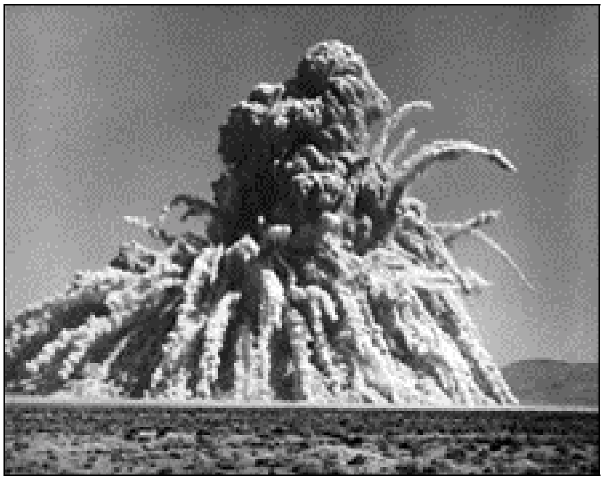


Nuclear Bunker Busters

Geoffrey Forden

The end of the Cold War and the accompanying rapid changes in the global security environment has reopened a debate in the U.S. about the utility of low-yield nuclear weapons as a means of addressing a wide range of U.S. security objectives. Proponents of such systems argue that they are needed to destroy storage and production centers for weapons of mass destruction based in deep underground bunkers; deep underground command centers and hiding places of terrorist and other enemy leaders; and other deep underground facilities that pose a threat to U.S. security but are beyond the reach of conventional "bunker buster" bombs. The recent anthrax attacks have, if anything, increased the desire for such nuclear weapons and further widened the range of arguments being used by the proponents of these weapons.

But how effective would even a nuclear weapon be against such facilities? One former senior Pentagon official stated that these facilities might be buried under 300 meters of granite. Is that within the destructive range of even a nuclear bomb? Furthermore, it might be impossible for intelligence sources to pinpoint the precise position of the bunker inside a mountain. Satellite surveillance can be used to estimate the length of tunnel leading to the facility by observing the volume of material removed. It cannot, however, determine if a tunnel takes a sharp turn somewhere along its path. Even human intelligence has limited utility for targeting since small uncertainties in the direction of a tunnel can lead to large errors in its actual location at its end. These significant real-world operational uncertainties means that a nuclear weapon must be capable of destroying an underground facility even if it misses by hundreds of meters.

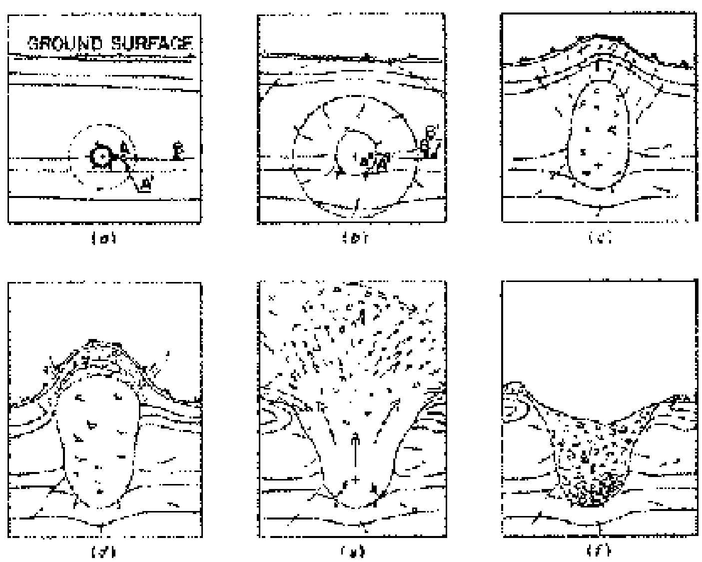
In the 2001 Defense Authorization Bill, Congress required the Energy Department's weapons labs to research these issues. However, enough information already exists in the open literature—mainly published in the 1960s as part of the Plowshare Program—to make rough estimates of how effective nuclear bombs would be at destroying buried facilities and how much radioactivity it would release into the environment. The importance of this latter point becomes more apparent each time a conventional bomb misses its target in Afghanistan.

There are limits to how deep a bomb can burrow underground. Even hardened steel bomb casings eventually yield to the tremendous forces a projectile generates as it plows through earth or rock. Increasing the length and weight of the bomb casing can, to some extent, compensate for these effects. However, practical considerations limit bomb lengths to about three meters and penetration depths to about 30 meters of rock.

Why Bother Putting a Nuclear Bomb Underground?

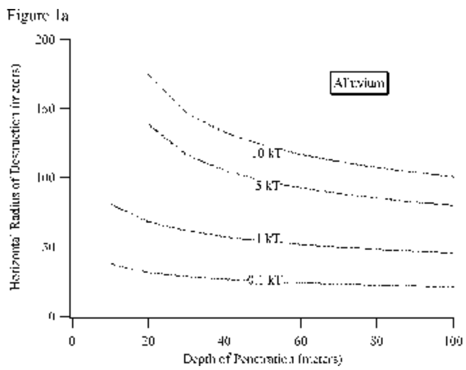
Delivery of an earth-penetrating nuclear bomb to even 30 meters underground results in an enormous increase in its destructive power against deeply buried facilities. This increase in lethal range greatly reduces the need for highly precise intelligence about the location of a targeted facility. The high lethal range from the nuclear explosion is due to the shattering of the surrounding earth, crushing of tunnels and equipment nearby, and a vast and devastating shockwave capable of destroying equipment and seriously injuring and killing people at even farther distances. If the weapon can be placed close enough to the target of concern it may even be possible for the nuclear fireball to consume equipment and material inside tunnels crushed by the blast, an important consideration when attacking biological weapons facilities.

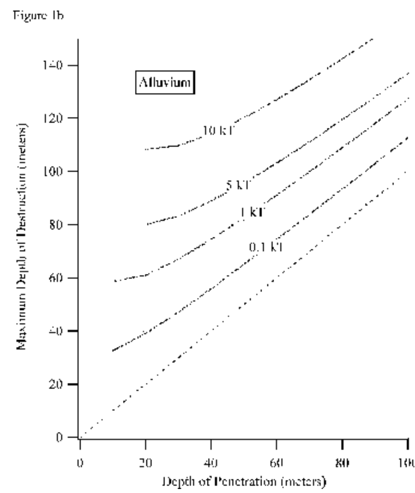
All this damage is possible because burying a nuclear bomb even a small distance below the surface greatly increases the fraction of energy coupled to the earth. This is because almost all of the energy initially released from such an explosion is in the form of intense light and heat. In the case of an airburst, roughly two thirds of this energy eventually gets transformed into a shock wave of enormous extent and power. It is this light that is the source of nearly all of the most destructive initial effects, including the air blast and fires, associated with nuclear weapons. Such airbursts are not very effective at damaging underground bunkers because most of the air blast is reflected by the Earth's surface. A deeply buried burst solves this problem because the initially released intense light and heat from the explosion is contained within the surrounding earth, very efficiently converting the energy into destructive mechanical effects. The mechanical energy pulverizes the region surrounding the bomb, generates an intense shockwave that travels to considerable distances, and causes severe ground motion that is highly damaging to underground structures and their contents.



The required depth of burst to contain the light from a nuclear explosion, and change most of that energy to ground motion, increases as the bomb's yield increases. Thus, the surrounding earth absorbs nearly all of the explosive energy released by a one-kiloton (KT) bomb's initial pulse of intense light if it is buried even five meters underground. Thirty meters depth is enough to absorb the initial radiation from a 200 KT bomb. However, even a one-kiloton bomb is far from being "contained" at even 30 meters depth.

Since the mechanisms at play lead to important insights about both the destructive effects and radiation release into the surrounding area, the next section will briefly describe an underground nuclear explosion.





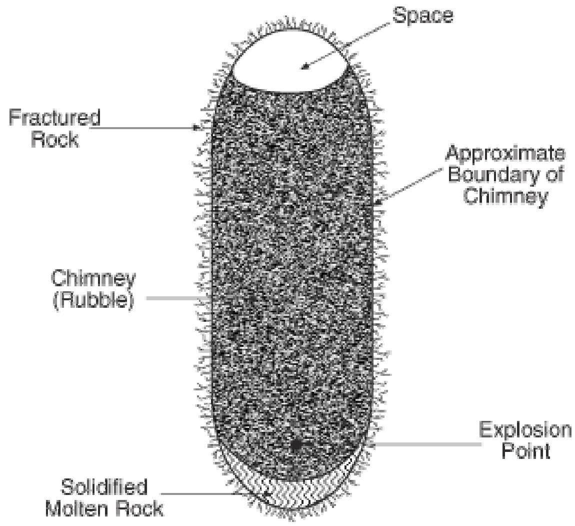
Underground Nuclear Explosions

In the first millionth of a second almost all of a nuclear explosion's energy is released in the form of light and heat, predominantly soft X-rays. When the explosion is buried, this extraordinarily intense light and heat vaporizes vast quantities of the surrounding earth and rock, creating a "fireball" of fast-expanding superheated gas of vaporized bomb materials and surrounding earth. This fireball expands until its pressure is balanced by the weight of earth and rock above the explosion, creating a spherical cavity. A fireball generated by a 1 KT nuclear explosion roughly 20 meters deep in granite would just rise to the pre-explosion level of the ground. In the process of expanding, the fireball would, of course, have lifted most of the 20 meters or so of earth above it, causing much of it to be ejected from the crater where it will either land nearby or be carried off by local winds. Increasing the depth of a 1 KT bomb to 30 meters widens and deepens the crater at the same time it decreases the amount of radioactivity released.

The fireball's expansion also forms a maze of cracks and vents in the region immediately surrounding the initial cavity. This region, known as the rupture zone, extends nearly three times as far horizontally as it does below the cavity. When examined after an underground nuclear test explosion, these cracks and vents show evidence of burning and charring from the passage of super-heated gases from the fireball, indicating that an underground facility close enough to the detonation to lie inside the ruptured zone might be consumed by the nuclear conflagration. (Figures 1a and 1b show the destructive distances associated with this rupture zone horizontally and vertically respectively. Destruction zones for granite, the other extreme "soil" condition, are at most 20 percent smaller than those shown here.)

A tunnel or extensive underground facility responds to mechanical stresses in the same way as the surrounding medium. This can result in an increased range of destruction for loose soils such as alluvium where the so-called plastic zone extends much farther out then the rupture zone. However, not all materials are subject to extensive plastic deformation. Granite, which some analysts believe is the most likely geologic formation for building underground facilities, does not produce extensive zones of plastic deformation.

Equipment and personnel inside the structure can, however, be destroyed, killed, or severely injured far outside the plastic or rupture zones by the powerful shockwave generated during the explosion. Equipment is destroyed or disabled by being shaken until it breaks or deforms. Personnel can also be injured or killed by being shaken or possibly injured by bits of tunnel wall being broken off and flying across the room as the shockwave passes in process known as spallation. (The same process, but on a much larger scale, contributes to surface crater formation for buried nuclear explosions.) Facilities can, however, be protected from spallation by lining the walls with sheet metal.

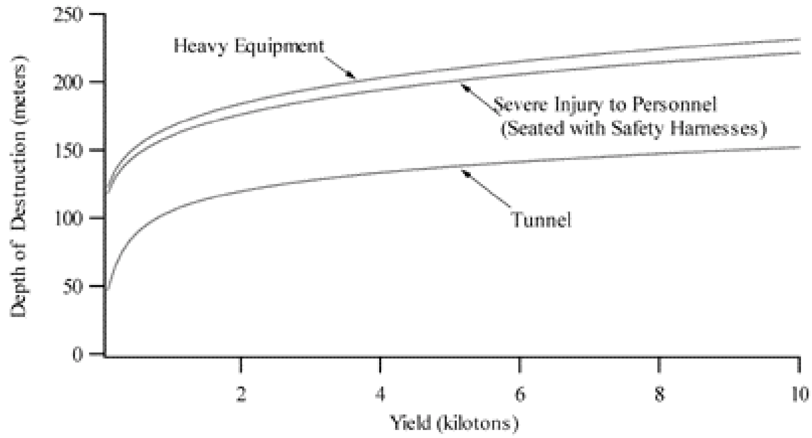


Damage from shockwave induced mechanical vibration depends critically on the frequencies associated with the blast. Fortunately for this analysis, the Plowshare Project published the vibrational spectrum associated with the 1961 GNOME shot together with its yield. This allows us to estimate the damage to medium and light equipment (pumps, condensers, biological centrifuges, small biological-agent fermentors), heavy equipment (large fermentors, generators, large motors) and injured personnel.

Heavy equipment is particularly sensitive to vibrations around 10 cycles per second (cps), which is close to the frequency where most of the vibrations are generated by a nuclear explosion. If these vibrations cause the equipment to accelerate at rates in excess of 20 times that caused by gravity, 20 G, it will cause significant damage. (It should be noted that this is a back and forth motion and does not require that the distances moved be more than a couple of centimeters maximum displacement.) Medium and light equipment, on the other hand, are most sensitive to frequencies far from the peak and also require accelerations of 40 G or greater for substantial damage. These two factors mean that a nuclear bomb will have to explode much closer to light and medium equipment than it does to heavy equipment to destroy it. In fact, a one-kiloton nuclear explosion, buried 30 meters underground, will destroy heavy equipment within about 160 meters of its burst while light equipment will only be destroyed if their tunnel is within the rupture zone.

Figure 2 shows the depths of destruction associated with a nuclear device buried 30 meters underground for various yields for these various mechanisms. Horizontal destruction distances would be caused by tunnel rupturing and not by shockwaves since horizontal rupturing extends much farther than the symmetric shockwave destruction, at least for the yields below 10 KT

Figure 2



considered here. Similar calculations have been made for human injury using data for seated individuals. While the resulting distances for injury to humans are shown, the available data is not as readily applied to nuclear explosions and that curve should be considered an estimate at best.

A facility can be hardened against the shockwave effects. For instance, placing all the equipment and personnel on a platform suspended by shock absorbers hardens them to a point that they can only be destroyed if the tunnel is in the rupture zone. This is the technique employed in Minuteman launch control centers.

Tarhunah Underground
Chemical Plant

Attacking Tarhunah

It is clear from this analysis that even a 10 KT nuclear weapon cannot destroy or even damage the equipment in an underground facility buried 300 meters in granite. But what about a facility that was not as deeply buried but whose position was not accurately known? The alleged chemical weapons production facility near Tarhunah, Libya makes an excellent example.

In the mid-1990s, the United States alleged that Libya had constructed an underground nerve-agent production plant, buried under at least 18 meters of earth, 60 kilometers southeast of Tripoli. The main difficulty with attacking this facility would not be its depth, which appears well within even a sub-kiloton weapons reach, but uncertainty about its location underground. Publicly available details about this plant are sketchy but it appears that there are twin entrance tunnels, between 60 and 140 meters long. According to eyewitness accounts, both tunnels go around a large rock formation near their entrance, purportedly to defeat cruise missile attacks. However, it is not clear if they continue on in the same direction or make a sharp turn after passing this rock. After all, it is hard for an inexperienced observer to keep track of directions passing through tunnels.

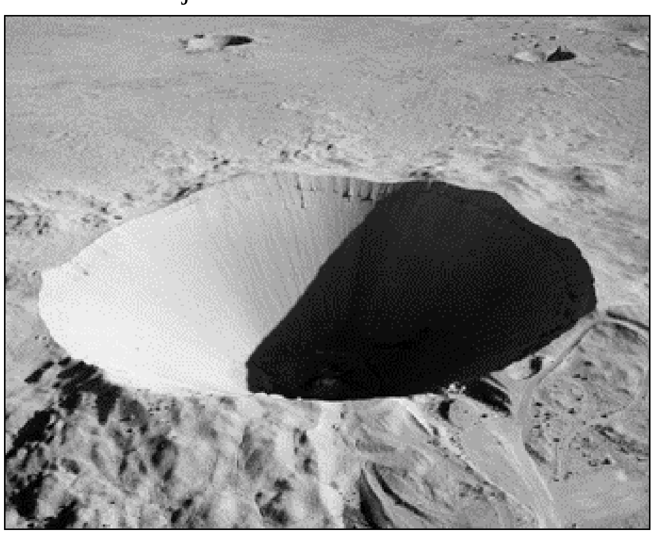
If the tunnels took up to a 60-degree turn around the rock formation, the main facility might be anywhere inside a roughly rectangular area 80 meters wide by 240 meters long. The best course of action would place a nuclear bomb in the center of this rectangle and size its yield to guarantee destruction of any facility within the rectangle, a maximum distance of 125 meters. If the facility does not have shock absorbers, a half-kiloton nuclear explosion could destroy any heavy equipment inside it even at the far reaches of the target area. If it is hardened with shock absorbers or military planners decide it must be totally destroyed, a five-kiloton explosive would have to be used. Of course, other geologic formations in the area could significantly reduce the effectiveness of such a nuclear weapon. For instance, deep crevasses, if they lay between the explosion and the underground facility, would effectively neutralize the bombs destructive power.

Nuclear Radiation, Fallout, and New Weapons Design

Nuclear radiation does not play a primary role in destroying deeply buried facilities. Prompt gamma radiation, X-rays, and neutrons are stopped and absorbed by the tens of meters of earth in the rupture zone. However, relatively long-lived radioactive isotopes resulting from the bomb material and the surrounding irradiated earth do pose a significant health hazard. It is likely that concerns for maintaining any coalition in support of the war—such as the countries neighboring the target area—as well as purely humanitarian concerns for innocent civilian populations will compel low yields as well as burrowing the bomb as deeply as possible, even if that does not produce significant increases in destruction on deeply buried facilities.

How much radiation released into the environment is acceptable is, of course, debatable. During the era of U.S. nuclear testing, explosions got progressively deeper as the acceptable amount of released radiation was continually reduced. Eventually, nuclear devices were only exploded at depths greater than a thousand feet because of concerns over low-level seepage. Comparable depths for nuclear bombs dropped from airplanes can never be achieved. Some analysts, however, might argue that such tight standards are not required in a wartime setting.

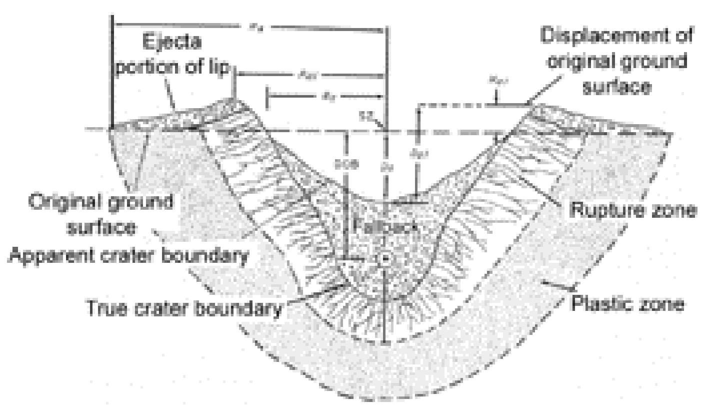
Instead, those analysts would argue that the level of radiation could be sufficiently reduced and contained over a limited enough area so that a coalition would not be threatened. This paper cannot determine what level might be acceptable. That is a political question. It can, however, estimate how much radiation would be released for a given yield and penetration depth by using data released during the Plowshare Project.



It is possible to reduce the radiation released into the environment by wrapping the “physics package”—the heart of the nuclear explosive—in materials that absorb the initial burst of neutrons. In the best of cases, this eliminates fallout produced by the surrounding earth that would ordinarily get bombarded by neutrons. (This does not weaken the destructive effect of the bomb since, as was pointed out above, those neutrons do not contribute to destroying underground facilities.) That leaves only the fission products produced in the initial explosion as fallout. However, that is still a large amount of radioactivity.

In the example above of attacking Tarhunah, a half a kiloton bomb would spread highly radioactive debris over a circle of 300-meter diameter. The five-kiloton bomb would do the same over a 700-meter diameter circle. Both bombs would also release significant fallout that could be carried by local winds for tens of miles before falling to earth. The crater walls as well as the immediately debris field will trap a significant amount of the radioactivity that would otherwise land as such “fallout” far from the explosion, but the size of contaminated areas will still be significant. If the fallout landed uniformly over a one square kilometer area, the radiation from the half-kiloton explosion would produce 3 rems per hour, 24-hours after the detonation, while the five-kiloton bomb would produce 50 rems per hour under the same conditions. These are significant amounts and threaten the health and safety of the populations far from the target. An eight-hour exposure to the larger bomb’s fallout would kill about half the people exposed. It is also likely that the exposure levels would be higher from breathing in or otherwise ingesting the fallout, causing even greater harm.

All these calculations assume that the nuclear weapon will survive being driven deep into the earth. In fact, a warhead will see, on average, forces well over ten thousand times the force of gravity as it plows through the earth. The only U.S. nuclear weapons publicly known to have been tested under such extreme conditions are the atomic artillery shells, which are no longer in the U.S. arsenal. On the other hand, if the development of a new weapon is undertaken, it might be possible to design new weapons that use far less fissionable material and have far less fallout. Such a program would, however, require a considerable number of underground nuclear tests.



Would the reintroduction of an old design require additional tests of the nuclear explosive? Some might argue that it does not even though the U.S. would employ new manufacturing techniques. This weapon, they might point out, will not be an integral component of U.S. general war plans and therefore does not need the high reliability required of strategic nuclear weapons. They would be willing to live with a small chance of having a weapon whose destructive power is reduced by some unknown factor. Others might argue that it is even more important to test this weapon. Any nuclear yield at all would release significant amounts of radioactive fallout into the environment and proponents of testing would view it as politically catastrophic if the explosion failed to destroy its intended target and a second bomb had to be dropped.

If the United States did decide to test this weapon, it would raise a whole host of politically charged questions long before the weapon's combat use. When the United States Senate refused to ratify the Comprehensive Test Ban Treaty, it essentially removed any international obligation for the United States not to test. At the time of the Senate vote, however, then-President Clinton promised to continue the unilateral moratorium on underground nuclear testing. This might have helped limit the international damage created by the Senate vote. A decision to conduct even one nuclear test of this weapon might cause a storm of international protest.

It would also weaken the international taboo on States acquiring nuclear weapons. Other countries are also faced with regional challengers who increasingly use underground facilities. A U.S. decision to use nuclear weapons for destroying deep underground bunkers would legitimate the proliferation of nuclear weapons by other States for this same purpose.

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BREAKTHROUGHS

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