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This report assesses the potential consequences of accidents involving commercial explosives. The analysis includes the identification and evaluation of existing listing and classification systems, along with any applicable criteria; review of existing regulations and codes dealing with commercial explosive materials; analysis of histories of accidents involving commercial explosives; and modeling potential consequences of overpressures and heat generation of commercial explosives. The results of this report may be used to support regulatory and non-regulatory objectives of EPA under the Superfund Amendments and Reauthorization Act (SARA) title III 1986 and theClean Air Act Amendments (CAAA) 1990.

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Office of Pollution Prevention and Toxics
U.S. Environmental Protection Agency
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February 1994

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COMMERCIAL EXPLOSIVES AND THEIR HAZARDS

1.0 Introduction

1.1 SARA Section 302

When the Superfund Amendments and Reauthorization Act (SARA) was enacted in 1986, a list of extremely hazardous substances was published under section 302 of Title III. Section 302 requires a facility that has an extremely hazardous substance (EHS) above its threshold planning quantity (TPQ) to notify the State Emergency Response Commission (SERC) that it is subject to the requirements for emergency planning.

The original list of EHSs was created using only acute toxicity criteria. The purpose of the list was to identify those substances that, if accidentally released, could cause death or serious irreversible health effects off-site. However, toxicity is not the only hazard posed by chemicals. SARA states that the Administrator may revise the list, and that such revisions "shall take into account the toxicity, reactivity, volatility, dispersibility, combustibility, or flammability of a substance."

Commercial explosives are one of the many classes of substances that may be added to the Section 302 list of EHSs under the additional criteria. In order to regulate them, EPA must distinguish extremely hazardous explosives from all other explosives. This report is intended to be used as technical support for the rulemaking by describing various ways of classifying explosives and their hazards. The report describes different types of explosives and how they are used, and provides analysis of past accidents involving explosives. It also gives a summary of existing regulations, and analysis of the quantity-distance relationship methodology on which those regulations are based.
n

EPA is aware that the Bureau of Alcohol, Tobacco, and Firearms (ATF) already has a rule on commercial explosives (27 CFR Part 55 - Commerce in Explosives). However, the ATF regulation does not require reporting of the presence of commercial explosives to local emergency planning authorities. Therefore, EPA is considering a rule that would add explosives to the list of EHSs under section 302 of SARA Title III, thereby requiring that the SERC be notified of the presence of explosives above a TPQ which EPA would set. Local Emergency Planning Committees (LEPCs) would then receive information that would enable them to carry out proper planning for the hazards associated with explosives at facilities in their communities. The regulatory history of local emergency planning is presented below.

1.2 Regulatory History

EPA originally developed the EHS list as part of the voluntary Chemical Emergency Preparedness Program (CEPP) which was designed to increase public awareness of chemical hazards in communities and focus effort on emergency planning. EPA believed that communities needed a starting point and intended that the list draw attention to the chemical substances and facilities that pose the most immediate concern from an emergency planning and response perspective. EPA recognized and emphasized that there are tens of thousands of compounds and mixtures in commerce that may pose a hazard under specific circumstances and that this list only deals with lethality or serious irreversible health effects associated with acute toxicity. The Agency chose lethality because it represents the most immediate concern in an emergency situation and is also an approximate measure of the overall toxicity of chemical substances.

In its analysis of toxic substances under SARA section 302, EPA used a 100-meter fenceline distance to provide a guideline for community emergency planners to use in setting priorities for planning for hazards in the community. The 100-meter fenceline distance has also been used by the Occupational Safety and Health Administration (OSHA) in its analysis for thresholds for chemicals listed in its Process Safety Management Standard and by the state of Delaware for thresholds under its prevention regulations. EPA recognizes that this distance may not be appropriate for protection of emergency responders. There is no absolute distance that would guarantee the safety of first responders in every situation.

Several commenters on the rulemaking for the EHS list noted that physical/chemical hazards such as flammability or explosivity may also lead to serious consequences, including death and irreversible injury. In an official inquiry to the Agency in 1987, Senator Frank Lautenburg also noted concern for hazards other than toxicity and asked that EPA focus on other hazards. The Agency agreed and noted its intent to evaluate hazards other than toxicity in the future.

A Physical/Chemical Criteria Workgroup was formed at EPA to address the concerns raised by Senator Lautenburg and others and to focus on the problem of identifying materials that are hazardous based upon their physical/chemical properties and could thereby be candidate EHSs. The Workgroup initially considered the hazards referred to in the Act and determined that they fell into two general categories: hazards related to toxic properties and hazards related to physical/chemical properties. The characteristics of reactivity, volatility, dispersibility, combustibility, and flammability, mentioned in the Act, are related to a variety of physical/chemical properties; the Workgroup chose to focus on the physical/chemical properties that lead to the greatest potential hazards to people.

1.3 Approach

Hazards associated with physical/chemical properties are primarily based on two phenomena that can cause serious personal injury or death. These phenomena are the result of the release of energy from highly reactive or flammable chemicals and are identified as overpressures from blast waves and thermal radiation from fires. Overpressures result from nearly instantaneous energy release, or detonation, while thermal energy is released during combustion, which occurs more slowly. Since explosive chemicals are highly reactive substances that can detonate and create overpressures, and flammable chemicals can burn and produce thermal radiation, the Workgroup focused on explosives and flammable chemicals as chemicals of concern.

The Workgroup elected to segregate the chemicals for review into separate categories for flammables, explosives, and reactives for purposes of analysis and possible regulation even though it was recognized that there may be overlap of the consequences; e.g., the detonation of a flammable material may yield the same results as the detonation of a commercial explosive. However, the Workgroup wanted to determine which parameters distinguish extremely hazardous explosives from all other explosives, extremely hazardous flammable substances from all other flammables, and so on. This report focuses on commercial explosives. Separate documents will address the consequences of accidents involving flammable materials, non-commercial explosives, and other reactive chemicals.

The Physical/Chemical Criteria Workgroup investigated several possible approaches to characterizing explosive materials, none of which provided any clear-cut means of placing certain commercial explosives into extremely hazardous categories. The data analyzed are presented below. Section 2 describes physical and chemical characteristics. Section 3 contains information on manufacture, handling, use, and storage of explosives. Section 4 presents data on past accidents, Section 5 describes existing regulations, and Section 6

presents methodology for determining affected distances and results of consequence analysis based on the methodology.

2.0 Characteristics of Explosive Materials

An explosion is defined as a sudden and violent release of energy (Lees 1980) accompanied by high pressure gases. The more rapid the release and the greater the available energy, the more violent the explosion (U.S. DOT 1988). Most of the available energy from an explosion is converted into some form of mechanical energy, manifesting itself in the form of blast waves, fragmentation, and ground shock. Of these damage effects, blast overpressure contributes the greatest damage in chemical explosions. The remaining portion of the explosive energy remains in thermal form and is of concern because of its fire hazard. Typically, the damage associated with the pressure wave is far greater such that the thermal wave can be ignored (Brasie and Simpson 1968). Blast waves from accidental explosions can cause damage to people and property by subjecting them to transient crushing pressures and winds. Relatively simple concepts have been used effectively to correlate blast wave properties with damage. These concepts and the results of consequence analysis based on them are discussed in Section 6 and Appendices A and B.

Explosive materials typically are classified as either "high" or "low" explosives or blasting agents. "High" explosives are defined by ATF as those materials that detonate if ignited, shocked, or subjected to heat or friction. Detonations result from exothermic chemical reactions that proceed at supersonic velocities, generating large volumes of high pressure gas and heat instantaneously, even though no confining vessel or structure exists. In an explosion caused by a high explosive, the rate of energy release is particularly rapid and the shock wave has a very short duration. Blasting agents also detonate, but are much less sensitive than high explosives. In contrast, "low" explosives deflagrate, or burn at subsonic velocities. Some examples of high and low explosives and blasting agents, and their manufacture, handling, and use, are discussed in Section 3 below.

A deflagration generates lower pressures and is less destructive than a detonation. A deflagration reaction propagates through the unreacted material via a diffusion mechanism rather than a shock wave. However, under the right conditions (e.g., confinement) some low explosives (or substances not normally considered explosives) may detonate; conversely, some high explosives may burn if ignited. According to several general references reviewed, factors that affect whether a deflagration or detonation may occur, or that affect the transition from deflagration to detonation (or detonation to deflagration) include:

- Type and intensity of initiation. Explosives that usually detonate may burn under carefully controlled conditions involving gentle ignition to avoid shock-wave formation, and propellants that normally burn quietly and controllably may detonate if initiated by a high-pressure, high-intensity shock wave (Kirk-Othmer 1980).

- Physical conditions, including:

  -- Particle size. Finely divided material is more likely to detonate (Kirk-Othmer 1980).

  -- Thickness of layers of explosive. A large mound of material is more likely to detonate than a thin layer (Kirk-Othmer 1980); there is a "critical thickness," which varies by substance, below which a detonation cannot propagate (Medard 1989).

-- Diameter of cylinder of explosive. There is a critical diameter which is the minimum diameter of an explosive charge at which detonation can occur; it is texture dependent, and may be very large for some materials (e.g., ammonium nitrate) (Meyer 1987).

- Confinement. Materials under heavy confinement are more likely to detonate (Kirk-Othmer 1980). Note that some high explosives are designed so that they will only detonate under confinement (Meyer 1987).

- Mass of explosive material. For some unconfined explosives, there is a critical mass below which the material will be consumed by deflagration before detonation can occur, and above which a detonation may be initiated by the heat of the deflagration (Medard 1989).

In general, conditions that minimize energy losses and promote the build-up of a shock wave increase the likelihood of a deflagration becoming a detonation (Kirk-Othmer 1980). According to Medard (1989), the transition from a deflagration to a detonation is not continuous, with the deflagration accelerating until it reaches the velocity of a detonation, but is always a discontinuous leap.

3.0 Manufacture, Handling, Use, and Storage of Commercial Explosives

The manufacture, handling, use, and storage of high and low explosives as well as blasting agents are briefly described in this section. Representative explosives of each type are used as examples. This section is intended to provide an overview of the explosives industry and current industrial practices.

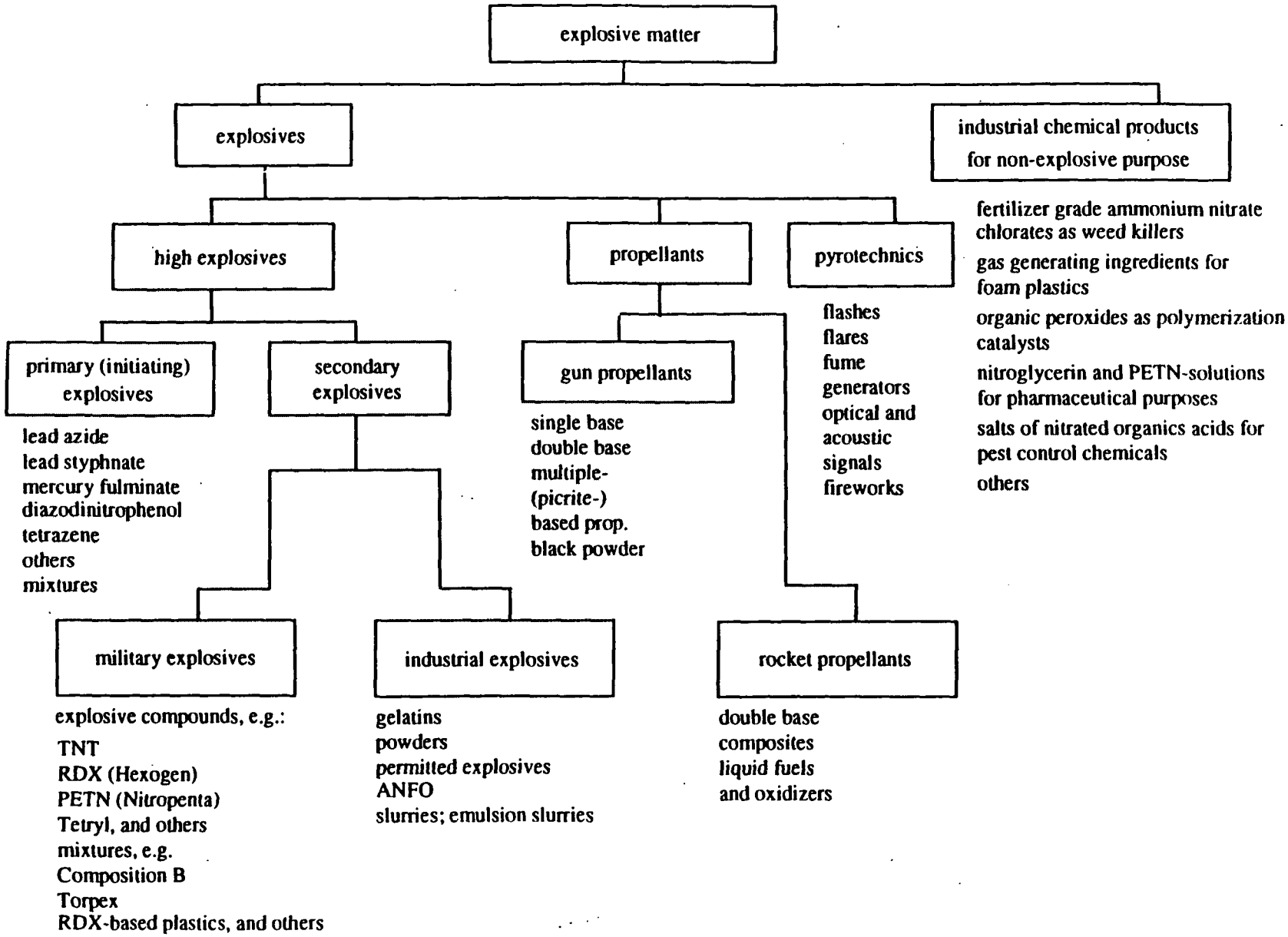
Explosives have been in use for more than ten centuries; the ancient Chinese used a crude form of black powder in early missiles and firecrackers. Explosives were used during the Renaissance to increase quarrying yields and black powder served as the chief propellent for early muskets and cannons. Current uses of explosives include mining, quarrying, construction, fireworks, and military uses. According to the Bureau of Mines (1991), total consumption of industrial explosives and blasting agents in the U.S. in 1990 was 4.7 billion pounds. The coal mining industry used 3.2 billion pounds, or 68 percent of the total (Bureau of Mines 1991). These explosives were produced by 24 companies. Blasting agents (discussed in Section 3.3 below) account for by far the greatest volume of industrial explosives; most blasting agents are based on ammonium nitrate. Exhibit 1 presents a breakdown of explosives by type and major applications.

3.1 Manufacture, Handling, and Use of High Explosives

The Bureau of Mines (1991) reports use of high explosives in coal mining, quarrying and nonmetal mining, metal mining, construction work, and other (unspecified) uses. Sales of industrial high explosives totalled 152 million pounds in 1990. Quarrying and nonmetal mining was reported to use the largest quantity of high explosives, 61 million pounds, or 40 percent of the total, followed by construction, with 40 million pounds, or 26 percent of the total (Bureau of Mines 1991).

High explosives are classified as primary or secondary based upon the explosive's sensitivity to energy inputs. Primary explosives, such as lead azide or mercury fulminate, are sensitive to small energy inputs caused by friction, shock, or static electricity (i.e., it takes a relatively small amount of energy to cause these explosives to detonate). A small energy input generates a shock wave which moves through the unreacted explosive. Secondary explosives have faster detonation rates and produce a larger energy output than do primary explosives. However, they require a larger energy input in order to initiate detonation (Kirk-Othmer 1980).

Exhibit 1. Explosive Materials and Their Application



Source: Meyer, R., Explosives, 3rd ed., Essen, Germany: WASAGCHEMIE, 1987.

Because of their sensitivity, primary explosives are used as initiator explosives to detonate secondary high explosives, which require a much larger energy stimulus. Primary explosives are used in detonators, blasting caps and percussion primers. A detonator usually contains a primary explosive, typically lead azide in quantities less than a gram, and several secondary explosives, as needed. The function of a detonator is to magnify a tiny energy input in a chain reaction which leads to the quick release of energy stored in secondary explosives (Kirk-Othmer 1980). A typical detonator is shown in Exhibit 2.

According to the United States Bureau of Mines (Cantrell 1991), the majority of high explosives manufactured in this country are nitro explosives. Nitroglycerine, a nitro explosive in common use in the explosives and medical industries, is discussed here as an example of a secondary high explosive. Information on its manufacture, handling, and use is presented below. Early references to nitroglycerine date back some 170 years. Alfred Nobel used this compound in his original formulation for guar dynamite, a mixture of nitroglycerine and kieselguhr, an inert base. Today, nitroglycerine is used as a prescription drug, as well as an explosive; it is used as a vasodilator and to relieve angina pectoris.

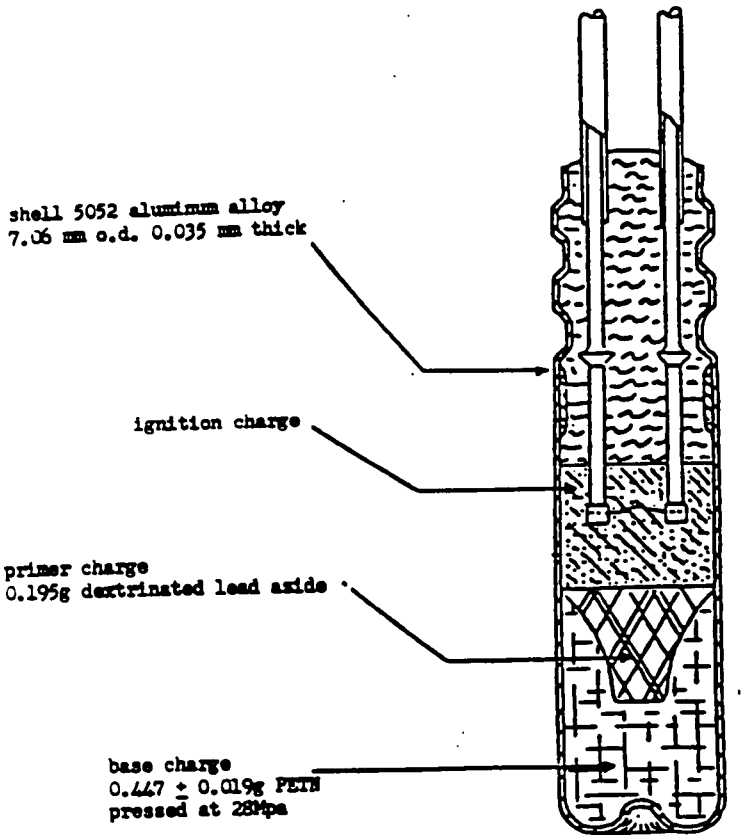
Nitroglycerine is very stable, and it does not decompose at room temperature. At higher temperatures, above 60°C, it begins to autocatalyze into its decomposition products: carbon monoxide, carbon dioxide, nitric oxide and water. Nitroglycerine burns rather than explodes if present in small quantities or if unconfined. Microbubbles of air present in liquid nitroglycerine increase its sensitivity to shock, since the shifting of bubbles increases the kinetic energy in the system. Nitroglycerine's sensitivity to shock is unusual in a secondary explosive. It is only employed when desensitized by other compounds, often triacetin, dibutyl phthalate, or nitrocellulose (Kirk-Othmer 1980).

The earliest methods for manufacturing explosives were batch methods, used to prepare a large quantity of an explosive at one time. The dangers of handling large amounts of explosives led to the development of continuous production methods and the eventual phase-out of batch processes. Continuous methods result in production of quantities of explosives that allow for safe handling. Production is continuous with the explosives being removed from the reaction immediately after synthesis. Two methods are used to manufacture nitroglycerine: the Biazzi Continuous Process and the Nitro Nobel Injector Process. Variations of these two methods may be used to synthesize other nitro explosives as well (Kirk-Othmer 1980).

In the Biazzi Continuous Process, oleum, nitric acid, and glycerol are metered into a nitrator. An emulsion quickly forms and a portion of the emulsion passes over cooling coils at 10-20°C. Nitroglycerine is separated from the emulsified working solution and spent acid is sent through a mechanical centrifuge and additional nitroglycerine is separated. Both the nitroglycerine and acidic working solution are washed with water until stability is assured, and a non-explosive emulsion of water and nitroglycerine is formed for temporary storage (Kirk-Othmer 1980).

There are many safety features built into the Biazzi Process. The emulsions formed ensure that the nitroglycerine is insensitive; a 3:1 water to nitroglycerine emulsion is stable and unlikely to explode. Production reactors are of highly polished, stainless steel, and operations are fully automated. Fail-safe features include water spray jets, signaling devices, and automatic shut-down. Control features include an overflow pipe and the ability to drown a runaway reaction with water to bring it under control (Kirk-Othmer 1980).

EXHIBIT 2. NO. 8 DETONATOR



Source: U.N. 1986. Recommendations on the Transport of Dangerous Goods, Tests and Criteria.

In the Nobel Process, warm glycerol is slowly injected into a cooled stream of nitric acid. The flow of glycerol is regulated by a vacuum generated by the flow rate of the acid. The glycerol quickly reacts, an emulsion forms, and the solution is immediately cooled. After cooling, the nitroglycerine is separated, washed, and temporarily stored as an emulsion. Safety features for this method are the same as those built into the Biazzi Process. In both processes detonation traps are used to prevent propagation of an accidental explosion throughout the entire reactor.

Pharmaceutical grade nitroglycerine can be manufactured using either the Biazzi or Nobel process. After synthesis, it is stabilized and mixed so that its concentration ranges from 1 to 20 percent pure nitroglycerine, in combination with inert chemicals, forming a non-explosive mixture (Wilcox 1991).

High explosives have many uses ranging from mining and quarrying to construction, seismology and petrogeology. Primary explosives are very sensitive, and they are generally not handled until placed in blasting caps and detonators. Secondary explosives have a wide range of uses; they are used in blasting caps and to sensitize blasting agents. Secondary explosives (e.g., nitroglycerine) may also be used in propellants (see Section 3.2 below). Modern dynamites are made from high explosives, usually nitroglycerine and an active base nitrocellulose, which contribute to the force of the explosion. Most dynamites are variations of straight dynamite or gelatin dynamite. Straight dynamite is manufactured by absorbing an active base in nitroglycerine. Gelatin dynamites are made from nitroglycerine and nitrocotton. Ammonium nitrate (which is widely used in blasting agents) is also often used in dynamites, in combination with nitroglycerine and various fuels. Dynamite is classified by strength according to its equivalence to or percentage of nitroglycerine (Wallace 1991). Dynamite is supplied in various cartridge sizes as needed to perform particular demolition and mining tasks. Cartridges are stored and shipped in fiberboard crates usually weighing fifty pounds. Large cartridges can weigh in excess of 50 pounds and are safely shipped uncased.

Storage facilities for explosives must meet the requirements for safe distances as specified in the American Table of Distances for Storage of Explosives established by the Institute of Makers of Explosives and adopted by ATF (see Section 6.2.2). These storage sites are required to be clearly marked with placards indicating the presence of explosive material.

Transportation of explosives is strictly regulated by DOT. Operators of vehicles transporting explosives are required to meet the qualifications specified in 49 CFR 391, Subpart B. High explosives must be transported in a magazine or a day box, which contains only enough explosive for one day, as regulated by 49 CFR 174. High explosives are currently classified by DOT as Division 1.1 or 1.2 under the international classification system, or Class A under the old system (see Section 5.1) and transportation of these explosives is regulated under 49 CFR 173.61-173.91. Explosives transported on land may not contain more than 60 percent liquid explosive ingredient; explosives transported by water may contain no more than 75 percent. DOT lists general packing requirements for high explosives and specific regulations for certain high explosives (e.g., nitroglycerine, nitroguanidine and lead azide). All packages and transporting vehicles must be clearly identified as containing explosives and possess the appropriate markings (i.e., labels and placards).

High grade nitroglycerine, a liquid high explosive, is regulated by DOT as Division 1.1 under the international classification system, or Class A under the old system (see Section 5.1). Pure (undesensitized) nitroglycerine is forbidden for transportation. Pharmaceutical grade nitroglycerine, however, passes the DOT required No. 8 Blasting Cap and Impact Fire Tests for propagation; it is not classified as an explosive.

3.2 Manufacture, Handling, and Use of Low Explosives

Low explosives deflagrate rather than detonate, that is, they burn at a rate that is subsonic, or less than the speed of sound. Propellants, used in guns and rockets, and pyrotechnic compositions, used, for example, in fireworks, flares, and theatrical devices, are examples of materials that may be classified as low explosives.

Propellants are mixtures of chemicals, including fuels and oxidizers, that function by burning to produce large volumes of gas at controlled rates. Propellants for guns are usually based on nitrocellulose; liquid explosives such as nitroglycerine and crystalline explosives such as nitroguanidine may also be included in the composition. Rocket propellants may be based on nitrocellulose and a liquid explosive or may be polymer-based (Kirk-Othmer 1980).

Pyrotechnic compositions are made up of a fuel and an oxidizer; reactions generally take place independently of any external oxidizer. The oxidation-reduction reactions involving pyrotechnic compositions produce little or no gas, in contrast to propellants. Magnesium and aluminum powders are the most commonly used fuels; alkali metal salts may be used as oxidizers. Fireworks, which are made from pyrotechnic compositions, are produced at approximately 100 plants nationwide that employ no more than 1,000 workers (Conkling 1986). Common or consumer fireworks (e.g., firecrackers) are regulated during their manufacture by ATF; however, they are not regulated as explosives by ATF in finished form. They are regulated in transportation by DOT as explosives in Division 1.4. Special or display fireworks are regulated by ATF both in manufacturing and in finished form. Pyrotechnic compositions also may be used as prime igniters for more powerful high explosives, as in a safety fuse (Kirk-Othmer 1980).

Black powder, which may serve as a propellant and fuse powder in fireworks, is classified by the ATF as a low explosive; however, it is listed as a high explosive under DOT regulations. Black powder is a mixture with a composition that has changed little in over 1,000 years of use. According to the Bureau of Mines (1991) report on consumption of industrial explosives and blasting agents, sales of black powder are "minor"; black powder sales have not been reported to the Bureau of Mines since 1971.

Manufacturing procedures for low explosives vary widely. Propellants of various types include a variety of compositions; manufacturing methods include both batch and continuous processes, and may be very different, depending on the propellant and its use.

Black powder, discussed above, is manufactured by only one company in the United States, Goex, Inc. of Moosic, Pennsylvania. Black powder is essentially a mixture; therefore, its properties rely on the blending of the ingredients. Either potassium nitrate or sodium nitrate is ground with charcoal and sulfur. The resulting mixture is dried, pressed and packaged. The process is highly automated. Water deluge systems are in place as a safety measure. If ultraviolet light sensors detect a flash, deluge systems are activated.

ATF regulations limit the quantities of explosive materials allowed in the process area of a special fireworks manufacturing plant to quantities reasonably necessary for a day's manufacturing or assembly operations. No more than ten pounds of flash powder and 500 pounds of other explosive materials may be kept in any process building or area. All explosive powders and mixtures, unfinished special fireworks, and finished fireworks must be stored in approved magazines at the end of the day (magazines are any buildings or structures used for storage of explosives) (Conkling 1986).

Burn tests on common fireworks conducted in 1983, in which 15,000 pounds of fireworks in steel shipping containers were burned in a wood and kerosene fire, indicated that although the fireworks burned, there was no detonation or pressure build-up strong enough to cause fragmentation of the container. Burn tests in 1985 on special fireworks, however, showed that certain types would detonate under confinement or in bulk quantities (quantities that might be found in manufacturing operations). The materials that detonated were flash powder, which is usually a mixture of an oxidizer (potassium perchlorate) and two fuels (sulfur and aluminum powder); finished "salutes", which consist of a cardboard casing containing about 57 grams of flash powder, with a 28-gram propelling charge of black powder at the bottom; and "stars", which usually consist of a mixture of an oxidizer (typically potassium perchlorate, potassium chlorate, or potassium nitrate), one or more fuels (e.g., charcoal, aluminum, or a carbon-containing gum or resin), and a color-producing agent. Tests on bulk quantities of finished "color shells" showed rapid burning, but no detonation or mass explosion (Conkling 1986).

Low explosives are categorized and regulated by DOT as Division 1.3 under the international classification system, or Class B under the old system (see Section 5.1 below). Individual pyrotechnic compositions (e.g., some flash powder compositions) may be classed as high explosives (1.1) depending on test results. Shipping containers and methods are listed in 49 CFR 173.88-114.

3.3 Manufacture, Handling, and Use of Blasting Agents

Blasting agents are mixtures of chemicals which, when used for blasting, do not detonate when initiated by a No. 8 Blasting Cap, according to 49 CFR 173.114a; blasting agents must also pass five other tests as required by DOT. All blasting agents must be approved as such by the U.S. Bureau of Mines Associate Director for Hazardous Materials Regulation. As noted earlier, blasting agents are in use in much larger quantities than other types of explosives. Ammonium nitrate and fuel oil mixture (ANFO) is by far the most common blasting agent. Roughly 85 percent of all blasting agents are variations of this mixture. The ease of use and high stability of ANFO has led to its replacement of dynamite as the most widely used blasting agent. Approximately 16 billion pounds of ammonium nitrate for all purposes was manufactured in the U.S. in 1989 (C&E News 1990). According to the Bureau of Mines (1991), sales of ammonium nitrate blasting agents included 3.2 billion pounds of unprocessed ammonium nitrate and 0.68 billion pounds of ANFO.

To manufacture ammonium nitrate, nitric acid is neutralized with ammonia, to yield the ammonium nitrate salt either in the form of prills or granules. The prills are obtained by spraying concentrated, liquid ammonium nitrate downward in a large tower. As the droplets fall and are cooled, they form spherical solids known as prills. Granulation is achieved in a process similar to the prilling process; however, a smaller volume of air is used and one-eighth inch granules are produced. Ammonium nitrate fuel oil is a simple mixture of 94 percent ammonium nitrate in unmilled porous prills, 6 percent absorbed fuel oil, and an anticaking agent.

Blasting agents have replaced dynamite as the explosive of choice for most uses, including mining, construction, and demolition. Greater safety can be maintained with blasting agents than dynamites because they may be transported as components and prepared on site. Blasting agents are frequently mixed on site and pumped as needed by pneumatic devices. Ammonium nitrate, the most widely used blasting agent, is easy to handle and inexpensive. Emulsions, slurries, and gels can also be classified as blasting agents, if they pass the testing criteria as specified by DOT in 49 CFR.

In 1947, an explosion of ammonium nitrate in a cargo ship, believed to be caused by the presence of flammable organics, led the Fire Prevention Bureau of Texas to issue the first storage guidelines for

ammonium nitrate. The U.S. Bureau of Mines concurred with these findings and national guidelines were adopted. If stored by itself, ammonium nitrate is quite stable. Ammonium nitrate must be considered a high explosive when in the presence of a priming explosive, confined at elevated temperatures, or found in the presence of readily oxidizable compounds. ATF specifies separation distances for ammonium nitrate (by itself) and blasting agents from explosives and other blasting agents (ATF 1990).

Transportation of blasting agents, Division 1.5 under the international classification system, is regulated by DOT (49 CFR 114a). Blasting agents may be stored in rigid containers which can withstand a four foot drop onto a concrete surface or a package (e.g., bag or tube) which can withstand three consecutive four foot drops. Blasting agents may not be transported in tanks, tankers or tank cars unless exempted by the Office of Hazardous Materials Regulation.

3.4 Storage of Explosives

ATF regulations include specifications for storage magazines, as well as specifications for storage distances. Type 1 (permanent) and type 2 (mobile and portable) magazines are designed for high explosives; other types of explosives may also be stored in them. These magazines must be bullet-resistant, weather-resistant, theft-resistant, and fire-resistant, except in the case of indoor type 2 magazines where the magazine itself need only be fire-resistant and theft-resistant if the building in which it is housed adequately provides bullet- and weather-resistance. Both of these magazine types must be adequately ventilated. Type 1 magazines are typically igloo, Army-type, tunnel or dugout designs and must have a bullet-resistant roof (or 24-inch earthen mound covering the top, sides, and rear) and no other openings besides entranceways and those for ventilation. Type 2 magazines are mobile or portable indoor and outdoor facilities for explosive storage. Common examples include boxes, trailers, and semi-trailers. Inside storage of high or other explosives in type 2 magazines may not exceed fifty pounds and magazine location may not be within a residence or dwelling. Type 3 magazines are portable outdoor magazines for the temporary storage of high explosives, and also may be used for low explosives and blasting agents. Often referred to as "day-boxes," these magazines must be fire-, theft-, and weather-resistant and, when containing explosives on-site, be within the line-of-vision of the blaster (ATF 1990).

Type 4 magazines are indoor or outdoor magazines for the storage of low explosives, and also may be used for blasting agents, and electric blasting caps not subject to mass detonation. Typical structures meeting type 4 requirements include army-type structures, tunnels, dugouts, trailers, semi-trailers, or buildings. These magazines must be constructed so as to be fire-, theft-, and weather-resistant (if outdoors or if the building itself fails to provide adequate weather protection).

Type 5 magazines are permanent or portable, indoor or outdoor, theft- and weather-resistant structures for the storage of blasting agents. Typical structures that serve as type 5 magazines are igloo or army-type structures, dugouts, bins, trailers, semi-trailers, bulk trailers, tank trailers, or other mobile containers. Indoor type 5 magazines may not be located in a residence or dwelling and can not contain more than fifty pounds of blasting agent (ATF 1990). Magazines of Types 1 through 4, for high and low explosives, are normally smaller and of heavier construction than Type 5 magazines for blasting agents and are brightly colored (U.S. Fire Administration).

Additional information on explosives magazines may be found in Appendix C. Storage distances for explosives are discussed in Sections 5.2, 6.2.2, and 6.2.3.

4.0 Past Incidents Involving Commercial Explosives

This section discusses accidents involving commercial explosives that have been reported in EPA, DOT, and other hazardous materials databases and in Bureau of Mines reports. This analysis of past accidents was undertaken because the lesson of Bhopal, India, cautions that knowledge of potentially catastrophic situations may be of value even though the occurrence of a large accident is rare. Of special consideration would be any emergency planning activities that require only minimal effort, but could provide maximum benefit in case of a serious accident.

4.1 Explosives Accidents Reported in EPA's AHE Data Base and Other Hazardous Materials Databases

The Acute Hazardous Events Data Base (AHE/DB) was developed by EPA to provide a historical perspective on accidents involving the release of hazardous substances in the United States (EPA 1988). The 1988 version of the database includes data on 5,827 events that occurred between the 1960s and 1987 (the majority of the incidents appear to have occurred in the 1980s). The AHE database lists approximately 36 incidents resulting in fires or explosions that may have involved commercial explosives.[1] This database does not appear to provide clear evidence that commercial explosives should be considered extremely hazardous based solely on their accident history. It does show that commercial explosives have been involved in accidents that resulted in death and injury in the past.

A recent accident not included in the AHE/DB occurred in Kansas City, MO, on November 29, 1988. In this incident, six fire fighters were killed in an explosion of a blend of ammonium nitrate and fuel oil (ANFO). Two other firefighters about a quarter of a mile away received minor injuries; the windshield of their car was blown in. The explosion broke windows far from the site. The explosion involved about 50,000 pounds of ANFO, a blasting agent, stored in two trailers at a construction site. Most of the stored ANFO was mixed with aluminum pellets, which increase the explosive power of ANFO. The trailers were Type 5 magazines specifically designed to transport and store blasting agents. The trailers were less than 100 feet apart; according to ATF regulations, they should have been 224 feet apart. The fire that led to the explosion is believed to have been caused by arson. The firefighters may not have been aware that the trailers were explosives magazines containing blasting agents (U.S. Fire Administration).

There have been several accidents in the past involving fireworks manufacturing plants. An explosion in a fireworks plant in Oklahoma in 1985 killed 21 workers and injured five. Although the exact cause of this explosion could not be determined, it is probable that it was caused by a quantity of spilled flash-and-sound powder (a combination of potassium perchlorate blended with aluminum or sulfur) that was ignited by friction. The initial explosion caused a series of explosions that leveled most of the facility and were felt 13 miles away (Kyte 1985).

The Fatal Hazardous Materials Accidents Database, developed by Resources for the Future, contains information on fatal accidents which involved the release of hazardous materials. Data were obtained from

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[1] The identities of the substances involved are not always known. In some cases the substances reported may be considered commercial explosives under certain conditions but not under others. For these reasons, the total number of incidents involving commercial explosives is an estimate.

encyclopedias, almanacs, books, reports, articles, newspapers and computer files (including AHE/DB). The database contains reported accidents which occurred during industrial production, storage, handling and transportation of hazardous materials. Only those accidents involving at least one reported death for U.S. accidents and five reported deaths for accidents outside the U.S. are included. Every such event between 1945 and 1991 is in the database, with the following exceptions: mining or mineral extraction accidents; handling, transportation, and storage of munitions, fireworks, and manufactured explosives (manufacture of such products was counted); and transmission and distribution of natural gas (i.e., pipelines).

There are 1,068 accidents in the database, of which 758 occurred in the U.S. Explosions of materials described as explosives (not including explosions of flammable substances) at fixed facilities accounted for 38 of these reports, with 446 to 500 associated deaths and 769 to 785 injuries. The database does not distinguish between on-site and off-site fatalities. Fireworks, pyrotechnics, and firecracker explosions comprised 11 of the explosion accidents. Additionally, 17 of the 38 accidents took place in the U.S. (6 of these were also reported in the AHE/DB).

The Major Hazard Incident Data Service (MHIDAS) is a world-wide databank maintained by the Safety and Reliability Business (SRD) of AEA Technology and the UK Health and Safety Executive. It is continually updated, and records and analyzes incidents involving hazardous materials that resulted in or had the potential to produce an off-site impact. Off-site impact includes incidents which involved evacuation and those which could, but for mitigating circumstances, have led to evacuation, casualties, or damage to property or the environment.

MHIDAS currently contains information on over 4,000 incidents. There were 193 accidents involving explosives, which includes munitions, explosives used in construction, fireworks, and pyrotechnics. Exhibits 3 and 4 describe some of the most serious of these 193 incidents. Of the 15 explosives incidents in Exhibit 3, four occurred in the U.S.; all U.S. incidents were transportation related. Exhibit 4 contains 16 fireworks and pyrotechnics incidents, all related to factories or transportation, including five in the U.S.

4.2 Transportation Accidents

Another database containing information on accidents involving hazardous substances is the Department of Transportation's (DOT) Hazardous Materials Information System (HMIS). The HMIS database contains transportation accident reports from 1971 through 1991 involving release of DOT regulated hazardous materials, including high explosives, low explosives, minimum hazard explosives (e.g., common fireworks), and blasting agents (reports for blasting agents are primarily from the 1980s and 1990s; the blasting agent hazard class did not exist earlier). A summary of information on the explosives incidents in the database is presented in Exhibit 5. Some general findings from the database include:

- The database contains reports on 351 incidents involving explosives for the twenty year period, an average of more than 17 reports per year. An explosive "incident" may involve a spill, a fire, an explosion or a combination of these.

- In these incidents, there were 10 deaths reported, no major injuries, 130 minor injuries, two evacuations, and over five million dollars in damages.

- Most high explosives incidents (approximately 90 percent) were only spills and did not lead to fires or explosions; a somewhat higher percentage of low explosives incidents involved fires, but the difference is probably not significant.

- The deaths and injuries reported resulted from only a few incidents, primarily involving high explosives (eight deaths and 121 injuries in six incidents).

- Blasting agents were not involved in any deaths, injuries, fires, or explosions.

No conclusion could be drawn regarding the causes of incidents or ways to avert them because no particular mode of release of materials appeared more often than any other or was linked to fires or explosions.

A report from the National Transportation Safety Board (NTSB) suggests that a single incident, rather than a historical pattern, can contribute to the regulation of explosives. This report describes an explosion of 2,600 bombs being carried by train through a sparsely populated area of Arizona. The explosion created a huge crater, scorched the desert for a quarter mile in all directions, and blew parts of railcars up to three quarters of a mile away. NTSB analysis indicated that the accident was probably initiated by sparks from the brakeshoes which started a fire in floorboards of one of the boxcars containing bombs. As a result of this accident, the Federal Railroad Administration issued a rule including requirements for special types of brakeshoes and steel subfloors or spark shields in railcars carrying Class A explosives, as well as additional inspection requirements for such cars

4.3 Blasting Accidents in Mines

Death and injuries due to blasting accidents are not uncommon in the coal and metal mining industries. Data on blasting accidents in coal mining indicate that deaths and injuries usually occur during planned rather than accidental explosions and do not affect the surrounding communities. Use of explosives and breaking agents in underground and surface coal mining and coal preparation plants caused a total of 64 deaths and 1,109 nonfatal injuries from 1971 through 1992. These data are presented in Exhibit 6. This is an average of 3 deaths and 50 nonfatal injuries per year (MSHA 1992). As Exhibit 6 indicates, the death and injury rate has declined since the '70's.

Blasting accidents are responsible for a relatively small percentage of the total number of deaths and injuries in the coal mining industry. Blasting accidents accounted for 2.3 percent of the annual average of 134 fatalities and 0.3 percent of the annual average of 20,014 nonfatal injuries in coal mining from 1971 through 1984 (Peltier, Fletcher, and D'Andrea 1986).

The data indicate that the great majority of the blasting accidents that occur were the result of human error and were not due to faulty or unsafe products (Peltier, Fletcher, and D'Andrea 1986). Abstracts from 297 accidents that occurred from 1978 through 1984 indicate that most accidents were due to failure of the blast area security system, i.e., failure to clear the blast zone, failure of personnel to follow instructions, inadequate guarding, and failure to retreat to a safe location and/or take adequate cover. This was especially true of underground coal mining, where 166 of 208 incidents were caused by some failure in the blast area security system (Peltier, Fletcher, and D'Andrea 1986).

EXHIBIT 3
INCIDENTS INVOLVING EXPLOSIVES

Incident Location,Date	Cause/Description	Death, Injuries, Damage
Thung Maphrao, Thailand 02/15/91	Truck carrying dynamite tipped at road. Lighted cigarette from looting villagers suspected explosion cause. 50 houses destroyed.	171 killed >100 injured
Garam Chashma, Pakistan 11/16/89	Ammunition depot explosion threw rockets and shrapnel onto nearby homes.	40 killed >20 injured
Gwynedd, UK 06/14/88	Nitroglycerine blast destroyed nitroglycerine mixing building and effluent dispersal building. Shops damaged up to 0.8 kilometers away, blast heard 3.2 km away.	2 killed, 8 injured
Arzamas, USSR 06/04/88	Explosion of 3 box cars (120 metric tons) of industrial-type explosive produced a crater 26 meters deep and 53 m wide. 150 homes destroyed. Improper segregation and high ambient temperatures suspected causes.	73 killed 230 injured 600 evacuated
Chaguaramas, Trinidad 04/26/88	Mountain brush fire engulfed ammunition bunker. Explosion levelled everything within 305 meters; nearby jeep and fire truck thrown 200 meters.	6 killed 15 injured
Islamabad, Pakistan 04/10/88	Series of explosions in a ammunition dump threw munitions, including rockets, bombs, shells, and shrapnel (up to 10 kilometers) into town.	>100 killed >1000 injured
Grantsville, UT 07/30/86	Three detonations initiated during unloading of four metric tons of explosives produced a hole 14 meters deep and threw debris 1.6 kilometers.	5 killed
Checotah, OK 08/04/85	Collision between munitions vehicle and car and subsequent rupture of fuel tank resulted in three bomb explosions. Produced a crater 8 meters x 10 meters.	49 injured 6,000 evacuated
Deh-Boz Org; Iran 08/19/80	Welding on door of construction firm explosives store resulted in fire and subsequent explosion of 0.5 metric ton of contents.	80 killed 45 injured
Shelbyville, KY 01/29/81	Overturned truck carrying explosives caught fire and exploded. Explosion felt 40 kilometers away.	3 fire fighters 200 yards away hurt
Bangkok, Thailand 11/16/80	Munitions factory accidents, including poor rocket fuse connection, led to series of explosions at ordnance depot. Most victims were local families. Area 500 m^2 levelled.	54 killed 353 injured
Tauriano, Italy 10/12/79	Flying debris from explosion in a factory making dynamite and emptying shells killed five, including one 11-year old child offsite. Buildings hundreds of meters away were damaged; electric lines down, resulting in Tauriano power loss.	5 killed, 19 injured
Roseville, CA 04/28/78	Explosion on ammunition train caused fire and subsequent explosions over a period of seven hours. Railyard, 6,000 unfused bombs, and 24 buildings destroyed. Area of 4.8-kilometer radius evacuated.	52 injured, 2000 evacuated, $10 mil.damage
Iri, South Korea 11/12/77	Watchperson falling asleep knocked over candle which caught fire and spread to cargo load of dynamite. Explosion of load occurred at a crowded station. Caused damage to buildings and produced 15 meter crater.	57 killed 1300 injured 10,000 homeless
Seoul, South Korea 08/14/70	Explosion of 50 40kg bags of gunpowder exploded during attempted disposal. Explosion leveled 2 houses and damaged as many as 200 houses up to 2 km away. Fire consumed over 3,000 drums of chemicals.	9 killed (5 off-site), 59 injured, 1,500 evacuated

Source: MHIDAS Database 1993.

EXHIBIT 4
INCIDENTS INVOLVING FIREWORKS AND PYROTECHNICS

Incident Location, Date	Cause/Description	Death, Injuries, Damage
Candelaria, Philippines, 08/08/90	Four explosions and a fire occurred at a fireworks factory.	>10 killed 19 injured
Columbus, Mississippi, 06/13/90	Explosions that leveled fireworks factory were felt 48 kilometers away.	2 killed 2 injured
Henan Province, China, 01/19/89	Illegal fireworks factory explosion destroyed 45 houses and damaged 176 others.	27 killed 22 injured
Surabaya, Indonesia, 03/18/88	Heat of sun thought to have caused ignition of truckload of fireworks	11 killed 26 injured
Enid, Oklahoma 06/16/87	Small explosion in railcar carrying fireworks led to a subsequent explosion that spread fire to several fireworks warehouses.	1 injured
Bocaue, Philippines 06/04/86	A series of three explosions in a fire-cracker factory obliterated the factory and shattered windows more than 1.6 kilometers away.	11 killed 8 injured (2 seriously)
Salisbury, UK 02/21/86	Explosion at flare factory resulted in extensive damage to the factory.	2 killed, 1 injured
Hallett, Oklahoma 06/25/85	Explosion at a fireworks company possibly caused by fire in a pick-up truck. If not extinguished, grass fires could have spread to other magazines.	22 killed >4 injuries
Monte Carlo, Monaco 05/03/85	Container of fireworks exploded while being loaded onto a truck. Those killed were standing next to truck during loading, while the injured were in a warehouse that caught fire.	3 dead 14 injured
Bellport, New York 11/26/83	Three blasts at a fireworks company cut power to 7000 homes, severely damaged residential property up to 334 meters away, and threw empty container 4 miles. Shock wave felt 16 kilometers away. Caused $1 million in damage.	2 killed 24 injured 300 evacuated.
Ipswich; Suffolk; UK, 10/14/82	Welding started a fire in a warehouse containing ammonium/potassium nitrate/charcoal which led to a series of explosions and evacuation of 750 local residents.	$2 million (U.S.)
Ponte Da Barca, Portugal, 08/08/80	Passers-by among killed and wounded after fireworks factory explosion.	7 killed 14 injured
Raipur; West Bengal; India, 05/04/80	Children offsite among those killed by explosion at fireworks factory.	40 killed 11 injured
Hery, France 12/11/79	A blast from a machine coiling detonator fuzes completely destroyed the pyrotechnics factory in which it was located. Blast felt 10 kilometers away.	20 injured
Jakarta, Indonesia 08/29/73	There were 170 workers in fireworks factory when gunpowder exploded. Those killed were trapped in locked section of the factory. Ten nearby residents were evacuated.	52 killed, 24 injured
Chicago, Illinois 03/06/72	Nine explosions at a fireworks factory destroyed 16 out of 18 aerial buildings of the 3.2-square kilometer factory, including the manufacturing facility. Hundreds of windows in nearby houses and buildings broken.	3 killed 17 injured 1 missing

Source: MHIDAS Database 1993.

EXHIBIT 5. TRANSPORTATION ACCIDENTS INVOLVING EXPLOSIVES

Explosive Type	Number of Incidents Total	Number of Incidents With Deaths	Number of Incidents With Injuries	Number of Incidents With Fires	Number of Incidents With Explosions	Number of Incidents With Both Fire & Exp.
High Explosives (A or 1.1)	119	2 (2% of total) (8 deaths)	5 (4% of total) (121 injuries)	9 (8% of total)	5 (4% of total)	4 (3% of total)
Low Explosives (B)	52	1 (2% of total) (1 death)	1 (2% of total) (3 injuries)	9 (17% of total)	3 (6% of total)	3 (6% of total)
Low Hazard Explosives (C)	128	1 (1% of total) (1 death)	5 (4% of total) (6 injuries)	13 (10% of total)	8 (6% of total)	2 (2% of total)
Blasting Agents (1.5)	52	0	0	0	0	0
Total	351	4 (1% of total) (10 deaths)	11 (3% of total) (130 injuries)	31 (9% of total)	16 (5% of total)	9 (3% of total)

Source: U.S. DOT, Hazardous Materials Information System (HMIS), 1971-1991.

Injuries due to blasting accidents are less frequent in metal mining than in coal mining. Use of explosives and breaking agents in underground and surface metal mines and metal mills caused a total of three deaths and 63 nonfatal injuries from 1985 to 1992 (see Exhibit 7). This is an annual average of 0.4 deaths and 8 nonfatal injuries per year. No data on the causes of blasting accidents in metal mines were found.

4.4 Black Powder Accidents Reported by Department of Defense

According to a list of accidents involving black powder provided by the Department of Defense Explosives Safety Board (DODESB 1992), 91 world-wide accidents over a 128-year period from 1844-1972 accounted for 337 deaths and 336 injuries. These accidents included 46 in the U.S. with 97 deaths and 106 injuries. Worldwide in the 50 years prior to and including 1972, 75 black powder accidents accounted for 256 deaths and 284 injuries. During this period, there were 40 accidents in the U.S. accounting for 54 injuries and 53 deaths. Accidents in the U.S. with black powder involved mostly manufacturing.

In addition, somewhat more detailed information on some black powder incidents was provided by DODESB. This information indicates that in at least some cases, there was detonation of the black powder; little information was provided in these cases about the quantities involved or the conditions under which the detonations occurred. For most of the reported incidents, information was not available as to whether a detonation or deflagration occurred (DODESB 1992).

5.0 Existing Regulations, Standards, and Classification Systems

The Bureau of Alcohol, Tobacco and Firearms (ATF) and the Department of Transportation (DOT) are the two principal regulatory groups that oversee explosives. Explosives and explosive mixtures generally are not distinguished in any classification schemes. Most organizations recognize that a "mixture" containing an explosive substance can be just as hazardous as a "pure" explosive substance. Therefore, the classification of explosives by ATF, DOT, and others is not based directly on chemical properties, rather it is based on empirical data obtained from tests performed on the substance or mixture. These standardized tests typically are performed by the Bureau of Mines and other agencies. Because classification is based on empirical tests rather than chemical formulation, and there are many different chemical formulations for explosives, the number of specific chemicals and chemical mixtures classified as explosives is unknown (White 1989, Dowling 1989, McCune 1989, Schultz 1989).

5.1 DOT Standards

The DOT regulates the transportation of explosives. DOT published a final rule on December 21, 1990 (55 FR 52402) including changes to the Hazardous Materials Regulations with regard to explosives, based on the United Nations Recommendations on the Transport of Dangerous Goods. The rule harmonizes domestic regulations for explosives with those used internationally. Under this rule, an explosive is defined as, "any substance or article, including a device, which is designed to function by explosion (i.e., an extremely rapid release of gas and heat) or which, by chemical reaction within itself, is able to function in a similar manner even if not designed to function by explosion...." Explosives are listed in Class 1, which is divided into the following six divisions:

EXHIBIT 6. FATAL AND NONFATAL INJURIES DUE TO BLASTING ACCIDENTS IN COAL MINING

Year	Underground		Surface		Preparation Plants		TOTAL	
	F	NF	F	NF	F	NF	F	NF
1971	2	74	2	6	0	0	4	80
1972	2	94	1	17	0	0	3	111
1973	1	66	1	16	0	0	2	82
1974	1	87	2	4	0	0	3	91
1975	0	64	1	18	0	1	1	83
1976	0	58	0	23	0	0	0	81
1977	3	57	3	26	0	2	6	85
1978	3	51	0	19	0	0	3	70
1979	0	49	1	12	1	2	2	63
1980	7	48	1	13	0	1	8	62
1981	3	28	2	9	0	1	5	38
1982	3	19	1	5	0	0	4	24
1983	0	18	0	7	0	2	0	27
1984*	1	16	1	13	0	0	2	29
1985	6	32	0	3	0	0	6	35
1986	0	18	3	8	0	0	3	26
1987	0	23	1	2	0	0	1	25
1988	2	20	0	11	0	1	2	32
1989	0	15	2	12	0	0	2	27
1990	3	15	1	6	0	0	4	21
1991	2	10	1	5	0	0	3	15
1992*	0	2	0	0	0	0	0	2
TOTAL	**39**	**864**	**24**	**235**	**1**	**10**	**64**	**1,109**
Annual Average	**1.8**	**39.3**	**1.1**	**10.7**	**0**	**0.5**	**2.9**	**50.4**

F=Fatal Injuries
NF=Nonfatal Injuries
* Preliminary data, January-December 1984, January-March 1992.
Sources: Peltier, M.A., L.R. Fletcher, and D.V. D'Andrea, "Coal Mining Blasting Accidents," Engineering Health and Safety in Coal Mining, Proceedings of the Society of Mining Engineers Symposium, March 2-6, 1986; Department of Labor, Mine Safety and Health Administration.

EXHIBIT 7. FATAL AND NONFATAL INJURIES DUE TO BLASTING ACCIDENTS IN METAL MINING

Year	Underground		Surface		Mills		TOTAL	
	F	NF	F	NF	F	NF	F	NF
1985	0	5	0	0	0	0	0	5
1986	0	4	0	2	0	0	0	6
1987	0	5	0	3	0	1	0	9
1988	0	9	0	0	0	0	0	9
1989	1	11	0	3	0	1	1	15
1990	0	7	0	2	0	0	0	9
1991	2	4	0	0	0	1	2	5
1992*	0	5	0	0	0	0	0	5
TOTAL	**3**	**50**	**0**	**10**	**0**	**3**	**3**	**63**
Annual Average	**0.4**	**6.2**	**0**	**1.2**	**0**	**0.4**	**0.4**	**7.9**

F=Fatal Injuries
NF=Nonfatal Injuries
* Preliminary data, January-March 1992.
Source: Department of Labor, Mine Safety and Health Administration.

- **Division 1.1:** Explosives that have a mass explosion hazard, where a mass explosion hazard is one that affects almost the entire load instantaneously.

- **Division 1.2:** Explosives that have a projection hazard but not a mass explosion hazard.

- **Division 1.3:** Explosives that have a fire hazard and either a minor blast hazard or a minor projection hazard or both, but not a mass explosion hazard.

- **Division 1.4:** Explosive devices that present a minor explosion hazard and do not contain more than 25 grams (0.9 ounce) of a detonating material.

- **Division 1.5:** Explosives that have a mass explosion hazard but are so insensitive that there is very little probability of initiation or of transition from burning to detonation under normal conditions of transport.

- **Division 1.6:** Articles that contain only extremely insensitive detonating substances and which demonstrate a negligible probability of accidental initiations or propagation.

Test methods and procedures for classifying explosives according to these divisions are described in the U.N. document, Recommendations on the Transport of Dangerous Goods, Tests and Criteria. Classification procedures are as follows:

- Any material that is designed to have an explosive effect is first tested to determine if it is too sensitive for transport, using tests for shock sensitivity and thermal sensitivity. Materials found to be thermally unstable are not permitted to be transported. Materials that do not pass the tests for shock sensitivity must be de-sensitized or encapsulated and submitted for another series of tests before they can be transported.

- Materials that are designed to have an explosive effect and that are not too sensitive for transport are accepted for Class 1 (explosives). Further tests (described in Appendix D) are carried out to determine the hazard division (1.1, 1.2, 1.3, or 1.4).

- Materials that are not designed to have an explosive effect are also tested for shock sensitivity and thermal sensitivity. If they are not too sensitive for transport, they are further tested to determine whether they have explosive properties, using tests that determine whether the materials detonate under confinement (see Appendix D for a description of the tests). If they are found to have explosive properties, they are tested to determine the hazard division, as described for materials designed to have an explosive effect.

- Very insensitive explosive materials with a mass explosion hazard are subjected to a series of tests to determine cap sensitivity, tendency to undergo a transition from deflagration to detonation, and behavior under fire conditions (explosion in a fire or tendency to ignite readily).

Assignment of a substance to specific hazard classes and divisions depends on the composition of the substance and on the tests the Department of Transportation performs on the substance. Theoretically, the same substance could receive different classifications depending on test results. Nitrocellulose, which is used in furniture finishes, nail polish, and ink (approximately two-thirds of total production), as well as in

gunpowder and propulsion systems (Aqualon 1992) has eight individual listings in the DOT Hazardous Materials Table. These listings are as follows:

Description	Hazard Class and Division
• Nitrocellulose, *dry or wetted with less than 25 per cent water (or alcohol), by mass*	1.1 (high explosive)
• Nitrocellulose, plasticized *with not less than 18 per cent plasticizing substance, by mass*	1.3 (low explosive)
• Nitrocellulose, solution, *flammable with not more than 12.6 per cent nitrogen, by mass, and not more than 55 per cent nitrocellulose*	3 (flammable liquid)
• Nitrocellulose, *unmodified or plasticized with less than 18 per cent plasticizing substance by mass*	1.1 (high explosive)
• Nitrocellulose, wetted *with not less than 25 per cent alcohol, by mass*	1.3 (low explosive)
• Nitrocellulose with alcohol *not less than 25 per cent alcohol by mass, and not more than 12.6 per cent nitrogen, by dry mass*	4.1 (flammable solid)
• Nitrocellulose with plasticizing *not less than 18 per cent plasticizing substance, by mass, and not more than 12.6 per cent nitrogen, by dry mass*	4.1
• Nitrocellulose with water *not less than 25 per cent water, by mass*	4.1

Black powder is listed on the DOT Hazardous Materials Table as a high explosive (1.1). Fireworks are listed with five classifications: 1.1, 1.2, 1.3, and 1.4, depending on test results. Common or consumer fireworks (e.g., firecrackers) would fall in Division 1.4, while special fireworks used for display purposes usually would be classed as 1.3.

DOT's rule, containing the classifications presented above, provides a five-year transition period for the changeover to the new classifications and requirements. Under the previous DOT regulations, an explosive is defined as "any chemical compound, mixture, or device, the primary or common purpose of which is to function by explosion, i.e., with substantially instantaneous release of gas and heat..." (49 CFR 173.50). Explosives are further defined by the DOT according to the following classifications:

- ***Class A -- Detonating or otherwise of maximum hazard:***
  Type 1: Solid explosives which can be caused to deflagrate by contact with sparks or flame but cannot be detonated by means of No. 8 test blasting cap.[2] Example: black powder.

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[2]. A No. 8 blasting cap is one containing two grams of a mixture of 80% mercury fulminate and 20% potassium chlorate, or a cap of equivalent strength (49 CFR 173.53).

Type 2: Solid explosives which contain a liquid ingredient and which when unconfined can be detonated by means of a No. 8 test blasting cap; or which can be exploded in at least 50% of the trials in the Bureau of Explosives' Impact Apparatus under a drop of 4 inches or more, but cannot be exploded in more than 50% of the trials under a drop of less than 4 inches. Example: commercial dynamite containing a liquid explosive ingredient.

Type 3: Solid explosives which contain no liquid ingredient and which can be detonated by means of a No. 8 test blasting cap; or which can be exploded in at least 50% of the trials in the Bureau of Explosives' Impact Apparatus under a drop of 4 inches or more, but cannot be exploded in more than 50% of the trials under a drop of less than 4 inches. Examples: commercial dynamite containing no liquid ingredient, TNT, amatol, picric acid, urea nitrate, pentolite, and commercial boosters.

Type 4: Solid explosives which can be caused to detonate when unconfined, by means of contact with sparks or flame; or which can be exploded in the Bureau of Explosives' Impact Apparatus, in more than 50% of the trials under a drop of less than 4 inches. Examples: lead azide, fulminate of mercury.

Type 5: Desensitized liquid explosives are explosives which may be detonated separately or when absorbed in sterile absorbent cotton, by a No. 8 test blasting cap; but which cannot be exploded in the Bureau of Explosives' Impact Apparatus under a drop of less than 10 inches. Example: desensitized nitroglycerine.

Type 6: Liquid explosives that can be exploded in the Bureau of Explosives' Impact Apparatus under a drop of less than 10 inches. Example: nitroglycerine.

Type 7: Detonators and initiating devices.

Type 8: Any solid or liquid compound, mixture, or device which is not specifically included in any of the above types, and which under special conditions may be so designated and examined by the Bureau of Explosives. Example: shaped charges.

Type 9: Propellant explosives, class A (solid chemicals or solid chemical mixtures which are designed to function by rapid combustion of successive layers) which detonate in their package in one out of five test trials, when ignited.

- ***Class B -- Flammable Hazard:***

Those explosives that in general function by rapid combustion rather than detonation and include some explosive devices such as special fireworks, flash powders, some pyrotechnic signal devices and liquid or solid propellant explosives which include some smokeless powders.

- *Class C -- Minimum Hazard:*

  Certain types of manufactured articles which contain Class A, or Class B explosives, or both, as components but in restricted quantities, and certain types of fireworks.

DOT also regulates transportation of blasting agents, defined under the old rule as materials designed for blasting that have been tested in accordance with a series of specified tests and found to be so insensitive that there is very little probability of accidental explosion.

DOT provides the following comparison of the old and new hazard classifications:

Old Classification	New Classification
Class A explosives	Division 1.1
Class A or Class B explosives	Division 1.2
Class B explosives	Division 1.3
Class C explosives	Division 1.4
Blasting agents	Division 1.5
No applicable class	Division 1.6

5.2 ATF Standards

The manufacture, processing, use, distribution, and storage of explosive materials is regulated also by the Bureau of Alcohol, Tobacco, and Firearms (ATF) as set forth in 27 CFR Part 55. The ATF defines an explosive material as follows:

> *"Any chemical compound, mixture, or device, the primary or common purpose of which is to function by explosion. The term includes, but is not limited to, dynamite and other high explosives, black powder, pellet powder, initiating explosives, detonators, safety fuses, squibs, detonating cord, igniter cord, and igniters."*

Explosive materials have been divided into three classes by the ATF for purposes of regulating storage:

- **High Explosives:** those explosives which can be detonated by means of a blasting cap when unconfined (e.g., TNT, dynamite).

- **Low Explosives:** those explosive materials which can be caused to deflagrate when confined (e.g., black powder, safety fuses, and DOT Class B explosives).

- **Blasting Agents:** any material or mixture consisting of a fuel and oxidizer that is intended for blasting and not otherwise defined as an explosive, provided that the finished product cannot be detonated by a No. 8 blasting cap when unconfined (e.g., ammonium nitrate/fuel oil (ANFO) and certain water gels).

Note that blasting agents are very insensitive and unlikely to explode; however, in the event that they do explode, the consequence may be a detonation, with accompanying overpressure, as for high explosives, rather than a deflagration (intense fire), as for low explosives. For example, an explosion of the blasting agent ANFO killed six fire fighters in Kansas City, MO (see Section 4.1).

The ATF regulations contain a table, called the "Table of distances for storage of explosive materials" (ATF 1990), which must be used by explosive materials handlers to determine acceptable minimum separation distances for storing and handling high explosives and blasting agents. The table also states the maximum quantities of explosives allowed in any one location. The table of distances is further discussed in Section 6.2 and is presented in Exhibit 9 in that section. Locations that contain explosives must be separated from:

- Inhabited buildings, including structures or other places not directly related to explosives operations where people usually assemble or work;
- Public highways;
- Passenger railways; and
- Other locations which contain explosives.

For example, if a site has from 40 to 50 pounds of high explosives in one magazine, there can be no unbarricaded inhabited building (e.g., a home) within 300 feet (91 meters) of that magazine. A separate table is provided for determining separation distances for the storage of low explosives (see discussion in Section 6.2 and Exhibit 10). These distance requirements differ from those for high explosives because the consequences of an accident involving low explosives are likely to result from thermal radiation rather than overpressure. In all instances, the separation distances increase as the quantity of explosives stored increases.

The ATF table of distances is based on the American Table of Distances for storage of explosives as revised by the Institute of Makers of Explosives (IME). The original American Table of Distances was published in 1910 based on the work of a special committee of the Association of Manufacturers of Powder and High Explosives. This committee gathered and evaluated information on a number of explosions ranging from small amounts of explosive materials to one million pounds. Since then, the table has been revised periodically to incorporate information obtained from past accidents. The explosions studied have covered a period of almost fifty years and have occurred in manufacturing, transportation, and storage, both in the United States and abroad. The last revision to the table was in 1985. The table is designed to cover manufacture and permanent storage of explosive materials and is not applicable for the incidental handling or temporary storage of explosive materials being transported.

ATF regulations also include requirements for special fireworks, pyrotechnic compositions, and explosive material used in assembling fireworks. Tables are provided for distances between fireworks process and fireworks nonprocess buildings, between fireworks process buildings and other areas (e.g., passenger railways, public highways, inhabited buildings), and distances for the storage of special fireworks. The ATF does not regulate common fireworks (e.g., firecrackers), except during manufacture.

5.3 NFPA Codes

The National Fire Protection Association (NFPA) publishes the National Fire code, intended to be referenced by public authorities in laws, ordinances, regulations, and administrative orders. NFPA 495, Explosive Materials Code (NFPA 1990) applies to manufacture, transportation, storage, sale, and use of explosive materials. The code includes detailed requirements related to explosives safety, including permitting, record keeping, and reporting; handling of blasting agents; transportation of explosives; storage requirements, including use of the American Table of Distances; and use and disposal of explosives. The code is intended to conform to federal regulations, including those promulgated by ATF, DOT, and the Mine Safety and Health Administration. NFPA has also published two codes for fireworks: NFPA 1124, Manufacture, Transportation and Storage of Fireworks, and NFPA 1123, Code for the Outdoor Display of Fireworks.

5.4 State and Local Regulations

Many state and local governments have regulations regarding licensing and safety requirements for explosives. Some of them may adopt the NFPA code for explosives, NFPA 495, described above, or the explosives provisions of the Uniform Fire Code, which are similar to the provisions of NFPA 495. In some localities there may be three or four sets of requirements (Federal, state, and one or more local, e.g., county and city). Some states have "home rule" provisions, leaving regulation of explosives to local authorities. There is no uniformity in the state and local regulations, however. For example, the permitting authority for explosives may be the fire marshal or the fire department, or it may be the police department, labor department, or other agency. The state of Massachusetts, for example, gives the fire department authority over explosives (Henry 1989). In Kansas City, MO, where six firefighters were killed in an explosion, the permitting authority was the City Engineer's office; at the time of the accident, there was no requirement that the fire department be notified (the regulation was subsequently modified to require that blasting permits be cleared through the Fire Marshal's office) (U.S. Fire Administration).

5.5 Clean Air Act Regulations

Under the Clean Air Act Amendments of 1990, OSHA was required to promulgate regulations intended to prevent accidental releases of chemicals which could pose a threat to employees. OSHA has published a standard, described below in 5.5.1. EPA is required to develop regulations for protection of the public, as discussed in 5.5.2.

5.5.1 OSHA Process Safety Management Standard

OSHA has developed a chemical process safety management standard (57 FR 6356, February 24, 1992) that applies to any process involving a highly hazardous chemical at or above a specified threshold quantity. The requirements of this standard also apply to the manufacture of explosives and pyrotechnics (no threshold quantity is specified in this case). The OSHA Process Safety Management Standard is intended to protect employees by preventing or minimizing the consequences of catastrophic releases of toxic, reactive, flammable, or explosive chemicals. The requirements include development of a compilation of written process safety information; process hazards analysis, carried out by a team with expertise in engineering and process operations; development of written operating procedures for processes involving highly hazardous chemicals; employee training; pre-startup safety reviews for new and significantly-modified facilities; maintenance of mechanical integrity of critical equipment; and establishment of procedures for management of changes to

process chemicals, technology, equipment, and procedures; investigation of incidents; emergency action plans; and compliance and safety audits to ensure programs are in-place and operating properly.

5.5.2 EPA Chemical Accident Prevention Regulations

Under section 112(r) of the Clean Air Act (CAA), EPA is required to develop a list of at least 100 regulated substances that, when released, can cause death, injury, or serious adverse effects to human health or the environment. This list could include explosives, although Congress did not specifically mandate inclusion of explosives. Facilities that use these chemicals above threshold quantities developed by EPA need to comply with new CAA regulations on release prevention, detection, and emergency response. One accident prevention provision of the CAA mandates the development of regulations requiring facilities to prepare and implement risk management plans. EPA is currently developing a list of regulated substances and threshold quantities, as well as risk management plan regulations. EPA's proposed rule on the list of regulated substances and threshold quantities for accidental release prevention (58 FR 5102, January 19, 1993) includes commercial explosives as defined by DOT in Division 1.1; the proposed threshold quantity is 5,000 pounds.

5.6 Other Standards

Other agencies such as the Mine Safety and Health Administration (MSHA), Department of Defense (DOD), the International Maritime Organization (IMO), and others regulate certain aspects of the explosives industry. For example, DOD regulates the storage of munitions and military explosives, OSHA regulates worker safety at explosives manufacturing sites, the IMO is concerned with international shipments of hazardous materials, and MSHA regulates worker safety and includes provisions for explosives. The standards of these organizations are not related to hazards to the community from explosives; therefore, they were not considered further in this analysis.

6.0 Methodology for Determining Affected Distances for Commercial Explosives

6.1 Approach

The Agency's Physical/Chemical Criteria Workgroup used the ATF's American Table of Distances, and the equations on which the table is based, to estimate the consequences of explosions and evaluate the relationship of quantity exploded to the distance affected at various overpressure levels. Several other widely recognized explosives consequence methodologies, including the K-factor and the Automated Resource for Chemical Hazard Incident Evaluation (ARCHIE) computer program, are discussed in Appendix B. For this analysis, commercial explosives have been grouped into three categories: high, low, and blasting agents, in the same way ATF has classified explosives for storage purposes. These categories can also be related to the new DOT/international hazard classes and divisions, described in Section 5.1 above; i.e., high explosives correspond to materials in Division 1.1, low explosives correspond to materials in Division 1.3, and blasting agents correspond to materials in Division 1.5 (as noted in Section 3, blasting agents make up the bulk of explosives in commercial use). Materials in Division 1.2 have a projection hazard rather than a mass explosion hazard; the method of consequence analysis described here is not applicable to such materials, nor is it applicable to materials in Divisions 1.4 or 1.6, which have only minor blast hazards.

6.1.1 Damage Criteria

The next step in the consequence analysis is the identification of credible accident scenario(s). For high explosives, only one scenario is likely: a quantity of explosive is somehow detonated. Damage from accidents involving explosives is a function of the peak overpressure resulting from the blast wave. This is discussed further in Section 6.2.1 below and in Appendix A. In the analysis which was used to determine the threshold planning quantities for acutely toxic materials, lethality was chosen as the endpoint. In the case of

explosions, human deaths and injuries may be caused directly by blast waves or indirectly by flying glass or other objects. Very high overpressures are needed for fatality as a direct result of an explosion; various sources cite threshold levels for fatality of 14.5 pounds per square inch (psi) to 120 psi (see Appendix A). However, much lower overpressures may cause property damage that might lead to human injury or death. For this analysis, EPA considered blast overpressures of 0.5 psi, 1.0 psi, 2.0 psi, and 3.0 psi. An overpressure of 0.5 psi can cause shattering of glass windows (Brasie and Simpson 1968, US Air Force 1983, US DOT 1988, Lees 1980). An overpressure of 1.0 psi can cause partial demolition of houses, and is the threshold for skin laceration from flying glass (Lees 1980). An overpressure level of 2.0 psi can lead to the partial collapse of walls and roofs of houses and shattering of non-reinforced concrete or cinder block wall panels (Brasie and Simpson 1968, Air Force 1983, U.S. DOT 1988, Lees 1980). Overpressures between 2.0 and 3.0 psi can cause eardrum rupture (Lees 1980). Overpressure of 3.0 psi can cause a steel frame building to become distorted and pull away from its foundations (Lees 1980); it can also hurl a person to the ground (Brasie and Simpson 1968).

Appendix A contains more detailed background information on blast overpressures and their effects. The results of consequence analysis at different overpressures are presented in Section 6.3.1. The results show that, as would be expected, if a higher overpressure is chosen, the blast effect extends over a shorter distance. However, the affected distance does not change linearly with overpressure; the rate of decrease in distance is considerably greater between overpressures of 0.5 psi and 1.0 psi than between 1.0 psi and 2.0 psi or 2.0 psi and 3.0 psi (see Section 6.3.1 and Exhibit A-6).

Effects of explosions can also include damage and injury from fragments of the casing of the explosive (primary fragments) and debris from the blast. Such fragments and debris can have high velocities and travel some distance from the site of the blast. Their effects can be very serious, including secondary explosions and fires, structural damage, and human injury. However, these effects are highly variable, depending on site-specific and incident-specific factors. Therefore, it would be very difficult to take these effects into account in a generalized consequence analysis.

Fragments and debris from explosions can injure people by skin penetration and by the force of impact. People can also be injured or killed by impact if the force of the blast wave throws them against a stationary object, such as a wall. The severity of the injuries depend on the mass and velocity of the fragments and debris, as well as a number of other factors, such as the shape of the fragments, the angle of impact, and the point of impact. In the case of glass fragments from windows broken by an explosion, the initial mass and velocity depend on the dimensions of the window pane and the blast overpressure compared to the minimum overpressure at which the glass fails. Whether or not the glass causes injury, and the severity of the injury, depend on how close a person is to the window and the position of the person (TNO 1992).

6.1.2 Assumptions

The following assumptions were made in the consequence analysis:

- Explosions occur at ground level; and
- The area surrounding the explosion is characterized by flat open terrain.

In actuality, potential reflections of the blast or shock wave from building walls or the sides of other obstacles and surfaces may cause damage to be more erratic than that predicted using these assumptions; in fact, damage may be increased, especially if there are obstacles parallel to the shock wave front. However, the above assumptions are used widely in performing consequence analyses for explosive materials.

6.1.3 Quantities Modeled

The following quantities of material were utilized in the analysis: 50, 100, 250, 500, 1,000 and 5,000 pounds. These amounts were chosen to provide a wide range of values in the analysis. In addition, quantities of 10,000 and 100,000 pounds were considered for low explosives, to provide a wider range of distances.

6.2 Methodology for Determining Explosive Distances

6.2.1 Scaling Law for Explosives

Damage from explosions is primarily a function of the peak overpressure resulting from the blast wave and is not dependent upon one specific physical or chemical property. It is a function of an empirically derived function, known as the scaling law:

$$D = (K)(W^{1/3})$$

where: D = Required, or potentially affected, distance, ft
K = Protection factor depending upon the degree of risk assumed or permitted; the relationship between the peak overpressure and the K factor is shown in Exhibit 8 (e.g., using this exhibit, a K-factor of 11 (K11) corresponds to a peak overpressure level of 8 psi)
W = TNT equivalent weight, lb

The TNT equivalent weight is the weight of TNT that would yield the same peak pressure or impulse at a given distance as the total weight of explosive material under consideration.

The scaling law relates peak overpressure, explosive weight, and distance for the purpose of evaluating the effects of blast waves. Blast waves generated during an explosion of a given material are compared to those which would have resulted from an explosion involving TNT (i.e., TNT is used as a reference material). This approach is used because of the large amount of experimental data available on blast waves from TNT explosions and on damage produced by TNT explosions. This relationship is applicable to any explosion provided the equivalent weight of TNT is known. The scaling law is the basis for the Table of Distances used for consequence analysis as discussed below. The scaling law is not applicable to assessment of consequences of flying fragments from a blast.

There are several limitations of the scaling law using TNT equivalent weights that need to be recognized (U.S. DOT 1988). They are:

- Not all of the accidentally-released material may be involved in the explosion. Part of the material may disperse without reacting and part may react at a different time or location from the initial explosion. As such, measured TNT yields of explosive materials depend upon accident conditions, duration, and failure mode;

- Of the portion of released material that reacts in the explosion, part may detonate and part may deflagrate, with the latter contributing little energy to the blast. Predicting whether a detonation or a deflagration (or a combination) will occur is very complex. The outcome depends on the materials' properties and on the conditions of the accident;

- The blast characteristics of the released material may be different from those of a TNT charge with an equivalent energy. For example, measured

overpressure amplitudes are generally lower and durations are longer for low explosives than for TNT because of slower reaction rates; and

- TNT yields are only available for materials which have been tested. New chemicals would require testing before consequence analyses could be performed.

As the above limitations indicate, the TNT yield of a material is not an absolute property such as density or molecular weight. Instead, it depends upon the test conditions under which it is measured. These limitations, however, do not present a serious problem in the use of the scaling law equation since the dependence of blast parameters on yield is low due to the cube-root exponent in the equation. The prediction of a hazard distance is not very sensitive to the TNT equivalent weight. Further, the limitations of the equation will generally lead to a worst-case estimate and, hence, a conservative analysis. The TNT method of analysis has been used effectively over many years despite the limitations mentioned above.

The scaling law is accepted widely and well established in the published technical literature. It has been adopted by several government agencies, including the Bureau of Alcohol, Tobacco, and Firearms, the Department of Defense, and the U.S. Air Force, and private companies for related uses, including hazards assessment and emergency response and planning. It is used in some of the existing classification systems for commercial explosives which are described above in Section 5.0. No other methods of estimating blast wave effects have been found. The results of several other methods of consequence analysis for explosives, all based on the scaling law, are presented in Appendix B for comparison with the results presented in this section.

6.2.2 ATF Table of Distances for High Explosives

The primary purpose of the ATF regulations is to control the distribution of explosive materials to authorized persons. As part of this goal, the ATF regulations specify a set of standards to be used in the safe storage of explosives. The standards are set forth in tabular form in two tables: (1) the "Table of Distances" for high explosives and blasting agents as shown in Exhibit 9, and (2) a second table for low explosives as shown in Exhibit 10. The distance requirements in these tables are designed to ensure that explosives stored in accordance with the regulations will not present an off-site hazard. The original Table of Distances is based upon the scaling law and was developed by the Institute of Makers of Explosives (IME) (Dowling 1989). As noted in Section 5.2, the table takes into account the results of explosions that have occurred over a 50-year period in manufacturing, transportation, and storage, both in the United States and abroad.

Since the equation that the table is based upon is known, additions may be made to the table depending upon the needs of the analysis. For example, the table for high explosives and blasting agents (Exhibit 9) has several columns representing different overpressures and damage criteria. In calculating the safe distance to an unbarricaded inhabited building (fourth column), an overpressure of 0.4 psi is used. In contrast, in determining the safe distance to a barricaded inhabited building (third column), an overpressure of 1.0 psi is used, and distance requirements are lower. Barricades, by ATF definitions, can be natural barriers, such as hills or dense timber, or artificial barriers, such as mounds or walls of earth. Such barricades must be high enough that a straight line from the top of the barricaded magazine (explosives storage building) to the eave line of another magazine or building, or to a point 12 feet above a railway or highway, will pass through the barricade. The table of distances provides data for six overpressure levels.[3] However, distances

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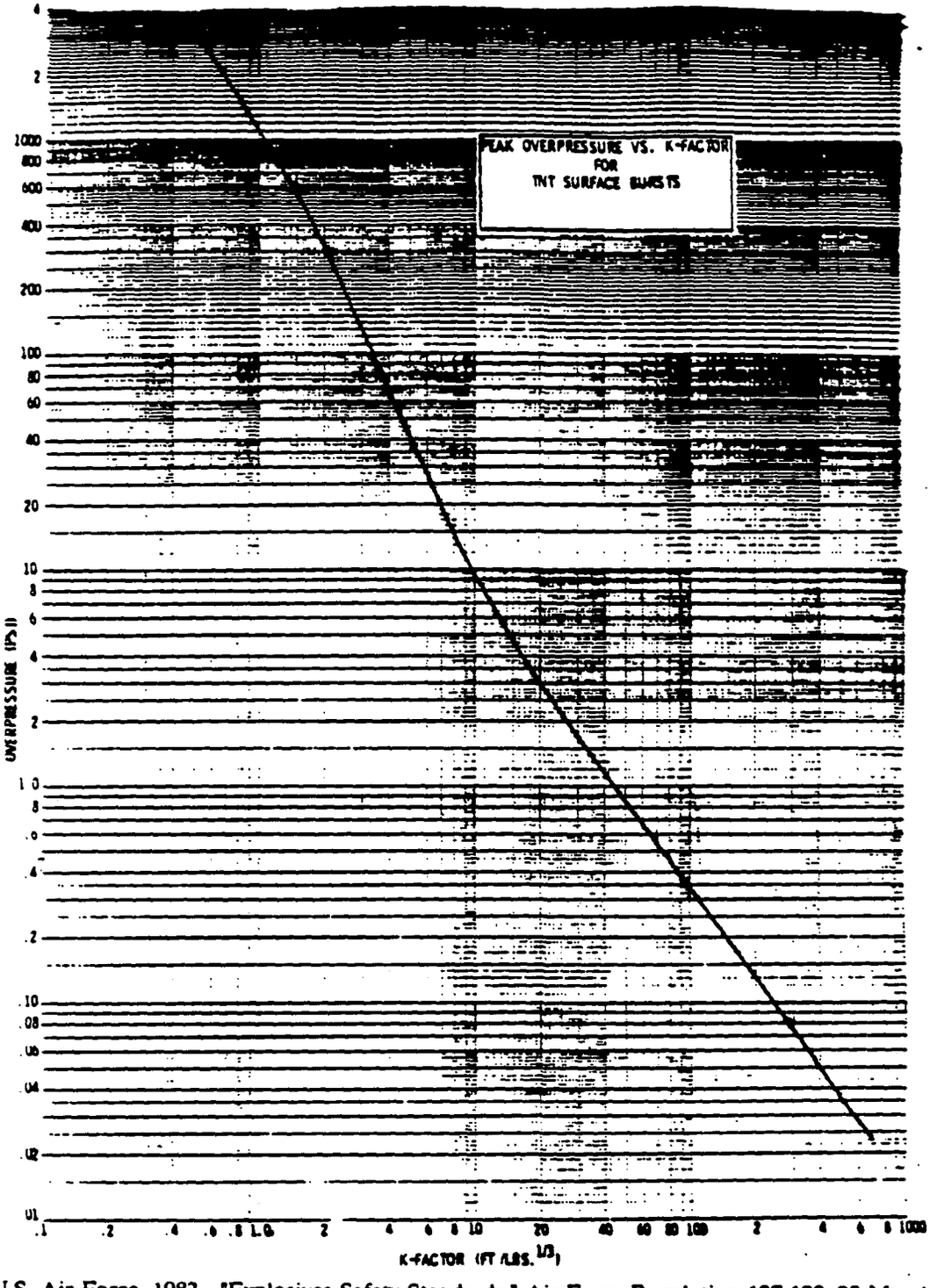
[3] In determining the safe distance to a barricaded public highway, an overpressure of 4.5 psi is used; for unbarricaded public highways and barricaded passenger railways and high volume public highways, an overpressure of approximately 1.75 psi is used; for unbarricaded railways and high traffic public highways, an overpressure of between 0.6 and 0.7 psi is used; and for unbarricaded inhabited buildings, an overpressure of

EXHIBIT 8. K-FACTORS AS A FUNCTION OF PEAK OVERPRESSURES



Source: U.S. Air Force. 1983. "Explosives Safety Standards," Air Force Regulation 127-100. 20 May 1983.

based on various other overpressures can be calculated since the equation on which the data in the table are based is known.

The differences between the scaling law and the table for high explosives are the following:

- The ATF assumes that all high explosives and blasting agents have roughly equivalent explosive energies and therefore does not calculate an explosive weight based upon TNT equivalents ($W = M_{chem}$ rather than $W = [M_{chem} \times \%TNT]$) for each high explosive material,

where:

W = TNT equivalent weight
M_{chem} = Total mass of the explosive material
$\%TNT$ = TNT equivalent (fraction).

- The Tables provide specific distances for ranges of weights, resulting in some degree of error, especially at the endpoints. For example, the distance determined using the table for a high explosive weighing 4,000 pounds is the same as the distance for one weighing 5,000 pounds.

Although the ATF Table of Distances allows shorter distances in cases where barricades are present, there is evidence that barricades may be ineffective for protection against the effects of blast waves; although peak pressure may be reduced in a region adjacent to the site of the explosion, it may be increased at greater distances (Filler et al. 1967). A study of accidental explosions has shown that barricades did not reduce damage to adjacent buildings in any significant way (Filler et al. 1967). Barricades may protect against fragments from a blast; however, if the barricade is destroyed by the blast, which often happens in an accident, it may be a source of additional fragments (Filler et al. 1967).

6.2.3 ATF Table of Distances for Low Explosives

The Table of Distances for low explosives (see Exhibit 10) was originally developed by the Department of Defense and adopted by ATF for application to the private sector. It is designed for use with materials that deflagrate rather than detonate. The distances are based on levels of heat flux produced by a fireball rather than blast overpressures. The heat flux level used for determining distances is 4 calories per square inch; no exposure time is specified. When the table was developed, this heat flux was considered to be a level at which people could avoid injury by moving away. To calculate distances, the following equation (empirically derived) is used for inhabited buildings and public railroads and highways (Moran 1989):

$$D = 8\ W^{1/3}$$

where:

D = Required, or affected, distance in feet
W = Weight of material in pounds.

For determination of distance to magazines, the equation is $D = 5\ W^{1/3}$ (Moran 1989). Because the table of distances for low explosives is based on thermal radiation, the scaling law for explosives and the methodologies based on it do not give comparable results. None of the models reviewed that give thermal radiation results (e.g., models for pool fires and BLEVEs) appear to be applicable to explosives that deflagrate (i.e., low explosives). Therefore, only the equation presented above, used for the ATF Table of Distances for low explosives, was used for analysis of low explosives.

EXHIBIT 9. AMERICAN TABLE OF DISTANCES -- HIGH EXPLOSIVES & BLASTING AGENTS*

QUANTITY OF EXPLOSIVES (IN POUNDS)		DISTANCES (IN FEET)							
		INHABITED BUILDINGS		PUBLIC HIGHWAYS, CLASS A to D**		PASSENGER RAILWAYS & PUBLIC HIGHWAYS: With traffic volume of more than 3,000 vehicles per day		SEPARATION OF MAGAZINES	
OVER	NOT OVER	BARRICADED	UNBARRICADED	BARRICADED	UNBARRICADED	BARRICADED	UNBARRICADED	BARRICADED	UNBARRICADED
2	5	70	140	30	60	51	102	6	12
5	10	90	180	35	70	64	128	8	16
10	20	110	220	45	90	81	162	10	20
20	30	125	250	50	100	93	186	11	22
30	40	140	280	55	110	103	206	12	24
40	50	150	300	60	120	110	220	14	28
50	75	170	340	70	140	127	254	15	30
75	100	190	380	75	150	139	278	16	32
100	125	200	400	80	160	150	300	18	36
125	150	215	430	85	170	159	318	19	38
150	200	235	470	95	190	175	350	21	42
200	250	255	510	105	210	189	378	23	46
250	300	270	540	110	220	201	402	24	48
300	400	295	590	120	240	221	442	27	54
400	500	320	640	130	260	238	476	29	58
500	600	340	680	135	270	253	506	31	62
600	700	355	710	145	290	266	532	32	64
700	800	375	750	150	300	278	556	33	66
800	900	390	780	155	310	289	578	35	70
900	1,000	400	800	160	320	300	600	36	72
1,000	1,200	425	850	165	330	318	636	39	78
1,200	1,400	450	900	170	340	336	672	41	82
1,400	1,600	470	940	175	350	351	702	43	86
1,600	1,800	490	980	180	360	366	732	44	88
1,800	2,000	505	1,010	185	370	378	756	45	90
2,000	2,500	545	1,090	190	380	408	816	49	98
2,500	3,000	580	1,160	195	390	432	864	52	104
3,000	4,000	635	1,270	210	420	474	948	58	116
4,000	5,000	685	1,370	225	450	513	1,026	61	122
5,000	6,000	730	1,460	235	470	546	1,092	65	130
6,000	7,000	770	1,540	245	490	573	1,146	68	136
7,000	8,000	800	1,600	250	500	600	1,200	72	144
8,000	9,000	835	1,670	255	510	624	1,248	75	150
9,000	10,000	865	1,730	260	520	645	1,290	78	156
10,000	12,000	875	1,750	270	540	687	1,374	82	164
12,000	14,000	885	1,770	275	550	723	1,446	87	174
14,000	16,000	900	1,800	280	560	756	1,512	90	180
16,000	18,000	940	1,880	285	570	786	1,572	94	188
18,000	20,000	975	1,950	290	580	813	1,626	98	196
20,000	25,000	1,055	2,000	315	630	876	1,752	105	210
25,000	30,000	1,130	2,000	340	680	933	1,866	112	224
30,000	35,000	1,205	2,000	360	720	981	1,962	119	238
35,000	40,000	1,275	2,000	380	760	1,026	2,000	124	248
40,000	45,000	1,340	2,000	400	800	1,068	2,000	129	258
45,000	50,000	1,400	2,000	420	840	1,104	2,000	135	270
50,000	55,000	1,460	2,000	440	880	1,140	2,000	140	280
55,000	60,000	1,515	2,000	455	910	1,173	2,000	145	290
60,000	65,000	1,565	2,000	470	940	1,206	2,000	150	300
65,000	70,000	1,610	2,000	485	970	1,236	2,000	155	310
70,000	75,000	1,655	2,000	500	1,000	1,263	2,000	160	320
75,000	80,000	1,695	2,000	510	1,020	1,293	2,000	165	330
80,000	85,000	1,730	2,000	520	1,040	1,317	2,000	170	340
85,000	90,000	1,760	2,000	530	1,060	1,344	2,000	175	350
90,000	95,000	1,790	2,000	540	1,080	1,368	2,000	180	360
95,000	100,000	1,815	2,000	545	1,090	1,392	2,000	185	370
100,000	110,000	1,835	2,000	550	1,100	1,437	2,000	195	390
110,000	120,000	1,855	2,000	555	1,110	1,476	2,000	205	410
120,000	130,000	1,875	2,000	560	1,120	1,521	2,000	215	430
130,000	140,000	1,890	2,000	565	1,130	1,557	2,000	225	450
140,000	150,000	1,900	2,000	570	1,140	1,593	2,000	235	470
150,000	160,000	1,935	2,000	580	1,160	1,629	2,000	245	490
160,000	170,000	1,965	2,000	590	1,180	1,662	2,000	255	510
170,000	180,000	1,990	2,000	600	1,200	1,695	2,000	265	530
180,000	190,000	2,010	2,010	605	1,210	1,725	2,000	275	550
190,000	200,000	2,030	2,030	610	1,220	1,755	2,000	285	570
200,000	210,000	2,055	2,055	620	1,240	1,782	2,000	295	590
210,000	230,000	2,100	2,100	635	1,270	1,836	2,000	315	630
230,000	250,000	2,155	2,155	650	1,300	1,890	2,000	335	670
250,000	275,000	2,215	2,215	670	1,340	1,950	2,000	360	720
275,000	300,000	2,275	2,275	690	1,380	2,000	2,000	385	770

* A separate table is provided by ATF for determining required distances between blasting agents and explosives or other blasting agents.

** Highways with an average traffic volume of 3,000 or fewer vehicles per day.

EXHIBIT 10. TABLE OF DISTANCES -- LOW EXPLOSIVES

Pounds		Distances (ft)		
Over	Not Over	From Inhabited Building	From Public Railroad & Highway	From Above Ground Magazine
0	1,000	75	75	50
1,000	5,000	115	115	75
5,000	10,000	150	150	100
10,000	20,000	190	190	125
20,000	30,000	215	215	145
30,000	40,000	235	455	155
40,000	50,000	250	250	165
50,000	60,000	260	260	175
60,000	70,000	270	270	185
70,000	80,000	280	280	190
80,000	90,000	295	295	195
90,000	100,000	300	300	200
100,000	200,000	375	375	250
200,000	300,000	450	450	300

Source: ATF P 5400.7 (6/90), "ATF: Explosives Law and Regulations," Bureau of Alcohol, Tobacco, and Firearms, Department of the Treasury.

6.3 Results

This section presents the results of application of the methodology discussed in the previous section. Results for application of the scaling law of distances for high explosives and blasting agents are presented first, followed by results for low explosives obtained from the equation for thermal radiation effects used by ATF.

6.3.1 High Explosives and Blasting Agents

Exhibit 11 presents the results of analysis of high explosives (Division 1.1) and blasting agents (Division 1.5) using the scaling law as applied by ATF for the table of distances, using unbarricaded distances, for overpressure levels of 0.4 psi (the level used for development of the table), 1.0 psi, 2.0 psi, and 3.0 psi. The analyses were carried out for 50, 100, 250, 500, 1,000, and 5,000 pounds of high explosive material. As noted above, TNT equivalents are not taken into account in using the Table of Distances (i.e., all materials are assumed to have the same explosive potential); therefore, distances are the same for all high explosives. At an overpressure level of 0.5 psi (a level that will shatter glass), distances range from 79 meters for 50 pounds of high explosive to 365 meters for 5,000 pounds of high explosive. At an overpressure level of 1.0 psi (which can cause partial demolition of houses), distances of 48 meters, for 50 pounds of explosive, to 224 meters, for 5,000 pounds of explosive, were calculated. At an overpressure level of 3.0 psi, the distance calculated for a given quantity of explosive is approximately half the distance calculated for 1.0 psi.

6.3.2 Low Explosives

Exhibit 12 presents the distances calculated for the deflagration of a low explosive (Division 1.3), based on the equation used in developing the ATF Table of Distances for low explosives. Distances are reported in meters for comparison to the distances calculated for high explosives. The results for deflagration were obtained from the following equation, used for the derivation of the ATF Table of Distances for low explosives (see Exhibit 10):

$$D = 8\ W^{1/3}$$

where:

D = required, or affected, distance, ft
W = weight of material, lb

(The table itself was not used because of the wide ranges of quantities presented.)

Distances calculated for low explosives are much smaller than those calculated for high explosives, as would be expected from the equation used and from the fact that the primary hazard of low explosives is heat rather than blast waves.

6.4 Findings

Analysis of the consequences of detonations of high explosives (Division 1.1) and blasting agents (Division 1.5), based on the ATF Table of Distances for high explosives and blasting agents, indicates that the effects of the blast from the detonation of such substances can extend for considerable distances. The distance affected is dependent on the quantity of explosive (to the one-third power) and on the overpressure or damage level of interest. For example, the detonation of about 440 pounds of a high explosive would produce an overpressure of about 1.0 psi at a distance of 100 meters from the site of the explosion; it would take 2,000 pounds of the same explosive to produce an overpressure of 2.0 psi at the same distance. The results of the analysis do not consider the probability of an accidental explosion. The magnitude of the consequences of

EXHIBIT 11. AFFECTED DISTANCES FOR COMMERCIAL HIGH EXPLOSIVES *AND BLASTING AGENTS, DETERMINED USING THE ATF METHOD*
(Peak Overpressure = 0.5 psi - 3.0 psi)

Quantity (lbs)	Affected Distance for Various Overpressures (meters)				
	0.4 psi	0.5 psi	1.0 psi	2.0 psi	3.0 psi
50	97	79	48	29	22
100	119	99	61	37	28
250	160	134	83	50	38
500	206	168	104	63	48
1,000	251	213	131	79	61
5,000	431	365	224	136	104

EXHIBIT 12. AFFECTED DISTANCES FOR LOW EXPLOSIVES, DETERMINED USING THE ATF TABLE OF DISTANCES FOR LOW EXPLOSIVES

(Assuming Deflagration; Results Based on Thermal Radiation)

Quantity (lbs)	Affected Distance (meters)
50	9
100	11
250	15
1,000	24
5,000	42
10,000	66
100,000	113

accidents appears to be the same for blasting agents and high explosives; however, blasting agents are much less sensitive to shock and much less likely to explode than high explosives, and individual high explosives differ in sensitivity.

The consequences of explosions of materials whose blast hazards are primarily due to projectiles have not been analyzed. These hazards may be significant; however, the scaling law is based on damage from overpressure waves and is not applicable to projectiles.

ATF's table of distances for high explosives and blasting agents applies to all high explosives and blasting agents for setting storage distances, regardless of whether the explosive has a mass explosion hazard or a projection hazard. Under the ATF rules, high explosives and blasting agents in quantities greater than 50 pounds must be stored more than 100 meters from inhabited buildings if unbarricaded. If there are barricades, the distances are based on an overpressure of 1.0; 444 pounds could be stored 100 meters from a barricaded inhabited building.

The primary hazard of low explosives (Division 1.3) is thermal radiation from a fire, although projectiles from a deflagration of low explosives may also represent a significant hazard. Consequence analysis based on ATF's Table of Distances for low explosives indicates that in the event of a deflagration of low explosives, the effects would not extend over a very great distance. To reach the heat radiation level used to develop the Table of Distances for low explosives at a distance of 100 meters from the site, about 70,000 pounds of low explosives would have to be involved in the deflagration.

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Appendix A

Damage Criteria/Overpressure Data

This appendix contains background on blast overpressure damage criteria and its effects. Also contained within this appendix are graphs illustrating the effect of varying overpressures on consequences.

A.1 Damage Criteria

Blast waves from accidental explosions can cause damage to people and property by subjecting them to transient crushing pressures and winds. Relatively simple concepts have been used to quite effectively correlate blast wave properties with damage. The concept states that damage is primarily a function of either the peak overpressure, the impulse or some combination of these factors. Peak overpressure is most commonly used.

Criteria for peak overpressures causing personal injury are given in Exhibit A-1, including injury from direct blast effects and from flying glass. Guidelines for peak overpressures required to produce property damage are presented in Exhibit A-2. These data are largely based on empirical observations. There seems to be general agreement between sources on the data presented in Exhibit A-2; however, the same is not true for the data presented in Exhibit A-1. According to Exhibit A-1, lung damage may occur at overpressures of 10 psi. According to other sources, threshold lung damage may not occur until peak overpressures reach 30 to 40 psi (Grelecki, Richmond 1968). The values for corresponding fatalities also vary. According to the Exhibit, the lowest overpressure cited for fatality from direct blast effects is 14.5 psi. According to another source, a 1% mortality rate is probable at 27.0 psi. Others cite values in the range of 35 to 120 psi as the threshold overpressure value for fatalities, 20.5 to 180 psi for a 50% fatality rate, and 29 to 250 psi for a 99% fatality rate (Grelecki, Richmond 1968, Lees 1980).

Exhibits A-3 and A-4 show how lethality and injury vary with both overpressure and the duration of the blast wave. Exhibit A-5 shows similar data as a function of both pounds of TNT and range in feet.

Exhibits A-3 through A-5 present potential injury levels resulting from direct exposure to blast overpressures in an open area. They do not take into account injuries resulting from property damage presented in Exhibit A-2. For example, substantial injury and possible deaths may result from the shattering of concrete walls at 2.0 to 3.0 psi. In planning with regard to injury to personnel, the following guidelines have been recommended (Brasie and Simpson 1968):

- Personnel in areas subject to overpressures greater than about 2 psi are likely casualties from fragmentation or self-impact against objects.

- Personnel beyond the under 1 psi overpressure range should be reasonably safe inside a reinforced structure away from windows or, if outdoors, lying on the ground.

EXHIBIT A-1. HUMAN INJURY CRITERIA
(Includes Injury from Flying Glass and Direct Overpressure Effects)

Overpressure (psi)	Injury	Comments	Source
0.6	Threshold for injury from flying glass*	Based on studies using sheep and dogs	(Fletcher, Richmond, and Yelverton 1980)
1.0 - 2.0	Threshold for skin laceration from flying glass	Based on Army data	(Lees 1980)
1.5	Threshold for multiple skin penetrations from flying glass (bare skin)*	Based on studies using sheep and dogs	(Fletcher, Richmond, and Yelverton 1980)
2.0 - 3.0	Threshold for serious wounds from flying glass	Based on Army data	(Lees 1980)
2.4	Threshold for eardrum rupture	Conflicting data on eardrum rupture	(Lees 1980)
2.8	10% probability of eardrum rupture	Conflicting data on eardrum rupture	(Lees 1980)
3.0	Overpressure will hurl a person to the ground	One source suggested an overpressure of 1.0 psi for this effect	(Brasie and Simpson 1968)
3.4	1% eardrum rupture	Not a serious lesion	(U.S. DOT 1988)
4.0 - 5.0	Serious wounds from flying glass near 50% probability	Based on Army data	(Lees 1980)
5.8	Threshold for body-wall penetration from flying glass (bare skin)*	Based on studies using sheep and dogs	(Fletcher, Richmond, and Yelverton 1980)
6.3	50% probability of eardrum rupture	Conflicting data on eardrum rupture	(Lees 1980)

* Interpretation of data tables presented in reference.

EXHIBIT A-1. HUMAN INJURY CRITERIA
(Includes Injury from Flying Glass and Direct Overpressure Effects)
(continued)

Overpressure (psi)	Injury	Comments	Source
7.0 - 8.0	Serious wounds from flying glass near 100% probability	Based on Army data	(Lees 1980)
10.0	Threshold lung hemorrhage	Not a serious lesion (applies to a blast of long duration (over 50 msec); 20-30 psi required for 3 msec duration waves)	(U.S. DOT 1988)
14.5	Fatality threshold for direct blast effects	Fatality primarily from lung hemorrhage	(Lees 1980)
16.0	50% eardrum rupture	Some of the ear injuries would be severe	(U.S. DOT 1988)
17.5	10% probability of fatality from direct blast effects	Conflicting data on mortality	(Lees 1980)
20.5	50% probability of fatality from direct blast effects	Conflicting data on mortality	(Lees 1980)
25.5	90% probability of fatality from direct blast effects	Conflicting data on mortality	(Lees 1980)
27.0	1% Mortality	A high incidence of severe lung injuries (applies to a blast of long duration (over 50 msec); 60-70 psi required for 3 msec duration waves)	(U.S. DOT 1988)
29.0	99% probability of fatality from direct blast effects	Conflicting data on mortality	(Lees 1980)

EXHIBIT A-2. PROPERTY DAMAGE CRITERIA

Overpressure (psi)	Damage	Source(s)
0.03	Occasional breaking of large glass windows already under strain	(Lees 1980)
0.04	Loud noise (143dB). Sonic boom glass failure	(Lees 1980)
0.10	Breakage of windows, small, under strain	(Lees 1980)
0.15	Typical pressure for glass failure	(Lees 1980)
0.30	"Safe distance" (probability 0.95 no serious damage beyond this value). Missile limit. Some damage to house ceilings. 10% window glass broken.	(Lees 1980)
0.4	Minor structural damage	(McRae 1984, Lees 1980)
0.5 - 1.0	Shattering of glass windows, occasional damage to window frames. One source reported glass failure at 0.147 psi	(Brasie and Simpson 1968, Air Force 1983, U.S. DOT 1988, Lees 1980)
0.7	Minor damage to house structures	(Lees 1980)
1.0	Partial demolition of houses, made uninhabitable	(Lees 1980)
1.0 - 2.0	Shattering of corrugated asbestos siding Failure of corrugated aluminum/steel paneling Failure of wood siding panels (standard housing construction)	(Brasie and Simpson 1968, Air Force 1983, U.S. DOT 1988, Lees 1980)
1.3	Steel frame of clad building slightly distorted	(Lees 1980)
2.0	Partial collapse of walls and roofs of houses	(Lees 1980)

EXHIBIT A-2. PROPERTY DAMAGE CRITERIA
(continued)

Overpressure (psi)	Damage	Source(s)
2.0 - 3.0	Shattering of non-reinforced concrete or cinder block wall panels (1.5 psi according to another source)	(Brasie and Simpson 1968, Air Force 1983, U.S. DOT 1988, Lees 1980)
2.3	Lower limit of serious structural damage	(Lees 1980)
2.5	50% destruction of brickwork of house	(Lees 1980)
3.0	Steel frame building distorted and pulled away from foundations	(Lees 1980)
3.0 - 4.0	Collapse of self-framing steel panel buildings Rupture of oil storage tanks Snapping failure - wooden utility tanks	(Brasie and Simpson 1968, U.S. DOT 1988, Lees 1980)
4.0	Cladding of light industrial buildings ruptured	(Lees 1980)
4.8	Failure of reinforced concrete structures	(McRae 1984)
5.0	Snapping failure - wooden utility poles	(Brasie and Simpson 1968, Lees 1980)
5.0 - 7.0	Nearly complete destruction of houses	(Lees 1980)
7.0	Loaded train wagons overturned	(Lees 1980)
7.0 - 8.0	Shearing/flexure failure of brick wall panels (8-12 inches thick, not reinforced)	(Brasie and Simpson 1968, Air Force 1983, U.S. DOT 1988, Lees 1980)
	Sides blown in of steel frame buildings	(Air Force 1983)
	Overturning of loaded rail cars	(Brasie and Simpson 1968, U.S. DOT 1988)

EXHIBIT A-2. PROPERTY DAMAGE CRITERIA
(continued)

Overpressure (psi)	Damage	Source(s)
9.0	Loaded train box-cars completely demolished	(Lees 1980)
10.0	Probable total destruction of buildings	(Lees 1980)
30.0	Steel towers blown down	(Brasie and Simpson 1968, Air Force 1983)
88.0	Crater damage	(McRae 1984)

EXHIBIT A-3. LETHALITY CURVES
(For a 154 lb Person in Free Stream Situations)

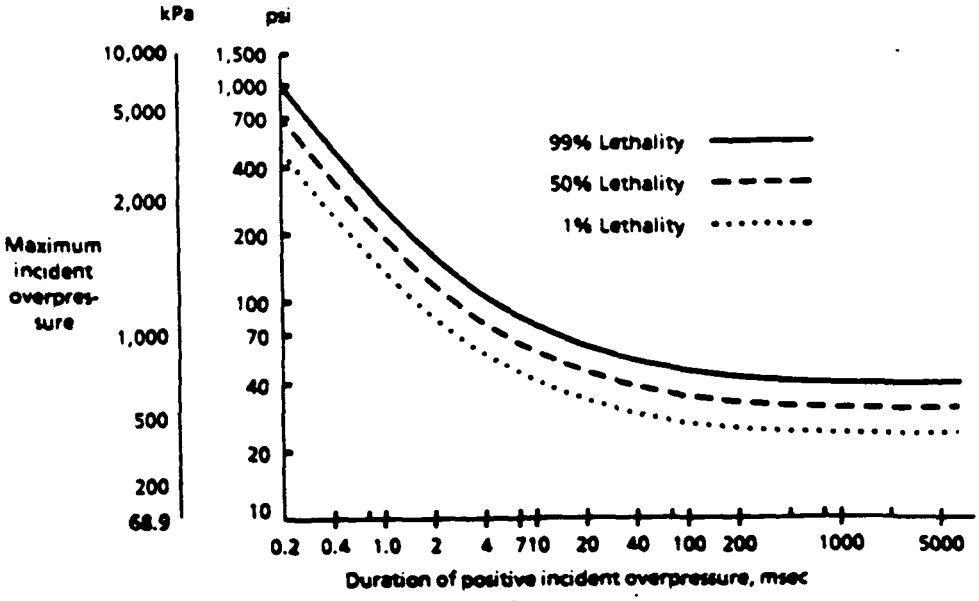
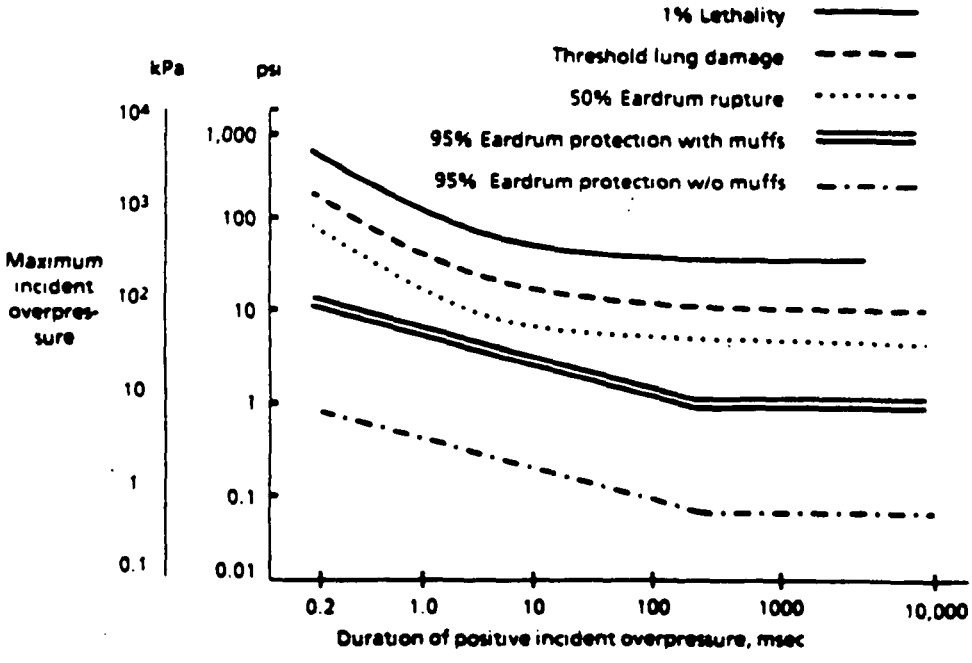


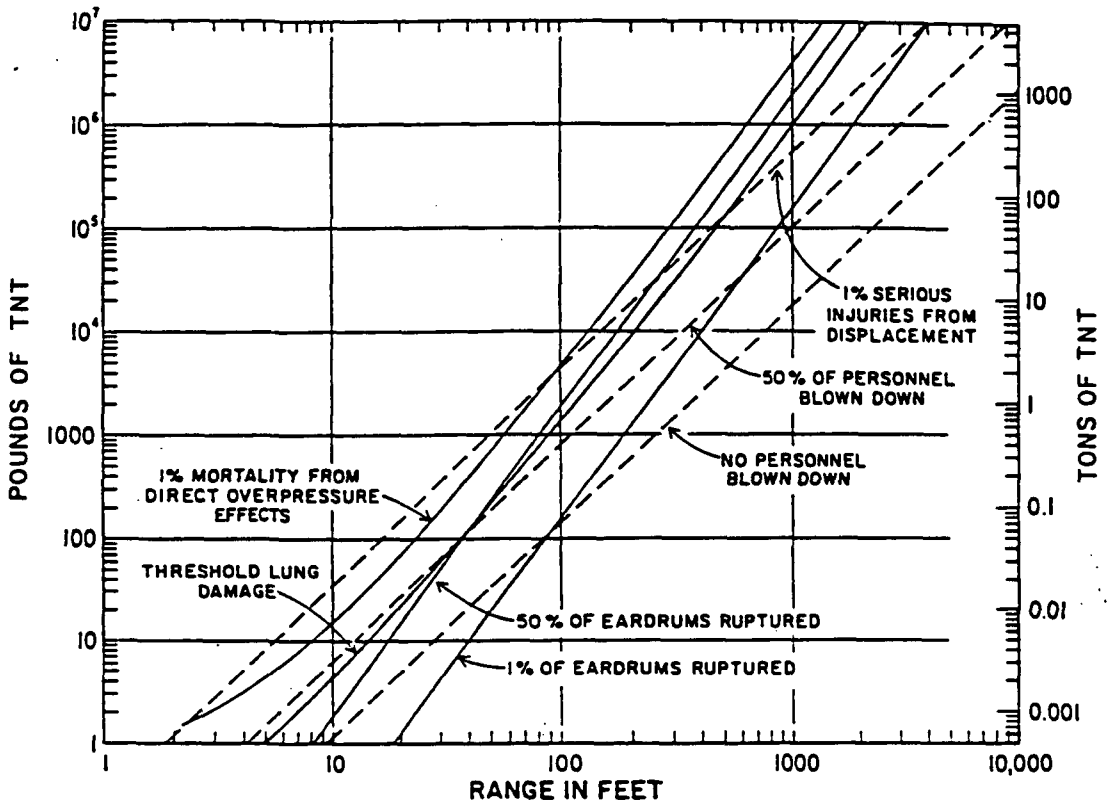
EXHIBIT A-4. LETHALITY AND INJURY CURVES
(For a 154 lb Person in Free Stream Situations)



Notes: msec = milliseconds
kPa = kilopascals = 6.895 psi
psi = pounds per square inch = 0.1450 kPa

Source: U.S. DOT 1988.

EXHIBIT A-5. AIR-BLAST CRITERIA FOR PERSONNEL STANDING IN THE OPEN



Source: U.S. DOT 1988.

The values presented in the Exhibits may be used to relate damage or injury criteria to safe distances for emergency planning, using the scaling law described in the text.

Note that although glass is reported to shatter at an overpressure level of 0.5 psi (see Exhibit A-2), there is evidence that human injury from flying glass is unlikely at this level. Lees (1980) cites a report stating that risk of injury from flying window glass is negligible for an explosion that gives a peak overpressure of 0.6 psi or less. Lees also cites a report giving the skin laceration threshold for flying glass as 1-2 psi and the serious wound threshold as 2-3 psi (see Exhibit A-1). Fletcher, Richmond, and Yelverton (1980) carried out experiments on the effects on sheep and dogs of glass fragments from windows shattered by various blast overpressures. Their results (briefly cited in Exhibit A-1) appear to agree reasonably well with the data reported by Lees. Their data indicate that the threshold for injury from flying glass is about 0.6 psi. Multiple injuries from skin penetration (i.e., ten or more) may occur for bare skin at overpressures of 1.5 psi or higher. Flying glass may penetrate the body-wall at 5.8 psi or higher if the skin is bare. The authors point out that the skin and body-wall thickness of men and sheep are approximately the same (Fletcher, Richmond, and Yelverton 1980); therefore, the data reported should be roughly applicable to humans.

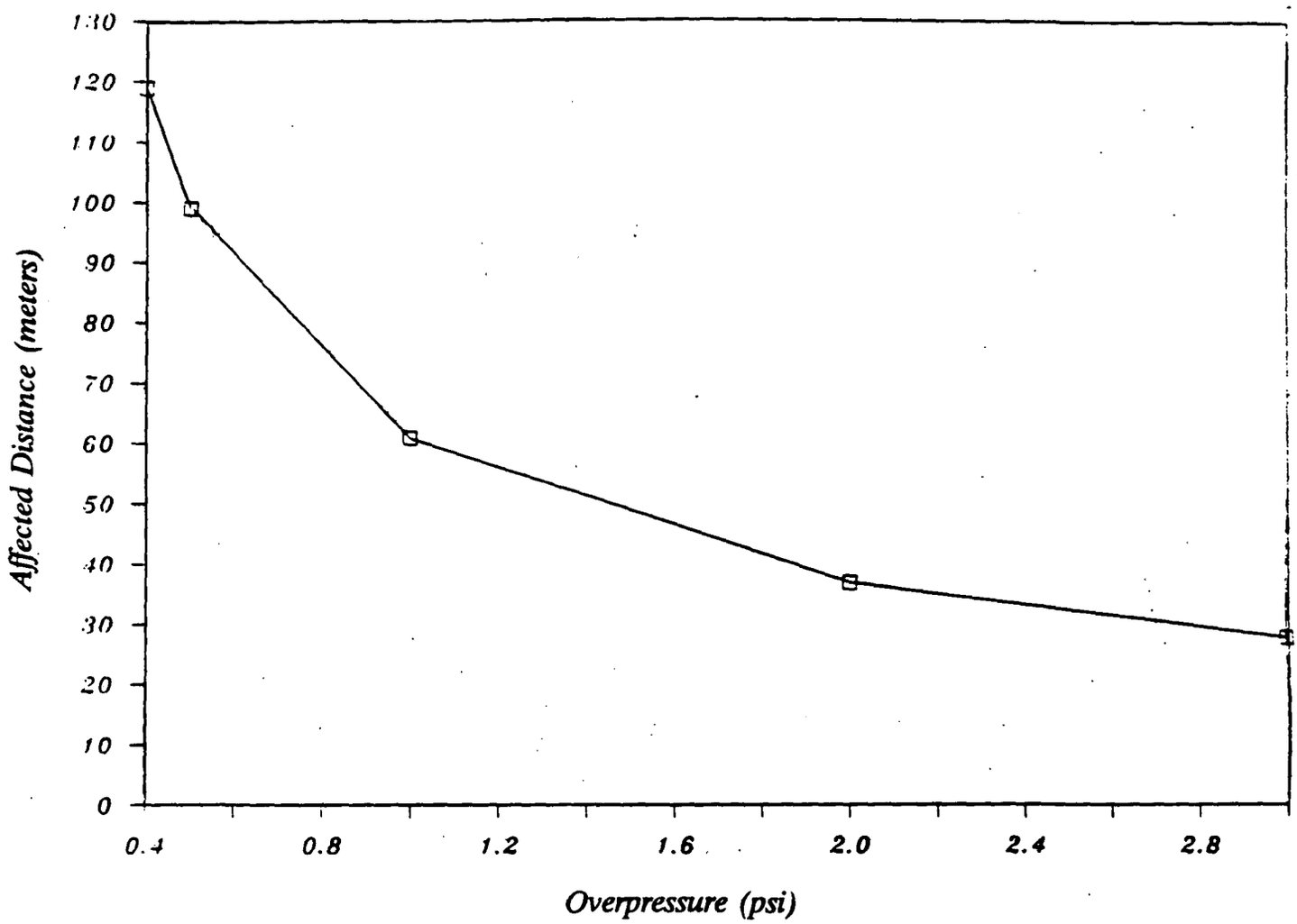
A.2 Effects of Varying Overpressures

To determine the effect on distance of choosing different overpressure levels, analysis was carried out at four different overpressures for high explosives. ATF methodology was used, and calculations were carried out for a quantity of 100 pounds at overpressures of 0.4, 0.5, 1.0, 2.0, and 3.0 psi.

Exhibit A-6 presents a graph of overpressure versus distance for commercial high explosives. The exhibits indicate that higher overpressures occur at lower distances (i.e., closer to the explosion site), and overpressure falls off as distance increases. This is as expected from the scaling law. Distance and K are directly proportional in the scaling law. Therefore, as K increases, so does the affected distance. However, as K increases, overpressure decreases (as is indicated by Exhibit 5 in the main text of this study).

The decrease in distance affected with increase in overpressure appears to occur more rapidly at low overpressures than at higher overpressures; note that the distance decreases much more sharply between 0.4 and 0.5 psi than between 1.0 and 2.0 psi or 2.0 and 3.0 psi (see Exhibit A-6).

EXHIBIT A-6
OVERPRESSURE VERSUS DISTANCE FOR 100 POUNDS OF HIGH EXPLOSIVES



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Appendix B
Other Methods of Consequence Analysis Based on the Scaling Law

EPA selected two commonly used methodologies for estimating distances affected by explosions, both based on the scaling law, for comparison with the ATF standards. These methods are:

- ***ARCHIE***: A computerized hazard assessment model developed for DOT, FEMA, and the EPA; and

- ***K-Factor***: Use of the scaling law, as described in the text, with TNT equivalence.

The methods and the results obtained for examples of high explosives and blasting agents are described below. These methods are not appropriate for substances that deflagrate rather than detonate; therefore, no results are presented for low explosives.

B.1 ARCHIE

The Automated Resource for Chemical Hazard Incident Evaluation (ARCHIE) computer program was developed for FEMA, DOT, and EPA to provide emergency planning personnel with the tools necessary to assess the vapor dispersion, fire, and explosion impacts associated with hazardous materials accidents. Contained within the program are several methods for evaluating the consequences of an explosion, depending upon the type of material involved. Model "K", the Condensed-Phase Explosion Model, was used for this analysis. The model is based upon the scaling law discussed earlier and is appropriate for use with commercial explosives. The Condensed-Phase Explosion Model differs from the scaling law in that the TNT-equivalent weight is calculated as a function of heat of combustion and empirically derived yield factors, rather than as a function of an empirically derived TNT equivalence. (Heat of combustion represents the total combustion energy of a substance and is likely to be higher than the heat of explosion.) In addition, the curve relating K to overpressure has been approximated by a logarithmic expression. The ARCHIE manual presents the following equation for determining distance:

$$X = (M_{TNT}^{1/3})(\exp(3.5031 - 0.7241\ln(O_p) + 0.0398(\ln O_p)^2))$$

where:

	X	= Required distance, ft
	M_{TNT}	= Adjusted equivalent mass of TNT, lb
		= $[M_{chem} \times [(\Delta H_c/1155) \times Y_f]]$
	M_{chem}	= Original mass of explosive material
	ΔH_c	= Lower heat of combustion of explosive material, kcal/kg
	Y_f	= Yield factor
	O_p	= Peak overpressure, psi
	1155	= Heat of explosion of TNT, kcal/kg

The ARCHIE manual recommends using a yield factor of one for condensed-phase explosions (i.e., it is assumed that all of the energy is available for the explosion).

The following expression, from the above equation, gives an approximation of the K-factor at a given overpressure:

$$\exp\,(3.5031 - 0.7241\,\ln(O_p) + 0.0398(\ln O_p)^2)$$

The primary limitation of this method is that it attempts to estimate TNT equivalence, an empirically derived parameter, with heats of combustion using yield factors, another empirically derived parameter. Note also that the heat of explosion given for TNT, 1155 kcal/kg, is higher than the heat of explosion reported elsewhere, 1011 to 1090 kcal/kg (Kirk-Othmer 1980, Meyer 1987). In addition, the equation approximating the curve relating overpressure to K is imprecise at the endpoints.

While the ARCHIE manual presents the above equation for estimating the K-factor, it appears, based on an analysis of the model results for several chemicals, that the model actually uses selected values of the K-factor corresponding to specific consequences rather than the equation for the K-factor and, therefore, the results produced by the computer model are somewhat different from the results obtained from the equation. The model results are presented as distances (or ranges of distances) to 14 damage levels. Apparently the K-factor for the overpressure related to each of these damage levels is included in the model.

Exhibit B-1 presents a sample printout of ARCHIE model results for 1,000 pounds of TNT (heat of combustion 6,512 BTU/lb). The expected damage levels presumably correspond to the overpressures and expected damage presented in the ARCHIE manual, i.e., "Windows usually shattered; some frame damage" corresponds to overpressures of 0.5 psi - 1.0 psi. An overpressure of 0.5 psi would be reached at 368 feet from the explosion; an overpressure of 1.0 psi would be reached at 212 feet. (See Appendix A for more information on the effects of various overpressure levels.)

B.2 "K-Factor" Methodology

The K-factor methodology is equivalent to the straight usage of the scaling law. The scaling law is represented by the following equation:

$$D = (K)(W^{1/3})$$

where:

D = Required, or affected, distance, ft
K = Protection factor (see Exhibit 1)
W = TNT equivalent weight, lb.

W in the above equation is equal to the TNT equivalent weight of the material of concern as follows:

$$W = [M_{chem} \times \%TNT]$$

where:

M_{chem} = Total mass of chemical
%TNT = TNT equivalent; the ratio of the quantity of TNT to the quantity of explosive material that will have an equivalent effect.

The %TNT, or TNT equivalent, varies and is derived for each explosive material from empirical tests and actual accidents involving TNT and other explosive materials.

EXHIBIT B-1. SAMPLE PRINTOUT OF ARCHIE MODELING RESULTS FOR 1,000 POUNDS OF TNT (HEAT OF COMBUSTION 6,512 BTU/LB.)

CONDENSED-PHASE EXPLOSION EFFECTS

DISTANCE FROM EXPLOSION (feet)	EXPECTED DAMAGE
11751	Occasional breakage of large windows under stress.
1656	Some damage to home ceilings; 10% window breakage.
618 - 1072	Windows usually shattered; some frame damage.
618	Partial demolition of homes; made uninhabitable.
159 - 618	Range serious/slight injuries from flying glass/object.
373	Partial collapse of home walls/roofs.
285 - 373	Non-reinforced concrete/cinder block walls shattered.
127 - 330	Range 90-1% eardrum rupture among exposed population.
321	50% destruction of home brickwork.
238 - 285	Frameless steel panel buildings ruined.
208	Wooden utility poles snapped.
171 - 208	Nearly complete destruction of houses.
141	Probable total building destruction.
85 - 117	Range for 99-1% fatalities among exposed populations due to direct blast effects.

Note: The explosion is assumed to take place on or near the ground.

Note that the distances provided by the ARCHIE model are in feet. Since the Agency has used meters as the unit of measure in its evaluations, the values here should be divided by 3.25 for purposes of comparison.

The parameter K in the scaling law is referred to as the protection factor. It is a function of the peak overpressure and is independent of the material of concern. The value of K at a given overpressure is determined from the graph shown in Exhibit 5 of the main text.

B.3 Results

Several high explosives and ammonium nitrate fuel oil (ANFO), the most commonly used blasting agent, were analyzed to estimate the distance at which various overpressures would be reached. The high explosives included in this analysis are nitroglycerin, which is used in some dynamite formulations and other explosive formulations; pentaerythritol tetranitrate, which may be used as the base charge in blasting caps, the core explosive in commercial detonating cord, or in other formulations; and lead azide, which is a primary explosive used only in small quantities as an initiator for other explosives because of its sensitivity. Exhibit B-2 presents the factors used and the results of the analysis using the ARCHIE equation, the ARCHIE model, and the K-factor method at an overpressure of 0.5 psi, and the ATF table of distances for overpressure levels of 0.4 psi (the level used for development of the table) and 0.5 psi. Exhibits B-3, B-4, and B-5 show the results at overpressures of 1.0 psi, 2.0 psi, and 3.0 psi, respectively. Distances for 0.5, 1.0, 2.0, and 3.0 psi are not included in the ATF Table of Distances; the ATF distances at these overpressures were estimated from the K-factor for purposes of comparison. Distances from the ATF Table of Distances (based on 0.4 psi) are also included in these exhibits for comparison. The analyses were carried out for 50, 100, 250, 1,000, and 5,000 pounds of each high explosive material. The exhibits show the heat of combustion used for ARCHIE modeling and the TNT equivalent and K value used in carrying out the distance calculations using the K-factor method. A yield factor of one was used for ARCHIE modeling in all cases, as recommended for condensed-phase explosions. Affected distance in meters based on each of the methods is shown.

TNT equivalents are not taken into account in using the Table of Distances (i.e., all materials are assumed to have the same explosive potential); however, the TNT equivalent is taken into account in the K-factor method. Therefore, the Table of Distances gives greater distances than the K-factor method for materials with TNT equivalents less than one, while the K-factor method gives greater distances than the Table of Distances for materials with TNT equivalents greater than one. (It should be noted that the TNT equivalent is an experimentally-derived quantity, not a physical property, and values may vary, depending on the test used.)

The equation presented in the ARCHIE manual for calculating distance (see Section C.1) does not give results that are consistently higher or lower than the K-factor method or the Table of Distances. This equation is based on a calculated K-factor, which may be significantly different at a given overpressure from the K-factor value read from the graph, and a TNT equivalent weight calculated from the heat of combustion of the material. For an overpressure of 0.5 psi, the K-factor calculated using the ARCHIE equation is 56, compared to about 70 from the graph. At 1.0 psi, the equation gives 33, while the graph shows 43. At 2.0 psi, a K-factor of 20 is calculated from the equation, compared to 26 from the graph, and at 3.0 the calculated value is 16 and graph value is 20. The TNT equivalent used in the K-factor method is based on empirical tests comparing the substance to TNT. In all the cases considered, the TNT equivalent calculated from the heat of combustion using the ARCHIE method is greater than TNT equivalents reported in the literature. Because both the calculated K-factor and the calculated TNT equivalent may affect the results of the ARCHIE equation, but in opposite ways (the lower K-factor would tend to lead to lower distances and the higher TNT equivalents to higher distances), no clear-cut comparisons can be made between the ARCHIE equation and the other methodologies.

The ARCHIE model yields distances quite comparable to those calculated by the K-factor method. The ARCHIE model uses heat of combustion to calculate an approximate TNT equivalent, while TNT equivalent values derived from test results are used for the K-factor method. The K-factors used by the ARCHIE model (as estimated using the scaling law) are very close to the values read from the graph for use

EXHIBIT B-2. AFFECTED DISTANCES FOR COMMERCIAL HIGH EXPLOSIVES AND BLASTING AGENTS, DETERMINED USING FOUR DIFFERENT METHODS
(Peak Overpressure = 0.5 psi)

Explosive Material	Amount (lbs)	Heat of Combustion (kcal/kg)	TNT Equivalent *	Overpressure (psi)	K Value	Affected Distance (m)				
						ARCHIE Model	ARCHIE Equation	K-Factor	ATF (0.5 psi)**	ATF (0.4 psi)+
Nitroglycerin	50	1625	1.52	0.5	70	88	70	90	79	97
	100					111	89	114	99	119
	250					151	120	155	134	160
	500					190	152	195	168	206
	1000					239	191	245	213	251
	5000					409	327	419	365	431
Pentaerythritol Tetranitrate (PETN)	50	1960	1.52	0.5	70	94	75	90	79	97
	100					118	94	114	99	119
	250					160	128	154	134	160
	500					202	161	195	169	206
	1000					254	203	245	213	251
	5000					435	348	419	365	431
Lead Azide (Primary explosive)	50	630	0.40	0.5	70	67	51	58	79	97
	100					85	65	73	99	119
	250					115	88	99	134	160
	500					138	111	125	169	206
	1000					183	139	157	213	251
	5000					312	238	269	365	431
TNT	50	3620	1.00	0.5	70	120	92	79	79	97
	100					152	116	99	99	119
	250					206	157	134	134	160
	500					248	198	169	169	206
	1000					327	249	213	213	251
	5000					559	427	365	365	431
Ammonium Nitrate - Fuel Oil (ANFO) (Blasting Agent)	50	626 ++	0.77	0.5	70	67	51	72	79	97
	100					85	65	91	99	119
	250					115	88	123	134	160
	500					138	110	155	169	206
	1000					182	139	196	213	251
	5000					312	238	334	365	431

* Sources of TNT equivalents: NTIS 1971, NASA 1988, Kirk-Othmer 1980.
** Estimated for purposes of comparison.
\+ The value of K corresponding to an overpressure of 0.4 psi is 80 - 90.
++ Heat of combustion for pure ammonium nitrate (Kirk-Othmer 1980).

EXHIBIT B-3. AFFECTED DISTANCES FOR COMMERCIAL HIGH EXPLOSIVES AND BLASTING AGENTS, DETERMINED USING FOUR DIFFERENT METHODS
(Peak Overpressure = 1.0 psi)

Explosive Material	Amount (lbs)	Heat of Combustion (kcal/kg)	TNT Equivalent *	Overpressure (psi)	K Value	Affected Distance (m)				
						ARCHIE Model	ARCHIE Equation	K-Factor	ATF (1.0 psi)**	ATF (0.4 psi)+
Nitroglycerin	50	1625	1.52	1.0	43	54	42	56	48	97
	100					68	53	70	61	119
	250					93	71	95	83	160
	500					117	90	120	168	206
	1000					147	113	151	131	251
	5000					251	194	258	224	431
Pentaerythritol Tetranitrate (PETN)	50	1960	1.52	1.0	43	58	44	55	48	97
	100					73	56	70	61	119
	250					98	76	95	83	160
	500					124	96	120	104	206
	1000					156	121	151	131	251
	5000					267	207	257	224	431
Lead Azide (Primary explosive)	50	630	0.40	1.0	43	39	30	36	48	97
	100					49	38	45	61	119
	250					66	52	61	83	160
	500					85	66	77	104	206
	1000					105	83	97	131	251
	5000					180	141	165	224	431
TNT	50	3620	1.00	1.0	43	70	55	48	48	97
	100					88	69	61	61	119
	250					119	93	83	83	160
	500					152	118	104	104	206
	1000					188	148	131	131	251
	5000					322	253	224	224	431
Ammonium Nitrate - Fuel Oil (ANFO) (Blasting Agent)	50	626 ++	0.77	1.0	43	39	30	44	48	97
	100					49	38	56	61	119
	250					66	52	76	83	160
	500					85	66	95	104	206
	1000					105	83	120	131	251
	5000					180	141	205	224	431

* Sources of TNT equivalents: NTIS 1971, NASA 1988, Kirk-Othmer 1980.
** Estimated for purposes of comparison.
\+ The value of K corresponding to an overpressure of 0.4 psi is 80 - 90.
++ Heat of combustion for pure ammonium nitrate (Kirk-Othmer 1980).

EXHIBIT B-4. AFFECTED DISTANCES FOR COMMERCIAL HIGH EXPLOSIVES AND BLASTING AGENTS, DETERMINED USING FOUR DIFFERENT METHODS
(Peak Overpressure = 2.0 psi)

Explosive Material	Amount (lbs)	Heat of Combustion (kcal/kg)	TNT Equivalent *	Overpressure (psi)	K Value	Affected Distance (m)				
						ARCHIE Model	ARCHIE Equation	K-Factor	ATF (1.0 psi)**	ATF (0.4 psi)+
Nitroglycerin	50	1625	1.52	2.0	26	33	26	34	29	97
	100					41	32	42	37	119
	250					56	44	57	50	160
	500					70	56	72	168	206
	1000					89	70	91	79	251
	5000					152	120	156	136	431
Pentaerythritol Tetranitrate (PETN)	50	1960	1.52	2.0	26	35	27	34	29	97
	100					44	35	42	37	119
	250					60	47	57	50	160
	500					75	59	72	63	206
	1000					95	75	91	79	251
	5000					162	127	156	136	431
Lead Azide (Primary explosive)	50	630	0.40	2.0	26	23	19	22	29	97
	100					30	24	27	37	119
	250					40	32	37	50	160
	500					51	41	46	63	206
	1000					64	51	58	79	251
	5000					109	87	100	136	431
TNT	50	3620	1.00	2.0	26	42	34	29	29	97
	100					53	42	37	37	119
	250					72	58	50	50	160
	500					92	73	63	63	206
	1000					114	91	79	79	251
	5000					195	156	136	136	431
Ammonium Nitrate - Fuel Oil (ANFO) (Blasting Agent)	50	626 ++	0.77	2.0	26	23	19	27	29	97
	100					30	24	34	37	119
	250					41	32	46	50	160
	500					51	40	58	63	206
	1000					63	51	73	79	251
	5000					109	87	124	136	431

* Sources of TNT equivalents: NTIS 1971, NASA 1988, Kirk-Othmer 1980.
** Estimated for purposes of comparison.
\+ The value of K corresponding to an overpressure of 0.4 psi is 80 - 90.
++ Heat of combustion for pure ammonium nitrate (Kirk-Othmer 1980).

EXHIBIT B-5. AFFECTED DISTANCES FOR COMMERCIAL HIGH EXPLOSIVES AND BLASTING AGENTS, DETERMINED USING FOUR DIFFERENT METHODS (Peak Overpressure = 3.0 psi)

Explosive Material	Amount (lbs)	Heat of Combustion (kcal/kg)	TNT Equivalent *	Overpressure (psi)	K Value	Affected Distance (m)				
						ARCHIE Model	ARCHIE Equation	K-Factor	ATF (1.0 psi)**	ATF (0.4 psi)+
Nitroglycerin	50	1625	1.52	3.0	20	25	20	26	22	97
	100					32	25	33	28	119
	250					43	34	44	38	160
	500					54	43	56	168	206
	1000					68	54	70	61	251
	5000					117	92	120	104	431
Pentaerythritol Tetranitrate (PETN)	50	1960	1.52	3.0	20	27	21	26	22	97
	100					34	27	33	28	119
	250					46	36	44	38	160
	500					58	45	56	48	206
	1000					73	57	70	61	251
	5000					124	98	120	104	431
Lead Azide (Primary explosive)	50	630	0.40	3.0	20	18	14	17	22	97
	100					23	18	21	28	119
	250					31	25	28	38	160
	500					40	31	36	48	206
	1000					48	39	45	61	251
	5000					83	67	77	104	431
TNT	50	3620	1.00	3.0	20	32	26	22	22	97
	100					40	33	28	28	119
	250					55	44	38	38	160
	500					71	56	48	48	206
	1000					87	70	61	61	251
	5000					148	120	104	104	431
Ammonium Nitrate - Fuel Oil (ANFO) (Blasting Agent)	50	626 ++	0.77	3.0	20	18	14	21	22	97
	100					23	18	26	28	119
	250					30	25	35	38	160
	500					39	31	44	48	206
	1000					48	39	56	61	251
	5000					83	67	96	104	431

* Sources of TNT equivalents: NTIS 1971, NASA 1988, Kirk-Othmer 1980.
** Estimated for purposes of comparison.
\+ The value of K corresponding to an overpressure of 0.4 psi is 80 - 90.
++ Heat of combustion for pure ammonium nitrate (Kirk-Othmer 1980).

in the K-factor method. The ARCHIE model gives greater distances than the ATF Table of Distances in cases where the calculated TNT equivalent is greater than one (i.e., where the heat of combustion of the explosive is greater than 1155 kcal/kg, the heat of explosion of TNT cited by ARCHIE), and smaller distances where the TNT equivalent is less than one (i.e., where the heat of combustion is less than 1155 kcal/kg).

In general, the ATF Table of Distances, the ARCHIE model, the ARCHIE equation, and the K-factor method give results for high explosives and blasting agents that are of the same order of magnitude. As all three methods are based on the scaling law, similar results would be expected. In some cases, however, the results differ significantly, apparently because of the approximations made.

It is not clear that any of the three methods can be considered to have more validity or to give more conservative results than the others. However, it should be noted that the ATF Table of Distances is widely used and accepted, and that the Institute of Makers of Explosives and the Department of Defense favor the ATF method (Sawyer 1989, Dowling 1989).

Appendix C
Requirements for Explosives Magazines

This appendix provides additional details on ATF requirements for explosives magazines (discussed in Section 3.4 of the text).

C.1 General Requirements

Outdoor magazines must be located according to the distances specified in the table of distances for storage of explosive materials. The ground around an outdoor magazine must be sloped to provide for drainage away from the magazine or sufficient drainage must otherwise be provided.

Where lighting is necessary, it should conform to the following guidelines as put forth in ATF-Explosives Law and Regulations, 1990:

- Electric lighting must comply with National Electrical Code standards for conditions present.
- Electric switches must be placed outside the magazine and comply with the National Electric Code.
- Battery-activated safety lighting is permitted in explosives magazines of all types.

C.2 Requirements by Type of Magazine

Type 1 Magazines are permanent magazines for storage of high explosives; other classes of explosives also may be stored in type 1 magazines. A type 1 magazine may be a building, an igloo or "Army-type structure," a tunnel, or a dugout. The following requirements apply to type 1 magazines:

1) Must be bullet-resistant, fire-resistant, weather-resistant, theft-resistant, and ventilated.

2) Masonry wall construction can be no less than six inches in thickness and must have hollows packed with weak concrete (one part cement, eight parts sand, and sufficient water for packing) or coarse, dry sand. Interior walls must be nonsparking or covered with nonsparking material.

3) Metal wall construction must consist of at least 14-gauge steel or aluminum sheets fastened to a metal framework. Either brick, solid cement blocks, or hardwood not less than four inches thick or a six-inch sand fill between inner and outer walls must be used in conjunction with the metal wall construction. Interior walls must be made of or covered with nonsparking material.

4) Wooden frame wall construction must be covered with at least 26-gauge steel or aluminum. An inner wall (nonsparking) must be separated by at least six inches from the outer wall; this six-inch space must be filled with weak concrete or coarse, dry sand.

5) Floors must be constructed of or covered by a nonsparking material. Floors must be sufficiently strong to support the weight of the maximum amount of explosives that could be stored in that magazine. Iron nails in floor and walls which would come in contact with explosives must be covered by nonsparking material or otherwise countersunk or blind nailed.

6) Foundations must be constructed of brick, concrete, cement, block, stone, or wood posts. When posts are used, the space under the building must be enclosed with metal.

7) External roofing for type 1 magazines must be 26-gauge iron or aluminum affixed to 7/8-inch sheathing, except for buildings with fabricated metal roofs. If it is possible for a bullet to be fired through the roof, striking the explosives, protection must be provided by one of the following:

- A sand tray lined with paper, plastic, or some other nonporous material and filled with at least four inches of coarse, dry sand covering the entire ceiling area; or

- A metal roof constructed of 3/16 inch plate steel lined with four inches of hardwood, where for each additional 1/16 inch plate steel, hardwood may be decreased by one inch.

8) Doors are to be made of not less than 1/4 inch plate steel and lined with at least two inches of hardwood. Hinges and hasps must be attached by welding, riveting, or bolting, and must be not be removable when the door is closed and locked.

9) Each door must be equipped with two mortise locks, or two padlocks fastened in separate hasps and staples, or a combination of mortise lock and padlock, or a mortise lock requiring two keys to open, or a three-point lock. Padlocks themselves must have a 3/8 inch case-hardened shackle and have a 1/4 inch steel hood to prevent sawing or lever action on the lock, hasps, or staple. Lock requirements need not apply to doors adequately secured by a bolt, lock, or bar on the inside that can not be actuated from the outside.

10) Ventilation is to be provided to prevent dampness and heating of stored explosives. Clearance of roof and foundation ventilators from magazine contents must be maintained by a lattice lining or some sufficient equivalent: air circulation must be maintained. Ventilation openings must be screened to prevent entrance of sparks; side and foundation ventilation openings must be shielded or offset for bullet-resistance.

Type 2 Magazines are mobile and portable indoor and outdoor magazines for storage of high explosives; other classes of explosives also may be stored in type 2 magazines. A type 2 magazine may be a box, trailer, semitrailer, or other mobile facility. The following are requirements for type 2 magazines:

1) Outdoor Magazines.

   a) Must be bullet-resistant, fire-resistant, weather-resistant, theft-resistant, and ventilated.

   b) Must be supported to prevent direct contact with the ground.

   c) Exteriors and doors must be constructed of at least 1/4 inch steel and at least two inches of hardwood. Top-opening magazines must have lids that overlap the sides by one inch or have water-resistant seals.

   d) Hinges and hasps are to be attached to doors by welding, riveting, or bolting such that they can not be removed when the door is locked and closed.

   e) Each door is to be equipped with two mortise locks, or two padlocks fastened in separate hasps and staples, or a combination of a mortise lock and padlock, or a mortise lock that requires two keys to open, or a three-point lock.

2) Indoor Magazines.

   a) Must be fire-resistant and theft-resistant; need not be bullet-resistant and weather-resistant if located in a bullet-resistant and weather-resistant building.

   b) May not be located in a residence or dwelling.

c) Indoor storage of high explosives must not exceed a total of 50 pounds in one or more magazines. Detonators must be stored in a separate magazine; the total quantity of detonators must not exceed 5,000.

d) Sides, bottoms, and covers (or doors) shall be either two inch hardwood (with braced corners) and covered with at least 26-gauge sheet metal or at least 12 gauge metal lined inside with nonsparking material.

e) Hinges and hasps must be attached by welding, riveting, or bolting such that they can not be removed when the door is closed and locked.

f) Each door is to be equipped with two mortise locks, or two padlocks fastened in separate hasps and staples, or a combination of a mortise lock and padlock, or a mortise lock that requires two keys to open, or a three-point lock.

Type 3 Magazines are "day-boxes" or other portable outdoor magazines for the temporary storage of high explosives while attended; other classes of explosives also may be stored in type 3 magazines. The following requirements apply:

1) Must be fire-resistant, weather-resistant, and theft-resistant.

2) Must be constructed of at least 12-gauge steel and lined with 1/2 inch plywood or hardboard.

3) Doors must overlap openings by at least one inch.

4) At least one steel padlock with a 3/8 inch case-hardened shackle must be used. Explosives may not be left unattended and if they are to be unattended, must be moved to a type 1 or type 2 magazine.

Type 4 Magazines are magazines for the storage of low explosives; blasting agents also may be stored in type 4 magazines. A type 4 magazine may be a building, igloo or "Army-type structure," tunnel, dugout, box, trailer, semitrailer, or other mobile facility. Type 4 magazines must meet the following specifications:

1) Outdoor Magazines.

a) Must be fire-resistant, weather-resistant, and theft-resistant.

b) When unattended, vehicular magazines must be immobilized by removal of the wheels or use of a locking device.

c) Must be constructed of masonry, metal-covered wood, fabricated metal, or some combination of these and built on a brick, concrete, cement block, stone, or metal/wood post foundation. When built on piers or posts, the space under the building must be enclosed with fire-resistant material. The interior must be nonsparking.

d) Doors must be metal or solid wood covered with metal.

e) Hinges and hasps must be attached to doors by welding, riveting, or bolting such that they can not be removed when doors are closed and locked.

f) Each door is to be equipped with two mortise locks, or two padlocks fastened in separate hasps and staples, or a combination of a mortise lock and padlock, or a mortise lock that requires two keys to open, or a three-point lock.

2) Indoor Magazines.

a) Must be fire-resistant and theft-resistant; need not be weather-resistant if located in a weather-resistant building.

b) May not be located in a residence or dwelling.

c) More than one magazine may be located in the same building if the total quantity of explosives does not exceed 50 pounds. Detonators that will not mass detonate must be stored in a separate magazine; the total number of electric detonators must not exceed 5,000.

d) Must be constructed of masonry, metal-covered wood, fabricated metal, or a combination of these materials; interiors must be non-sparking.

e) Hinges and hasps must be attached to doors by welding, riveting, or bolting such that they can not be removed when door is closed and locked.

f) Each door is to be equipped with two mortise locks, or two padlocks fastened in separate hasps and staples, or a combination of a mortise lock and padlock, or a mortise lock that requires two keys to open, or a three-point lock.

Type 5 Magazines are magazines for the storage of blasting agents. A type 5 magazine may be a building, igloo or "Army-type structure," tunnel, dugout, bin, box, trailer, semitrailer, or other mobile facility. The following requirements apply to type 5 magazines:

1) Outdoor Magazines.

a) Must be weather-resistant and theft-resistant.

b) When unattended, vehicular magazines must be immobilized by removal of the wheels or use of a locking device.

c) Doors and covers shall be constructed of either solid wood or metal.

d) Hinges and hasps must be attached to doors by welding, riveting, or bolting such that they can not be removed when doors are closed and locked.

e) Each door is to be equipped with two mortise locks, or two padlocks fastened in separate hasps and staples, or a combination of a mortise lock and padlock, or a mortise lock that requires two keys to open, or a three-point lock.

2) Indoor Magazines.

a) Must be theft-resistant.

b) Doors shall be constructed of wood or metal.

c) Hinges and hasps must be attached to doors by welding, riveting, or bolting such that they can not be removed when doors are closed and locked.

d) Each door is to be equipped with two mortise locks, or two padlocks fastened in separate hasps and staples, or a combination of a mortise lock and padlock, or a mortise lock that requires two keys to open, or a three-point lock.

REFERENCE

ATF 1990. "ATF: Explosives Law and Regulations," P 5400.7, Bureau of Alcohol, Tobacco, and Firearms, Department of the Treasury, June, 1990.

Appendix D
Tests for Explosives in Transportation

This appendix briefly describes the tests used for materials in transportation to determine whether the explosives hazard class is applicable, and tests for assignment of hazard divisions for explosive materials.

D.1 Tests for Explosive Properties

Materials that are not designed to have an explosive effect, and that are tested and found to be not too sensitive for transport, are further tested to determine whether they have explosive properties. If positive results are obtained in one of the shock tests or thermal tests described below, the substance is considered to have explosive properties. The same tests are used, with less stringent conditions, to determine whether a substance is too insensitive to be eligible for Class 1.

Shock Tests

- BAM 50/60 steel tube test. This test measures sensitivity to shock under confinement by determining whether the test material propagates a detonation. The material to be tested is packed into a steel tube. A booster (50 grams of RDX/wax) is placed in the upper end of the tube and a detonator is inserted into the booster. The detonator is fired and propagation of detonation is noted if:

  -- the tube is completely fragmented, or

  -- the tube is fragmented at both its upper and lower ends, or

  -- a length of tube less than 21 centimeters from the upper end is fragmented and the substance has reacted completely with a velocity higher than the velocity of sound in the substance (method of determining the velocity is not described).

- TNO 50/70 steel tube test. This test also uses a steel tube and a booster to determine detonability of a substance. A velocity probe also is inserted in the tube. A determination is made as to whether or not the material has detonated based on fragmentation of the tube. If the tube is fragmented over its entire length, the substance is considered to have detonated. If fragmentation is not complete, the substance is still considered to have detonated if velocity measurements meet the following conditions:

  -- the total decrease in resistance measured by the velocity probe should correspond with the total original length of resistance wire in the tube,

  -- the propagation velocity should be constant in the second part of the tube,

  -- the constant velocity should be higher than the sound velocity in the substance.

- Gap test for solids and liquids. This test is used to measure shock sensitivity and detonation propagation. The substance is packed in a steel tube with a velocity of detonation probe. A booster is placed at the end of the tube and initiated with a detonator. The substance is considered to propagate detonation if two of the following criteria are met:

  -- stable propagation velocity greater than the velocity of sound in the substance is observed,

-- a hole is punched through the witness plate,

-- the sample tube is fragmented along its entire length.

- Second gap test for solids and liquids. This test subjects the substance to an intense shock to determine the possibility of propagation of detonation in a solid and occurrence of low velocity detonation in a liquid. The substance is packed in a steel tube with a booster at the end (a second booster is placed at the other end of the tube for solids as a reference). A detonator is used to initiate the booster. For solids, the substance is considered to propagate detonation if the witness plate is punctured in one of three tests. For liquids, fragmentation of the tube, a bulge in the witness plate, and measured velocity are considered in combination.

Combustion or Thermal Tests

- Koenen test. This test subjects solids and liquids to intense heat under partial confinement to determine whether an explosion will occur and to measure the limiting diameter for the explosion. The substance is put in a steel tube which is heated using a propane heater. Trials are carried out with orifice plates of various sizes, from 1 to 20 millimeters, attached to the tube, starting with 20 millimeters. Orifice sizes are varied until an explosion is observed. The limiting diameter of the substance is the largest diameter at which an explosion occurs in at least one of three trials. Occurrence of an explosion is determined by the condition of the tube; if the tube fragments into three or more pieces, an explosion has occurred.

- Internal ignition test. This test determine the response of substances to rapidly rising temperatures and pressures. The substance is put in a steel pipe with an igniter in the center and capped at both ends. The test is considered positive if firing the igniter leads to fragmentation of either the pipe or one of the end caps into at least two pieces.

- Small-Scale Cook-Off Bomb (SCB) test. This test subjects the substance to slow external heating. The substance is heated electrically in a steel vessel; the temperature is raised at a rate of 3° C per minute until a reaction occurs or up to 400° C. The test is considered positive if the vessel is ruptured or fragmented or the witness plate is deformed or punctured.

D.2 Tests for Assignment of Hazard Division

Materials designed to have an explosive effect or found by testing to have an explosive effect are assigned to hazard divisions based on tests carried out on the materials packaged as they are to be transported (or unpackaged if they are to be carried without packaging). The following tests are used to determine the hazard division:

- Single package test. Substances intended to function by detonation are tested with a standard detonator; substances intended to function by deflagration are tested with an igniter sufficient to ensure ignition of the substance; substances not intended for use as explosives are tested first with a standard detonator and then, if no explosion occurs, with an igniter. A single package or article is tested in the form in which it is to be shipped. If the total contents explodes, the material is considered a candidate for Division 1.1. Evidence of explosion of the total contents includes:

-- a crater at the test site,

-- damage to the "witness plate" under the package,

-- measurement of a blast,

-- disruption and scattering of most of the confining material.

- Stack test. Substances that are candidates for Division 1.1, based on results described above, are tested further. A similar test (using a detonator or igniter as described above) is carried out on a stack of packages or articles with a total volume of 0.15 cubic meters. If explosion of the total contents occurs practically instantaneously, the material is assigned to Division 1.1. Evidence of explosion of the total contents includes:

  -- a crater at the test site appreciably larger than the crater resulting from explosion of a single package,

  -- damage to the "witness plate" under the package that is appreciably greater than that from a single package,

  -- measurement of a blast that significantly exceeds that from a single package,

  -- violent disruption and scattering of most of the confining material.

- External fire (bonfire) test. Substances that are not identified as candidates for Division 1.1 in the single package test, or that are not assigned to Division 1.1 in the stack test, are tested to determine their behavior in a fire and the effect on the surroundings from blast waves, thermal effects, and projectiles. A stack of packages or articles with a total volume of 0.15 cubic meters or a minimum of three packages, whichever is greater, is exposed to external heating (e.g., from a wood fire or propane burner). The results are assessed as follows:

  For assignment to Division 1.1 (explosives with a mass explosion hazard:

  -- explosion of the total contents occurs practically instantaneously.

  For assignment to Division 1.2 (explosives with a projection hazard but not a mass explosion hazard):

  -- explosion of the total contents does not occur practically instantaneously, and

  -- there is perforation of the "witness screens", or

  -- more than ten metallic projectiles, each weighing more than 25 grams, are thrown more than 50 meters from the stack, or

  -- any metallic projectile weighing more than 150 grams is thrown more than 15 meters from the stack.

  For assignment to Division 1.3 (explosives with a fire hazard):

  -- criteria for assignment to Division 1.1 or 1.2 are not met, and

  -- a fireball is produced that extends beyond the witness screens, or

-- a jet flame is produced that extends more than three meters from the flames of the fire, or

-- thermal radiation from the burning product exceeds that of the fire by more than $4kW/m^3$ at a distance of 15 meters from the stack (thermal radiation is measured for five seconds and corrected to correspond to 100 kilograms of explosive material).

For assignment to Division 1.4 (explosive devices with a minor explosion hazard):

-- criteria for assignment to Division 1.1, 1.2, or 1.3 are not met, and

-- there is indentation of the witness screens, or

-- there are projectiles, thermal effects, or blast effects that could significantly hinder emergency response efforts in the vicinity (five meters), or

-- the product tested is an article intended to produce a practical explosive or pyrotechnic effect and there is some effect (projection, fire, smoke, heat, or loud noise) external to the device.

Tests for Very Insensitive Explosives

For assignment to Division 1.5 (very insensitive explosives), an explosive must pass all of the following tests:

- Cap sensitivity test. A standard detonator or blasting cap is used in three attempts to detonate the substance. A substance that detonates is too sensitive for Division 1.5.

- DDT test. The explosive is packed into a steel tube and ignited by a hot wire. The test is performed twice. A probe is used to monitor the shock wave. A substance that detonates in this test is too sensitive for Division 1.5.

- Second DDT test. This test is similar to the first DDT test, but a five gram igniter is used and a witness plate is used to determine whether a detonation occurs. The test is performed three times. If a hole is blown in the witness plate, the substance is too sensitive for Division 1.5.

- External fire test. A package or packages with a total volume of not less than 0.15 cubic meters, where the weight of explosive does not have to exceed 200 kilograms, is exposed to an external fire large enough to engulf the bottom of the package. The flames must reach at least halfway up the sides of the package. A substance that explodes in this test is too sensitive for Division 1.5. Evidence of explosion in the fire may be a loud noise or the projection of fragments from the fire area.

- Princess incendiary spark test. The explosive is tested in powder form (it is crushed and passed through a sieve if necessary). Three grams of the powdered explosive are put in a test tube and a fuse is placed on the surface of the sample. The fuse is lit; if the explosive is ignited, it is considered too sensitive for Division 1.5.

REFERENCE

U.N. 1986. United Nations. Recommendations on the Transport of Dangerous Goods, Tests and Criteria. New York: United Nations. Sales No. E.85.VIII.2. ISBN 92-1-139021-4.