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Warheads Primer

OBJECTIVES AND INTRODUCTION

INTRODUCTION

The basic function of any weapon is to deliver a destructive force on an enemy target. Targets of today include military bases, factories, bridges, ships, tanks, missile launching sites, artillery emplacements, fortifications, and troop concentrations. Since each type of target presents a different physical destruction problem, a variety of general and special-purpose warheads are required, within the bounds of cost and logistical availability, so that each target may be attacked with maximum effectiveness.

The basic warhead consists of three functional parts:

- Fuze (including the safety and arming devices)
- Explosive fill
- Warhead case

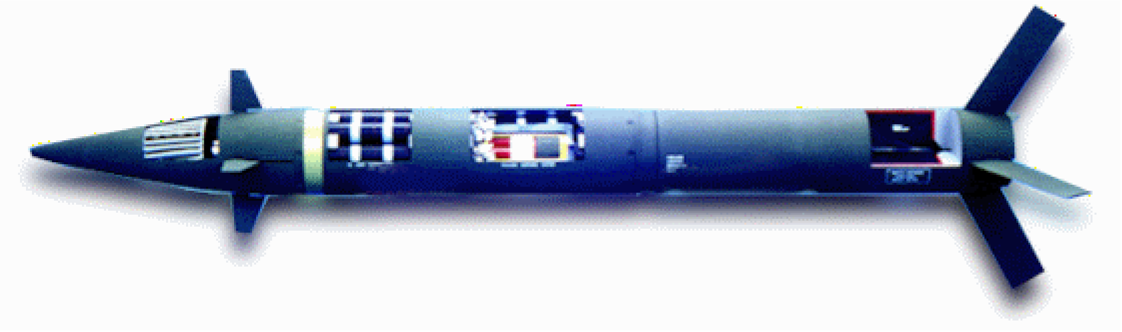
THE HIGH-EXPLOSIVE TRAIN

High explosives comprise one category of chemical explosives. This category is subdivided into primary and secondary explosives. Recall that primary explosives are considerably more sensitive than secondary explosives. The high-explosive train is usually composed of a detonator, booster, and main charge. The detonator may be initiated electrically or by mechanical shock and may contain an explosive relay, pyrotechnic delay, etc.

The detonator sets up a detonation wave when initiated. The output of the detonator is too low powered and weak to reliably initiate a high-order detonation in the main charge (secondary explosive) unless a booster is placed between the two. Detonation of the booster results in a shock wave of sufficient strength to initiate a high-order detonation of the main explosive charge.

Explosives are characteristically unstable chemical compounds or mixtures of unstable compounds, and some explosives are formulated with inert binders to achieve variations in the explosive properties. An explosion of a high-explosive substance is characterized by a chemically reinforced shock wave (detonation wave) traveling at a high velocity.

If the process were to be stopped momentarily, an observer placed inside the unreacted explosive portion would be unaware of what was taking place because he is ahead of the supersonic shock wave. The detonation process, while very rapid, does occur over a finite period of time. The detonation wave is a strong shock wave with pressures as high as 385 kilobars depending on the type of explosive. Levels of shock energy this high are easily capable of breaking the relatively unstable chemical bonds of explosive compounds. Therefore, as the detonation wave passes through the unreacted explosive, atomic bonds within the explosive molecules are broken. There is then a rapid process of chemical recombination into different compounds, principally gases like CO_2, H_2O, N_2, etc., that result in a heat energy release. This release causes rapid expansion of the gases, which reinforces the detonation wave and provides the energy that ultimately produces the destructive effect of a warhead.



WARHEAD CHARACTERISTICS

The warhead is the primary element of the weapon; it accomplishes the desired end result--effective damage to the target. Damage to the target is directly related to three parameters:

- **Damage Volume.**

The warhead may be thought of as being enclosed by an envelope that sweeps along the trajectory of the missile. The volume enclosed by this envelope defines the limit of destructive effectiveness of the payload.

- **Attenuation.**

As shock and fragments leave the point of origin, a reduction in their destructive potential per unit area takes place. Attenuation can be likened to an expanding sphere, in which the energy available per unit area constantly decreases until it is completely harmless.

- **Propagation.**

This is the manner in which energy and material, emitted by the warhead at detonation, travel through the medium in which the blast occurs. When the propagation of a payload is uniform in all directions, it is called isotropic. If not, it is called non-isotropic.

WARHEAD TYPES

For convenience of discussion, warheads will be classified into five major groups: blast (including air and underwater burst), fragmentation, shaped charge, continuous rod, and special-purpose.

- **Blast Warheads**

A blast warhead is one that is designed to achieve target damage primarily from blast effect. When a high explosive detonates, it is converted almost instantly into a gas at very high pressure and temperature. Under the pressure of the gases thus generated, the weapon case expands and breaks into fragments. The air surrounding the casing is compressed and a shock (blast) wave is transmitted into it. Typical initial values for a high-explosive weapon are 200 kilobars of pressure (1 bar = 1 atmosphere) and 5,000 degrees Celsius.

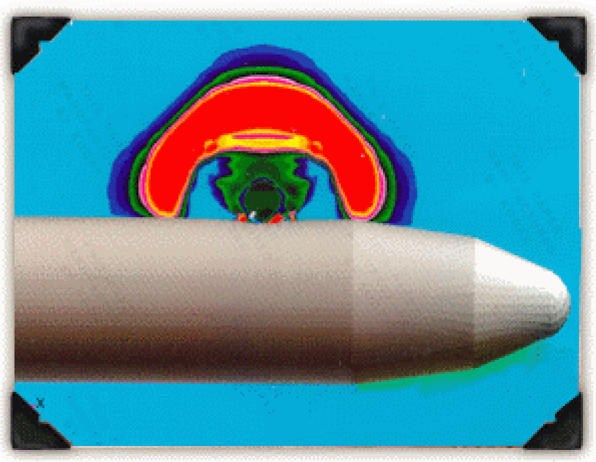
The shock wave generated by the explosion is a compression wave, in which the pressure rises from atmospheric pressure to peak overpressure in a fraction of a microsecond. It is followed by a much slower (hundredths of a second) decline to atmospheric pressure. This portion is known as the positive phase of the shock wave. The pressure continues to decline to subatmospheric pressure and then returns to normal. This portion is called the negative or suction phase. . The duration's of these two phases are referred to as the positive and negative duration's. The area under the pressure-time curve during the positive phase represents the positive impulse, and that during the negative phase, the negative impulse. The result of this positive/negative pressure variation is a push-pull effect upon the target, which causes targets with large volume to effectively explode from the internal pressure.

For a fixed-weight explosive, the peak pressure and positive impulse decrease with distance from the explosion. This is due to the attenuation of the blast wave. The rate of attenuation is proportional to the rate of expansion of the volume of gases behind the blast wave. In other words the blast pressure is in-inversely proportional to the cube of the distance from the blast center ($1/R3$). Blast attenuation is somewhat less than this in-side, approximately 16 charge radii from blast center. It should also be noted that there will be fragmentation when the warhead casing ruptures.

Another aspect of overpressure occurring in air bursts is the phenomenon of Mach reflections, called the "Mach Effect."

When a bomb is detonated at some distance above the ground, the reflected wave catches up to and combines with the original shock wave, called the incident wave, to form a third wave that has a nearly vertical front at ground level. This third wave is called a "Mach Wave" or "Mach Stem," and the point at which the three waves intersect is called the "Triple Point." The Mach Stem grows in height as it spreads laterally, and as the Mach Stem grows, the triple point rises, describing a curve through the air. In the Mach Stem the incident wave is reinforced by the reflected wave, and both the peak pressure and impulse are at a maximum that is considerably higher than the peak pressure and impulse of the original shock wave at the same distance from the point of explosion.

Using the phenomenon of Mach reflections, it is possible to increase considerably the radius of effectiveness of a bomb. By detonating a warhead at the proper height above the ground, the maximum radius at which a given pressure or impulse is exerted can be increased, in some cases by almost 50%, over that for the same bomb detonated at ground level. The area of effectiveness, or damage volume, may thereby be increased by as much as 100%. Currently only one conventional pure-blast warhead is in use, the Fuel Air Explosive (FAE).



- **Underwater Blast Warheads.**

The mechanism of an under-water blast presents some interesting phenomena associated with a more dense medium than air. An underwater explosion creates a cavity filled with high-pressure gas, which pushed the water out radially against the opposing external hydrostatic pressure. At the instant of explosion, a certain amount of gas is instantaneously generated at high pressure and temperature, creating a bubble. In addition, the heat causes a certain amount of water to vaporize, adding to the volume of the bubble. This action immediately begins to force the water in contact with the blast front in an outward direction. The potential energy initially possessed by the gas bubble by virtue of its pressure is thus gradually communicated to the water in the form of kinetic energy. The inertia of the water causes the bubble to overshoot the point at which its internal pressure is equal to the external pressure of the water. The bubble then becomes rarefied, and its radial motion is brought to rest. The external pressure now compresses the rarefied bubble. Again, the equilibrium configuration is overshot, and since by hypothesis there has been no loss of energy, the bubble comes to rest at the same pressure and volume as at the moment of explosion (in practice, of course, energy is lost by acoustical and heat radiation).

The bubble of compressed gas then expands again, and the cycle is repeated. The result is a pulsating bubble of gas slowly rising to the surface, with each expansion of the bubble creating shock wave. Approximately 90% of the bubble's energy is dissipated after the first expansion and contraction. This phenomenon explains how an underwater explosion appears to be followed by other explosions. The time interval of the energy being returned to the bubble (the period of pulsation's) varies with the intensity of the initial explosion.

The rapid expansion of the gas bubble formed by an explosion under water results in a shock wave being sent out through the water in all directions. The shock wave is similar in general form to that in air, although if differs in detail. Just as in air, there is a sharp rise in overpressure at the shock front. However, in water, the peak overpressure does not fall off as rapidly with distance as it does in air. Hence, the peak values in water are much higher than those at the same distance from an equal explosion in air. The velocity of sound in water is nearly one mile per second, almost five times as great as in air. Consequently, the duration of the shock wave developed is shorter than in air.

The close proximity of the upper and lower boundaries between which the shock wave is forced to travel (water surface and ocean floor) causes complex shock-wave patterns to occur as a result of reflection and rarefaction. Also, in addition to the initial shock wave that results from the initial gas bubble expansion, subsequent shock waves are produced by bubble pulsation. The pulsating shock wave is of lower magnitude and of longer duration than the initial shock wave.

Another interesting phenomenon of an underwater blast is surface cutoff. At the surface, the shock wave moving through the water meets a much less dense medium--air. As a result, a reflected wave is sent back into the water, but this is a rarefaction or suction wave. At a point below the surface, the combination of the reflected suction wave with the direct incident wave produces a sharp decrease in the water shock pressure. This is surface cutoff.

After the lapse of a short interval, which is the time required for the shock wave to travel from the explosion to the given location, the overpressure rises suddenly due to the arrival of the shock front. Then, for a period of time, the pressure decreases steadily, as in air. Soon thereafter, the arrival of the reflected suction wave from the surface causes the pressure to drop sharply, even below the normal (hydrostatic) pressure of the water. This negative pressure phase is of short duration and can result in decrease in the extent of damage sustained by the target. The time interval between the arrival of the direct shock wave at a particular location (or target) in the water and that of the cutoff, signaling the arrival of the reflected wave, depends upon the depth of burst, the depth of the target, and the distance from the burst point to the target. It can generally be said that a depth bomb should be detonated at or below the target and that a target is less vulnerable near the surface.

- **Fragmentation Warheads.**

The study of ballistics, the science of the motion of projectiles, has contributed significantly to the design of fragmentation warheads. Specifically, terminal ballistics studies attempt to determine the laws and conditions governing the velocity and distribution of fragments, the sizes and shapes that result from bursting different containers, and the damage aspects of the bursting charge fragmentation.

Approximately 30% of the energy released by the explosive detonation is used to fragment the case and impart kinetic energy to the fragments. The balance of available energy is used to create a shock front and blast effects. The fragments are propelled at high velocity, and after a short distance they overtake and pass through the shock wave. The rate at which the velocity of the shock front accompanying the blast decreases is generally much greater than the decrease in velocity of fragments, which occurs due to air friction. Therefore, the advance of the shock front lags behind that of the fragments. The radius of effective fragment damage, although target dependent, thus exceeds considerably the radius of effective blast damage in an air burst.

- **Fragment Velocity.**
  - The velocity of the fragments can be looked at in two parts: a) the initial velocity, and b) the velocity as a function of distance from the origin.
  - The initial static velocity of the fragments of a cylindrical warhead depends primarily upon two factors:
    - The charge-to-metal ratio, *C/M,* where *C* is the mass of explosive per unit length of projectile and *M* is the mass of metal per unit length of projectile.
    - The characteristics of the explosive filler, particularly its brisance and strength.
  - Fragment trajectories will follow paths predicted by the principles of external ballistics. For determining the effectiveness of almost all fragmenting munitions, the sub-sonic trajectory of the fragments can be ignored. As a result, the density of fragments in a given direction varies inversely as the square of the distance from the weapon. The probability of a hit on some unshielded target is proportional to the exposed projected area and inversely proportional to the square of the distance from the weapon.
- **Fragment Flight.**
  - The fragments of a warhead travel outward in a nearly perpendicular direction to the surface of its casing (for a cylindrical warhead there is a 7- to 10-degree lead angle). The tail and nose spray are frequently referred to separately as the "forty-five degree cone," which is an area of less dense fragmentation. If this payload were to be detonated in flight, the dense side spray would have a slight forward thrust with an increased velocity equal to missile flight velocity.
  - The angle of the side spray would be defined as the beam width of this fragmenting payload. Fragment beam width is defined as the angle covered by a useful density of fragments. Beam width is a function of warhead shape and the placement of the detonator(s) in the explosive charge.
  - The latest air target warheads are designed to emit a narrow beam of high-velocity fragments. This type of warhead, called an annular Blast Fragmentation warhead (ABF), has a fragmentation pattern that propagates out in the form of a ring with tremendous destructive potential. A newer type of fragmentation warhead is the Selectively Aimable Warhead (SAW). This "smart" warhead is designed to aim its fragment density at the target. This is accomplished by the fuzing system telling the warhead where the target is located and causing it to detonate so as to maximize the energy density on the target.

- **Fragment Material.**
    - The damage produced by a fragment with a certain velocity depends upon the mass of the fragment. It is therefore necessary to know the approximate distribution of mass for the fragments large enough to cause damage. Mass distribution of payload fragments is determined by means of a static detonation in which the fragments are caught in sand pits. In naturally fragmenting payloads where no attempt to control fragment size and number is made, fragmentation may randomly vary from fine, dust-like particles to large pieces. Modern warheads use scored casings and precut fragments to ensure a large damage volume.

- **Shaped Charge Warheads**

A shaped charge warhead consists basically of a hollow liner of metal material, usually copper or aluminum of conical, hemispherical, or other shape, backed on the convex side by explosive. A container, fuze, and detonating device are included. When this warhead strikes a target, the fuze detonates the charge from the rear. A detonation wave sweeps forward and begins to collapse the metal cone liner at its apex. The collapse of the cone results in the formation and ejection of a continuous high-velocity molten jet of liner material. This produces a velocity gradient that tends to stretch out or lengthen the jet. The jet is then followed by a slug that consists of about 80% of the liner mass.

When the jet strikes a target of armor plate or mild steel, pressures in the range of hundreds of kilobars are produced at the point of contact. This pressure produces stresses far above the yield strength of steel, and the target material flows like a fluid out of the path of the jet. This phenomenon is called hydrodynamic penetration. There is so much radial momentum associated with the flow that the difference in diameter between the jet and the hole it produces depends on the characteristics of the target material. A larger diameter hole will be made in mild steel than in armor plate because the density and hardness of armor plate is greater. The depth of penetration into a very thick slab of mild steel will also be greater than that into homogeneous armor.

In general, the depth of penetration depends upon five factors:

- Length of jet
- Density of the target material
- Hardness of target material
- Density of the jet
- Jet precision (straight vs. divergent)

The longer the jet, the greater the depth of penetration. Therefore, the greater the standoff distance (distance from target to base of cone) the better. This is true up to the point at which the jet particulates or breaks up (at 6 to 8 cone diameters from the cone base). Particulation is a result of the velocity gradient in the jet, which stretches it out until it breaks up.

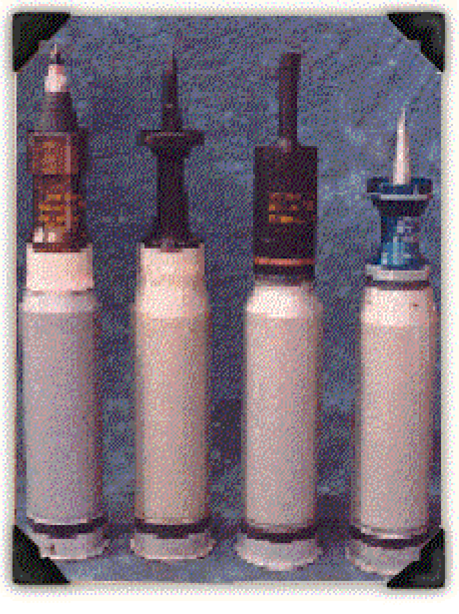
Jet precision refers to the straightness of the jet. If the jet is formed with some oscillation or wavy motion, then depth of penetration will be reduced. This is a function of the quality of the liner and the initial detonation location accuracy. The effectiveness of shaped charge warheads is reduced when they are caused to rotate. Spin-stabilized projectiles generally cannot use shaped-charge warheads.

The effectiveness of a shaped charge payload is independent of the striking velocity of the warhead. In fact, the velocity of the warhead must be taken into consideration to ensure that detonation of the payload occurs at the instant of optimum stand-off distance. The jet can then effectively penetrate the target. Damage incurred is mostly a function of the jet and material from the target armor detached off the rear face. This action of target material joining with the shaped charge jet is known as spalling. The extent of spalling is a function of the amount of explosive in the payload and the quality of the target armor.

- **Continuous-Rod Warheads**

Early warhead experiments with short, straight, unconnected rods had shown that such rods could chop off propeller blades, engine cylinders, and wings, and in general, inflict severe damage to a fighter aircraft. However, rod warheads were ineffective against larger planes because the nature of most bomber aircraft structures permits a number of short cuts in their skin without lethal damage occurring. It was found, however, that long, continuous cuts would do considerable damage to a bomber; therefore, the continuous-rod warhead was developed.

Upon detonation, the continuous-rod payload expands rapidly into a ring pattern. The intent is to cause the connected rods, during their expansion, to strike the target and produce damage by a cutting action. Each rod is connected end-to-end alternately and arranged in a bundle radially around the main charge. The burster is designed such that upon detonation the explosive force will be distributed evenly along the length of the continuous-rod bundle. This is important in order to ensure that each rod will maintain its configuration and consequently result in uniform integrity of the expanding circle.



Special-Purpose Warheads

There are other means of attacking targets than with blast, fragmentation, shaped charge, or continuous rod payloads. Several types of payloads are more specialized in nature, designed to perform a specific function. A few of these will be described.

- **Thermal Warheads**
    - The purpose of thermal warheads is to start fires. Thermal payloads may employ chemical energy to kindle fires with subsequent uncontrollable conflagrations, or nuclear energy to produce direct thermal destruction as well as subsequent fires. Thermal payloads of the chemical type may be referred to as incendiary or fire bombs. Many area targets are more effectively attacked by fire than by blast or fragmentation.
- **Pyrotechnic Warheads:** Pyrotechnics are typically employed for signaling, illuminating, or marking targets. In the simplest form they are hand-held devices. Some examples of more elaborate warhead payloads are as follows:
    - **Illumination**
        - These warheads usually contain a flare or magnesium flare candle as the payload, which is expelled by a small charge and is parachuted to the ground. During its descent the flare is kindled. The illuminating warhead is thus of great usefulness during night attacks in pointing out enemy fortifications. Illumination projectiles are used with great effectiveness in shore bombardment. Illuminating warheads are also used as aircraft flares and flare rockets to assist in the attack of the ground targets and submarines. Because these flares are difficult to extinguish if accidentally ignited, extreme caution in their handling is required.
    - **Smoke**
        - These warheads are used primarily to screen troop movements and play a vital role in battlefield tactics. A black powder charge ignites and expels canisters that may be designed to emit white, yellow, red, green, or violet smoke.
    - **Markers**
        - White phosphorus is commonly employed as a payload to mark the position of the enemy. It can be very dangerous, especially in heavy concentrations. The material can self-ignite in air, cannot be extinguished by water, and will rekindle upon subsequent exposure to air. Body contact can produce serious burns. Copper sulfate prevents its re-ignition.
- **Anti-Personnel Warheads:**
    - Such warheads are designed to destroy or maim personnel or to damage material enough to render it inoperable. In the area of field artillery, the flechette or beehive round is an example of an anti-personnel warhead. The payload in this projectile consists of steel-wire, fin-stabilized darts. Upon detonation the darts, or flechettes, are sprayed radially from the point of detonation. It is extremely effective against personnel in the open or in dense foliage.
- **Chaff Warheads:**
    - Chaff may be employed to decoy enemy weapons or blind enemy radar. The payload typically consists of metal-coated fiberglass strands cut in lengths determined by wavelength of the RF energy to be countered. Chaff may be dispensed in a variety of warheads, including projectiles and rockets.

- **Cluster Bomb Units (CBU)**
    - CBUs are air-delivered weapons that are canisters containing hundreds of small bomblets for use against a variety of targets, such as personnel, armored vehicles, or ships. Once in the air, the canisters open, spreading the bomblets out in a wide pattern. The advantage of this type of warhead is that it gives a wide area of coverage, which allows for a greater margin of error in delivery.
- **Mines**:
    - Mine warheads use the underwater blast principles described earlier to inflict damage on the target ship or submarine. The damage energy transmitted is approximately equally divided between the initial shock wave and the expanding gas bubble. If the target is straddling the gas bubble, then it will have unequal support and may be broken in two. As the detonation depth increases, the effect of the gas bubble causing damage is greatly diminished. Mines typically use the highest potential explosives. Captor mines have also been developed that launch a smart torpedo that passively and actively homes in on the target before detonation.
- **Torpedoes:**
    - Torpedo warheads must be capable of damaging both ships and submarines. Homing in on the screws can achieve a mobility kill. Detonation under the keel at midships can cause the severe gas-bubble damage mentioned with mines, and if the depth is shallow, the reflected shock wave can substantially increase the damage effects. Torpedoes that actually impact the hull of a ship or submarine have to overcome the double hull/void structure. Deep-diving submarines with especially thick hulls require highly specialized warheads. Shaped charge warheads are envisioned as the solution to this problem.
- **Anti-tank warheads**:
    - Tank projectiles are basically broken down into two types: shaped charge rounds and kinetic-energy penetrators. The two rounds differ in both composition and concept. Shaped round charges--or HEAT charges--focus the energy from an explosion into a small, concentrated area in order to penetrate armor plates. In order to defend against such projectiles, scientists developed combination armor that combined the hardness of steel with the fluid properties of ceramics. Combination armor combines a layer of honeycombed ceramic sandwiched by two layers of steel plates. Although the HEAT round easily penetrates the outer steel plate, the ceramics "flow" around the jet and break the jet into smaller components, spreading the force of the blast out into a larger area and reducing the effectiveness of the HEAT round.
    - The innovation of combination armor required the use of kinetic energy to punch through armor. This was no new inspiration, but was the original concept behind tank projectiles. Instead of relying on the HEAT round's explosive jet to pierce armor, kinetic-energy penetrators rely on mass and velocity. The armor-piercing fin-stabilized discarding-sabot (APFSDS) rounds contain very dense, long, slender darts, and are called long-rod penetrators. Commonly referred to as sabot rounds, these rounds burrow into a tank's armor upon impact. If the round contains enough kinetic energy, it will pass through the tank's armor and destroys whatever is inside. Often times, however, the round does not contain enough energy to penetrate all the way through. Although the round does not fully penetrate the armor, it creates many small armor fragments that discharge into the tank, causing destruction inside.
    - With rounds that use both kinetic-energy and the concentration of explosions to penetrate armor, scientists constantly research new ways to defend against such rounds and improve the survivability of armored vehicles. Using a combination of

armor thickness, innovative materials, (combination armor and depleted uranium, for example) and armor slope assists the scientist in protecting against the different types of projectiles. The latest type of protection comes from reactive armor. Reactive armor is described as a sandwich of explosive between metal plates that explodes when a round strikes it. The explosive in the reactive armor detonates at the same time as a HEAT round, throwing the steel plates out against the round and highly disrupting the jet. Reactive armor's effectiveness against long-rod penetrators, however, is less significant because the sabot round is too massive for the steel plates to block.

SUMMARY

High explosives are basically employed in warheads to produce damage. Initiation of the reaction is achieved through the high-explosive train. Rapidity of the reaction is enhanced by the phenomenon of detonation. The generation of heat and the evolution of gases produce pressure effects and radiation, which constitute the damage potential of the warhead.

Through a basic description of warheads, it may be seen how a specific target may determine the warhead characteristic to be employed in order to counter that target. Variation upon the five basic types of warheads results in more specialized designs developed to provide the military arsenal with greater flexibility.

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