.9 | 29.0 | - | 17.0 | - | - | - | 50.4 |
| Ammonium perchlorate | - | - | 44.0 | - | - | - | - | - | - | - | - | - |
| Woodflour | 7.0 | 5.8 | 1.0 | 5.2 | - | 3.5 | 5.0 | - | 5.0 | 3.0 | - | - |
| Dinitrotoluene | - | - | 10.0 | - | - | - | - | - | - | - | - | - |
| Trinitrotoluene | - | - | 5.0 | - | - | - | - | - | - | - | - | - |
| Sodium nitrate | 45.5 | 42.7 | 32.2 | 30.5 | 6.0 | 7.0 | - | - | 12.0 | 8.5 | - | 6.0 |
| Potassium nitrate | - | - | - | - | - | - | 18.5 | - | - | - | - | - |
| Calcium silicide | - | - | - | - | - | - | - | - | - | - | - | - |
| Oil | - | - | - | - | 2.0 | - | - | - | - | - | - | 2.5 |
| PETN | - | - | - | - | - | - | - | 40.75 | - | - | - | - |
| Ocher, red (hematite) | - | - | - | 0.3 | 0.5 | - | 0.5 | - | - | - | - | 0.5 |
| Ocher, yellow (limonite) | 1.0 | - | - | - | - | - | - | - | - | - | - | - |
| Sodium carbonate | 1.0 | 0.5 | - | 0.5 | - | - | - | - | 0.5 | 0.5 | - | - |
| Calcium carbonate | - | - | - | - | 0.3 | - | added 0.3 | - | - | - | - | 0.3 |
| Trauzl test, cc | 340 | 355 | 430 | 440 | 475 | 500 | 505 | 525 | 540 | 560 | 630 | 475 |
| Gap test, cm | 14 | 15 | 6 | 20 | 21 | 23 | 26 | 25 | 29 | 30 | 35 | - |
| Velocity of detonation, m/sec | 5,000 | 5,200 | 4,700 | 6,000 | 5,900 | 5,400 | 5,900 | 7,000 | 6,700 | 6,900 | 7,200 | - |

*Table 11-8. Esplosivi Da Mina Polverulenti Con Nitroglicerina (Pulverulent Mining Explosives with Nitroglycerin)*

| Composition (%) and some properties | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitroglycerin | 14.0 | 11.0 | 10.0 | 4.0 | 4.0 | 8.0 | 12.4 | 12.76 | 4.0 | 12.0 | 11.7 | 9.0 |
| Dinitrotoluene | - | - | - | 1.5 | - | 0.5 | 0.3 | - | - | - | - | - |
| Trinitrotoluene | - | - | - | - | - | - | - | - | 10.0 | 0.3 | - | 20.0 |
| Collodion cotton | 0.3 | - | 0.25 | 1.5 | 0.1 | 0.5 | 0.3 | 0.24 | - | - | 0.3 | 0.3 |
| Woodflour | - | 6.0 | - | - | - | - | - | - | - | - | - | - |
| Cereal flour | - | - | - | - | - | 5.0 | - | - | - | 3.0 | - | - |
| Ammonium picrate | 65.7 | 51.0 | 89.75 | 82.0 | 89.4 | 81.0 | 79.0 | 83.0 | 76.0 | 77.7 | 76.0 | 70.7 |
| Sodium nitrate | - | - | - | - | - | - | - | - | - | - | - | - |
| Potassium nitrate | - | - | - | - | - | - | - | - | - | - | - | - |
| Dinitronaphthalene | - | 10.0 | - | - | - | - | 8.0 | 4.0 | 10.0 | - | 10.0 | - |
| Potassium perchlorate | - | - | - | - | - | - | - | - | - | - | - | - |
| Sodium chloride | 20.0 | 22.0 | - | 11.0 | - | - | - | - | - | - | - | - |
| T4 (RDX) | - | - | - | - | 6.5 | - | - | - | - | - | - | - |
| Oil | - | - | - | - | - | - | - | - | - | 2.0 | 2.0 | - |
| Calcium silicide | - | - | - | - | - | 5.0 | - | - | - | 5.0 | - | - |
| Trauzl test, cc | 270 | 265 | 300 | 305 | 320 | 375 | 390 | 390 | 400 | 420 | 430 | 450 |
| Gap test, cm | 2 | 5 | 20 | 3 | 12 | 6 | 3 | 4 | 11 | 1 | 1 | 6 |
| Velocity of detonation, m/sec | 2,120 | 2,300 | 2,038 | 1,710 | 2,500 | 3,200 | 2,715 | 3,200 | 2,348 | 2,960 | 2,350 | 2,912 |

*Table 11-9. Esplosivi Da Mina Polverulenti Senza Nitroglicerina (Pulverulent Mining Explosives Without Nitroglycerin)*

| Composition (%) and some properties | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ammonium nitrate | 85.5 | 77.0 | 40.0 | 78.0 | 82.0 | 80.0 | 79.5 | 70.0 | 84.5 | 90.0 | - | 79.0 | 70.0 | 63.0 |
| Dinitronaphthalene | - | - | - | - | - | - | - | 5.0 | 10.0 | - | - | - | - | - |
| Dinitrotoluene | - | - | - | - | 1.0 | - | - | - | - | - | - | - | - | - |
| Trinitrotoluene | 4.5 | 15.0 | - | 16.0 | 14.0 | 20.0 | 10.0 | 10.0 | - | 8.0 | 90.0 | - | - | - |
| Ammonium perchlorate | - | - | 25.0 | - | - | - | - | - | - | - | - | - | - | - |
| Potassium perchlorate | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Potassium nitrate | - | - | 29.0 | - | - | - | - | - | - | - | - | - | - | - |
| Woodflour | 10.0 | 6.5 | 4.0 | - | 3.0 | - | 2.5 | - | - | 2.0 | - | 1.0 | - | 3.0 |
| Oil | - | - | 2.0 | - | - | - | - | - | - | - | - | - | - | - |
| Paraffin | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Sodium nitrate | - | - | - | 4.5 | - | - | 8.0 | 15.0 | - | - | - | - | - | 13.0 |
| Potassium bichromate | - | - | - | - | - | - | - | - | 4.5 | - | - | - | - | - |
| Carbon (pulverized) | - | 1.5 | - | - | - | - | - | - | 1.0 | - | - | - | - | - |
| Charcoal (pulverized) | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| PETN or RDX | - | - | - | - | - | - | - | - | - | - | 10.0 | 20.0 | 30.0 | 21.0 |
| Calcium carbonate | - | - | - | 1.0 | - | - | - | - | - | - | - | - | - | - |
| Ocher (hematite) | - | - | - | 0.5 | - | - | - | - | - | - | - | - | - | - |
| Trauzl test, cc | 330 | 330 | 350 | 400 | 420 | 430 | 450 | 360 | 395 | 375 | 400 | 425 | 450 | 480 |
| Gap test, cm | 1 | 2 | 3 | 6 | 6 | 7 | 7 | 2 | 3 | 1 | 4 | 5 | 3 | 6 |
| Velocity of detonation, m/sec | 1,900 | 2,300 | 2,400 | 3,600 | 3,700 | 4,300 | 3,500 | 1,600 | 3,100 | 2,300 | 7,000 | 2,850 | 2,100 | 3,000 |

m. *Esplosivi di Primari.* These are primary explosives. Mercury fulminate has been replaced by lead azide and lead styphnate.

n. *Esplosivi di Rinforzo.* These are the booster explosives. RDX, PETN, and tetryl are used.

o. *Esplosivi di Scoppio.* These are the high explosives. Those which have been used include amatolo, ammonal, HMX, PETN, pentolite, RDX, tetryl, TNT, tritolital (60 percent TNT, 20 percent RDX, and 20 percent aluminum), and tritolite (60 percent RDX, 39 percent TNT, 1 percent beeswax). The following bursting explosives have been patented in Italy for military use. One is a cast explosive that is prepared by incorporating 75 percent RDX or PETN with 25 percent nitroisobulylglycerol. Another explosive consists of 5 to 65 percent RDX or PETN with 30 to 90 percent TNT, and 5 to 30 percent powdered metals such as silicon, boron, magnesium, copper, iron, aluminum, or zinc. RDX and 8 to 14 percent castor oil pressed in the form of beads has also been patented. A process for directly producing a cast explosive has also been patented. Molds or bomb bodies are loaded with a granulated mixture of nitrocellulose and a high explosive followed by the addition of a solvent containing a nitrated ester, a stabilizer, a plasticizer, and sometimes an accelerating agent. The final composition of the explosive may be 5 to 36 percent nitrocellulose, 33 to 40 percent nitrate ester, 20 to 60 percent high explosive, 1.5 to 2.5 percent plasticizer, 0.5 to 0.6 percent stabilizer, and 0.4 to 0.5 percent accelerating agent. The granulated composition is obtained by mixing the nitrocellulose, the high explosive, a plasticizer (diethylphthalate), and a stabilizer (centralite) with a nitrocellulose solvent (acetone). The paste obtained is impregnated in the mold with nitroglycerin and the diethylphthalate in a solvent, centrifuged, and gelled at 50°C. Another explosive consists of RDX or PETN with high density nitrates such as lead nitrate, barium nitrate, and zinc stearate.

p. *Esplosivo Plastico.* This is a plastic explosive suitable for military use which consists of 85 to 89 percent RDX, 10 to 12 percent petrolatum, 0.5 to 2 percent plastic binder, and 0.5 to 1 percent glycerophthalic acid. An aluminized version consists of 64 to 75 percent RDX, 10 to 12 percent petrolatum, 10 to 25 percent aluminum powder, 0.5 to 2 percent plastic binder, and 0.5 to 1 percent glycerophthalic acid.

q. *Esplosivo S20.* This is a military explosive which contains 79 percent ammonium nitrate, 20 percent TNT, and 1 percent woodflour.

r. *Grisou Dinamite.* This is a permissible explosive containing 88 percent ammonium nitrate, 10 percent nitroglycerin, 0.5 percent collodion cotton, and 1.5 percent woodflour.

s. *Grisounite.* This explosive contains 95.5 percent ammonium nitrate and 4.5 percent trinitronaphthalene.

t. *Grisounite Gomma.* This explosive contains 70 percent ammonium nitrate, 29.5 percent nitroglycerin, and 0.5 percent collodion cotton.

u. *Grisounite Roccia or Rock Grisounite.* This explosive contains 91.5 percent ammonium nitrate and 8.5 percent trinitronaphthalene.

v. *Hexocire.* This is a mixture of RDX and beeswax.

w. *Hexocire-Aluminum.* This explosive is a mixture of 80 percent RDX, 5 percent beeswax, and 15 percent aluminum.

x. *Hexaliti.* These are mixtures of RDX and aluminum in various proportions.

y. *MAT.* This is the Italian name for picratol.

z. *Miscela C or PE.* A plastic explosive consisting of RDX and a plasticizer. Miscela $C_2$, which is waterproof, consists of RDX, collodion cotton, and a plasticizer. Miscela $C_3$ consists of RDX, tetryl, collodion cotton, and a plasticizer. Miscela $C_4$ consists of 91 percent RDX with polyisobutylene and other ingredients.

aa. *NA - OC.* This is the Italian name for ANFO explosives.

bb. *Nitroglicol.* This explosive is also called dinitroglicol in Italian. The English term is ethyleneglycol dinitrate. This compound is used in many countries as an antifreeze in nitroglycerin mixtures such as dynamite.

cc. *Nobelite Galleria.* This is a mining explosive consisting of 37 percent nitrocellulose, 34 percent $KClO_4$, 24 percent $NaNO_3$, 3 percent DNT, and 2 percent mineral oil. The temperature of explosion is 2,800°C. At about 130°C the explosive burns in air.

dd. *Nougat or MST.* This is an amatol type explosive used as a shell filler which consists of 49 percent ammonium nitrate, 44 percent TNT, and 7 percent dinitronaphthalene.

ee. *NTP.* This is a military explosive that consists of 77 percent ammonium nitrate, 20 percent RDX, and 3 percent paraffin.

ff. *Oxiliquite.* This is one of the liquid air explosives prepared in situ by pouring liquid air or liquid oxygen into a mixture of three parts carbon impregnated with two parts petroleum.

gg. *Oxilite.* This is another liquid air or oxygen explosive prepared in situ. The fuel in this explosive is fossil flour that has been impregnated with petroleum.

hh. *Pentritolo.* In Italian this is also called pentrol. The English name is pentolite.

ii. *PNP Esplosivo.* This is an explosive used for press loaded projectiles that consists of 20 percent PETN, 77 percent ammonium nitrate, and 3 percent wax.

jj. *Polvere FB.* There are 860 and 960 calorie types which contain 32 and 31 percent nitroglycerin, 57 and 61 percent nitrocellulose (12 percent nitrogen content), 9 and 5.5 percent butylphthalate, and 2 and 2.5 percent centralite. Both are used in rapid fire cannons.

kk. *Polvere FC.* There are 860 and 960 calorie types which contain 28 and 32 percent nitroglycerin, 64 and 62.5 percent nitrocellulose (12 percent nitrogen content), 4 and 3.5 percent centralite, and 1 and 0.5 percent vaseline. Both are used in rapid fire cannons.

ll. *Polvere NAC.* There are 860 and 960 calorie types which contain 27 and 32 percent nitroglycerin, 66 and 63 percent nitroacetylcellulose (11.2 percent nitrogen content), 7 and 4 percent centralite, and 0 and 1 percent DPhA. Both are used as cannon propellants.

mm. *Polvere Nera.* Italian for black powder.

nn. *Polvere al Nitrodiglical.* There are 860 and 730 calorie types which contain 68 and 27 percent DEGN, 30 and 63.5 percent nitroacetylcellulose, 0 and 5 percent acetylcellulose, and 2 and 4.5 percent centralite.

oo. *Polvere al Nitrometriolo.* These are propellants with TMETN. M4, M6, and M8 have compositions of 55.5, 57.5, and 59 percent TMETN; 40, 36, and 33 percent nitrocellulose; 2.5, 4.5, and 5.9 percent acetylmetriol; 2, 2, and 2.5 percent centralite.

pp. *Polveri da Lancio Senza Fumo.* These are the smokeless propellants. These are divided into single based propellants with a volatile solvent, double based propellants with nitroglycerin, double-base propellants without a volatile solvent, double-base propellants with a volatile solvent, and propellants with several components.

qq. *$T_4$ Plastico.* Two mixtures are known. One has 89 percent RDX and 11 percent vaseline and the other has 78.5 percent RDX, 17.5 percent DEGN (which contains 0.3 to 0.4 percent collodion cotton), and 3 percent vaseline.

rr. *Tetranitroauilina.* This is an explosive used in crystal form in some detonators.

ss. *Tetritol.* Italian for tetrytol.

tt. *Trinitrofloroglucinato di Piombo.* This compound is used in some initiating compositions in place of lead styphnate.

uu. *Umbrite.* There are two formulations of this explosive. Umbrite A contains 48.4 percent nitroguanidine, 37.3 percent ammonium nitrate, and 14.3 percent ferrosilicon. Umbrite B contains 45.1 percent nitroguanidine, 41.4 percent ammonium nitrate, and 13.5 percent ferrosilicon. Both are used as bursting charges in some projectiles.

**11-5. Japanese Energetic Materials.** Table 11-10 lists the Japanese explosives.

*Table 11-10. Japanese Explosives*

| English | Japanese |
|---|---|
| Lead azide | Chikkgen, chikka namari |
| Mercury fulminate | Raiko, raisan |
| Nitrocellulose | Shokamen |
| Guncotton | Menyaku |
| Nitroglycerin | Nitoroguriserin |
| PETN | Shoeiyaku |
| RDX | Shouyaku, tanayaku |
| Tetryl | Meiayaku, sanshoki, mechira nitroamin |
| Ammonium picrate | Picurinsan ammonia |
| TNT | Chakatsuyaku, sanshokitoruoru |
| Ammonium nitrate | Ammon shosanen |

The following limited data is available on the most currently used Japanese energetic material. Japan has no army but has a national self defense force. Energetic material research is done for this organization. Current developments and usage are along the lines of that in the western countries.

a. *Akatsuki.* This is an ammonium nitrate explosive containing 73 to 75 percent ammonium nitrate, 5 to 6 percent nitroglycerin gel, 3 to 5 percent cellulose, and 9 to 14 percent other ingredients. The explosive has a detonation velocity of 3,490 meters per second, an empirically determined detonation pressure of 42.3 kilobars, and a calculated detonation pressure of 33 kilobars.

b. *Ammonaru.* This is the Japanese name for ammonal.

c. *Kokushokuyaku.* This is the Japanese name for black powder.

d. *Chauyaku*. This is the Japanese name for 50/50 cyclotol.

e. *Dainamaito*. This is the Japanese name for dynamite. Japanese dynamites are based on nitroglycerin and are brown to buff in color. Some types of dynamites contain nitrocellulose and others contain diatomaceous earth. Some gelatin dynamites, the so-called faint smoke dynamites, contain borax or salt. Nonfreezing dynamites contain nitroglycol or dinitroglycerol. The Japanese also produce ammonium nitrate and semigelatin dynamites.

f. *Pentoriru*. This is the Japanese term for 50/50 pentolite.

g. *Shoanyaku*. These are a series of mining explosives which consist of the following:

(1) No. 1 contains 70 percent ammonium nitrate, 9 percent dinitronaphthalene, 1 percent woodmeal, and 20 percent salt.

(2) No. 2 contains 79 percent ammonium nitrate, 10 percent dinitronaphthalene, 1 percent sawdust, and 10 percent sodium chloride.

(3) No. 5 contains 64 percent ammonium nitrate, 12 percent TNT, 3 percent woodmeal, 1 percent wheat starch, and 13 percent sodium chloride.

(4) No. 7 contains 75 percent ammonium nitrate, 9 percent dinitronaphthalene, 1.5 percent TNT, 1.5 percent woodmeal, and 13 percent sodium chloride.

(5) Special contains 64 percent ammonium nitrate, 3 percent dinitronaphthalene, 7 percent TNT, 2 percent nitroguanidine, 2 percent sodium nitrate, 2 percent woodmeal, and 20 percent sodium chloride.

h. *Shotoyaku*. This is the Japanese name for amatol.

**11-6. Russian Energetic Materials.** Table 11-11 lists some explosives used by Russia.

*Table 11-11. Russian Explosives*

| English | Russian |
|---|---|
| Lead azide | Azid svintsa |
| Lead styphnate | Stifnat svintsa,<br>teneres |
| Tetracene | Tetratsin |
| Mercury fulminate | Gremoochaya rtoof |
| Guncotton | Khlopchatoboomazhnyi porokh |
| Pyroxylin $(N > 12\%)$ | Kolloksilin, piroksilin |
| Pyrocellulose $(11.5\% < N < 12\%)$ | Piroksilin No. 2,<br>pirokollodion |
| Nitroglycerin | Nitroglitserin |
| PETN | Ten |
| HMX | Oktoghen |
| RDX | Gheksoghen |
| Tetryl | Tetril |
| Ammonium picrate | Pikrat ammoniya,<br>pikrinovokislyi ammonii |
| TNT | Toe, trotil |
| Ammonium nitrate | Ammoniynaya selitra |

The following energetic materials are used by the Russians.

a. *A or AT*. This is the Russian abbreviation for amatol.

b. *A-IX-2*. This is an explosive mixture used as a projectile filler that contains 73 percent RDX, 23 percent aluminum powder, and 4 percent wax.

c. *Akvanity (Akvanites)*. These are a series of industrial explosives.

(1) Plastic akvanites No. 2 and No. 16 have, in contrast to dynamites, a plasticizing base consisting of an aqueous solution of potassium nitrate thickened to a gel-like consistency in which ammonium nitrate and other constituents (such as combustibles) are also partially dissolved. Their liquid phase at normal temperature is about 20 to 25 percent, of which 5 to 7 percent is water.

(2) Slurry-type akvanite 3L (where L stands for l'yonshchiysya-pourable), uses as a base a thickened aqueous solution of ammonium nitrate making up 45 percent of the liquid phase. Other ingredients are as in dynamites. Akvanite 3L has a liquid-viscous consistency and therefore is suitable for charging descending blastholes and drillholes by the method of casting or by compression under water.

d. *Akvatoly (Akvatols).* These are industrial slurry explosives. Akvatol 65/35 contains granulated ammonium nitrate as an oxidizer, 27 to 30 percent TNT as a combustible and sensitizer, and 2.5 to 3.5 percent of the sodium salt of carboxymethylcellulose which is a thickening agent. Akvatol M-15 contains granulated ammonium nitrate, 12.5 to 13.2 percent coarse aluminum powder, 21 to 22 percent TNT, and 1.0 to 1.5 percent of the sodium salt of carboxymethyl cellulose. The water content of akvatol slurries must not exceed 13 to 25 percent by weight. In some cases the sodium carboxymethylcellulose can be replaced by other binding agents such as borax or polyacrylamide powder. Akvatols are usually prepared at plants and shipped in the form of anhydrous friable mixtures, packed in paper bags for the addition of water at the site of use. They can also be shipped in ready to use water filled slurries.

e. *Alyumatoly (Alumatols).* These are combinations of ammonium nitrate, TNT, and aluminum. Russian alumatols are granulated and waterproof. They are used in open cut work for breaking very hard rock.

f. *Alyumit No. 1.* This is a Russian commercial explosive that consists of 80 percent ammonium nitrate, 12 percent TNT, and 12 percent aluminum.

g. *Alyumotol.* This is a granulated melt of TNT and aluminum.

h. *Amatol.* This is the same as amatol in English.

i. *Ammoksily or Ammoxyly.* This is a non-permissible mining explosive that consists of ammonium nitrate and trinitroxylene.

j. *Ammonaly.* This is the Russian name for ammonals.

k. *Ammonity (Ammonits).* Ammonits are ammonium nitrate mixtures of powdered structure in which TNT or other aromatic nitrocompounds are used as the explosive sensitizer and fuel. In grain or granulated form they are known as zernogranulity. The most current ammonits are:

(1) No. 6-ZhV and No. 7-ZhV are waterproof. The composition of the two is:

| | No. 6 | No. 7 |
|---|---|---|
| Ammonium nitrate (%) | 79 | 81.5 |
| TNT (%) | 21 | 16 |
| Woodmeal (%) | - | 2.5 |

(2) PZhV-20, AP-4ZhV, and AP-5ZhV are rock oriented. The composition of these is shown in table 11-12.

*Table 11-12. Some Ammonits Formulations*

| | PZhV-20 | AP-4ZhV | AP-5ZhV |
|---|---|---|---|
| Ammonium nitrate (%) | 64 | 68 | 70 |
| TNT (%) | 16 | 17 | 18 |
| Flame inhibitor (%) | 20 | 15 | 12 |

(3) Ammonit skal'nyi No. 1 is used in the pressed state for blasting hard rocks in open or underground works.

(4) Ammonit V-3, shnekovannyi is used in flooded drill holes.

(5) No. 9-2hV and No. 10-ZhV are waterproof mixtures used for blasting soft or medium rocks. Their compositions are:

| | No. 9 | No. 10 |
|---|---|---|
| Ammonium nitrate (%) | 87 | 85 |
| TNT (%) | 5 | 8 |
| Woodmeal (%) | 8 | 7 |

(6) Ammonit sernyi No. 1-ZhV, for use in sulfur mines, consists of 52 percent waterproof ammonium nitrate, 11.5 percent TNT, 1.5 percent woodmeal, 5 percent of a mixture of low freezing point nitroesters, and 30 percent flame inhibitor.

(7) Ammonit neftyanoy No. 3-ZhV, for use in mines with petroleum vapors, consists of 52.5 percent ammonium nitrate, 7 percent TNT, 1.5 percent calcium stearate, 30 percent flame inhibitors, 9 percent nitroesters, 0.3 percent collodion cotton, and 0.2 percent soda.

(8) Ammonit T-19, a safety explosive used in fiery mines, consists of 61 percent waterproof ammonium nitrate, 19 percent TNT, and 20 percent flame inhibitor.

(9) Shashki (demolition charges) skal'nago ammonita are compressed charges which serve as intermediate initiators for detonating nearly insensitive explosives.

l. *Ammonit Predokhranitel'nyi.* This is a safety commercial mine explosive which consists of 68 percent ammonium nitrate, 10 percent TNT, 2 percent powdered pine bark or oil cake, and 20 percent sodium chloride.

m. *Ammonit V-3V Poroshke.* This is a powdered explosive that contains 82 percent nonwaterproofed ammonium nitrate, 16.5 percent TNT, 1 percent asfal'tit, and 0.5 percent paraffin.

n. *Ammontol.* This is a castable high explosive mixture of 50 percent ammonium nitrate, 38 percent TNT, and 12 percent trinitroxylene that is used for loading some projectiles.

o. *Belity (Bellites).* These are extensively used commercial mining and blasting explosives. The following compositions are used; 35 percent ammonium nitrate and 65 percent dinitrobenzene, 87 percent ammonium nitrate and 13 percent dinitrobenzene, and 80 percent ammonium nitrate, 12 percent trinitroxylene, and 8 percent dinitrobenzene.

p. *Buryi Shokoladnyi Porokh.* These are the Russian brown powders. Brown powders are very similar to black powders except that the charcoal is brown because carbonization is only carried out to 70 to 75 percent. This is called buryi porokh, and is slower burning than black powder. A still slower brown powder is shokoladnyi porokh which has charcoal with a carbon content of 52 to 54 percent. Brown powders have been used in delay compositions and for time rings of fuses. The composition of some of these brown powders is listed in table 11-13.

*Table 11-13. Russian Brown Powders*

| | No. 1 | No. 2 | No. 3 |
|---|---|---|---|
| Brown coal (%) | 4 | 6 | 7 |
| Potassium nitrate (%) | 59 | 67 | 76 |
| Sulfur (%) | 37 | 27 | 17 |
| Velocity of burning (millimeters per second) | 3 | 3.8 | 3.4 |

q. *Charnyi Porokh.* This is Russian for black powders which are also called pymnyi (smoke) porokh. Table 11-14 lists typical compositions.

*Table 11-14. Russian Black Powders*

| | $KNO_3$ | Sulfur | Charcoal |
|---|---|---|---|
| Military (%) | 75 | 10 | 15 |
| Fuse powder (%) | 78 | 12 | 10 |
| Blasting (%) | 75 - 84 | 8 - 10 | 8 - 15 |
| Blasting (%) | 66.6 | 16.7 | 16.7 |
| Tubular (%) | 60 - 75 | 13 - 37 | 4 - 7 |
| Sulfurless (%) | 80 | - | 20 |
| Sporting (%) | 74 - 78 | 8 - 10 | 14 - 16 |
| Sporting (%) | 80 | 8 | 12 |

r. *Detonity.* These are powdery, water resistant explosives used in hard rock blasting. Table 11-15 lists typical compositions.

*Table 11-15. Detonity*

| Designation | 6A | 10A | 15A - 10 |
|---|---|---|---|
| Low freezing point organic nitrates (%) | 6.0 | 10.0 | 14.7 |
| Ammonium nitrate (water resistant ZhV) (%) | 78.0 | 76.0 | 74.0 |
| TNT (%) | 11.0 | 8.0 | - |
| Aluminum powder (%) | 5.3 | 5.2 | 10.0 |
| Calcium stearate (%) | 0.7 | 0.7 | 1.0 |
| Collodion cotton (%) | - | 0.1 | 0.3 |
| Soda (added above 100%) | 0.2 | 0.2 | 0.2 |
| Density, grams per cubic centimeter | 1.1 | 1.1 | 1.1 |
| Detonation velocity, meters per second | 4,000 | 4,200 | 4,300 |

s. *Dinaftalit.* This is an explosive mixture that is used to fill shells and as a commercial blasting agent. Dinaftalit contains 88 percent ammonium nitrate, 11.6 percent dinitronaphthalene, and 0.4 percent paraffin.

t. *Dinitronaftalin.* This is Russian for dinitronaphthalene. This explosive is very weak and has an unsatisfactory oxygen balance. Dinitronaphthalene is not used alone, but is used as an ingredient in several composite explosives.

u. *Dinamity.* These are the Russian dynamites. The following types are used:

(1) Gremuchii studen' is a blasting gelatin that contains 87 to 93 percent nitroglycerin and 7 to 13 percent collodion cotton.

(2) Plasticheskii dinamit is a plastic dynamite that contains 62 to 83 percent nitroglycerin, 3 to 6 percent collodion cotton, 27 to 29 percent potassium or sodium nitrate, and 2 to 8 percent woodmeal.

(3) Grisutin contains 12 to 30 percent nitroglycerin gelatinized by collodion cotton and 70 to 88 percent ammonium nitrate with an absorbent such as limestone or sawdust.

(4) AM-8 contains 89 percent ammonium nitrate, 8 percent paraffin, and 3 percent mineral oil.

(5) AM-10 contains 87.7 percent ammonium nitrate, 10 percent paraffin, and 2.3 percent mineral oil.

v. *Grammonal.* These are powerful, granulated ammonals with an increased aluminum content. They are used in open pit blasting of hard rocks.

w. *Granulity.* These are granulated mining explosives. Typical compositions are given in table 11-16.

*Table 11-16. Granulity*

| Components, granulites: | AC-8 | AC-4 | C-2 | M |
|---|---|---|---|---|
| Ammonium nitrate, granulated (%) | 89.0 | 91.8 | 92.8 | 94.5 |
| Aluminum, powdered (%) | 8.0 | 4.0 | - | - |
| Woodmeal (%) | - | - | 3.0 | - |
| Mineral oil (%) | 3.0 | 4.2 | 4.2 | 5.5 |
| Detonation velocity, meters per second | 3,000 | 2,600 | 2,400 | 2,500 |
| Trauzl test value, cubic centimeters | 410 | 390 | 320 | 320 |

x. *Igdanit.* This is an ammonium nitrate, fuel oil explosive that is prepared in situ just before use. Reported compositions vary from an ammonium nitrate composition of 94 to 97 percent.

y. *Mansit.* This is an explosive mixture that consists of 72 percent ammonium nitrate, 23 percent ammonium picrate, and 5 percent petroleum asphalt.

z. *Miporit.* This is an explosive used in gaseous mines that contains 65 percent waterproofed ammonium nitrate, 15 percent TNT, 18 percent flame inhibitor, and 2 percent foamed urea-formaldehyde resin.

aa. *Pobedit VP-4.* This is a permissible explosive used in fire damp mines that consists of 65.5 percent water resistant ammonium nitrate, 9.0 percent low freezing point organic nitrates such as nitroglycerin and nitroglycol, 12 percent TNT, 12 percent flame extinguisher, 1.5 percent woodmeal, 0.13 percent collodion cotton, 0.1 percent calcium stearate, and 0.1 percent soda.

bb. *Selectite No. 1 (Celektit No. 1).* This is a granulated, friable, water resistant ammonium nitrate explosive with 10 percent low freezing point nitrate esters.

cc. *Slurry Explosives.* These consist of ammonium nitrate in a thickened, water based suspension described in Chapter 8. Akvatols 65/35 and M-15 are considered slurry explosives.

dd. *Tetritoly.* This is Russian for tetrytol.

ee. *Uglenity.* These explosives, which are also called ooglenity, are coal mining explosives used in firedamp and dusty environments. They are ammonium nitrate based.

ff. *Zernogranoolity.* Waterproof ammonium nitrate explosives used for blasting rock of moderate hardness or hard rock on flooded faces.

**11-7. Spanish Energetic Materials.** Table 11-17 lists some of the explosives used by the Spanish.

*Table 11-17. Spanish Explosives*

| English | Spanish |
|---|---|
| Lead azide | Azido de plomo,<br>nitruro de plomo, plumbazida |
| Lead styphnate | Stifnato de plomo,<br>trinitroresorcinato de plomo,<br>triginato, tricinato |
| Tetracene | Tetraceno |
| Mercury fulminate | Fulminato de mercurio |
| Collodion cotton (N about 12%) | Algodon colodio,<br>cotone colodio |
| Guncotton (N>12%) | Algodon fulminate,<br>algodon polvora, fulmicoton |
| Nitroglycerin | Nitroglicerina<br>aceite explosivo |
| PETN | Pentrita, nitropenta,<br>nitropentaeritrita |
| RDX | Hexogeno, T4, exogeno,<br>ciclonita |
| Tetryl | Tetralita, tetralo,<br>tetranitrometilanilina |
| Ammonium picrate | Picrato amonico |
| TNT | Trilita, trotilo,<br>tol, trinitrotolueno |
| Ammonium nitrate | Nitrato amonico |

The following explosives are used by the Spanish.

a. *Amatolos.* This is Spanish for amatols.

b. *Amonales.* This is Spanish for ammonal.

c. *Amonitas.* These are explosives that contain from 50 to 100 percent ammonium nitrate, other nitrated products, and a small portion of other substances such as nitroglycerin, sawdust, and dichromates. Some explosives of this type are called explosivos favier, australita roburita, donarita, and perdita. Such mixtures are somewhat more sensitive to shock and friction and have a lower rate of detonation than other ammonium nitrate explosives. Their hygroscopicity and relative instability in prolonged storage are the principal disadvantages. They are used in mining operations and as main charges in some projectiles.

d. *Anagon.* This is an ammonal type explosive which contains 70 percent ammonium nitrate, 20 percent aluminum zinc alloy, and 10 percent charcoal.

e. *Antigrisu Explosives.* These are permissible explosives also known as explosivos de seguridad. Table 11-18 lists some compositions.

*Table 11-18. Spanish Artigrisu Explosives*

| | No. 1 | No. 2 | No. 3 |
|---|---|---|---|
| Ammonium nitrate (%) | 80.6 | 80.9 | 82.0 |
| Dinitronaphthalene (%) | 6.4 | 11.7 | - |
| Ammonium chloride (%) | 13.0 | 7.4 | 13.0 |
| Trinitronaphthalene (%) | - | - | 5.0 |

f. *Baratol.* These are high explosives that contain from 10 to 70 percent barium nitrate and TNT. They are used as bursting charges.

g. *Dinamitas.* This is Spanish for dynamite. These are considered industrial explosives. Spanish dynamites can be divided into two groups with variable composition.

(1) Dinamitas a base inerte are dynamites with an inert base. To this class belong the compositions containing 75, 50, or 30 percent nitroglycerin with kieselguhr. They are called number 1, 2, and 3 depending upon the nitroglycerin content. Dynamite 3 is the most popular type.

(2) Dinamitas a base activa are dynamites with an active base. These dynamites contain a combustible material or explosive material as the active base. The type of base material further divides these into classes.

(a) Dinamitas a base de nitratos use nitrates of ammonium, sodium, or potassium and a combustible such as carbon, sawdust, or flour.

(b) Dinamitas a base de chloratos use potassium or sodium chlorate in place of nitrates.

(c) Dinamitas gelatinas contain collodion cotton in sufficient proportion to gelatinize the nitroglycerin. Compositions that contain only nitroglycerin and collodion cotton are called goma. All others are called gelatina dinamita, nitrogelatina, or simply gelatina. If a dynamite less sensitive than gomas is desired, three to five percent camphor is added. Such compositions are called gelatinas explosivas de guerra (military gelatins).

h. *Dinamones.* Dinamones are permissible explosives similar to amonitas except that they do not contain aluminum or aromatic nitrocompounds.

i. *Donarita.* This is a mining explosive that contains 80 percent ammonium nitrate, 12 percent TNT, 4 percent gelatinized nitroglycerin, and 4 percent woodmeal.

j. *Explosivos cloratado.* This class of explosives contains 60 to 80 percent chlorates or perchlorates of sodium, potassium, or ammonium mixed with a combustible material such as carbon, sulfur, or aluminum. Organic combustibles such as vaseline, paraffin, or oils may also be used. These explosives are similar to ammonium nitrate but have a greater packing density and are more sensitive to impact. The explosives are used as a substitute for dynamite in mining operations.

k. *Explosivo Plastico "La Maranosa."* This plastic explosive consists of 85 percent RDX, 5.5 percent rubber, and 9.5 percent gelatinizing oil. The composite is of low sensitivity. At 200°C decomposition without explosion occurs but with the evolution of heavy nitrous fumes. A carbonaceous residue is left.

l. *Hexogeno Plastico.* These are also called plastex or PE. They correspond to American composition C. The explosive is prepared by coating granular RDX with 12 percent vaseline and other oily substances. The product is a yellow colored, plastic material which can be cut, perforated, and handled without extra precaution. Initiation is relatively easy with a blasting cap or various detonators. In extreme climates this explosive must be stored in protected areas. No casing is required in some demolition applications.

m. *Hexonitas.* These consist of 80 or 50 percent RDX and 20 or 50 percent nitroglycerin. The 50/50 composition can be further gelatinized and plasticized with some collodion cotton. A mixture of 50 percent RDX, 46 percent nitroglycerin, and 4 percent collodion cotton is called hexonita gelatinizada.

n. *Qxiliquita y Aire Liquido.* This is an explosive of liquid oxygen or liquid air with finely pulverized charcoal, cork dust, or other absorbent fuel.

o. *Polvoras Negras.* This is Spanish for black powder. Spanish black powders are divided into three groups.

(1) Polora de guerra, military black powder, contains 75 percent potassium nitrate, 12.5 percent charcoal, and 12.5 percent sulfur.

(2) Polvora de caza, sporting powder, contains 80 percent potassium nitrate, 11 percent charcoal, and 9 percent sulfur.

(3) Polvora de mina, blasting powder, contains 80 percent potassium nitrate, charcoal, and sulfur. The exact percentages of charcoal and sulfur are unknown.

p. *Tetritol.* This is Spanish for tetrytol. The Spanish use tetritol as a bursting charge and as a booster.

q. *Tonita.* This is a mixture of 68 percent barium nitrate, 13 percent dinitrobenzene, and 19 percent guncotton.

r. *Triplastita.* This is a gelatinized mixture of dinitrotoluene and guncotton that is less sensitive and more dense than TNT. Triplastita is used as a bursting charge in some ammunition.

s. *Tritolita.* This is Spanish for 50/50 cyclotol.

t. *Tritolital.* This explosive, also called torpex, is a castable mixture of 60 percent TNT, 20 percent RDX, and 20 percent aluminum. Tritolital is used as a bursting charge in depth charges and bombs.

**11-8. Swedish Energetic Materials.** As in the United States, Sweden's explosive industry consists of both privately owned and government facilities. Together they provide virtually all of the country's explosives plus significant amounts for export. The only items obtained abroad are initiating components such as primers and detonators. Sweden, however, is heavily dependent on imports for certain basic raw materials such as petroleum, coal, coke, cotton, sulfur, and others. Table 11-19 lists some of the explosives used by the Swedish.

*Table 11-19. Swedish Explosives*

| English | Swedish |
|---|---|
| Lead azide | Blyazid, blyacid |
| Lead styphnate | Blystyfnat, blytrinitroresorcinat |
| Tetracene | Tetrazen |
| Mercury fulminate | Knallkvicksilver |
| Nitrocellulose | Nitrocellulosa |
| Pyroxylin | Piroxilina |
| Nitroglycerin | Nitroglycerin |
| RDX | Hexogen |
| PETN | Pentyl |
| Tetryl | Tetryl |
| TNT | Trotyl |

a. *Ammongelatin Dynamit.* This is a gelatin dynamite. One formulation contains 71 percent nitroglycerin, 4 percent collodion cotton, 23 percent ammonium nitrate, and 2 percent charcoal. Another formulation contains 25 percent nitroglycerin, 1 percent collodion cotton, 62 percent ammonium nitrate, and 12 percent charcoal. The first of these two compositions is gelatinous while the second is crumbly and plastic. The basic formulations change by incorporating other explosives such as liquid DNT, TNT, trinitroxylene, nitrostarch, or nitroglycols. Such additives act not only as sensitizers for ammonium nitrate, but some also serve as antifreeze compounds.

b. *Ammoniakkrut.* This is an ammonium nitrate dynamite that consists of 80 percent ammonium nitrate and 20 percent charcoal. A modification of this mixture contains 80 percent ammonium nitrate, 12 percent nitroglycerin, and 8 percent charcoal. This modified mixture has been used somewhat but was found to be hygroscopic and exuded.

c. *Blastin.* This is a cheddite type safety explosive consisting of 63 percent ammonium perchlorate, 23 percent sodium nitrate, 8 percent DNT, and 6 percent paraffin. Blastin is reported to be 50 percent more powerful than dynamite and has been used extensively as a blasting and demolition explosive.

d. *Bonit.* This is Swedish for cyclotol. Three mixtures of RDX/TNT have been used: 50/50, 70/30, and 60/40.

e. *Bonocord.* This is a Swedish detonating cord which consists of a PETN core covered with braided cotton threads and protected by an outer coating of plastic which is based on polyvinyl chloride or polyethylene. Bonocord weighs 30 grams per meter and has an outer diameter of 5.5 millimeters. The quantity of PETN is 12 grams per meter. The detonation velocity is 6,000 to 7,000 meters per second. Bonocord is initiated with a number six exploder and is used for direct detonation of all types of explosive charges.

f. *Gelatinerad Dynamit.* These are gelatin dynamites. A typical composition is 62.5 percent nitroglycerin, 2.5 percent collodion cotton, 27 percent potassium nitrate, and 8 percent woodmeal.

g. *Hexotol.* This is the specific Swedish name for 60/40 cyclotol. Hexotol is considered a bonit and is used as a cast bursting charge in shells, land mines, demolition charges, boosters, and other military applications.

h. *Hexotonal.* This name is applied to several torpex type mixtures used as bursting charges. Some known compositions are listed in table 11-20.

*Table 11-20. Hexotonal*

| | No. 1 | No. 2 | No. 3 |
|---|---|---|---|
| RDX (%) | 40 | 40 | 30 |
| TNT (%) | 44 | 40 | 50 |
| Al (%) | 15 | 15 | 20 |
| Refined paraffin wax (%) | 1 | 5 | - |
| Wax added to mixture (%) | - | - | 1 |
| Carbon black added to mixture (%) | - | - | 1.5 |

i. *Nobelit.* This is a permissible gelatin dynamite containing 28 percent nitroglycerin, 1 percent collodion cotton, 40 percent ammonium nitrate, 13.5 percent combustibles (such as flour, woodmeal, and dextrin), 17 percent sodium chloride, and 0.5 percent vegetable oil.

j. *Reolit A, B, C, D, or E and Reomex A or B.* These are trade names for slurry blasting explosives.

k. *Seramin.* This is an ammonium nitrate dynamite consisting of 72.5 percent ammonium nitrate, 18 percent nitroglycerin, 8.7 percent sawdust or charcoal, and 0.8 percent benzene or creosote.

l. *Sprangdeg.* These are plastic explosives that usually contain RDX or PETN with a desensitizing oil and special plasticizers. One such explosive consists of 84 percent PETN and 16 percent mineral oil that is mixed by a special procedure. The product is moldable at temperatures below −15°C.

m. *Spranggelatin.* This is a blasting gelatin that is prepared by dissolving seven to eight percent collodion cotton in slightly warm nitroglycerin. On cooling, a stiff jelly is formed that is one of the most powerful explosives known.

n. *Startex A.* This is another slurry blasting agent.

o. *Svartkrut.* This is Swedish for black powder. The composition falls within the following limits: potassium nitrate 74 to 78 percent, charcoal 12 to 15 percent, and sulfur 10 to 12 percent. For different grades of black powder, charcoals of different origin and methods of preparation are used. Powders used in shotgun shells contain charcoal from black alder carbonized in furnaces. Ordinary powders use charcoal made from birch, alder, willow, or linden and blasting powders use pinewood charred in kilns or furnaces.

p. *Territ.* This is a cheddite type blasting explosive that consists of 43 percent ammonium perchlorate, 28 percent sodium nitrate, 27.8 percent liquid DNT/TNT, and 1.2 percent collodion cotton. Another formulation is 43 percent ammonium chlorate, 26 percent ammonium nitrate, and 31 percent of a mixture that contains 96 percent TNT and 4 percent nitrocellulose. Territ is comparable in properties to some low freezing point dynamites and is safe to handle. The brisance of the mixture is such that in mining coal or other mining operations, no small dust particulates are formed. Territ is sometimes difficult to detonate so present formulations contain some nitroglycerin.

**11-9. Swiss Energetic Materials.** In Switzerland the production of black powder and propellants is a monopoly of the government. The Swiss government, however, does not manufacture explosives except for small quantities of primary explosives. Commercial firms produce the explosives used by the army under strict control by military authorities. Switzerland does not generally export military explosives, however, during times of low usage some export has taken place to keep facilities open. Table 11-21 lists some of the explosives used by the Swiss.

*Table 11-21. Swiss Explosives*

| English | Swiss |
|---|---|
| Lead styphnate | Bleitrinitroresorzinat,<br>bleistyphnat |
| Nitroglycerin | Nitroglycerin |
| PETN | Pentaerythrit-tetranitrat,<br>nitropentaerythrit, pentrit |
| TNT | Trinitrotoluol, trotyl |

a. *Aldofit.* This is a permissible explosive that contains 81 percent ammonium nitrate, 17 percent TNT, and 2 percent woodmeal.

b. *Ammonpentrinit.* These are blasting explosives with the compositions shown in table 11-22.

*Table 11-22. Ammonpentrinits*

| Compositions | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| PETN (%) | 40.9 | 40.6 | 37.0 | 31.0 | 33.8 |
| Nitroglycerin (%) | 40.9 | 7.6 | 7.2 | 7.5 | 50.7 |
| Nitroglycol (%) | - | 2.6 | 2.0 | - | - |
| Collodion cotton (%) | 1.6 | - | 0.8 | 0.5 | 0.5 |
| Ammonium nitrate (%) | 16.6 | 47.5 | 48.0 | 59.0 | 15.0 |
| DNT (liquid) (%) | - | - | 5.0 | - | - |
| Vaseline (%) | - | 1.7 | - | 2.0 | - |

Compositions with collodion cotton are also called gelatinepentrinit. Aluminum can be incorporated to increase the blast effect of the explosives.

c. *Amolit.* This is the trade name of a free flowing bulk packaged ANFO.

d. *Detonierande Zundschnur (Krallzundschnur).* This is Swiss for detonating cord. One such cord contains a core of PETN or RDX in a gel of collodion cotton and a liquid explosive such as nitroglycerin or nitroglycol. This formulation is coated on several textile threads and covered with a fabric coating.

e. *Gelatine - Cheddit.* This is a plastic chlorate explosive which contains 79 percent sodium chlorate, 5 percent of a liquid mixture of castor oil that coats the sodium chlorate, 2 percent liquid DNT, and 14 percent TNT that has been preheated to 40°C. Some collodion cotton may also be incorporated into the mixture.

f. *Gelatine - Penthrinits.* These are plastic, nonexudable, explosive blends of PETN and nitroglycerin and other ingredients. If the amount of PETN in the formulation is below 60 percent, 6 to 7 percent collodion cotton is added to improve plasticity. Compositions of some of the gelatine-penthrinit and penthrinit are given in table 11-23.

g. *Hexal.* This is an antiaircraft ammunition filler that contains RDX and aluminum. The aluminum is coated with a water insoluble wax to prevent water-aluminum reactions that release hydrogen.

h. *Hexonite.* These are plastic explosives. One formulation consists of from 20 to 50 percent RDX and 80 to 50 percent nitroglycerin. Another formulation consists of 50 percent RDX, 46 percent nitroglycerin, and 4 percent collodion cotton.

i. *Matter Explosives.* These explosives are named after their inventor O. Matter. One explosive is a gelatin dynamite that consists of tar distillates mixed with inorganic oxidizers such as nitrates, chlorates or perchlorates. Another formulation uses water soluble chlorinated hydrocarbons such as chloronaphthalene as a fuel with a thickening agent.

j. *Nitrogelatinedynamit.* These are the gelatin dynamites that contain 20 to 25 percent nitroglycerin gelatinized with collodion cotton, ammonium nitrate, and a liquid aromatic nitrocompound serving as a sensitizer. The nitroglycerin may be a 4:1 mixture of nitroglycerin and an antifreeze such as nitroglycol. The liquid aromatic nitrocompound may be drip oil which is a byproduct of TNT manufacture. Some explosives which belong to the class sicherheitsdynamite (safe to handle and transport) include aldorfit, gamsit, and telsit.

*Table 11-23. Penthrinits*

| Composition and properties | Penthrinits | | | | | | Gelatine penthrinits | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 1 | 2 | 3 | 4 |
| PETN (%) | 80 | 85 | 70 | 50 | 40 | 80 | 50 | 59.0 | 15.5 | 50 |
| Nitroglycerin (%) | 20 | 15 | 30 | 50 | 60 | 15 | 46 | 24.7 | 77.5 | 46 |
| Nitroglycol (%) | - | - | - | - | - | 5 | - | - | - | - |
| Collodion cotton (%) | - | - | - | - | - | - | 4 | 0.6 | 7.0 | 4 |
| $NH_4ClO_4$ (%) | - | - | - | - | - | - | - | 15.7 | - | - |
| Al (added) (%) | - | - | - | - | - | - | - | - | - | 30 |

k. *Nizol.* This is an explosive that contains meta dinitrobenzene made more sensitive to initiation by the addition of 30 percent PETN. The mixture is castable because of meta dinitrobenzene's low melting point, 80°C.

l. *Pentostit.* This is the trade name for a military explosive in which PETN is desensitized with pentaerythritol tetrastearate.

m. *Pentro.* This is pentolite, which is also called pentryl.

n. *Plastolit.* This is a safe to handle plastic explosive that contains 57 percent sodium nitrate, 15 percent nitroglycerin, 4 percent nitroglycol, 1.3 percent collodion cotton, 13 percent liquid DNT, 9.6 percent woodmeal, and 0.1 percent sodium bicarbonate.

o. *Totalit.* This is a military explosive used as a bursting charge that contains 95.5 percent ammonium nitrate and 4.5 percent paraffin wax.

p. *Tramex.* This is the trade name for a powdered nitroglycerin sensitized explosive.

# CHAPTER 12
# SAFE HANDLING, HAZARD CLASSIFICATION, AND TOXICITY OF ENERGETIC MATERIALS

**12-1. General.** This section contains general information about safe handling, hazard classification, and toxicity of military explosives. All tables indicating quantity distance separations, minimum distances, etc., have been removed from this manual. Applicable information may be found in DoD 6055.9-STD, Ammunition and Explosives Safety Standards.

**12-2. Personnel and Materials Limits.**

a. The cardinal principle to be observed in any location or operation involving explosives, ammunition, severe fire hazards, or toxic materials is to limit the exposure of a minimum number of personnel, for a minimum time, to a minimum amount of the hazardous material consistent with safe and efficient operations. All operations shall be scrutinized to devise methods for reducing the number of people exposed, the time of exposure, or the quantity of material subject to a single incident. Determination of personnel limits requires that first, jobs not necessary to a particular hazardous operation not be accomplished there; second, unnecessary personnel are not permitted to visit the location; and third, too many consecutive operations not be permitted in the same room or building without adequate dividing walls, fire walls, or operational shields, depending upon the nature of the hazard. Personnel limits must allow for necessary supervision and transients. Key employees should be appointed as monitors to assist in enforcing the established limits.

b. Determination of limits for hazardous materials requires a careful analysis of all facts including operation timing, transportation methods, size of the items, and the chemical and physical characteristics of the material. Stricter limits are required for the more sensitive or hazardous materials. Limits should be established for each operation rather than on an overall basis so that each worker may be charged with the responsibility of not exceeding the established limit. Limits need not be expressed in units of weight or in the number of items as such. They may be given in terms of trays, boxes, racks or any other unit which may be more easily observed and controlled. Explosive limits shall not be established on the basis of the maximum quantity of explosives allowable as defined by the existing quantity-distance separation to nearby exposures when lesser quantities of explosives will suffice for the operations. The responsibility for determination of personnel and hazardous material limits rests with the local commanding officer.

c. All buildings, cubicles, cells, rooms, and service magazines containing hazardous materials shall have posted in a conspicuous place a placard stating the maximum number of workers and transients permitted in the room at any one time. In addition, other placards shall be posted to set forth important local regulations as needed. Personnel and materials limits and the placard must be kept current. The supervisor, foreman, or worker-in-charge shall prevent accumulations of excess materials or excess personnel. Any accumulated excess materials, when found, shall be removed immediately. Likewise, proper steps shall be taken to have excess personnel, when found, leave the premises. The personnel and quantity limits for building or process subdivisions (including sumps, wet scrubber buildings and other facilities that may contain only trace amounts of explosives) shall be recorded on a plant layout and maintained on file. Personnel limits need not be posted in storage magazines, magazine areas, and transfer points. Material limits need only be posted in storage magazines for which the limit is not the same as that for other magazines in the block or when the limit would not be readily apparent due to some unusual circumstance.

d. Prior to starting any operation involving ammunition explosives, or other hazardous operation, adequate standing operating procedures shall be developed and then approved by the Commanding Officer of the establishment or by a qualified member of his staff who has been delegated the responsibility for review of and authority for approval of standing operating procedures. (Preparation of standing operating procedures for ammunition operations shall be in accordance with DARCOM-R 385-1.) Controlled tests may be necessary in order to establish standing operating procedures for certain operations. Standing operating procedures shall include, as a minimum, such items as safety requirements, personal protective clothing and equipment, personnel and explosives or material limits, equipment designation, and location and sequence of operations. No deviation from this procedure shall be permitted without the approval of the Commanding Officer or his designated representative.

e. All personnel involved in these operations shall become cognizant of their respective duties. Supervisors shall be responsible for assuring this is accomplished.

f. Applicable portions of the approved standing operating procedures shall be conspicuously posted convenient to all stations involved in the operation for the guidance of all personnel. Supervisory personnel shall maintain copies of the overall standing operating procedure and be responsible for the enforcement of its provisions.

g. Action to be taken in the event of electrical storms, utilities or mechanical failures and the like occurring during the manufacturing, handling, or processing of explosives and other hazardous materials shall be set forth in standing operating procedures required by paragraph a. above or shall be set forth in separate standing operating procedures prepared specifically for such purposes. The emergency action thus prescribed shall conform with paragraphs 12-6a, 12-6b, and 12-2d, e and f, where applicable.

## 12-3. Storage in Operating Buildings.

a. Hazardous materials, including explosive and pyrotechnic materials, shall not be stored, except as stated below, within an operating building except for the minimum quantities necessary to maintain individual operations. Supplies exceeding approximately a four-hour work requirement shall be kept in a service storage building. In the case of explosive materials, the service storage building (service magazine) shall be located at appropriate intraline distance from the operating building, based on the quantity of explosives in the service storage building. If required by operational necessity, ammunition and explosives which are part of the work in process within the building may be stored during nonoperational hours in operating buildings providing the following requirements are strictly observed:

(1) Explosive limits are not exceeded.

(2) Compatibility requirements are met.

(3) Containers of bulk explosives or propellants are properly secured and covered.

(4) Processing equipment, such as powder hoppers and pipelines, is empty.

(5) Building is equipped with an automatic sprinkler system. (For new operations, this provision is mandatory. For existing operations, a local waiver is required if deviation from this provision is desired.)

b. The operating buildings used for overnight storage of ammunition and explosives, as provided for in paragraph a. above, shall be specifically included in the security patrol schedule of the installation. Guards shall check these buildings during their patrol and the buildings shall receive such additional inspections during nonworking hours as are considered necessary by the local commander commensurate with the added explosives storage risk involved. In addition, the fire department shall be specifically advised of buildings which will contain explosives and such buildings shall have appropriate fire symbols properly displayed. If the operation in a building is to be inactive for a period in excess of a normal weekend or holiday period (not to exceed four days) then every effort must be made to process all hazardous materials through that particular facility prior to shutting down. If this is not possible, no new material will be introduced into the process and as much of the in process material as possible will be completed and transferred to an approved storage area prior to shut down. The additional precautions in paragraph a. above will then apply, and the installation commander must give written permission for this extended storage.

## 12-4. Housekeeping in Hazardous Areas.

a. Structures containing explosives shall be kept clean and orderly.

b. In explosives areas, waste materials such as oily rags, combustible and explosive scrap, and paper shall be kept separate from each other. Such waste should be placed in approved, marked containers for each, preferably located outside the buildings. Containers for scrap black powder, scrap initiating explosives, scrap explosives of similar sensitivity, and rags contaminated with these explosives must be provided with covers and contain enough water (No. 10 mineral oil or fuel oil for certain pyrotechnic, tracer, flare, and similar mixtures) to cover the scrap or rags. Where water is used in containers for scrap pyrotechnic, tracer, flare, and similar mixtures, the possibility that dangerous gases may be evolved must be recognized. In order to minimize the hazards from such gases, scrap should be introduced in a manner to provide for immediate immersion. Combustible or explosive scrap shall not be left in buildings when unoccupied.

c. Exudate from ammunition shall be removed by use of approved solvents such as acetone. Unpacked ammunition, loose explosives, or those not in process, and combustible materials shall not be permitted to accumulate and must be placed in designated receptacles or in designated storage space.

d. Explosives, explosives dusts, and other hazardous materials shall not be allowed to accumulate on structural members, radiators, heating coils, steam, gas, air, water supply pipes, or electrical fixtures.

e. Spillage of explosives and other hazardous materials shall be prevented so far as practicable by proper design of equipment, training of employees, provision of catch pans, etc. For example, hoppers shall be large enough to comfortably accommodate the size of charges used. A painted stripe on the inside of the hopper will serve as a reminder of the proper filling height. Catch pans or splash pans shall be provided beneath drawoff pipes and TNT flakers, around transfer piping, beneath powder bags on small arms ammunition charging machines, etc. Spillage must be removed promptly.

f. A regular program of cleaning shall be carried on as frequently as local conditions require for maintaining safe conditions. General cleaning should not be conducted while hazardous operations are being performed. Explosives and ammunition should be removed from the building prior to general cleaning operations, when practicable.

g. Hot water or steam should be used wherever practicable for cleaning floors in buildings containing explosives. Sweeping compounds which are nonabrasive and compatible with the explosives involved may be used where the use of steam or hot water is not practicable. Such compounds may be combustible but must not be volatile (closed cup flash point must not be less than 111°C [230°F ]). Sweeping compounds containing wax shall not be used on conductive flooring. Where nitrated organic explosives are involved which may form sensitive explosive compounds with caustic alkalies, the use of cleaning agents containing caustic alkalies is prohibited.

h. Wire brushes may be used in cleaning explosives processing equipment only when other methods of cleaning are ineffective. If wire brushes are used, thorough inspection should be made after cleaning to ensure that wire bristles do not remain in the equipment. Where practicable, nonferrous wire brushes should be used. This applies also to cleaning magnesium ingot molds and molds for any other metal which may be used as an explosive constituent. Use of fiber brushes in place of hair brushes is recommended to reduce generation of static.

i. The working supply of packing materials, such as excelsior and shredded paper, should not exceed the capacity of bins or boxes provided for the purpose. These bins should be built of metal-lined wood or noncombustible material and have an automatic or self-closing cover.

## 12-5. Safety Hand Tools.

a. Safety hand tools are constructed of wood or other nonsparking or spark resistant materials such as bronze, lead, beryllium alloys, and "K" Monel metal which, under normal conditions of use, will not produce sparks. Properly maintained, nonferrous hand tools shall be used for work in locations which contain exposed explosives or hazardous concentrations of flammable dusts, gases, or vapors. Hand tools or other implements used in the vicinity of hazardous materials must be handled carefully and kept clean. All tools should be checked in before beginning work and checked out at its completion.

b. Metal hand tools determined to be spark resistant by tests conducted in accordance with paragraph 4.6.3, MIL-W-19928A, dated 15 February 1967, may also be used as in a. above.

c. If the use of ferrous metal hand tools, not in accordance with b. above, is required because of strength characteristics, the immediate area should be free from exposed explosives and other highly combustible materials except in specific operations approved by the Commander, AMC.

## 12-6. Emergency Shutdown.

a. When buildings containing explosives are evacuated during periods of electrical storms, operations requiring attention at all times shall continue to be manned by the minimum number of personnel consistent with safety requirements. When the process has been brought to a condition in which it is considered safe to leave and when it would not produce rejected components requiring reworking with accompanying hazards, the building shall be completely evacuated. Every effort shall be made to anticipate shutdown and, during such critical periods, any explosives process requiring complete attention should not be started unless absolutely necessary. Because of the possibility of power failure, alternate emergency power equipment should be manned during such times.

b. Whenever an electrical storm approaches the installation, personnel shall be evacuated from locations at which there is a hazard from explosives which could be initiated by lightning. Such locations include:

(1) Operating buildings or facilities without approved lightning protection systems which contain explosives or explosive-loaded ammunition and locations within intraline distance of such facilities.

(2) Buildings containing explosive dust or vapors, whether or not equipped with approved lightning protection systems, and locations within intraline distance of such buildings.

(3) Magazines, open storage sites, or loading docks which are not equipped with approved lightning protection systems and vehicles and railroad cars on ungrounded tracks containing explosives and explosive-loaded ammunition, and locations within magazine distance of such structures, sites, vehicles, or cars.

(4) Locations (with or without lightning protection) where operations involving electro-explosive devices are being performed.

c. When personnel are to be evacuated from explosives operations, the operations should be shut down in accordance with this paragraph, windows and doors closed, and electric switches thrown to the off position.

d. A responsible and qualified person should be empowered with final decision as to the necessity for evacuation. Where operations are of such nature as to require advance warning from shutdown, a net of volunteer observers or an electronic static detector (lightning detection system) may be utilized.

e. In an operating line, evacuated personnel shall be retired to approved suitable protective shelters located at intraline distance from operating buildings or other hazardous locations. In a magazine area, evacuated personnel should be retired to such approved shelters at magazine distance (column 9 of table 12-1) from magazine or other hazardous locations, or to empty earth covered magazines. When such shelters are not available, personnel shall be withdrawn to places at inhabited building distances from the hazardous locations.

f. Personnel in direct charge of railroad trains and motor trucks containing explosives should, when possible, move the equipment to locations of comparative safety before retiring to designated bombproofs or change houses.

## 12-7. Explosives Recovery and Reuse.

a. All loose explosives recovered as sweepings from floors of operating buildings shall be destroyed. Explosives which are recovered from other than ammunition breakdown operations or from operation equipment shall be thoroughly inspected by operating supervisors and reused, screened, reprocessed or destroyed as the situation warrants. Explosives which are contaminated with dirt, dust, grit or metallic objects must be reprocessed to remove all foreign matter before they can be reused, otherwise they must be destroyed. Melt-loaded explosives known to be contaminated shall not be reused unless it is practicable to remelt and draw off clean material.

b. Explosives salvaged from loaded ammunition shall be stored in buildings by themselves.

## 12-8. Maintenance and Repairs to Equipment and Buildings.

a. Before being placed into routine operations, all new or newly repaired process equipment for use in hazardous operations must be examined and actually tested by a specifically designated competent person to assure that it is in safe working condition. If machinery or equipment does not appaar to function properly, operations shall be discontinued if the immediate stoppage does not create a new hazard.

b. Before repairs are permitted on any equipment that has been exposed to explosives, a tag signed by operating supervision shall be placed on the equipment certifying that all explosives have been removed (in accordance with TB 700-4). If it has been impossible to clean some part, it shall be noted on the tag together with adequate instruction to maintenance personnel concerning safe methods of handling.

c. Major repairs or changes shall not be undertaken in a hazardous building during regular operations without removal of the hazard material and without the knowledge of the employee in immediate charge of the building.

d. Only competent persons shall be permitted to affect repairs. Before repairs are started in an explosives location, the immediate area shall be inspected for the presence of explosives and dust, and all such material shall be removed from equipment, crevices, beneath floors, within walls and pipes and under fittings where explosives may be ignited. The entire area should preferably be wet or should be washed down thoroughly.

e. When machines and equipment have been oiled, repaired or adjusted, all tools used for the repairs shall be removed. All operators must inspect their equipment to be assured of its safe operating condition before resuming work.

f. Certain operations require that nonsparking tools be used. If the maintenance department, in repairing a machine where nonsparking items are normally required, must use steel tools, not only shall the machine and surrounding area be cleaned, as indicated in subparagraph b, c, and d above, but all explosives operations in the immediate vicinity shall be discontinued to guard against accidental ignition of materials by flying sparks. Where steel tools are used in such maintenance operations all contact surfaces should be oiled to reduce likelihood of sparks.

g. Maintenance men entering buildings in which conductive shoes are required shall wear conductive shoes or conductive overshoes with ankle straps. Since electricians shall not be allowed to work on live electrical equipment while wearing conductive shoes, all exposed explosives and other static sensitive hazardous material must be removed before electrical work is done.

h. Safe practices elsewhere specified in this regulation shall apply to maintenance employees as well as to those engaged in actual production.

i. Maintenance and tool rooms in an operating line shall be separated from explosives by intraline distance. When intraline distance separations cannot be provided, protection equivalent to that afforded by a substantial dividing wall must be provided.

### 12-9. Electrical Testing of Ammunition and Ammunition Components.

a. *Type of Test Equipment.* Electrical (including electronics) test equipment shall utilize the weakest possible power source. Battery-powered equipment should be used in lieu of that with a 110-volt source. The power source shall be incapable of initiating the explosive item under test. Where greater power must be used, positive means must be provided to prevent delivery of power to the explosive item in quantities sufficient to initiate the item. The possibility of human error on the part of operators and other personnel must be recognized and safeguards provided.

b. *Layout of Test Equipment.* Test equipment should not be placed in hazardous atmospheres unless absolutely necessary. When the test equipment or parts thereof must be placed in hazardous atmospheres, its suitability must be attested to by Underwriters' Laboratories approval, or specific approval must be obtained from the Commander, AMC. Special attention must be given to equipment containing vacuum tubes because of inherent ventilation requirements. Unless the test equipment, under any circumstances, is incapable of initiating the item being tested, operational shields are required for protection of personnel. The most reliable means for attaining and retaining this initiation incapability is to protect the test equipment, including leads, from electromagnetic (induction and radiation fields) and electrostatic energy and to provide the test equipment with a weak power source.

c. *Use of Test Equipment.* Test equipment shall be used only in the manner and for the purpose for which approval is granted. The equipment shall be maintained in good working order by qualified personnel. Operator adjustments must be limited to those required by design of the equipment.

### 2-10. Heat Conditioning of Explosives and Ammunition.

a. All ovens, conditioning chambers, dry houses, and similar devices and facilities shall be provided with dual independent automatic heat controls. For devices or facilities heated by steam only, the requirements for dual automatic heat controls shall be satisfied if the steam pressure is controlled by a reducing valve with a maximum pressure of 0.35 kilograms per square centimeter (5 psi) unless otherwise authorized on the main building steam supply and a thermostat on the device or in the facility.

b. Heat conditioning devices shall be constructed to effectively vent overpressure resulting from an internal explosion. Blow-out panels, doors, and other venting apparatus should be restrained by barriers or catching devices to prevent excessive displacement in the event of an accidental explosion.

c. Heat conditioning devices shall be effectively vented to permit the escape of dangerous gases that may evolve during the conditioning process.

d. Steam shall be used as the heating media for the conditioning devices wherever practicable. Whenever electric heating elements must be used, the elements shall be located where there is no possibility of contact with explosives or flammable materials.

e. If the heat conditioning device utilizes a fan for circulation of air, the blades shall be of nonsparking material and, where possible, the electric motor shall be installed on the exterior of the device. The air used for heating shall not be recirculated if the heating surfaces exceed a temperature of 110°C (228°F) or if the air contains materials which may collect on the heating coils.

f. Electrical equipment and fixtures in or on a heat conditioning device used for explosives or flammable material shall be approved for operation in the appropriate hazardous atmospheres.

g. The interior of heat conditioning devices should be free of crevices and openings and other difficult to clean protuberances where dust or flammable material may lodge.

h. All noncurrent carrying metal parts of a heat conditioning device shall be electrically interconnected and grounded.

i. Heat conditioning devices should be installed in an isolated location and arranged to afford maximum protection to personnel from the effects of an incident. Operational shields and other personnel protection measures should be utilized when warranted.

j. Heat conditioning devices should be separated from each other by distance or protective construction to prevent an explosive incident in one device from propagating to adjacent devices. No hazardous materials shall be stored or located in a room or cubicle containing a heat conditioning device unless it can be shown that an incident in the conditioning device will not involve the other materials.

k. Heat conditioning device operating procedures shall include the following conditions:

(1) The explosive materials in the device shall be limited to the type and quantity authorized for the specific device.

(2) The critical parameters of explosives compositions shall be known before processing in a heat conditioning device. Care will be exercised to ensure that the conditioning device does not exceed limits established for the hazardous composition being conditioned.

(3) Heat conditioning device temperatures will be checked during operation at specified intervals. The checks should be conducted at more frequent intervals during periods of conditioning.

(4) The conditioning devices, ducts, vacuum lines and other parts of the equipment subject to contamination by hazardous materials, shall be cleaned prior to introducing a different item or composition for conditioning.

## 12-11. Quantity-Distance for Explosives and Solid Propellants.

a. *General.*

(1) Ammunition and explosives are classified on the basis of their reactions to specified initiating influences (TB 700-2). Where circumstances exist at an installation that may modify the normal behavior of the material, the Safety Office, HQ, AMC, (AMCSF) may reclassify that material for the specific instance upon request of the installation commander. The grouping of explosives and ammunition into the several hazard classes does not necessarily mean that the different items in a class may be stored together. Items which may be stored together in one location are identified in paragraph 12-13. The maximum amount of explosives permitted at any location is determined by the prevailing distance from that location to other exposures and the applicable quantity-distance table in this chapter. Greater distances than those shown in the tables should be used wherever practicable.

(2) When an appropriate degree of protection can be provided either by hardening a target building or construction of a source building to suppress explosion effects, these factors may be taken into account and the distance required by the standard quantity-distance tables may be reduced. Site and general construction plans for ammunition and explosives facilities which propose reduced distances based upon protective construction must be accompanied by the rationale or test results which justify the reduction when they are submitted for approval.

(3) Explosive limits must never exceed the minimum required for efficient, safe operation. Operations and personnel shall be arranged (consistent with efficient, safe operation) to constitute the smallest exposure to any one explosion or fire hazard (para 12-2).

b. *Inhabited Building Distance.*

(1) Inhabited building distance is the minimum permissible distance between an inhabited building and an ammunition or explosives location. Inhabited building distances are also used between explosives locations and administrative areas, between adjacent operating lines, and between explosives locations and other exposures within an establishment. Except as otherwise specifically prescribed herein, inhabited building distances shall also be provided between ammunition and explosives locations and the boundaries of AMC establishments.

(2) Inhabited building distances (based on damage from blast or shock effects) provide a high degree of protection to frame or masonry buildings from structural damage, to their occupants from death or serious injury, and reasonable protection to superficial parts such as window frames, doors, porches, and chimneys. They do not provide protection against glass breakage, or injury to personnel from glass breakage or hazardous fragments.

(3) In order to protect personnel in the open from the potential fragment hazard created by an accidental explosion of Class 1.1 material, a minimum inhabited building distance or fragment distance has been established. See paragraph 12-11f for a detailed explanation.

(4) Inhabited building distances for ammunition and explosives which are not mass-detonating are based on the most severe hazard involved.

c. *Public Traffic Route Distance.*

(1) This distance is the minimum permitted between a public traffic route and an explosives hazard. The distance at which motor vehicles and rail cars are considered safe from the blast effects of explosions has been fixed at 60 percent of the inhabited building distance. The use of lesser distances is based on the smaller height and area of motor vehicles and rail cars exposed to blast, the greater resistance of these vehicles to blast as compared to buildings, and the fact that while a building is stationary and subject to risk constantly, the presence of a motor vehicle or train is only temporary. For other than Class 1.1 materials, inhabited building distances are required to public traffic routes.

(2) For public traffic routes, the fragment distance minimum for Classes 1.1 and 1.3 (para 12-11f) may be reduced to 60 percent of the minimum fragment distance which is appropriate for the explosion source under consideration. However, in no case may a public traffic route distance be used that is less than that required by the applicable Class 1.1 or 1.3 quantity-distance table.

d. *Intraline Distance.*

(1) This distance is the minimum permitted (except as indicated in e. below) between any two buildings within one operating line. Intraline distances are also used for separating certain specified areas, buildings, and locations even though actual line operations are not involved. All unpackaged ammunition and explosives except Classes 1.3 and 1.4 in such a line are considered Class 1.1. Intraline distance is expected to protect buildings from propagation of explosions due to blast effects but not against the possibility of propagation due to fragments. Buildings separated by intraline distances will probably suffer substantial structural damage.

(2) A service type magazine shall be located at intraline distance, based on the quantity of explosives within the magazine, from the nearest operating building of the line of which it forms a part. Service type magazines shall be separated from each other by intraline distances.

(3) Separate facilities (excluding service magazines) servicing a single explosives operating building may be located at less than intraline distances but not less than 30.5 meters (100 feet) from the operating building, but must be at least intraline distance from other explosive buildings. Such facilities include low pressure heating boilers and paint storage buildings. (Low pressure heating boilers may be located in an operating building.)

e. *Magazine Distance.* This distance is the minimum permitted between any two storage magazines. Distance required is determined by the type(s) of magazine and also the type and the quantity of ammunition or explosives stored therein. It is expected to prevent propagation of explosion from one magazine to another from blast and provides a reasonable degree of protection against propagation of explosion due to fragments. It does not, except possibly for earth covered magazines, protect the magazines from severe structural damage. Magazine distance is also used for certain quantity-distance computations where other than two magazines are involved (para 12-11j).

f. *Fragment Distance.*

(1) The fragment distance for a particular ammunition/explosives item is based on the range to which a hazardous fragment density may be created by an explosion of the particular item involved. A hazardous fragment is one having an impact energy of at least 8.02 kilogram-meters (58 ft-lbs) and a hazardous fragment density is constituted by at least one hazardous fragment impacting in an area of 55.7 square meters (600 square feet) or less. Fragment distances do not indicate the maximum range to which fragments may be projected.

(2) Fragment distance, applicable to Class 1.1 through 1.3, is indicated by a numerical figure in parentheses placed to the left of the division designators 1.1 through 1.3, such as (18) 1.1, (08) 1.2, and (06) 1.3 when required. This number is used to indicate the fragment distance in hundreds of feet.

(3) A minimum fragment distance number shall be used for all items in Class 1.2. The fragment distance indicated by the minimum distance number corresponds to the inhabited building distance for the various categories within Class 1.2.

(4) For items in Class 1.1 and 1.3, a minimum distance number will be used where separation distances greater than specified for inhabited buildings by the applicable explosives quantity-distance table are necessary for specific hazards (projection of debris, fragments, or firebrands). These minimum fragment distances are to protect personnel in the open and will be applied, except as described in subparagraph (e), to installation boundaries, administrative and housing areas, athletic fields and other recreation areas. They need not be applied to separations between and within explosive operating lines, nor to relatively static inert storage areas including parking areas for dead storage of military vehicles.

(a) If a minimum distance number is not shown for ammunition items of Class 1.1 from which primary fragments would constitute a hazard, the minimum distance, or that required by the quantity-distance table, will be used, whichever is greater.

(b) For bulk high explosives, propellant ingredients, pyrotechnics, other in-process materials, and ammunition items of Class 1.1 from which primary fragments would not constitute a hazard, the minimum distance specified in DoD 6055.9-STD will be used unless it can be shown that debris from structural elements of buildings or process equipment will not present a hazard beyond the specified distances. for the quantity involved.

(c) Rationale for using fragment distances less than the requirements specified in DoD 6055.9-STD for Class 1.1 shall be included in all site plans and safety reviews. Where there are no existing test data to substantiate lesser distances, analogies to similar items or facilities, fragment dispersions from previous accidents, or analytical modeling of the debris spread, should be investigated.

(d) For public traffic routes which are not possible sites for future targets, and for other exposures permitted at public traffic route distances from potential explosion sites, fragment and firebrand distance minima for divisions 1.1 and 1.3 may be reduced to 60 percent of distance minima indicated in subparagraphs (1) and (2).

(e) Examples where minimum fragment and firebrand distances for divisions 1.1 and 1.3 need not be applied are:

1 Recreation or training facilities if these facilities are for the exclusive use of personnel assigned to the potential explosion site.

2 Related and support AMC controlled functions for which intermagazine and intraline distances are the usual protection levels.

3 Between potential explosion sites and relatively static inert storage areas, including parking areas for dead storage of military aircraft or vehicles.

4 Between facilities in an operation line; between operating lines; and between operating lines and storage locations which are normally separated by inhabited building distances to protect workers and insure against interruption of production.

g. *Quantity-Distance Determinations*.

(1) The location of explosives facilities with respect to each other and to other exposures shall be based on the total quantity of explosives in the individual facilities. When the total quantity is so subdivided that an incident involving any of the subdivisions will not produce simultaneous initiation of others, the net weight of the mass-detonating explosives in the largest subdivision shall apply.

(2) The quantity of explosives to be permitted in each of two or more facilities for which the same quantity-distance table applies shall be determined by considering each as a potential explosion site and limiting the quantity of explosives to be permitted in the facility to the least amount allowed for the distance(s) separating the facilities. Quantities in the facilities shall be further limited by prevailing distances to the installation boundary, inhabited buildings, public traffic routes, etc.

(3) The quantity of explosives permitted in each of two or more facilities for which different quantity-distance tables apply shall be determined as follows:

(a) Consider each facility, in turn, as a potential explosion site.

(b) Refer to the table applicable to each target facility.

(c) Determine the quantity of explosives permitted for the distance between explosion site and each target.

(d) Record the quantity in each instance as that to be permitted in the site facility and the least quantity recorded shall be the maximum permitted.

(4) Measurement of distances for determining the maximum allowable quantity of explosives shall be made from the nearest outside point, or wall of the room, cubicle, or building proper involved which contains the explosives to the nearest outside point, or wall of the other location under consideration. Separation distances are measured along a straight line.

(5) Where the total quantity of explosives in a magazine or operating building is so separated into piles or stacks that the possibility of simultaneous detonation is limited to the quantity in any one pile or stack, distances shall be measured from the outside of the wall nearest the controlling explosives pile or stack to the nearest outside wall of another structure. If the separation to prevent simultaneous detonation is provided by one or more substantial dividing walls, distances may be measured from these walls, if appropriate, instead of from the outside walls of the building.

(6) Where rail cars, motor vehicles, or any other transport vehicles containing explosives and ammunition are so located with respect to an explosives facility that simultaneous detonation can occur, the total quantity of explosives in the facility and the transportation vehicle must be considered as a unit for quantity-distance purposes. Distances must be measured from the outside wall of the facility or the transport vehicle, whichever is nearest the target. When explosives in transport vehicles outside of a multi-bay operating building combined with explosives in the adjacent exposed bay(s) exceeds the amount for which the walls are designed to be effective in preventing detonation propagation, quantity-distances must be based on the total quantity of explosives susceptible to simultaneous detonation. Distances must be measured from the transport vehicle or wall of the bay(s) involved nearest to the target.

(7) When items of different explosives hazard classes are stored together, quantity-distance requirements are determined as follows:

(a) The explosives weights for the individual classes are determined in accordance with paragraph 12-11h.

(b) Using the explosives weight so determined and referring to the quantity-distance tables applicable to the individual explosives hazard classes involved, the distance required for each class is established. The maximum distance so established is the minimum acceptable for the storage facility.

(8) Throughout these standards, net explosive weight (NEW) is used to calculate distance by means of formula of the type $D = KW^{1/3}$, where $D$ is the distance in feet, $K$ is a factor depending upon the risk assumed or permitted, and $W$ is the net explosive weight in pounds. When metric units are used, the symbol $Q$ denotes net explosive quantity in kilograms. In the formula $D = KQ^{1/3}$, the distance $D$ is expressed in meters. Thus the respective units of $K$ are ft/lb$^{1/3}$ and m/kg$^{1/3}$ in the two systems. The value of $K$ in English units is approximately 2.5 times its value in metric units. For example, if $D(m) = 6Q^{1/3}$, then $D(ft) = 15W^{1/3}$. Distance requirements determined by the formula with English units are sometimes expressed by the value of $K$, using the terminology $K9$, $K11$, $K18$, ... to mean $K = 9$, $K = 11$, $K = 18$, etc.

h. *Quantity of Explosives.* The explosives content of ammunition or components is shown on approved AMC drawings. If these are not available, the information desired should be requested from the Commander, AMC, ATTN: AMCSF. The total quantity of explosives in a magazine, operating building, or other explosives facility shall be the net weight of the explosives calculated upon the following basis. Such calculations are intended for use with the tables in these standards.

(1) Mass-detonating explosives. The net explosives weight (NEW).

(2) Non mass-detonating explosives.

(a) Propellants. The net propellant weight.

(b) Pyrotechnic items. The sum of the net weights of the pyrotechnic composition and the explosives involved.

(c) Bulk metal powders and pyrotechnic composition. The sum of the net weights of metal powders and pyrotechnic composition in containers.

(d) Other ammunition. The net weight of high explosives plus a suitable contribution, if any, from propellant, pyrotechnic components, or expelling charges.

(3) Combinations of mass-detonating and non mass-detonating ammunition and explosives (excluding class 1, division 4) shall be treated on the basis that all explosives are subject to mass-detonation and the total quantity used. In the event that the non mass-detonating items require a greater distance than the total explosives so computed, the greater distance is mandatory.

(4) Combinations of non mass-detonating ammunition and explosives of different Class 1 Divisions shall be treated as follows: The amount of each division will be separately computed according to the rules in b(1) through (4) above. The distance required for the total of (1), (2), and (3), or the distance required by (4), whichever is greater, will govern. The maximum quantities allowed will be the summation of the quantities in b(1) through (3) for those types of material and the summation of the quantities calculated under b(4) for the other types. The two totals are treated separately for determination of allowable quantities.

i. *Magazine Area Arrangement.*

(1) Ammunition and explosives storage areas shall be subdivided into blocks of storage facilities in accordance with the following:

(a) No limit to the number of magazines with earth cover on the top and at least three sides and with earth covered or reinforced concrete front walls. Revetted outdoor storage sites may be located between these magazines.

(b) Not more than 100 storage facilities of other types may be located in a single block.

(2) It is preferred that magazines with earth cover on the top and at least three sides and without door end barricades be oriented as follows:

(a) Unbarricaded door ends facing the same direction.

(b) Exterior faces of unbarricaded front walls of adjacent magazines all on one imaginary straight line.

(3) Storage blocks consisting of magazines with earth cover on the top and at least three sides and with earth covered or reinforced concrete front walls shall be separated from blocks consisting of magazines of other types by a distance of not less than 365.8 meters (1,200 feet).

(4) Storage blocks consisting of facilities of other than the earth covered type should be separated from each other by a minimum distance of 365.8 meters (1,200 feet) if storage therein is restricted to categories (04), (08), and (12) of Class 1.2 and Classes 1.3 and 1.4.

(5) Magazines within a storage block shall be separated from each other by distances not less than those prescribed in applicable quantity-distance tables in this section.

j. *Separation of and Within Areas.*

(1) Explosives and ammunition operating lines and storage areas shall be separated from each other, inert areas (warehouses, shops, administrative facilities, etc), and the installation boundary by appropriate inhabited building distance. Where adjacent lines are manufacturing the same explosive, they may be separated from each other by intraline distance.

(2) A building, group of buildings, or operation conducted in the open, when serving more than one explosive line or area, constitutes a special area and shall be separated from these lines or areas by inhabited building distance. A facility or activity that serves a single explosives line or area may be separated from the line or area by intraline distance; however, it must be separated from all other lines or areas by inhabited building distance. These general principles shall govern in all cases except:

(a) Facilities listed in (4)(a) and (4)(b) below.

(b) Normal maintenance operations may be performed in a magazine area when authorized by the Commander, AMC, or the installation commander. Normal maintenance of small arms ammunition may be performed in magazines containing small arms ammunition only.

(c) Ammunition workshops buildings shall be located at a minimum of inhabited building distance from magazines, depending on the material in the workshop building or magazine, whichever requires the greater distance.

(d) Where sufficient backup capacity is available such that the loss of a facility, building, or operation will not reduce the production capacity for all remaining lines, an existing facility serving more than one line may be located at intraline distance from one of these lines and inhabited building distance from the remaining lines.

(e) Sumps or catch basins containing less than 6.8 kilograms (15 pounds) of explosives in water or in a wetted (desensitized) state and wet scrubber facilities containing no more than trace amounts of explosives, serving a single facility, are exempt from QD requirements with respect to the facilities which they serve. The explosives limit of the building served by these facilities will include the maximum amount of explosives permitted in the sump/catch basin and scrubber facility, whichever is closer.

## 12-12. Hazard Classes and Class Divisions.

a. *General.*

(1) The hazard classification system is based upon the systems recommended for international use by the United Nations Organization (UNO). The system consists of nine classes for dangerous goods with ammunition and explosives included in UNO Class 1, Explosives. Ammunition without explosive components which contains toxic chemical agents in bulk are included in UNO Class 6, Poisonous (Toxic) and Infectious Substances.

(2) The new ammunition and explosives hazard classes are further subdivided into divisions based on the character and predominance of the associated hazards and of the potential for causing personnel casualties or property damage; not upon compatibility groupings or intended use. The list of items for each division contains examples of the type of product in that division, but does not enumerate all articles which may be included in the division.

(3) The separation of the ammunition and explosives hazard classes into the several divisions does not necessarily mean that the different items in a division may be stored together. Some items may appear in more than one division depending upon such factors or combinations thereof as the degree of confinement or separation, type of packaging, storage configuration, or state of assembly.

(4) The maximum amount of explosive or chemical agent permitted in any location is limited by the quantity-distance criteria of these standards. Explosives and chemical agent limits shall be established in amounts no greater than those consistent with safe and efficient operations.

(5) Class 1 is divided into four divisions which indicate the types of hazards expected:

| Hazard class and division designators | Hazards |
|---|---|
| 1.1 | Mass-detonating |
| 1.2 | Non mass-detonating fragment producing |
| 1.3 | Mass-fire |
| 1.4 | Moderate fire, no blast |

(6) A numerical figure is used to indicate the minimum separation distance for protection from debris, fragments, and firebrands. This number will be placed to the left of the division designators 1.1 through 1.3, such as (18) 1.1, (08) 1.2, and (06) 1.3. A minimum distance will be used for all items in division 1.2. For divisions 1.1 and 1.3, a minimum distance number will be used where the ranges of hazardous fragments and firebrands exceed the distances specified for inhabited buildings in the applicable quantity-distance table.

(7) Quantity-distance classes/divisions for ammunition and explosives items are listed in the most recent edition of the Joint Hazard Classification System.

b. *Class 1, Division 1 (Mass-Detonating).* These items shall be those for which practically instantaneous explosion or detonation of virtually the entire quantity may be expected.

c. *Class 1, Division 2 (Non Mass-Detonating, Fragment Producing).*

(1) Items in this division are those for which the principal hazards are fragment and blast, either individually or in combination, depending on such factors as storage configuration type of packing and quantity. The designated minimum distances which are specified are based on the limiting range of fragments for which protection by distance is to be provided and shall be used for inhabited building and public traffic route distances. Because fragment producing types can be grouped according to the range of fragments produced, four fragment distance categories are established to permit flexibility of storage.

(2) The fragment hazard from items within a specified minimum distance category varies with existing conditions, but is essentially the same for one as for many items or components. For these items the required separation distances are influenced heavily by packing, state of assembly, charge weight ratio, and caliber. Items in this division usually explode progressively when involved in a fire or otherwise initiated. Therefore, the distances prescribed shall not be lessened if the quantity to be sorted is less than the maximum quantity specified by the appropriate table.

(3) When items classified as Class 1 division 2 present a mass detonation hazard because of storage configuration or other reason, the fragment distance specified for categories (04) through (18) or the distance required for mass detonating explosives Class 1.1 based on the NEW, whichever is greater, will govern.

d. *Class 1, Division 3 (Mass Fire).*

(1) Items in this division are those which burn vigorously with little or no possibility of extinguishment in storage situations. Explosions normally will be confined to pressure ruptures of containers and will not produce propagating shock waves or damaging blast overpressure beyond the specified magazine distances in DoD 6055.9-STD. One severe hazard is the spread of fire which may result from tossing burning containers, materials, propellants, or other flaming debris. Toxic effects normally will not exist beyond the inhabited building distances specified for this division.

(2) This division includes items such as solid propellant compositions determined by card gap tests (TB 700-2) to have a detonation sensitivity value less than 70 cards. See table 12-1 for other items in this division.

Table 12-1. *Summary of Hazard Classification and Storage Compatibility Groupings*

| Item | Storage compatibility group | Hazard class |
|---|---|---|
| Aluminum powder (in original shipping container or equivalent) | L | 1.4 |
| Aluminum powder (not in original shipping container or equivalent) | L | 1.4 |
| Ammonium nitrate (in original shipping container or equivalent) | L | 1.4 |
| Ammonium nitrate (not in original shipping container or equivalent) exposed to fire hazards only or to detonation hazards at more than intraline distance | D | 1.3 |
| Ammonium nitrate (not in original shipping container or equivalent) exposed to detonation hazards at less than intraline distance | L | 1.1 |
| Ammonium perchlorate (particle size 15 microns or less) | D | 1.1 |
| Ammonium perchlorate (particle size over 15 microns) in original shipping containers or equivalent | L | 1.4 |
| Ammonium perchlorate (particle sizes over 15 microns) not in original shipping container or equivalent, exposed to fire hazards only or exposed to detonation hazards at more than intraline distance | D | 1.3 |
| Ammonium perchlorate (particle sizes over 15 microns) not in original shipping containers or equivalent, exposed to detonation hazards at less than intraline distances | D | 1.1 |
| Ammonium picrate (Explosive D) | D | 1.1 |
| Baratol | D | 1.1 |
| Benite | C | 1.1 |
| Black powder, bulk | D | 1.1 |
| Boron potassium nitrate | C | 1.1 |
| Cartridge cases, primed (without propellant) | B | 1.4 |

*Table 12-1. Summary of Hazard Classification and Storage Compatibility Groupings (Cont)*

| Item | Storage compatibility group | Hazard class |
|---|---|---|
| Chlorates (not in original shipping container or equivalent) | L | 1.3 |
| Compositions A, A-2, A-3, and A-4 | D | 1.1 |
| Compositions B and B-3 | D | 1.1 |
| Compositions C, C-2, C-3, and C-4 | D | 1.1 |
| Cyclonite (RDX), dry | D | 1.1 |
| Cyclonite (RDX), wet | D | 1.1 |
| Cyclotol | D | 1.1 |
| DNT (exposed to detonation hazard at less than intraline distance) | D | 1.1 |
| DNT (exposed to detonation hazard at more than intraline distance) | D | 1.3 |
| Ednatol | D | 1.1 |
| Fuel (solid), emergency power unit | C | 1.1 |
| HMX, dry | D | 1.1 |
| HMX, wet | D | 1.1 |
| Lead azide, wet | A | 1.1 |
| Lead styphnate, wet | A | 1.1 |
| Magnesium powder (in original shipping container or equivalent) | L | 1.4 |
| Magnesium powder (not in original shipping container or equivalent) | L | 1.3 |
| Mercury fulminate, wet | A | 1.1 |
| Nitrates (inorganic) except ammonium nitrate (in original shipping container or equivalent) | L | 1.4 |
| Nitrocellulose, wet, containing 8 to 30 percent water, that is exposed to detonation hazards at less than intraline distances | D | 1.1 |

*Table 12-1. Summary of Hazard Classification and Storage Compatibility Groupings (Cont)*

| Item | Storage compatibility group | Hazard class |
|---|---|---|
| Nitrocellulose, wet, containing 8 to 30 percent water that is exposed only to such fire hazard materials as other class 1.3 items | D | 1.3 |
| Nitroguanidine | D | 1.1 |
| Nitrostarch | D | 1.1 |
| Octol | D | 1.1 |
| PBX | D | 1.1 |
| Pentolite | D | 1.1 |
| Perchlorates[1] (in original shipping container or equivalent) | D | 1.4 |
| Perchlorates[1] (not in original shipping container or equivalent) | D | 1.3 |
| Peroxides, solid (in original shipping container or equivalent) | L | 1.4 |
| Peroxides, solid (not in original shipping container or equivalent) | L | 1.3 |
| PETN, wet | D | 1.1 |
| PETN, dry | A | 1.1 |
| Picratol | D | 1.1 |
| Picric acid | D | 1.1 |
| Propellant, single-base, multiperforated, with web thickness greater than .48 millimeters (0.019 inch) (excluding single-base propellant containing 98 percent or more nitrocellulose | C | 1.3 |
| Propellant, single-base, containing 98 percent or more nitrocellulose | C | 1.1 |
| Propellant, single-base, single perforated, rifle | C | 1.3 |
| Propellant, single-base (FNH and NH compositions), single perforated, cannon, with web thickness not greater than 0.889 millimeter (0.035 inch) | C | 1.3[2] |

*Table 12-1. Summary of Hazard Classification and Storage Compatibility Groupings (Cont)*

| Item | Storage compatibility group | Hazard class |
|---|---|---|
| Propellant, single-base, low pressure, for pistols and shotguns, etc. | C | 1.3[2] |
| Propellant, double-base, containing not more than 20 percent nitroglycerin, with web thickness of 0.1905 millimeters (0.0075 inch) or greater | C | 1.3[2] |
| Propellant, double-base (for artillery ammunition) containing over 10 percent nitroglycerin | C | 1.1 |
| Propellant, double-base, with web thickness less than 0.1905 millimeters (0.0075 inch) regardless of nitroglycerin content | C | 1.1 |
| Propellant, multiperforated, cannon and rifle, with web thickness not greater than 0.4826 millimeters (0.019 inch). | C | 1.3[2] |
| Propellant, double-base and composite grains that have been determined to be non mass-detonating in tests conducted in accordance with TB 700-2. | C | 1.3 |
| Propellant, double-base and composite grains that have been determined to be mass detonating in tests conducted in accordance with TB 700-2. | C | 1.1 |
| Propellant grains, polysulfideperchlorate, containing not more than 74 percent oxidizer | C | 1.3 |
| RDX (cyclonite), dry | A | 1.1 |
| RDX (cyclonite), wet | D | 1.1 |
| Tetracene (wet) | A | 1.1 |
| Tetranitrocarbazole (TNC) | D | 1.1 |
| Tetryl | D | 1.1 |
| Tetrytol | D | 1.1 |
| Torpex | D | 1.1 |
| Tritonal | D | 1.1 |
| TNT | D | 1.1 |

*Table 12-1. Summary of Hazard Classification and Storage Compatibility Groupings (Cont)*

| Item | Storage compatibility group | Hazard class |
|---|---|---|
| Zirconium (types I and II, spec. FED 1665) in original shipping container or equivalent | | |
| Zirconium (types I and II, spec. FED 1665) not in original shipping container or equivalent | L | 1.3 |

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[1] Excluding ammonium perchlorate.

[2] Class 1.3 applies when stored in metal-lined wooden boxes; when stored in all metal containers not specifically designed for quick release of pressure, Class 1.1 applies.

e. *Class 1, Division 4 (Moderate Fire, No Blast).*

(1) Items in this division are those which present a fire hazard with no blast hazard and virtually no fragmentation or toxic hazard beyond the fire hazard clearance ordinarily specified for high-risk materials. Separate facilities for storage and handling of the division should not be less than the distances from other facilities as specified in DoD 6055.9-STD.

(2) See the Joint Hazard Classification System for items in this division.

f. *Class 6, Division 1 (Toxic and Incapacitating Chemicals).* No quantity-distance tables are established for Class 6.1 items since those items are not explosive hazards. Class 6.1 is composed of group A and some group B chemical ammunition without explosive components. Other group B chemical ammunition without explosive components is assigned to Class 1.4. Agent distances are prescribed in 385-series DARCOM-R's and AMCR's for certain chemical agents.

## 12-13. Hazard Classification and Storage Compatibility System.

*General.*

(1) Quantity-distance relationships for specific classes of ammunition and explosives (para 12-11) are based on levels of risk considered acceptable for stipulated exposures. Items of ammunition and explosives are assigned to these classes in accordance with AMCR 385-21 on the basis of hazard classification procedures presented in TB 700-2. Hazard classifications are assigned in the following categories:

(a) Final. This classification applies to end items or resupply items stored and transported in the approved container and packaging.

(b) Interim. This classification is assigned to permit limited shipment and storage during research, development, and testing phases prior to assignment of the final hazard classification.

(c) In process. This classification is assigned to items or materials used during manufacture, load, assembly, pack or other processes that require the materials or items to be in other than an approved storage or transportation packaging configuration. The classification assigned may be dependent on conditions in the associated process and may vary from process to process and installation to installation.

(2) Factors which determine ammunition and explosives storage compatibility groupings are listed in paragraph 12-13c. These factors are evaluated on the basis of data obtained from ammunition drawings, tests required by TB 700-2, and other tests during research and development to determine characteristics.

(3) Tables 12-1 and 12-2 present limited hazard classification information for items and materials not generally considered end or resupply items. Hazard classification information pertinent to specific items is presented in the Joint Hazard Classification System listing described in TB 700-2, or may be requested through safety channels.

b. *Hazard Classification.*

(1) The hazard classification system herein discussed is based upon the system recommended for international use by the United Nations Organization (UNO) which consists of nine classes for dangerous goods with ammunition and explosives included in UNO Class 1, Explosives. Ammunition without explosive components which contains toxic chemical agents, and containers of toxic chemical agents in bulk are included in UNO Class 6, Poisonous (Toxic) and Infectious Substances.

(2) The ammunition and explosives hazard classes are further subdivided into divisions based on the character and predominance of the associated hazards and of the potential for causing personnel casualties or property damage, not upon compatibility groupings or intended use. Additionally, fragment distance category numbers are used for some items of Class 1, Divisions 1, 2 and 3, as shown in table 12-3, column 1, and described in detail in paragraph 12-11f.

(3) Table 12-4 illustrates the structure of the hazard classification system.

*Table 12-2. Storage Compatibility Groups for Explosives*

*Group A*

Lead azide, wet
Lead styphate, wet
Mercury fulminate, wet
PETN, dry
Tetracene, wet

*Group C*

Benite
Boron potassium nitrate
Charge, propelling, not assembled to projectiles
Fuel (solid), emergency power unit
Propellant

*Group D*

Ammonium nitrate, except in original shipping container or equivalent

*Table 12-2. Storage Compatibility Groups for Explosives (Cont)*

Ammonium perchlorate, except when particles size is over 15 microns and in original shipping container or equivalent
Ammonium picrate
Baratol
Black powder, bulk
Compositions A, A-2, A-3, A-4, B, B-3, C, C-2, C-3, and C-4
Cyclonite (RDX)
Cyclotol
Ednatol
HMX
Nitrocellulose
Nitroguanidine
Nitrostarch
Octol
PBX
Pentolite
PETN, wet
Picratol
Picric acid
RDX (Cyclonite)
Tetranitrocarbazole (TNC)
Tetryl
Tetrytol
Torpex
Tritonal
TNT

*Group L*

Aluminum powder
Ammonium nitrate (in original shipping container or equivalent) Ammonium perchlorate (particle size over 15 microns) in original shipping container or equivalent
Chlorates
Magnesium powder
Nitrates (inorganic) except ammonium nitrate (in original shipping container or equivalent)
Perchlorates
Peroxides, solid
Zirconium (types I and II, spec. FED 1665)

*Table 12-3. Classification System*

| Minimum distance to protect against expected fragment hazard | Hazard class and division | Expected hazard |
|---|---|---|
| NA | 6.1 | Toxic chemical |
| M (XX)[1,2] | 1.1 | Mass-detonating with possible primary and secondary fragments |
| 549 (18) | 1.2 | Non mass-detonating with majority of primary fragments falling within indicated minimum distance |
| 366 (12) | 1.2 | |
| 244 (08) | 1.2 | |
| 122 (04) | 1.2 | |
| M (XX)[1,2] | 1.3 | Mass-fire with firebrands falling within minimum distance |
| NA | 1.4 | Moderate fire |

[1] See paragraph 12-11f(4).

[2] Distance in meters (hundreds of feet).

*Table 12-4. Hazard Classifications/Compatibility Groups*

| Items | *SCG | Class 1 division |
|---|---|---|
| 1. Initiating explosives. | A | 1 |
| 2. Detonators and similar initiating devices. | B | 1, 2, or 4 |
| 3. Bulk propellants, propellant propelling charges, and devices containing propellant with or without means of ignition. | C | 1, 2, 3, or 4 |
| 4. Black powder, high explosives, and high explosive ammunition without their own means of initiation and without a propelling charge. | D | 1 or 2 |
| 5. High explosive ammunition without its own means of initiation with a propelling charge. | E | 1 or 2 |
| 6. High explosive ammunition with a means of initiation with or without a propelling charge. | F | 1 or 2 |

*Table 12-4. Hazard Classifications/Compatibility Groups (Cont)*

| Items | *SCG | Class 1 division |
|---|---|---|
| 7. Fireworks and illuminating, incendiary, smoke, or tear producing ammunition other than ammunition that is activated by exposure to water or the atmosphere. | G | 1, 2, 3, or 4 |
| 8. Ammunition containing white phosphorus or other pyrophoric material with or without explosives. | H | 2 or 3 |
| 9. Ammunition containing flammable liquids, liquids or gel fillers with or without explosives. | J | 2 or 3 |
| 10. Ammunition containing toxic chemical agents with explosives. | K | 2 |
| 11. Ammunition not included in other groups requiring separate storage. | L | 1, 2, 3, or 4 |
| 12. Ammunition which presents no significant hazards. | S | 4 or none |
| 13. Ammunition or bulk containers containing toxic chemical agents without explosives. | K | Class 6, division 1 |

*Storage Compatibility Group

c. *Storage Compatibility Grouping.*

(1) General. All ammunition and explosives shall be assigned to an appropriate storage compatibility group (SCG) for storage at DARCOM activities.

(2) Storage principles.

(a) The highest degree of safety in ammunition and explosives storage could be assured if each item or division were stored separately. However, such ideal storage generally is not feasible. A proper balance of safety and other factors frequently requires mixing several types of ammunition and explosives in storage.

(b) Ammunition and explosives shall not be stored with dissimilar materials or items which present positive hazards to the munitions. Examples are mixed storage of ammunition and explosives with flammable or combustible materials, acids, or corrosives.

(c) Different types, by item and division, of ammunition and explosives may be mixed in storage provided they are compatible. Ammunition and explosives are assigned to an SCG when they can be stored together without significantly increasing either the probability of an accident or, for a given quantity, the magnitude of the effects of such an accident. Considerations which are used in developing the storage compatibility groups include but are not limited to:

<u>1</u> Chemical and physical properties.
<u>2</u> Design characteristics.
<u>3</u> Inner and outer packaging configuration.
<u>4</u> Hazard classification.
<u>5</u> Net Explosive Weight (NEW).
<u>6</u> Rate of deterioration.
<u>7</u> Sensitivity to initiation.
<u>8</u> Effects of deflagration, explosion, or detonation.

(d) Subject to application of these standards and particularly to compatibility as defined herein, ammunition and explosives should be mixed in storage only when such mixing will facilitate safe operations and promote overall storage efficiency.

(e) As used in these standards, the term "with its own means of initiation" indicates that the ammunition has its normal initiating device assembled to it and this device is considered to present a significant risk during storage. However, the term does not apply when the initiating device is packaged in a manner which eliminates the risk of causing detonation of the ammunition in the event of accidental functioning of the initiating device, or when fuzed end items are so configured and packaged as to prevent inadvertent arming of the fuzed end items. The initiating device may even be assembled to the ammunition provided its safety features preclude initiation or detonation of the explosives filler of the end item in the event of an accidental functioning of the initiating device.

(3) Compatible ammunition and explosives.

(a) Different kinds of explosives within any one of the following three groups are compatible and may be stored together.

1 The various kinds of initiating explosives.

2 The various kinds of propellants, regardless of hazard classification.

3 The various kinds of high explosives.

(b) Different types of ammunition within any one of the following seven groups are compatible and may be stored together:

1 All types of initiating devices.

2 All types of high explosive ammunition without their own means of initiation and without a propelling charge.

3 All types of high explosive ammunition without their own means of initiation and with a propelling charge.

4 All types of high explosive ammunition with their own means of initiation, with or without propelling charge.

5 All pyrotechnics and all types of ammunition containing both explosives and illuminating, incendiary, smoke, or tear producing agents except:

a Water activated pyrotechnics and ammunition.

b Ammunition containing white phosphorus or flammable liquids or gels.

6 All types of ammunition containing both explosives and white phosphorus.

7 All types of ammunition containing both explosives and flammable liquids or gels.

(c) Ammunition items in any one of the above groups are not generally compatible with items in any other groups.

(d) Certain kinds of explosives may be stored with certain types of ammunition:

1 Bulk propellants are compatible with propelling charges and cartridges with inert or solid projectiles or without projectiles.

2 Bulk high explosives are compatible with high explosive ammunition without their own means of initiation and without a propelling charge.

(e) Ammunition and explosives in substandard or damaged packaging, in a suspect condition, or with characteristics which increase the risk in storage are not compatible with other ammunition and explosives and shall be stored separately.

(4) Storage compatibility groups. In view of ammunition and explosives storage principles and the considerations for mixed storage, ammunition and explosives are assigned to the appropriate one of twelve storage compatibility groups (A through H, J, K, L, and S).

(a) Group A - initiating explosives. Bulk initiating exolosives which have the necessary sensitivity to heat, friction, or percussion to make them suitable for use as initiating elements in an explosive train. Examples are wet lead azide, wet lead styphnate, wet mercury fulminate, wet tetracene, and dry PETN.

(b) Group B - detonators and similar initiating devices. Items containing initiating explosives that are designed to initiate or continue the functioning of an explosive train. Examples are detonators, blasting caps, small arms primers, and fuzes without two or more safing features.

(c) Group C - bulk propellants, propelling charges, and devices containing propellant with or without their own means of ignition. Item that upon initiation will deflagrate, explode, or detonate. Examples are single-, double-, triple-base, and composite propellants, rocket motors (solid propellant), and ammunition with inert projectiles.

(d) Group D - black powder, high explosives, and ammunition containing high explosives without their own means of initiation and without propelling charge. Ammunition and explosives that can be expected to explode or detonate when any given item/component thereof is initiated.

**NOTE**

Where sufficient storage space is available, it is desirable to store bulk high explosive separately from ammunition containing high explosive even though they are both in the same compatibility group.

(e) Group E - ammunition or devices containing both high explosive and propelling charges without their own means of initiation[1]. Examples are artillery ammunition, rockets, or guided missiles.

(f) Group F - ammunition containing high explosive with a means of initiation[2] and with or without propelling charge. High explosive ammunition or devices (fuzed) with or without propelling charges. Examples are grenades, sounding devices, and similar items having an in-line explosive train in the initiator.

(g) Group G - fireworks, illuminating, incendiary, smoke (including HC), or tear producing munitions other than those munitions that are water activated or which contain white phosphorus or flammable liquid or gel. Ammunition that, upon functioning, results in an incendiary, illumination, lachrymatory, smoke, or sound effect. Examples are flares, signals, incendiary or illuminating ammunition, and other smoke or tear producing devices.

(h) Group H - ammunition containing white phosphorus or other phyrophoric material with or without explosives. Ammunition in this group contains fillers which are spontaneously flammable when exposed to the atmosphere. Examples are WP, PWP, or other ammunition containing pyrophoric material.

(i) Group J - ammunition containing flammable liquids or gels with or without explosives. Ammunition in this group contains flammable liquids or gels other than those which are spontaneously flammable when exposed to water or the atmosphere. Examples are liquid or gel filled incendiary ammunition.

(j) Group K - ammunition (with or without explosive components) and bulk containers containing toxic chemical agents.

1 Storage compatibility mixing does not apply to the storage of working quantities of one liter or less of RDT&E stocks per container, of chemical agents, properly packaged in approved containers, within laboratories.

2 The chemicals contained in the ammunition and bulk containers of this group are those that were specifically developed for incapacitating effects more severe than lacrymation. Examples are artillery or mortar ammunition, fuzed or unfuzed, grenades, rockets, bombs, spray tanks or bulk containers filled with a lethal or incapacitating chemical agent.

(k) Group L - ammunition not included in other compatibility groups. This is ammunition that has characteristics that do not permit storage with other types of ammunition, kinds of explosives, or dissimilar ammunition of this group. Examples are water activated devices, prepackaged hypergolic liquid-fueled rocket engines, fuel-air explosive devices (FAE), TPA (thickened TEA), and damaged or suspect ammunition of any group. Types presenting similar hazards (i.e., oxidizers with oxidizers, fuels with fuels, etc) may be stored together but not mixed with other groups.

(l) Group S - ammunition presenting no significant hazard. Ammunition in this group is designed or packed that when in storage all hazardous explosive effects are confined and self-contained within the item or package. An incident may destroy all items in a single pack but must not be communicated to other packs so all are destroyed. Examples are thermal batteries, explosive switches or valves, and other ammunition items packaged to meet the criteria of this group.

(5) Mixed storage.

(a) Mixing of SCG's is permitted as indicated in figure 12-1.

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[1] Reference paragraph 12-13c(2)(e).

[2] Not meeting requirements of paragraph 12-13c(2)(e).

| GROUPS | A | B | C | D | E | F | G | H | J | K | L | S |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | X | Z | | | | | | | | | | Z |
| B | Z | X | | | | | | | | | | X |
| C | | | X | Z | Z | | Z | | | | | X |
| D | | | Z | X | X | | | | | | | X |
| E | | | Z | X | X | | | | | | | X |
| F | | | | | | X | | | | | | X |
| G | | | Z | | | | X | | | | | X |
| H | | | | | | | | | X | | | X |
| J | | | | | | | | | X | | | X |
| K | | | | | | | | | | Z | U | |
| L | | | | | | | | | | U | | |
| S | Z | X | X | X | X | X | X | X | X | | | X |

*Figure 12-1. Storage compatibility mixing chart.*

**NOTES**

1. The marking "X" at an intersection of the above chart indicates that these groups may be combined in storage. Otherwise, mixing is either prohibited or restricted per note 2 below.

2. The marking "Z" at an intersection of the above chart indicates that, when warranted by operational considerations or magazine non-availability and when safety is not sacrificed, these groups may be combined in storage. Operational considerations include conditions that waste resources such as money, manpower, and energy; or compromise security, readiness, or the ability to accomplish the installation/command mission. Storage personnel, after consultation with safety and surveillance personnel, should determine when operational considerations exist that warrant "Z" storage compatibility mixing. Combinations that violate the principles of paragraph 12-13c (2) require justification by a waiver or exemption. Examples of acceptable combinations of Class 1 are:

a. Division 1 Group C bulk propellants with Division 1 bulk HE.

b. Division 1 Group C rocket motors with Division 1 Group D Bombs (HE) without their own means of initiation.

c. Group C rocket motors with Group E complete rocket systems having the same rocket motor.

d. Division 3 Group C bulk propellants or bagged propelling charges with Division 3 Group G pyrotechnics without their own means of initiation.

3. Equal numbers of separately packaged components of complete rounds of any single type of ammunition may be stored together. When so stored, compatibility is that of the assembled round, i.e., WP filler in Group H, HE filler in groups D, E, or F, as appropriate.

4. Group K requires not only separate storage from other groups, but also requires that munitions having different toxic chemical agent fillers be stored separately from each other.

5. The marking "U" on the above chart indicates that leaking toxic chemical munitions of one agent type, i.e., GB, with or without explosive components, may be stored together in one magazine specifically designated for storage of leakers of that agent type.

(b) Items from SCG's C, D, E, F, G, J and S may be combined in storage provided the net quantity of explosives in the items or in bulk does not exceed the amount specified in DOD 6055.9-STD, per storage site. These items must be packaged in accordance with approved drawings.

(c) In addition to (2) above, ammunition 30mm and less assigned to hazard class 1.4, storage compatibility groups C, G, or S may be combined in storage without regard to explosive quantity limitations.

d. *Hazard Classifications and Compatibility Groups*. The automated Joint Hazard Classification System contains a comprehensive listing of hazard classifications and storage compatibility groups for currently classified ammunition items and explosives materials. Microfiche copies of this listing may be obtained by sending a written request to Commander, US Army Materiel Development and Readiness Command, ATTN: DRCSF-E, 5001 Eisenhower Avenue, Alexandria, VA 22333. Distribution will normally be limited to safety, quality assurance, supply, and transportation offices.

*Table 12-5. Quantity-Distance Classes for Explosives and Ammunition*

*Class 1.1*

Ammonium nitrate (not in original shipping container or equivalent) exposed to detonation hazards at less than intraline distances
Ammonium perchlorate (particle size 15 microns or less)
Ammonium perchlorate (particle size over 15 microns) not in original shipping containers or equivalent, exposed to detonation hazards at less than intraline distance
Ammonium picrate
Baratol
Benite
Black powder, bulk
Boron potassium nitrate
Compositions A, A-2, A-3, A-4, B, B-3, C, C-2, C-3, C-4
Cyclonite (RDX)
Cyclotol
DNT (exposed to detonation hazard at less than intraline distance)
Dynamite
Ednatol
HMX
Lead azide, wet
Lead styphnate, wet
Mercury fulminate, wet

*Table 12-5. Quantity-Distance Classes for Explosives and Ammunition (Cont)*

Nitrocellulose, wet, containing 8 to 30 percent water that is exposed to detonation hazards at less than intraline distances
Nitroguanidine
Nitrostarch
Octol
PBX
Pentolite
PETN
Picratol
Picric acid
Propellant, double-base (for artillery ammunition) containing over 20 percent nitroglycerin
Propellant, double-base, with web thickness less than 0.1905 millimeters (0.0075 inch), regardless of nitroglycerin content
Propellant, double-base and composite grains that have been determined to be mass detonating in tests conducted in accordance with TB 700-2
Propellant, single-base, containing 98 percent or more nitrocellulose
RDX (cyclonite)
Tetracene, wet
Tetranitrocarbazole (TNC)
Tetryl
Tetrytol
Torpex
Tritonal
TNT

*Class 1.3*

Ammonium nitrate (not in original shipping container or equivalent) exposed to fire hazards only or to detonation hazards at more than intraline distance
Ammonium perchlorate (particle size over 15 microns) not in original shipping container or equivalent, exposed to fire hazards only or exposed to detonation hazards at more than intraline distance
Chlorates (not in original shipping container or equivalent)
DNT (exposed to detonation hazard at more than intraline distance)
Magnesium powder (not in original shipping container or equivalent)
Nitrocellulose, wet, containing 8 to 30 percent water, that is exposed only to such fire hazard materials as other Class 2 items

*Table 12-5. Quantity-Distance Classes for Explosives and Ammunition (Cont)*

Perchlorates (not in original shipping container or equivalent)
Peroxides, solid (not in original shipping container or equivalent)
Propellant, double-base and composite grains that have been determined to be non mass-detonating in tests conducted in accordance with TB 700-2
Propellant, double-base, containing not more than 20 percent nitroglycerin, with web thickness of 0.1905 millimeters (0.0075 inch) or greater
Propellant grains, polysulfide-perchlorate, containing not more than 74 percent oxidizer
Propellant, multi-perforated, cannon and rifle, with web thickness not greater than 0.4826 millimeters (0.019 inch)
Propellant, single-base, low pressure, for pistols and shotguns, etc.
Propellant, single-base, multi-perforated, with web thickness greater than 0.4826 millimeters (0.019-inch) (excluding single-base propellant containing 98 percent or more nitrocellulose
Propellant, single-base, single perforated, rifle
Propellant, single-base, single perforated, cannon, with web thickness not greater than 0.889 millimeters (0.035 inch)
Zirconium (type I and II, spec. FED 1665) not in original shipping container or equivalent

*Class 1.4*

Aluminum powder
Ammonium nitrate (in original shipping container or equivalent)
Ammonium perchlorate (particle size over 15 microns) in original shipping container or equivalent
Chlorates (in original shipping container or equivalent)
Magnesium powder (in original shipping container or equivalent)
Nitrates (inorganic) except ammonium nitrate (in original shipping container or equivalent)
Perchlorates (in original shipping container or equivalent)
Peroxides, solid (in original shipping container or equivalent)
Zirconium (types I and II, spec. FED 1665) in original shipping container or equivalent

### 12-14. Toxicity of United States Military Explosives.

a. Many explosives, because of their chemical structures, are somewhat toxic. To be acceptable, a military explosive must be of minimum toxicity. Careful attention must be paid to this feature because the effects of toxicity may vary from mild dermatitis or a headache to serious damage to internal organs.

b. Table 12-6 is a concise presentation of the toxicological properties of selected United States military explosives.

*Table 12-6 Toxicity of United States Military Explosives*

| Explosive | Health hazard | Protective measures |
|---|---|---|
| *Initiating explosives* | | |
| Lead azide | Lead azide is not considered to be particularly toxic but inhalation of the dust should be avoided since this causes a headache and distention of the blood vessels. | Avoid inhalation. Tolerance level below 0.2 milligrams per cubic meter in air. |
| Mercury fulminate | Poisoning has symptoms of mercury poisoning. At low levels causes dermatitis and irritation of the mucous membranes. | Avoid all routes of exposure. Tolerance level below 0.01 milligrams per cubic meter in air. |
| *Boostering explosives* | | |
| PETN | PETN is not unduly toxic since it is nearly insoluble in water and usually is handled while wet. It, therefore, cannot be absorbed through the skin and inhalation of the dust is improbable. Tests have shown that small doses of PETN cause decrease in blood pressure; larger doses cause dyspnea and convulsions. | |
| Tetryl | Moderately toxic by inhalation or ingestion. | Avoid inhalation or ingestion. |
| | Tetryl has a strong coloring action on the human skin and can cause a dermatitis. | To minimize these effects, use cold cream containing 10 percent sodium perborate. |
| | Inhalation of tetryl dust has recognized toxic effects. | Avoid inhalation. Tolerance level below 1.5 milligrams per cubic meter in air. |

Table 12-26. *Toxicity of United States Military Explosives (Cont)*

| Explosive | Health hazard | Protective measures |
|---|---|---|
| RDX | Munitions workers have experienced acute RDX intoxication, mainly from inhaling the fine particles; ingestion may have been a contributing factor. Troops have occasionally suffered symptoms of RDX intoxication following consumption of Composition C-4, a plastic explosive containing 91 percent RDX. Composition C-4 was chewed by soldiers to produce the "high" of ethyl alcohol or it was used as a fuel for cooking. In the latter case, the victims may have inhaled the fumes or inadvertently introduced RDX into their food. Acute effects were seen within a few hours of exposure, ie, after a latent period. The course of acute RDX poisoning appears to follow a general sequence, though some symptoms may be missing in any individual case: restlessness and hyperirritability; headache; weakness; dizziness; severe nausea and vomiting; aggravated and prolonged epileptiform seizures (generalized convulsions) which are often repeated; unconsciousness between or after convulsions; muscle twitching and soreness; stupor, delirium, disorientation and confusion; then gradual recovery accompanied in the beginning by amnesia. In a few cases, workers have suffered irritation to the skin, mucous membranes, and conjunctivae by fine particles of RDX.<br>The clinical findings in RDX intoxication may include fever; rapid pulse; hematuria due to effects on the proximal tubules of the kidney; proteinuria; azotemia; occasional mild anemia; neutrophilic leukocytosis; elevated SGOT (serum glutomic oxalacetic transaminase), which may explain the muscle soreness; nitrites in the gastric juices; and electroencephalographic abnormalities. There appears to be no liver involvement and cerebrospinal fluid is normal. Patients evidently recover completely from the effects of RDX poisoning, the length of time depending on the extent of exposure. The period of recovery varies from a few days to about three months. Thus, RDX intoxication involves gastrointestinal, central nervous system, and renal effects. The potential routes of exposure are inhalation of fine particles or fumes, or ingestion. Because RDX is a high-melting solid and not very lipid soluble, skin absorption is very unlikely. Although the symptoms may be severe, deaths have apparently been quite few, and no permanent damage seems to have resulted among survivors. | Avoid inhalation or ingestion. |

*Table 12-26. Toxicity of United States Military Explosives (Cont)*

| Explosive | Health hazard | Protective measures |
|---|---|---|
| *Bursting charge explosives* | | |
| Amatol | Highly to moderately toxic by inhalation, ingestion, and absorption. Contact may cause dermatitis. | Avoid inhalation, ingestion, or skin contact. |
| Ammonium picrate | Highly toxic by inhalation, ingestion, and skin absorption. | Inhalation of the dust should be minimized and frequent baths and changes of clothes are desirable for those working with the material in quantity. |
| DBX | Generally considered non toxic. | |
| HBX-6 or H-6 | Highly toxic by inhalation or ingestion. | Avoid inhalation and ingestion. |
| HMX | The low solubility of HMX has caused difficulties that have cast in doubt the validity of all toxicological research done on this compound to date. It would appear that, weight-for-weight, HMX is somewhat less toxic than RDX but exhibits similar effects. Experiments are in progress to confirm or contradict this opinion. | |
| Pentolite | See TNT and PETN. | |
| Picratol | See TNT and ammonium picrate. | |
| RDX compositions | See RDX - boostering explosives. | |
| Tetrytol | See TNT and tetryl. | |
| TNT | TNT exposures can occur by inhalation of the dust, through ingestion, and via skin absorption. Among the first signs of TNT intoxication are changes in the blood: the red blood cell count and hemoglobin content decrease; abnormal red cells are seen; and there is a transitory increase in leukocytes and lymphocytes. Rashes and skin eruption may be associated with these effects. Increased capillary fragility leads to nose bleeds and hemorrhages of the skin and mucosa. At sufficiently high and prolonged exposures, more serious blood phenomena appear. These include methemoglobinemia, with consequent cyanosis; hyperplasia of the bone marrow leading to aplastic anemia (because the marrow no longer produces blood cells); and a drastic loss of blood platelets. Petechiae often occur in conjunction with aplastic anemia. | Avoid inhalation and skin contact. Tolerance level below 1.5 milligrams per cubic meter in air. |

*Table 12-26. Toxicity of United States Military Explosives (Cont)*

| Explosive | Health hazard | Protective measures |
|---|---|---|
| | A second type of symptom, toxic jaundice, indicates toxic hepatitis. This ultimately leads to yellow atrophy of the liver.<br>Death can occur from either anemia or (especially in younger people) toxic hepatitis.<br>Effects of TNT on the kidney are manifest in increased filtration rates. In mild cases of TNT intoxication, urgency, frequent urination, and lumbar pain may be the only symptoms.<br>Individuals exposed to TNT may complain of a constant bitter taste, excessive salivation, nausea, vomiting, and gastritis. The latter is due to reduced secretion of pancreatic enzymes.<br>According to European accounts, chronic work-place exposure to TNT was associated with cataracts of the eyes. There have been various reports of central nervous system intoxication (neurasthenia, polyneuritis). No carcinogenic effects of TNT on human beings have been reported. | |
| Torpex | See TNT. | |
| Tritonal | Highly toxic by inhalation and ingestion. | Avoid inhalation and ingestion. |
| *Solid propellants* | | |
| *Single-base propellants* | | |
| Nitrocellulose | Nitrocellulose is a water-insoluble fibrous polymer. Consequently it is not absorbed through the intestinal wall or cell membranes. This accounts for its total lack of oral toxicity to mammals. Subchronic and chronic feeding to rats and dogs at contents as high as 10 percent and to mice at 3 percent of the solid diet resulted in no effects other than those of fiber bulk, ie, as if they had been fed cotton linters.<br>Suspended nitrocellulose in concentrations as high as 1,000 milligrams per liter showed no effect on four species of fish and four invertebrates in various acute toxicity tests. | Adequate ventilation is recommended. |

*Table 12-26. Toxicity of United States Military Explosives (Cont)*

| Explosive | Health hazard | Protective measures |
|---|---|---|
| *Double-base propellants* | | |
| Nitrocellulose | See nitrocellulose above. | |
| Nitroglycerin | Nitroglycerin has been used as a vasodilator drug in medicine, especially for the treatment of angina; thus, there is a fairly extensive literature on its biochemical and clinical aspects. The most common medicinal dose is 0.65 milligrams (roughly 0.01 milligrams per kilogram), but many patients safely receive 20 times this (about 0.2 milligrams per kilogram) daily. Survival has been noted after quantities up to 400 milligrams (about six milligrams per kilogram) were administered orally or sublingually. Two of the more noticeable symptoms are headache and falling blood pressure.<br>Chronic human exposure to nitroglycerin is characterized by methemoglobinemia and the development of tolerance to the drug. Withdrawal from frequent exposure to nitroglycerin causes severe headaches, "Monday head," among munitions workers.<br>Since nitroglycerin is not very volatile, skin absorption is the most likely route of exposure. A TLV of 0.2 parts per million, or 2 milligrams per cubic meter, in air was adopted by the American Conference of Government Industrial Hygienists in 1972, to encompass cutaneous exposure - including mucous membranes and the eye - as well as inhalation. But a reduction in this value may be desirable in view of withdrawal headaches suffered by volunteers after exposure to such a level. | Avoid inhalation or skin contact. |
| *Military pyrotechnics* | | |
| HC smoke mixtures | Moderately toxic by inhalation and ingestion. Skin contact can cause dermatitis. | Avoid inhalation, ingestion, and skin contact. |
| Black powder | Moderately toxic by inhalation and ingestion. | Avoid inhalation and ingestion. |

# CHAPTER 13
# DETECTION AND IDENTIFICATION OF ENERGETIC MATERIALS

**13-1. Introduction.** This chapter discusses the methods used to detect and identify energetic materials. Almost all of the analytical chemistry techniques are used. Normally, identification involves a series of tests, each providing a clue to the identity of the compound. In addition to the techniques discussed in this chapter, identifying information can be obtained from physical properties such as melting point, crystalline structure, density, physical state, color, and indicies of refraction.

**13-2. Wet Chemical Methods.** When a test sample is treated with an appropriate reagent, a coloration is produced which is characteristic of the compound being tested. These reactions are known as color reactions and may help identify the sample. The compound which produces the color change is called the color reagent. Color reactions are used to some degree for preliminary identification and confirmation but have largely been replaced by the more modern instrumental techniques. Table 13-1 lists some of the common color reactions used to identify explosives.

*Table 13-1. Color Tests*

| | Water Solution or Extract of Energetic Material | | | Solid of Energetic Material | | |
|---|---|---|---|---|---|---|
| | Color of solution | Color of universal pH test | Color of precipitate with Nessler's reagent | Color effect of test with solution of- | | |
| | | | | Ethylenediamine | Diphenylamine | Thymol |
| TNT | (Insoluble) | - | - | Maroon | Colorless | - |
| Tetryl | (Insoluble) | - | - | Red | Blue | Green |
| Picric acid | Yellow | Red | (No ppt) | Orange | - | - |
| Explosive "D" | Yellow | - | Brown | Orange | - | - |
| Haleite | None | - | (No ppt) | None | Blue[1] | Orange |
| Nitroguanidine | None | - | White | - | Blue | Green |
| Ammonium nitrate | None | - | Brown | None | Dirty green | Green[1] |
| PETN | (Insoluble) | - | - | None | Dirty green | Green |
| Nitroglycerin | None | - | (No ppt) | - | Deep blue | Green |
| DEGN | None | - | (No ppt) | - | Deep blue | Brown[2] |
| Nitrocellulose | None | - | - | - | Blue | Green |
| Tritonal | (Insoluble) | - | - | Maroon | Colorless | - |
| Tetrytol | (Insoluble) | - | (No ppt) | Maroon | Intense blue | Green |
| Picratol | Yellow | - | Brown | Maroon | - | - |
| Ednatol | None | Orange | (No ppt) | Maroon | Intense blue | Orange |
| Amatol | None | - | Brown | Maroon | Dirty green | Green |
| Ammonal | None | - | Brown | Maroon | Dirty green | Green |
| Pentolite | None | - | (No ppt) | Maroon | Dirty green | Green |
| Black powder[3] | None | No change | - | - | Blue | Green |

[1] Color appears immediately.

[2] Sometimes explodes mildly (puffs) upon addition of sulfuric acid.

[3] Tests of dried water extract.

The tests are performed in the following manner.

a. *Test 1.* Place 0.05 gram of the explosive in a 5 milliliter beaker, add 2 to 3 milliliters of distilled water, and stir for 5 minutes.

(1) Observe color of liquid.

(2) Wet one end of a strip of universal pH indicator paper and note any change in color.

(3) Add a drop of Nessler's reagent and note the color of any precipitate formed. Prepare the reagent by dissolving five grams of potassium iodide in a minimum quantity of cold distilled water and adding a saturated aqueous solution of mercuric iodide until a faint precipitate is formed. Add 40 milliliters of 50-percent potassium hydroxide solution. After the solution has clarified by settling, dilute to 100 milliliters with distilled water, allow to settle, and decant.

b. *Test 2.* Place 0.05 gram of the unknown material in an indenture of a white porcelain spot-test plate. Add two or three drops of a 65 to 68 percent aqueous solution of ethylenediamine and stir. Note the color of the solution (not the solid).

c. *Test 3.* Place 0.05 gram of the unknown material in an indenture of a white porcelain spot-test plate and add three or four drops of a diphenylamine solution. Stir the mixture and, after one minute, note the color of the solution. Prepare the diphenylamine solution by dissolving one gram of diphenylamine in 100 milliliters of concentrated CP sulfuric acid.

d. *Test 4.* Place 0.05 gram of the unknown material in an indenture of a white porcelain spot-test plate. Add an equal amount of crystalline thymol and three drops of concentrated sulfuric acid. Stir the mixture and note its color after five minutes or more.

e. *Additional Tests.* If the unknown material is not identified completely by the tests in subparagraphs 13-2 a. through d. and data listed in table 13-1, tests should be performed to determine whether the material is one of those indicated in (1) through (14) below.

(1) RDX. Place several milligrams of the white, unknown material in a test tube and add about 200 milligrams of thymol and six drops (0.3 ml) of concentrated sulfuric acid. Warm the tube for five minutes at 100°C, and add 5 to 10 milliliters of ethanol. RDX produces a rich blue color. Under these conditions sugars and aldehydes give a brown color, and HMX gives a pale blue-green color. RDX can be further distinguished from HMX by repeating the test at 150°C. Under these conditions RDX still gives a blue color, but HMX produces an olive color.

(2) Composition A-3. Place 0.1 gram of the material in a 10 milliliter beaker and add two or three drops of acetone. Warm the mixture and allow to stand for five minutes. Evaporate the acetone by gently warming on a steambath, cool, and add 2 milliliters of carbon tetrachloride. Cover the beaker and warm the contents, occasionally swirling the mixture. Cool the mixture and allow the undissolved material to settle. Decant the supernatant liquid into a 5 milliliter beaker, evaporate to dryness, and note if a waxy (not tarry) residue is obtained. Dry the undissolved material in the 10 milliliter beaker and test for RDX as described in (1) above.

(3) Composition B. Place 0.2 gram of the pale yellow to medium brown material in a 10 milliliter beaker and add 2 to 3 milliliters of chloroform. Cover the beaker. Warm and digest the mixture for 10 minutes with occasional swirling. Decant the supernatant liquid through a filter paper and evaporate the filtrate to dryness. Repeat digestion of the insoluble residue in the beaker with three more portions of chloroform discarding the decanted liquid in each case. Dry the insoluble residue by evaporating any adherent chloroform. If the original material was composition B, the residue from the chloroform solution consists of TNT and wax. Test the TNT and wax mixture with ethylenediamine and diphenylamine as described above. The insoluble residue obtained by extraction with chloroform consists of RDX. Test as described in (1) above.

(4) Composition C-3. Place 0.2 gram of the putty-like explosive in a 10 milliliter beaker and add 5 milliliters of benzene. Mix and digest for 10 minutes crushing any lumps present. Decant the supernatant liquid through a filter paper and evaporate the benzene with gentle heating. Note whether a dark, tarry residue remains. Wash the insoluble residue left by benzene extraction with two or three, 3 milliliter portions of a 2:1 ether-ethanol mixture and dry the washed residue. Test this as described under RDX in (1) above. To the decanted ether-ethanol washings, add 15 milliliters of distilled water and heat the mixture until all ether and alcohol are removed. If a white precipitate (nitrocellulose) is noted, catch the precipitate on a filter, wash with ethanol, dry by evaporation of the ethanol, and test for nitrocellulose as indicated in table 13-1.

(5) Torpex. Place 0.2 gram of the explosive in a five milliliter beaker and extract with three, 3 milliliter portions of acetone. Dry the insoluble residue and examine under a microscope. Note if the residue has the characteristic appearance of metallic aluminum. Place 0.2 gram of the explosive in a 5 milliliter beaker and digest with two, 3 milliliter portions of benzene, decanting the benzene into a small evaporating dish. Evaporate the benzene solution to dryness and test for TNT as indicated in table 13-1. Dry the insoluble residue from the benzene extraction and test for RDX as described in (1) above.

(6) Tritonal. Place 0.2 gram of the explosive in a 10 milliliter beaker and add 5 milliliters of acetone. Stir, allow any undissolved material to settle, and decant the liquid. Wash the insoluble matter with two, 5 milliliter portions of acetone, dry, and examine under a microscope. Note if the insoluble matter has the characteristic appearance of metallic aluminum. Subject the separated explosive to the tests prescribed for TNT in table 13-1.

(7) Amatol. Place 0.2 gram of the yellow material in a 5 milliliter beaker, add 3 milliliters of distilled water, and stir for five minutes. Decant the liquid through a filter and evaporate to dryness. Test the dried solid as prescribed for ammonium nitrate in table 13-1. Dry the water-insoluble residue and test as prescribed for TNT above.

(8) Ammonal. Place 0.2 gram of the explosive in a 10 milliliter beaker and digest with 3 milliliters of distilled water. Decant the liquid through a filter and evaporate to dryness. Test the dried solid as prescribed for ammonium nitrate. Digest the insoluble residue in the beaker with three, 3 milliliter portions of acetone decanting these through a filter. Dry the insoluble residue and examine under a microscope. Note if the residue has the characteristic appearance of metallic aluminum. Evaporate the filtrate to dryness by warming gently. Test the dried solid as prescribed for TNT above.

(9) Lead azide.

(a) Test the explosive for solubility in water. Lead azide is insoluble in water.

(b) Transfer 5 milligrams of the sample explosive to a 10-milliliter beaker and add 10 drops of a 10-percent ceric ammonium nitrate solution. A reaction accompanied by evolution of nitrogen oxides (red fumes) is indicative of the presence of azide.

(c) Treat the solution of the sample obtained in (b) above with a few drops of a 10 percent aqueous solution of potassium dichromate. A yellow to reddish-yellow precipitate is indicative of the presence of lead.

(d) Transfer 2 milligrams of the sample to a 5 milliliter beaker. Add 5 milliliters of a 10 percent aqueous solution of ferric chloride solution. A red color is formed which disappears slowly when 2 to 3 milliliters of dilute mercuric chloride solution are added. This confirms that the explosive is lead azide.

(10) Mercury fulminate.

(a) Test the explosive for solubility in water. Mercury fulminate is insoluble in water.

(b) Transfer 10 milligrams of the sample explosive to a fritted glass crucible of medium porosity. Extract the sample with a 20 percent aqueous solution of sodium thiosulfate, catching the washings in a 50-milliliter beaker containing 10 drops of a one percent phenolphthalein indicator solution. When the mercury fulminate is treated with sodium thiosulfate, it dissolves with formation of alkali (NaOH) which changes the color of the indicator solution from colorless to red.

(c) Transfer 10 milligrams of the sample to a 10-milliliter beaker and add three drops of concentrated hydrochloric acid solution and 2 milliliters of water. Transfer the solution to another beaker containing one drop of a five percent aqueous solution of potassium iodide. The formation of a bright red precipitate indicates the presence of the mercuric ion.

(11) Diazodinitrophenol (DDNP). Dissolve 0.05 gram of the greenish-yellow to brown explosive in acetone. Upon adding a larger volume of ice water, the explosive should appear as bright yellow crystals. Prepare a saturated solution of the explosive in 200 milliliters of water. Add to this 5 milliliters of a 20 percent solution of sodium hydroxide and mix. The evolution of a colorless gas and the appearance of a reddish-brown color in the solution indicate the explosive to be diazodinitrophenol.

(12) Lead styphnate. Wet 0.1 gram of the heavy, light orange to reddish-brown material with 10 milliliters of water and then add slowly 10 milliliters of a 20 percent solution of ammonium acetate. Agitate the mixture until solution is complete. Add 10 milliliters of a 10 percent aqueous solution of potassium dichromate. The appearance of a bright yellow precipitate indicates the presence of lead. To 0.1 gram of the explosive in a beaker add 10 milliliters of a 10 percent solution of hydrochloric acid. Heat the mixture in a steambath and evaporate to dryness. Cool the beaker and contents and add 10 milliliters of ether. Mix the contents and allow to settle. Decant or filter off the yellow ether solution and evaporate this to dryness at ordinary temperature. Dissolve the residue in 25 milliliters of water and add 0.1 gram of solid potassium cyanide. The absence of color indicates the explosive to be lead styphnate.

(13) Tetracene. Wet 0.25 gram of the fluffy, pale yellow explosive with 5 milliliters of a 10 percent solution of sodium hydroxide and warm the mixture in a steambath until solution is complete. Note if there is an odor of ammonia. Cool the solution and add 1 milliliter of a five percent solution of copper acetate. The appearance of a bright blue precipitate indicates the explosive is tetracene.

(14) Black powder. Place 0.2 gram of the black material in a 5 milliliter beaker, add 2 to 3 milliliters of distilled water, and stir for five minutes. Decant the liquid through a filter and catch the filtrate in a beaker. Evaporate this to dryness and subject the dried white solid to the tests shown in table 13-1. Dry the water-insoluble residue in the beaker, cool, and digest with two 5 milliliter portions of carbon disulfide, decanting these into an evaporating dish. Evaporate the carbon disulfide solution to dryness at room temperature. By means of a microscope, examine the yellow residue so obtained and the insoluble black residue from the carbon disulfide extraction. Note if they have the characteristic appearances of sulfur crystals and charcoal, respectively.

### 13-3. Chromatography.

a. *Column Liquid Chromatography.* This is the oldest form of chromatography and is sometimes called column chromatography. The equipment consists of a vertical glass or quartz column which is constricted at the lower end. The column is filled with a fine, granulated material which is most commonly silica gel but may be metal oxides (alumina), sugars, etc. This is called the stationary phase. A chemical mixture in a suitable solvent is placed in the top of the column and allowed to diffuse downward. The solvent is called the mobile phase. Vacuum is sometimes applied to the bottom of the column. The chemical components of the mixture will diffuse at different rates due to their difference in affinity for the column material. After sufficient time the components will be separated into bands along the length of the column. If the components are colored, the bands can be easily detected. Colorless or white component bands can be detected by adding a fluorescent material to the column material contained in a quartz column and irradiating with ultraviolet light. The column is then extruded from the tube and cut into bands. The separated compounds in the bands are eluted by suitable solvents and subjected to quantitative and qualitative analyses procedures. The solvent has a significant effect on the interaction between the material under test and the column material. Therefore, the proper combination of column material and solvent must be used for each material under test. Column liquid chromatography has been implemented by other modern chromatographic techniques because the procedures are time consuming and tedious.

b. *Paper Chromatography.* In paper chromatography both the stationary and mobile phase are liquids. The stationary phase liquid, which is usually water, is supported on a filter paper. A spot of the mixture to be tested is placed on the filter paper. The spot is then dried. The filter paper is then placed in a trough which contains the mobile phase. The liquid mobile phase is immiscible with the liquid of the stationary phase. The mobile phase is usually a mixture of organic solvents. The eluent is allowed to migrate either upward or downward on the paper. As the eluent migrates, the compounds in the mixture separate, each traveling with the eluent but at a different rate. After the eluent front has advanced between 15 and 30 centimeters the paper is removed from the trough and dried. A color reagent is sprayed on the paper to locate all the separated compounds. The ratio of the distance traveled by the separated compound to the distance traveled by the eluent front is then computed. In some cases the filterpaper is impregnated with hydrophobic substances such as oils or paraffins and the mobile phase is aqueous. This is called reverse phase paper chromatography. Most work with energetic material has been done using the reverse phase technique. Paper chromatography is not generally used for identification of energetic material as is thin layer chromatography.

c. *Thin Layer Chromatography.* A thin layer chromatographic plate consists of a thin layer of powdered material mixed with a binder that is applied to a smooth surface such as a glass, aluminum, or plastic sheet. The powdered material, which constitutes the stationary phase, usually consists of silica gel or aluminum oxide of uniform particle size. A solution of the mixture to be tested is spotted near the bottom of the plate. The plate is then placed vertically in a trough of solvents, called the developing solvents, contained in a closed developing tank. The level of the developing solvent in the trough is below the spot of test material. The developing solvents constitute the mobile phase. The mobile phase is drawn up into the stationary phase by capillary action. As the level of the mobile phase rises, the compounds of the test mixture are separated, each traveling with the mobile phase but at different rates. The liquid phase is allowed to rise to the desired level, usually near the top, and the plate is removed from the trough and dried. Colorless spots are detected by either spraying with a color reagent or incorporating a fluorescent material in the chromatographic plate such that exposure to ultraviolet light will cause luminescence except where spots of ultraviolet absorbing compounds are present. The rate of flow is defined as the ratio of the distance traveled by the compound to the distance traveled by the developing solvent. The rate of flow is affected by many factors such as the plate material, the developing solvent used, plate thickness, dryness of the plate, temperature, and others. Therefore compound identification is made by running the test solution on the same plate as known compounds, not by comparing the rate of flow to published data. When more than one elution is required, thin layer chromatography can be run in two dimensions. The plate is spotted near one of the corners at the bottom. Then the plate is developed normally in a developing solvent that separates the mixture into groups rather than single compounds. The plate is then dried, rotated 90° so that the separated groups are along the bottom, and placed in a second solvent trough. The second solvent separates the groups into single compounds. Thin layer chromatography is used extensively as a qualitative analysis technique. The developing solvents and plate material used vary according to the test material so no single combination of solvent and material can be used for separating all the energetic materials.

d. *Gas Chromatography*. In gas chromatography the vapor of the material to be tested is injected into a stream of inert gas such as nitrogen, and passed through a column. The carrier gas is the mobile phase, the material in the column is the stationary phase. The stationary phase can be either a solid or a liquid supported on a solid. If the stationary phase is solid the method is called gas-solid chromatography (GSC). If the stationary phase is a liquid supported on a solid then the method is called gas-liquid chromatography (GLC). Two types of columns are used in GLC; packed columns, which contain an inert nonvolatile liquid, and capillary columns, which are long, open tubes of small diameter that have a thin, liquid film on their inner surface. Capillary columns offer a greater resolution of mixture. As the carrier gas flows through the column the components of the test mixture separate, each traveling through the column material at a different rate. A detector at the end of the column detects when the gas being tested emerges. Three types of detectors are commonly used; thermal conductivity, flame ionization, and electron capture. A thermal conductivity detector detects changes in the thermal conductivity of the carrier gas. This type detector is simple and nondestructive but the sensitivity is low and the test results are highly dependent on gas temperature and rate of flow. A flame ionization detector measures the electrical conductivity of the product gases when the carrier and test sample are decomposed in an air/hydrogen flame. This type detector is destructive but more sensitive and does not have a great dependence on the gas temperature. The current carried across the product gas is proportional to the number of carbon atoms but inversely proportional to the number of oxygen and nitrogen atoms. This is the most commonly used detector. An electron capture detector uses a radioactive beta emitter to ionize the carrier gas. An electron capturing compound will remove some of the ions. The resulting decrease in the current carrying capability of the gas indicates the presence of one of these compounds. This method of detection is very sensitive to electronegative compounds, but is insensitive to compounds such as hydrocarbons which do not capture electrons. The detector output is recorded as a function of time, as shown in figure 13-1. Each peak corresponds to a compound in the mixture. There is a general correlation between the area under the peak and the content of the compound in the mixture. However, the area ratio for two compounds does not necessarily represent their weight ratio in the sample. This could be due to several reasons: difference in the detector response for different compounds, adsorption or decomposition of a compound before detection, or a faulty sampling technique. Therefore, to use the recorder output quantitatively a specific amount of a known compound is added to the sample. The sample must react similarly in the gas chromatographic unit to the unknown. Relative weight percentages can then be computed by comparing the area under the curve for the unknown and known sample. Gas chromatography is used for energetic materials, however, in some cases, application of this method is limited by the high temperature at which the test must be run. Nitroaromatics are generally stable at their boiling point, but nitramines and aliphatic nitrated esters are not. For the unstable compounds several techniques are recommended to reduce decomposition; glass rather than metal columns, short column length, lower temperatures, low polarity liquid in the GLC stationary phase, and low loading percentage of the liquid. These precautions also minimize reaction between the compounds in the column. This is a consideration when analyzing the stabilizer content of propellants as the higher temperature tends to drive off nitrogen oxides from the aliphatic nitrated ester and nitrate the stabilizer. Gas chromatography can be run isothermally or with a programed temperature change.

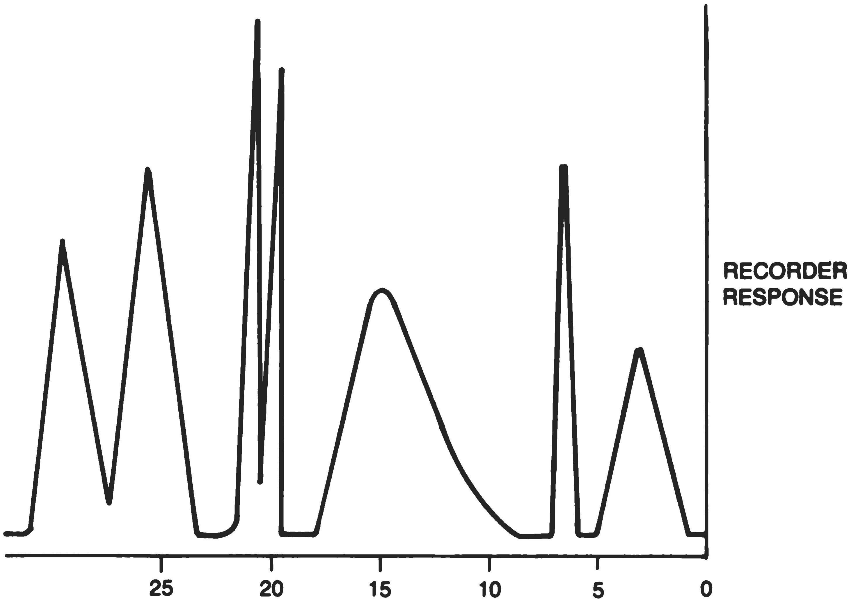

*Figure 13-1. Gas chromatograph output.*

e. *High Performance Liquid Chromatography (HPLC).* HPLC is also known as high speed or high pressure liquid chromatography. Separation is done in a glass or stainless steel column that is packed with a fine powdered material, usually silica. Column dimensions are usually 15 to 30 centimeters in length and three to four millimeters in diameter. The packing material, or stationary phase, consists of particles in the 5 to 10 micrometer diameter range. A solvent, the mobile phase, is pumped through the column under pressure in the range of 1,379 to 6,895 kilopascals (200 to 1,000 pounds per square inch). The test mixture to be separated is injected. Separation in the column is accomplished in the same manner as in the other forms of chromatography: the various constituents diffuse down the column at different rates. The composition of the mobile phase can be held constant (isocratic elution) or varied (gradient elution) during the procedure to improve separation. When the column material is silica, surface adsorption is the mechanism of separation. When the silica is coated with a liquid, partition between the two liquid phases is the separation mechanism. The liquids of the stationary and mobile phase must be immiscible. Normal HPLC is performed with a polar stationary phase and a somewhat nonpolar mobile phase. Reverse phase HPLC is performed with a nonpolar stationary phase and polar mobile phase. Another column material is the chemically bonded stationary phase. Silica contains free hydroxyl groups. The hydrogen can be replaced by organic compounds, although direct replacement with a carbon bond is less stable than bonding the oxygen to another silicon which is bound to the organic compound. As the mobile phase emerges from the column an ultraviolet spectrophotometer is used to detect the test material in the eluent. The detector output is plotted as a function of time. The graph obtained is very similar to the one shown in figure 13-1. The area under the peaks in the curve is proportional to the concentration of each component in the test material. A tentative identification of the compounds in the mixture can be made by comparing the graph of the output of the unknown to the graph for known compounds run under the same conditions. This identification, however, is not as specific as other methods and cannot be used in forensic work, for example, where an exact identification is required. The separated compounds can be collected and analyzed individually using one or a combination of other methods for positive identification such as mass spectrometry, infrared spectrometry, and nuclear magnetic resonance.

f. *Ion Chromatography*. Ion chromatography is instrumentally very similar to HPLC, the difference between the methods being the column material. Ion chromatography uses an ion exchange resin stationary phase which can be applied to glass microbeads for packing. While HPLC is based on absorption and partition phenomena, ion chromatography is based on the exchange of ions between the resin and the mobile phase. It is a very good technique for separating cations and anions from each other.

**13-4. Polarography.** Polarography measures current in microamperes, generated through the reduction/oxidation of chemical species in an electrolytic solution at an applied potential specific to the specie. A reference electrode and polarizable electrode are used. The polarizable electrode normally used is the Dropping Mercury Electrode (DME) which consists of a glass capillary filled with mercury. The mercury is allowed to drip from the capillary at a controlled rate. As a droplet forms at the end of the tube the surface area of mercury exposed to the solution increases. This causes an increase in the current conducted through the solution at any given voltage. There is a sharp decrease in the current when the drop falls. The current then increases during the formation of the next drop. Several forms of polarography are used: DC, single sweep, AC, and differential pulse. These four forms differ only in the manner in which voltage is applied between the electrodes. In DC polarography, a DC potential, which is increasing linearly at the rate of 1 to 10 millivolts per second, is applied between the electrodes. At low voltages a small current, called the residual current, flows. This current is due to charging the capacitance between the DME and the solution and miscellaneous impurities in solution. At a critical voltage depending on the chemical specie the current begins to increase with increasing voltage. The current continues to increase until a maximum current is attained, at which point further increases in voltage do not increase the current. The plot of the applied voltage versus the current is called a polarogram. The difference between the residual current and maximum current is called the diffusion current. The diffusion current is proportional to the concentration of the chemical specie. In single sweep polarography, a DC potential increasing at the rate of 100 to 500 millivolts is applied between the electrodes. The voltage is applied at a specific time during the formation of the mercury drop. The applied voltage is plotted against the current to obtain a polarogram. Single sweep polarography is more accurate than DC polarography because the shorter time frame in which the measurement is made allows less change in the surface area of the mercury drop. In AC polarography, a small AC signal is placed on the DC waveform used in DC polarography. The effects of the DC potential are electronically removed and a polarogram with peaks in the waveform is obtained. In differential pulse polarography, a pulse is applied just as the mercury drop attains maximum size. The pulse has an amplitude of 5 to 100 millivolts and a width of 50 to 60 milliseconds. The current is measured twice, just before the pulse and during the last 10 to 20 milliseconds of the pulse. The type and concentration of species present is made by comparing polarograms. Polarography is a very sensitive method of detection. Applications include pollution control and analysis of sensitive material such as primary explosives, in which sample sizes are held to a minimum because of safety considerations.

**13-5. Spectroscopy and Spectrometry.**

a. *Ultraviolet and Visible Spectroscopy*. In ultraviolet and visible spectroscopic techniques, a solution of the sample to be analyzed is irradiated with discreet frequencies from the entire range of either the ultraviolet or visible spectrum. To obtain a spectrum of the component, the absorbance, which is defined as the log of quotient of the intensity of the incident and transmitted radiation, is measured and plotted as a function of the frequency of the incident radiation. Usually a blank sample, which consists of only the solvent, is run at the same time so the absorbance of the solvent can be subtracted from the total absorbance of the solution. Ultraviolet and visible spectra are not generally used to identify energetic materials because they are not distinctive. However, the methods may be used for quantitative analysis. The concentration of the compound in solution is determined by measuring the absorbance of the material under test and comparing the value obtained to the value obtained for a solution of the same compound with a known concentration. The same solvent, temperature, and optical path length through the solution must be used. With a limited number of exceptions, the concentration is a linear function of the absorbance.

b. *Infrared Spectroscopy.* Infrared spectroscopy is one of the most widely used methods of identification. The technique can be used with gases, solids, or liquids. Gases or liquids are contained in cells containing salt windows, such as sodium chloride or potassium bromide, that are transparent to infrared radiation over a certain wavelength range. Solids may be in solution in which case a blank cell that contains only the solvent is tested in tandum with the material under test to compensate for the effects of the solvent. Solids may also be prepared for testing by grinding with mineral oil and placing between two sodium chloride plates or grinding with potassium bromide and pressing into a pellet. The mineral oil interferes with the spectra over a small wavelength range, but the potassium bromide does not. In the identification of an explosive ingredient, the spectrum of the unknown is examined and classified in terms of groups present in the molecule (OH; NH; C =0; $N\text{-}NO_2$; aromatic $NO_2$; C-O-C; $C\text{-}O\text{-}NO_2$; etc.) and then compared with the standard spectra that contain the same groups. Table 13-2, which gives spectral correlations of aromatic nitro compounds, nitramines, and nitrates, is useful for this purpose. Using infrared spectroscopy for identification depends on having a library of spectra for comparison to the spectra of unknowns. The spectra can be digitized and a computer used to search rapidly among known spectrum. Usually the programs do not identify the compound completely, but narrow the possibilities to about 10 compounds. Infrared spectroscopy is most effective when the sample is a pure compound, so separation techniques such as solvent extraction or chromatography may be used on a sample before irradiation.

*Table 13-2. Spectral Correlations of Aromatic Nitro Compounds, Nitramines, and Nitrates*

| Structure | Band assignments, μm | Comments |
|---|---|---|
| *sym*-trinitro | 9.25 | Found in all *sym*-trinitro compounds examined which have the following additional groups: $OC_2H_5$, $CH_3$, OH, $C_2H_5$, COOH, $OCH_3$, $NH_2$. The band appears to shift to about 9.35 μm in the presence of acidic groups such as COOH or OH. |
| *m*-dinitro | 10.85-10.95 | Found in all *m*-dinitro compounds examined which have contained the following additional groups: $CH_3$, $C_2H_5$, OH, N =$NH_2$, COOH, CHO, $OCH_3$, $CH_3NH$, $C_2H_5NH$, $NO_2$ (trinitro). In the trinitro compounds the position of the band has been found from 10.75 to 11.0 μm. |
|  | 11.90-12.05 | Found in *m*-dinitro compounds examined where other additional groups, if any, were ortho to the nitro. Not found in *sym*-trinitro compounds but present in 2,3,4- and 2,4,5-trinitrotoluene. Absent in 3,5-dinitrobenzoic acid and 4,6-dinitro-*o*-cresol. It appears that a group meta to the nitro inhibits the band. |
| *o*-mononitro | 12.7-12.8 | Found in all mononitro compounds containing any one of the following groups ortho to the nitro: $CH_3$, $C_2H_5$, CHO, $NH_2$, COOH. Not usually found in dinitro or trinitro compounds. |
| *p*-mononitro | 9.0 | Found in all mononitro compounds containing any one of the following groups ortho to the nitro: $CH_3$, $C_2H_5$, CHO, $NH_2$, COOH. Not usually found in dinitro or trinitro compounds. |
| nitramines | 7.8 | Found in all nitramines examined. Presumed to be caused by the N-N vibration. |
| nitrates | 6.0 | Found in all organic nitrates examined. From the analysis made of methyl nitrate it is presumed that this band is caused by the symmetrical stretching vibration of the $NO_2$. |
|  | 7.8 | Found in all organic nitrates examined. From the analysis made of methyl nitrate it is presumed that this band is caused by the symmetrical deformation vibration of the $NO_2$. |
|  | 12.0 | Found in all organic and inorganic nitrates. |

c. *Magnetic Resonance.* Two forms of magnetic resonance are used; nuclear magnetic resonance and electron spin resonance.

(1) Nuclear Magnetic Resonance (NMR). When a charged particle spins, a magnetic field or dipole is produced in a manner analogous to the magnetic field produced by current flowing in a loop of wire. An external magnetic field aligns the dipoles, either with the field or 180 degrees out of phase with the field. The out of phase position, in which the north and south poles are reversed, is referred to as against the field. Alignment with the field is more stable than alignment against the field so the application of suitable frequency electromagnetic radiation will cause the dipoles which are against the field to flip into alignment with the field. The frequency at which this occurs is called the resonant frequency. Any nucleus which has a net spin can flip, but the hydrogen nucleus is the most commonly used in NMR. The hydrogen nucleus consists of a single proton, so this method is referred to as proton magnetic resonance. The frequency at which resonance occurs depends on the nucleus and the surrounding medium. The magnetic field that is used to align the protons also changes the configurations of the electrons around the nucleus in such a way that they produce a magnetic field in the opposite direction of the externally applied field. This field shields the nucleus and must be overcome before any of the protons can be flipped. The strength of the field depends on the structure of the electrons around the nucleus. If the atom is bound into a compound and valence electrons are missing, added, or being shared, the effectiveness of the shielding is changed. This alters the resonant frequency for a given magnetic field strength or alters the magnetic field strength required to flip the protons at a given frequency. Either method of scanning, varying the magnetic field strength at fixed frequency or varying the frequency at fixed magnetic field strength, can produce an NMR spectrum. In an NMR spectrum, the resonance of tetramethlylsilane (TMS) is taken as the standard and defined as zero. All twelve of the protons (hydrogen atom nuculei) in the methyl groups are in the same chemical state, so the spectra of TMS consists of one very sharp peak. The resonance peaks in the spectra of other compounds are defined in units of chemical shift, ppm's. The chemical shift of a resonant peak is the frequency of resonance of TMS divided by the spectrometer frequency in megahertz at which the analysis is being performed. Dipoles in close proximity can cause peaks to split into doublets, triplets, etc. The difference between the lines of the multiplet in cycles per second is defined as the coupling constant, J. The value of J yields useful information concerning the positions of the protons in the molecule. The area under the spectra peak is proportional to the number of hydrogen nuclei in a given state. Chemical shift, J, and the area under the peaks provide useful analytical information. Multiple peaks in the spectrum on a single compound are caused by hydrogen nuclei which are in different states. The spectrum of PETN shows one sharp peak because all the protons are in the same chemical state. TNT, however, shows two peaks, one due to the protons in the methyl group and one due to the protons in the ring. The solvent has a considerable effect on the NMR spectrum of a sample, so standard procedures must be used. An exchange takes place between the deuteriums used in the solvent and the active hydrogens in the material under test. This can cause changes in the spectrum: line shifts, intensity shifts, and the creation of new multiplet lines. Stabilized spectra are obtained after the solution has been given enough time to come to equilibrium. This is called the development time. Careful attention must be paid to ensure that the proper development time specified in the specific procedure is used. NMR spectra of unknown compounds can be compared to those of known compounds for identification purposes, or identification can be made on the basis of the analytical information obtained.

(2) Electron Spin Resonance (ESR). This test is sometimes referred to as electron paramagnetic resonance (EPR). ESR can only be performed on samples which contain unpaired electrons. An electron has an intrinsic spin which creates a magnetic dipole along the axis of rotation. In an external magnetic field, the dipoles will align either with or against the field. By applying high frequency energy at right angles to the aligning magnetic field, the magnetic moment, and thus the direction of the electron spin, can be reversed or flipped. Alignment with the field is the preferred direction. Flipping occurs when the frequency of the incident energy is equal to the frequency of precession of the electrons. Flipping does not occur in paired electrons because the opposite spin quantum state is already occupied. Scanning is done by either varying the magnetic field strength at fixed frequency or varying the frequency at fixed magnetic field strength. The former method is preferred. ESR, while of limited applicability to the energetic material field, can be used to identify paramagnetic compounds, transition metal ions, and free radicals of organic compounds. Free radical detection has been used in pyrolysis studies.

d. *Mass Spectrometry (MS)*. In mass spectrometry, molecules of the sample to be analyzed are ionized. These ions are then accelerated by an electromagnetic field. The acceleration acquired by each ion in a field of given strength will depend on the fragment's mass and charge. Most of the ions will have a charge of plus one electron unit so separation is on the basis of mass; the more massive of the ions are accelerated less than the fragments having less mass. Two types of electromagnetic fields are generally used for separation: the magnetic selector and the quadrupole. In the magnetic selector, a stream of ions is accelerated to a potential at several kilovolts and introduced into a magnetic field. The direction of the stream is at a right angle to the direction of the field. The magnetic field deflects the path of the ions into a semicircle. The radius of the semicircular path for any fragment for a given magnetic field strength is proportional to the initial or tangential velocity and inversely proportional to the magnetic field strength. A detector is placed at a point in a chosen semicircular trajectory that the ion fragments can travel. For a given initial accelerating potential and magnetic field strength, fragments of a particular mass to charge ratio will strike the detector. The spectra, plotted as a function of the mass to charge ratio, is obtained by scanning the magnetic field strength or the initial accelerating voltage. The former technique is the preferred method in low resolution mass spectrometry. High resolution mass spectrometers use both methods simultaneously to improve separation. In the quadrupole the field produced by a combination of DC and radio frequency power applied to four parallel rods is used to focus the ion fragments rather than a magnetic field. A quadrupole unit is less sensitive than a magnetic selection unit. The ions can be produced by several methods. In electron impact mass spectrometry, the sample is bombarded by electrons boiled off a hot filament.When the sample is ionized in this way organic molecules break up into fragments of various masses. The spectra obtained can be compared with a spectral library to identify unknown compounds, or analytical information from the spectra can be used to identify groups within a molecule. Electron impact of organic compounds produces many products from bond cleavage fragments to complex fragments which have undergone significant rearrangement. In chemical ionization mass spectrometry, the sample reacts with an ionizing compound to produce a positive ion. The ionizing compounds are produced by electron impact of ammonia, hydrogen, isobutane, methane, or water. The ionizing compounds produce positively charged molecules. The molecules do not fragment as much as in electron impact mass spectrometry. In negative ion mass spectrometry, electrons are absorbed by the sample molecules. Absorption may be accompanied by decomposition of the molecule into charged ions. Field ionization and field desorption mass spectrometry use high voltage electrostatic fields to produce ions. In field ionization mass spectrometry the sample in gas form is passed over a point or edge on which a potential of $10^7$ or $10^8$ volts per centimeter is maintained. Quantum tunneling by electrons in the gas to the high potential forms ions. In field desorption the sample molecules are absorbed, or deposited,on a surface. A strong electromagnetic field is applied to desorb the molecules as ions.

## 13-6. Detection and Identification of Residues.

a. Detecting and collecting the residue of explosives left after detonation is a difficult task. Detonation is a relatively complete reaction and the small amount of explosive left is scattered over a large area. The general destruction of the area also hampers the collection effort. The most likely places for the residue to be found is in the soil and other debris in the blast seat; wood, plastic, and other materials which can catch and hold the flying residue particles; and metal objects which were close to the point of detonation such as a part of the bomb. The debris from the explosion site is first microscopically examined. Many times black and smokeless powders can be identified by the shape and color of the residue. A vapor trace analyzer can be used on the debris to identify volatile explosives such as nitroglycerin. The vapor trace analyzer consists of a vapor preconcentrator and a gas chromatograph with an electron capture detector. The residue in the post detonation debris is of little chemical integrity. Solvent extraction is used to dissolve the residue for analysis. Solvent selection is important. Extraction of substances that could interfere with the subsequent analysis of the explosive is undesirable. Large amounts of solvent are used to extract even small amounts of explosive residue, so only analytical techniques which can handle trace amounts are used. The methods described in paragraphs 13-2 through 13-5 can be used. In addition X-ray diffraction patterns can be compared to patterns of known compounds for identification. Residues on hands and clothes are extracted and tested similiarly.

b. Detection and identification can be made easier by adding a taggant to explosives. One taggant system which has been proposed consists of small layered particles which are laminated to increase the probability of surviving detonation. Each layer can be one of a number of colors. The sequence of colors can be decoded to determine the explosive and manufacturer. Magnetic particles and fluorescent indicators which respond to ultraviolet radiation are added to make the taggant particle easier to find after a detonation. Another taggant system which has been proposod uses layers of magnetic material with different Curie points. The Curie point is the temperature at which ferrimagnetism ceases.

## 13-7. Detection of Hidden Explosives.

a. Explosives can be detected using a variety of techniques. Many of the methods depend on vapor detection. Two methods, gas chromatography and mass spectrometry, have already been described. Electron capture detectors work on the same principle as the electron capture detector in gas chromatography which is discussed in paragraph 13-3d. In plasma chromatography the vapors are ionized at atmospheric pressure. An electrostatic field is applied to cause the ions to drift. Heavier ions will drift slower than lighter ones due to collisions with the inert gas at atmospheric pressure. In chemiluminescence, the reaction between ozone and NO, which produces luminescence, is used. In bioluminescence, microorganisms that luminesce in the presence of explosive vapors are used. For improved detection, two microorganisms may be used, one which gets brighter in the presence of the vapor while the other gets dimmer. In laser optoacoustic spectroscopy a modulated laser beam is tuned to the proper frequency to excite the vapors of explosives in a closed cell. The energy of the excited state is changed to translational energy through collisions with surrounding molecules. The translational energy is detected acoustically.

b. Animals, such as dogs, can also be used to detect explosive vapors. Vapor detection can be defeated with hermetic sealing. However, several methods are considered practical for detection of bulk explosives. The nuclear magnetic resonance techniques can be used. X-ray contrast can also be used. In this method gamma rays are passed through the material under test. The attenuation through the material is measured, then analyzed by a computer. Thermal neutron activation can be used to detect bulk explosives. In this method a thermal neutron is absorbed by a nitrogen-14 nucleus to produce a nitrogen-15 nucleus in an excited state. The nitrogen-15 nucleus will go to ground level by emission of a gamma ray. Neutron-nitrogen reactions can be differentiated from the neutron-other element reactions by the energy of the gamma rays produced. A system to make explosives easier to detect is to add a vapor taggant to the explosive material.