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**BARRIER PLANNING WITH
NUCLEAR CRATERING EXPLOSIVES**

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Louis J. Circeo, Jr.

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BARRIER PLANNING WITH NUCLEAR CRATERING EXPLOSIVES*

Louis J. Circeo, Jr.

Captain, Corps of Engineers, U. S. Army

Lawrence Radiation Laboratory

University of California, Livermore, California

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In July 1962, a 100-kiloton nuclear explosive was detonated at a depth of 635 feet in alluvium at the Nevada Test Site. This detonation, code-named Project Sedan, produced a crater 1,200 feet in diameter and 320 feet deep, releasing only about 10 percent of the total radioactivity produced to the atmosphere. The experiment was conducted under the Plowshare Program to extend present data on the phenomena of nuclear cratering explosions and the nature of the associated safety problems. As a result of this advance in the industrial utilization of nuclear explosives, military concepts of barrier planning may become subject to great revision.

The Plowshare Program was established in 1957 to investigate possible industrial applications of nuclear explosives. Currently under investigation are applications relating to excavation, mining, and isotope and power production. Large-scale excavation is one of the most promising uses of nuclear explosives. The great energy released by a buried nuclear explosion shatters and imparts a sufficient velocity to the overlying material to produce a crater. A row of explosives, spaced about a crater radius apart and detonated simultaneously, produces a ditch the depth and width of a single crater.

*Work done under the auspices of the U. S. Atomic Energy Commission.

The crater produced by the Sedan detonation is shown in Fig. 1. Its diameter is comparable to that of the Pentagon Building. The ability to quickly excavate such a crater in strategic locations offers a great potential application for producing obstacles. An emplacement hole for the explosive could be drilled far in advance of anticipated military action. If attack became imminent, the nuclear explosive could be emplaced and detonated within a few hours. The resulting crater would be an impassable obstacle to tanks, vehicles, and mass troop formations. With use of properly designed explosives and emplacement techniques, radioactivity levels would be low enough to allow the crater to be covered immediately by close-in fire.

Surface Burst vs Burial

It has been observed that as the depth of burial increases for a given explosive weight, crater size increases until it reaches a maximum (optimum burial). Beyond this depth of burial, the crater size decreased until the explosion is completely contained. Further, as an explosion is buried deeper and deeper, the amount of radioactivity released to the atmosphere is steadily reduced to virtually zero at containment. This is illustrated in Fig. 2, showing cratering curves developed for desert alluvium. It can be seen that at maximum crater dimensions, almost 90 percent of the radioactivity is safely contained in the crater rubble.

These curves are valid for a yield (W) of 1 kiloton, an energy release equivalent to 1000 tons of TNT. For any other yield, experience has indicated that crater parameters will be proportional to the 3.4 root of the yield (i. e., $W^{1/3.4}$). Thus, if a given crater dimension is divided by the 3.4 root of its charge weight (in kilotons), it will be scaled to the curves shown in Fig. 2. Using this rule, crater dimensions approximately double when the charge

yield is increased tenfold. To date, most nuclear cratering experiments have been in alluvium. Experience in hard rock indicates that crater dimensions are about 20 percent less than in soil.

The great advantage of burial can be seen in Table I. Three craters produced by 1.2-kiloton detonations at the Nevada Test Site are shown, along with the expected crater dimensions from a 1.2-kiloton explosion at optimum burial. The amount of radioactivity released to the atmosphere is also shown. Figure 3 illustrates the profiles of these craters. It is interesting to note the various crater sizes and shapes available with a single yield. Regardless of explosive yield, the same approximate crater shapes prevail at the same scaled depths of burst in the same medium.

Any depth of burial, however small, significantly increases crater dimensions. The Johnnie Boy crater was produced in alluvium by a 500-ton nuclear explosive buried 21 inches below the ground surface. The crater has a diameter of 122 feet and a depth of 30 feet. The volume of the 500-ton crater is three times that of the crater produced by the 1.2-kiloton Jangle S surface detonation. A similar enhancement of crater dimensions would be expected if the device were emplaced under a few feet of water, such as in a streambed.

The main conclusions to be observed from these examples are:

1. Burial of nuclear explosive greatly increases crater size. Relatively deep burial produces maximum crater dimensions.
2. Radioactivity release is significantly reduced with depth of burial.
3. As the depth of burial is increased to optimum, the sides of the crater become steeper and lip heights increase, thus presenting a more formidable obstacle to an aggressor.

Thus, it is obvious that optimum burial combines all three effects to the best possible advantage as an obstacle to an advancing enemy.

Generally, in order to produce a specified crater width, a surface detonation would require a yield about 10 times the yield necessary at optimum burial. For a specified crater depth, a surface yield 100 times greater than the optimum burial yield would be needed. Hence, a 1000-kiloton and a 10,000-kiloton surface burst would be required to obtain the crater diameter and depth, respectively, which was achieved by the 100-kiloton Sedan detonation. The safety problems associated with these yields make surface bursts unfeasible for producing large craters as obstacles. For example, comparing surface detonation with optimum burial to produce a specified crater width, radioactivity released to the atmosphere would increase about 100 times; direct air blast would increase about 500 times; and ground shock would increase at least 5 times.

Safety

There are several safety advantages of optimum burial which should be emphasized. The fireball associated with a nuclear detonation is completely contained. Thus, the thermal energy is converted into "excavation" energy and presents no surface hazard. Close-in air blast is attenuated by a factor of 50 to 100 over a surface burst. Similarly, long-range air blast resulting from refraction in the upper atmosphere is attenuated by a factor of 3 to 10. This reduction decreases the air blast hazard much below that of a surface shot. A disadvantage in burial is a possible increase in the ground shock; however, this does not present a significant problem. For example, the ground shock from the Sedan detonation might have caused damage to sensitive structures out to a radius of about 3 miles. For a 1000-kiloton detonation

this range would increase to about 10 miles. Geological considerations, however, would greatly influence both air blast and ground shock. It has been observed that in a dry rock medium, air blast is reduced and ground shock is increased compared to a soil medium.

Most of the radioactivity is trapped in the fused glass material formed around the shot point and the material in and around the crater. In a thermonuclear (fusion) detonation only a small fraction of the total yield is due to fission, which produces most radionuclides. Thus in the Sedan detonation, less than 30 percent of the total yield was due to fission. The 10 percent of the radioactivity which was released to the atmosphere would be the equivalent of the radioactivity released from less than a 3-kiloton fission surface burst. Research is currently being conducted on "clean" thermonuclear explosives for Plowshare applications. The Atomic Energy Commission has stated that altogether a hundredfold reduction in radioactive debris is expected from 1962 Sedan levels. This could essentially eliminate the radioactivity hazard associated with nuclear explosives.

The concept that area contamination by radioactivity would deny an area to an enemy is invalid for defensive barrier systems. Radioactivity would be more harmful to defenders than to aggressors. Except for very large fission yields, enemy forces can quickly pass through a highly contaminated area with little decrease in combat effectiveness. On the other hand, friendly forces could not occupy territory even close to this area for any period of time without incurring casualties. Assuming a constant 50-roentgen-per-hour field, an aggressor requiring a few hours to pass through the area would not be greatly affected by the radiation. However, defenders could not occupy defensive positions longer than 9 hours without receiving

lethal doses. Also, radioactivity intensity decays quickly and the contamination would have to be periodically renewed.

The foregoing analysis of safety problems indicates that a cratering detonation can be conducted in the vicinity of populated areas with minimum hazard to structures or inhabitants. Moreover, military units along a planned barrier line would not be greatly affected by the detonation. An evacuation of only a few miles would be necessary from a 100-kiloton detonation. Friendly forces could occupy the area to within a few hundred yards of the crater immediately following the detonation, and thus be able to cover the obstacle by fire. The low radioactivity levels associated with nuclear cratering would allow its use during a stabilized situation or when engaged in conventional warfare.

Emplacement Holes

The major disadvantage to this concept of barrier planning would be the requirement for a prepared emplacement hole. The excavation of the hole would involve a considerable amount of time and labor. Large-diameter drilling equipment would be required in most cases. The location of the hole would probably be known to the potential aggressor and the possibility of adverse reaction from local inhabitants must also be considered.

The diameter of the emplacement hole would depend on the yield and type of nuclear explosive used. A casing might also be required in some media to maintain the hole's integrity. The Sedan device required a 36-inch cased hole. This would probably be the largest diameter required for any device below about 1000 kilotons. The diameter could be much smaller, depending on the explosive used. An 8-inch hole would accommodate an explosive similar to the 155-mm nuclear artillery shell. Even though only

low yield explosives may be available in this size, the crater produced would still be considerable. The 420-ton nuclear Danny Boy shot was detonated in basalt at a depth of 110 feet. The resulting crater had a diameter of 215 feet and a depth of 63 feet (Fig. 4). Thus, depending on the explosives and equipment available, a small-diameter emplacement hole might be feasible.

The depth of the emplacement hole would depend on optimum burial parameters of the medium and the yield. The depth could be as deep as 1300 feet for a 1000-kiloton explosion in soil. The resulting crater would be almost one-half mile in diameter and 650 feet deep. The Sedan emplacement hole was backfilled with sand and gravel. In a military situation, backfilling would be undesirable and probably unnecessary. For optimum depths of burial greater than about 100 feet, backfilling and tamping is not expected to significantly alter crater dimensions. The rarefaction wave returning from the surface would collapse the emplacement hole before cavity expansion from the explosion reaches the surface. Therefore without backfilling, a nuclear explosive could be easily emplaced and withdrawn if necessary.

Enemy knowledge of the location of emplacement holes would not necessarily be detrimental. Obstacles must be placed to tie in with natural terrain. Therefore, there are only a few locations in a given area where obstacles would be feasible. The aggressor would probably be aware of these locations and expect to meet some type of opposition there. If an emplacement hole is located in a defile which a subsequent crater would make impassable, the aggressor might be deterred from planning an advance through this area. Thus, the presence of an emplacement hole itself could serve as an obstacle to the enemy. An entire theatre of operations could be "saturated" with emplacement holes at strategic locations. Each hole would indicate a potential impassable obstacle to the enemy. The deterrent effect

of the presence of these emplacement holes could be great. Within a few hours after an actual attack, selected emplacement holes could be loaded and detonated. In this way the flexibility and mobility required for conventional or atomic warfare can be used to the fullest extent.

A pre-placed hole should not cause an adverse reaction from local citizens. In most cases, an excavation can be planned and located so that inhabitants of the area would not be greatly affected by the detonation. Proper education in the safety associated with nuclear excavation and the great benefits to be derived from such an obstacle should convince local citizens of their value. If a crater would divert an enemy invasion from the land and possessions of local citizens, this concept should have their support. If the location must be provided with an obstacle, the alternatives could be far more devastating to a local area than a nuclear crater.

Nuclear Craters as Obstacles

An obstacle is an obstruction that stops, delays, or diverts movement. A barrier system consists of a series of obstacles, either natural or artificial. The effectiveness of a barrier system depends on the ability to accomplish its mission within the limitations imposed by time, labor, and materials available in a given situation. Nuclear cratering can produce obstacles which will far exceed other artificial obstacles in these respects.

A crater can be excavated to meet specific size requirements as dictated by a particular situation. Provided an emplacement hole is properly located, the crater can be produced shortly after authority has been given. Figures 5 and 6 are photographs taken from the top and bottom of the Sedan crater. The dilemma facing an enemy approaching such an obstacle blocking a defile is obvious. If the depth of the crater is below the ground water table,

the additional effect of water filling the excavation could increase the effectiveness of the obstacle.

Tanks can negotiate slopes of 60 percent, at best. Optimum burial produces slopes near the ground surface of about 100 percent. The material on the crater surface is loose and difficult to negotiate. The height of the slope would severely hinder troop movement. The size of a large crater would eliminate any practical possibility of bridging or filling. The Sedan crater has a volume of about 6,500,000 cubic yards. Unlike other artificial obstacles, the crater cannot effectively be destroyed by atomic weapons. Thus, a crater would leave the enemy no choice but to delay and divert his ground advance.

Employment

Nuclear cratering at optimum burial is feasible only for defensive barrier planning. Emplacement hole requirements eliminate their construction in an offensive situation or in a fast-moving tactical situation where the terrain has not been previously controlled by friendly forces. Deliberate barrier planning with nuclear craters requires the occupation of an area long enough for emplacement hole construction. This limitation should not deter their value, however. The Western Nations are now engaged in a militarily defensive role. Thus, there are distinct requirements for defensive barrier plans in depth. This role is well adapted to barrier planning with nuclear cratering explosives.

The use of nuclear craters would not be significantly different from conventional obstacle employment. Craters would be tied in with natural obstacles to form a coordinated barrier system. They would be used to

delay and disrupt the enemy advance, limit or canalize movement of penetrating or enveloping enemy forces, and assist in flank and rear-area security.

Obviously, the best place to produce a crater would be in a defile with steep sides. This would effectively eliminate the defile as an avenue of approach. If this were done in several locations along a barrier system, further enemy advances would require concentration of forces through other areas of access. Thus, the mobility and flexibility of the enemy would be severely hindered.

A crater could be placed in any location that a barrier minefield would ordinarily be located. If the distance to be blocked is too extensive for a single crater, a row of smaller-yield detonations, spaced approximately one to one-and-a-half crater radii apart, could be employed. This would produce a ditch about the width and depth of a single crater, extending the length required to obstruct passage. This solution would be better than a minefield for several reasons: A large minefield could take several days with the expenditure of considerable manpower and resources. A minefield also presents a hazard to both sides and it can eventually be breached or destroyed by nuclear weapons. During a surprise attack, adequate time would not be available to properly lay a large minefield.

Craters would be quite effective in destroying multi-lane highways. The crater would necessitate the construction of a large detour. Vehicles would have to circumvent both the crater and the major portion of the lip material which surrounds the crater a distance about equal to the diameter of the crater. Such an obstacle every few miles would render the highway completely useless. In many cases this would be as effective as the destruction of bridges along the highway. A crater or ditch could be placed to perma-

nently obstruct a good avenue of approach during a stabilized situation. Thus, a border could be effectively sealed off from possible future invasion or mass infiltration.

Perhaps a classic example of this application would be related to the 1962 border invasion of India by China. The defensive barrier system relied on control of the mountain passes separating the two countries. Once a penetration of these passes was accomplished, the plains of India were open to invasion. If nuclear craters had been properly located in these passes, mass invasion on the ground would not have been possible. Even if control of the passes were ultimately gained by the Chinese, the movement of men and supplies through the passes would have been severely hindered, with tank and vehicular traffic virtually eliminated for several weeks.

In Western Europe, many invasion routes from the East exist which require a large on-hand counter force from the NATO countries. Emplacement holes across some of these routes could deter invasion through these areas. If several routes were now blocked, a smaller surveillance force would be necessary and the counter force presently required could be deployed elsewhere.

In addition to the use of nuclear cratering explosives as obstacles, it would be appropriate to mention an application in defensive denial operations. Airfields or other large strategic structures such as railyards, docks, or depots could be destroyed by nuclear craters. This is especially applicable when the structures are in the vicinity of populated areas. Any facilities included in the area covered by the crater and lip material would be destroyed. Proper cratering parameters would ensure a minimum amount of blast and ground shock damage to structures outside this zone. The 420-ton Danny Boy detonation would have a diameter of destruction of about 650 feet (Fig. 4).

This could destroy a railyard in the middle of a large city without seriously affecting the rest of the community. This is perhaps the most efficient method of quickly and completely destroying such facilities.

Future technology in missile or bomb penetration mechanics could develop an offensive barrier capability for nuclear craters. A nuclear explosive could then produce a crater at strategic locations in a tactful situation or behind enemy lines. Even slight penetration, such as the Johnnie Boy scaled depth of burst, would produce an obstacle which could severely disrupt vehicular traffic. The requirement for an emplacement hole would be eliminated, and nuclear cratering would have broader applications.

Summary

Nuclear cratering has been shown to be a quick and efficient method for constructing effective obstacles for a defensive barrier system. The positioned emplacement hole could serve as a deterrent to a possible enemy advance through the area. Proper cratering parameters would ensure a crater or ditch of a specified length, width and depth to block a selected location. The detonation could be conducted safely, with little effect on local communities or other portions of the barrier system. The area around the crater could be reoccupied immediately after the detonation to cover the obstacle by fire.

Nuclear excavation technology has been developed sufficiently so that immediate application into barrier planning can be considered. Nuclear explosive development is such that the technology exists for the employment of large yield, clean nuclear explosives. Commanders should be made aware of this potential application of nuclear cratering explosives. In situations where this concept might be applicable, impassable obstacles could become a flexible on-call item and a great deterrent to possible enemy aggression.

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Table I. Cratering data for a 1.2-kiloton nuclear explosion in desert alluvium.

Shot name	Depth of burst (ft)	Crater diameter (ft)	Crater depth (ft)	Lip height (ft)	Radioactivity released (%)
Jangle S	3.5 ft above surface	90	21	2	100
Jangle U	17	260	53	8	95
Teapot ESS	67	292	90	19	70
Optimum Burial	137	380	100	25	15

Fig. 1. The Sedan crater, produced by a 100-kiloton nuclear explosive buried at a depth of 635 feet. The crater has a diameter of 1200 feet and a depth of 320 feet.

Fig. 2. Apparent crater dimensions and radioactivity release vs depth of burst of a nuclear explosive.

Fig. 3. Nuclear crater profiles from a 1.2-kiloton nuclear explosive at various depths of burst.

Fig. 4. The Danny Boy crater, produced by a 420-ton nuclear explosive buried at a depth of 110 feet. The crater has a diameter of 215 feet and a depth of 63 feet.

Fig. 5. View from the top of the Sedan crater. Note the photographer and camera in the bottom of the crater.

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Fig. 6. View from the bottom of the Sedan crater. Note the steep, stable upper slopes of the crater and the loose surface material on the lower slopes.

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