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FM 5-29

DEPARTMENT OF THE ARMY FIELD MANUAL

# PASSAGE OF MASS OBSTACLES



HEADQUARTERS, DEPARTMENT OF THE ARMY  
SEPTEMBER 1962



**FM 5-29**

FIELD MANUAL }  
No. 5-29 }

HEADQUARTERS,  
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**PASSAGE OF MASS OBSTACLES**

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	Paragraphs	Page
CHAPTER 1. INTRODUCTION.....	1-8	2
2. TREE BLOWDOWN.....	9-25	7
3. RUBBLING IN URBAN AREAS.....	26-33	33
4. FIRE.....	34-45	40
5. CRATERS.....	46-50	66
6. NATURAL OBSTACLES.....	51-58	72
7. ARTIFICIAL OBSTACLES.....	59-69	77
GLOSSARY.....	-----	82
APPENDIX REFERENCES.....	-----	85
INDEX.....	-----	87

# CHAPTER 1

## INTRODUCTION

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### 1. Purpose

The purpose of this manual is twofold: to provide commanders of all arms and services and their staffs with information on the characteristics of, and the problems imposed by all types of obstacles, both artificial and natural (excluding minefields, see FM 20-32); and to present suggested solutions for their passage.

### 2. Scope

The bulk of the manual relates to the passage of massive obstacles which can be expected to develop on a nuclear battlefield: extensive tree blowdown, mass fires resulting from thermal radiation, rubble in highly developed and built-up areas, and cratering from surface or underground bursts. The remaining portion is concerned with the passage of extensive obstacles resulting from natural terrain formations; those caused by extremes of climate; and the relatively smaller antipersonnel and antivehicular obstacles such as barbed wire, abatis, walls, and demolished bridges. The breaching and clearing methods suggested in this manual are limited to mechanical means. The use of explosives and demolitions as a means for breaching obstacles is covered in FM 5-25.

### 3. References

The manual is for use in conjunction with other current Department of the Army literature dealing in detail with related subjects. Taken together with its references, the manual provides a complete coverage of all obstacles which could be encountered under a multitude of conditions in widely varying locales.

### 4. Concepts

a. *Primary Objective.* The primary objective in reducing any obstacle is to create or restore routes of advance and supply essential to the immediate military mission. When dealing with obstacles resulting from nuclear bursts there may be concurrent requirements for rescue, salvage, and rehabilitation operations, but such operations are subordinate to the primary objective and should not be initiated at its expense.

*b. Constricting Passage (Defiles).* When faced with a massive and difficult obstacle, such as a severe tree blowdown or an extensive major swamp, it may be impossible, in many instances, to clear or construct more than one narrow lane. This constricting corridor then becomes a defile, similar to a mountain pass, a gap through a minefield, a bridge, or a river-crossing site; and adds measurably to the obstacle passage problems. Provision must be made for the rapid and uninterrupted passage of the force: hence, all major engineer work must be accomplished prior to any movement. Engineer elements and equipment must be scattered liberally throughout the advancing column in order to repair bad stretches as they occur and before they deteriorate enough to slow, significantly, the momentum of the passage. It is desirable to have airmobile engineer elements available to cope with special emergencies. Engineers must be available at difficult points to remove disabled vehicles from the road before they block passage. The order of march, especially with respect to engineers, must be so prescribed as to eliminate any need for subsequent changes: on narrow roads it is impossible to move any unit from the rear of the column to the front without causing serious difficulties. Turnouts must be prepared at frequent intervals, and engineer material should be stockpiled throughout the passage in order to facilitate continuous maintenance of potential trouble spots that may break down from heavy and repeated traffic. Natural terrain defiles present the same problems as do artificially created defiles, and require the same planning and considerations. For a further discussion of the passage of defiles see FM's 5-135 and 61-100.

*c. Factors Involved in a Successful Passage.* The successful passage of an obstacle depends primarily upon the effective employment of the most appropriate available means and the efficient application of the best techniques. Factors for consideration in the attainment of complete success in passage include: accurate knowledge of the tactical situation; timely, accurate, and correctly evaluated reconnaissance and intelligence data; detailed planning and preparation; and thorough training of troops in obstacle passage techniques. The true measure of success of an obstacle passage operation is the attainment of the objective beyond the obstacle with no appreciable loss of time, personnel, or equipment; and with no change in the unit tactical formation. It is particularly important that the commander of an advancing element have prior knowledge of any obstacle he may encounter. He must be able to choose a course of action in regard to each obstacle before he reaches it, in order to hold any loss of momentum or regrouping of his unit's combat disposition to a minimum.

## **5. Planning in Regard to Obstacles Created by Nuclear Weapons**

*a. Anticipated Damage.* Successful passage or clearance of an extensive obstacle created by a nuclear weapon depends to a great degree

upon thorough prior planning. Anticipation of the creation of such an obstacle will aid immeasurably the speed with which the actual breaching or clearing operations can be initiated and conducted. The types of damage that can be inflicted in varying environments can be predicted with reasonable accuracy by thorough terrain analysis. Potential problem areas that could result in extensive tieups, such as portions of a main route within a heavily forested area or concentrated urban area, railroad yards and terminals, or an air-landing complex, can be located in advance, and work estimates and projected plans can be established in anticipation of their being within the target area (table I). This information can best be obtained by local observation, and reconnaissance and intelligence reports. Specific studies of blowdown, rubble, and mass fire data for each area can be requested through engineer intelligence channels or command channels. Such studies should include data on—

- (1) Location of forested and urban areas and those areas particularly susceptible to mass fires.
- (2) Location and extent of obstacles created by past nuclear attacks.
- (3) Location and extent of obstacles that would be created by projected use of nuclear weapons.
- (4) Significant changes in blowdown or other obstacles and mass fires expected from changes in height of burst, delivery means, and yield.
- (5) Time and effort required to breach each blowdown obstacle requiring passage.
- (6) Evaluation of enemy capability to use blowdown obstacle, radiological contamination, or mass fires from nuclear weapons to impede movement of our forces.
- (7) Fire potential present, and if available, projected for period of operation.
- (8) Planned friendly nuclear fires that may cause radiological contamination, fire storms, or conflagrations.
- (9) Evaluation of effect of mass fire and radiological contamination caused by friendly nuclear fire plans on our own operations.

*b. Alternate Routes.* A vital part of prior planning is the location of alternate routes that, with minor effort, will permit bypassing of anticipated obstacles.

*c. Tentative Labor and Equipment Assignments.* Prior planning permits tentative assignments of available troops and equipment and provides a basis for assistance or augmentation if the anticipated effort justifies such additional aid.

*d. Modifying Predictions.* If the anticipated obstacle becomes an actuality, reconnaissance will show wherein the actual obstacle is at variance with the anticipated obstacle. Modification of the estimates, prior plans, and troop assignments is then a relatively minor task.

*e. Obstacle Prevention Measures.* When the threat of obstacles from nuclear explosions is great, and when the military situation and labor and equipment resources permit, preventive measures can be taken to lessen the clearing and passage effort. Standing timber adjacent to routes of communication can be felled in advance. In heavily built-up areas, rubbleproof routes can be created by controlled demolition of adjacent rubble-producing structures. Firebreaks can be created in areas presenting a high fire potential. Areas can be carefully policed to locate and remove large accumulations of combustible materials. Before the decision to take such measures is made, consideration must be given to what, if any, camouflage discipline will be violated by the action.

*Table 1. Tabular Form of Estimated Time and Effort Information*

Obstacle	Minimum time for passage	Effort to pass (for own troops or enemy as appropriate)	Evaluation of effect on projected operations	Remarks (e.g. time to pass if certain equipment cannot be made available)
5 KT air burst in forest at (coord).	2½ hr (to open 2 routes).	1 Engr Co w/ organic equip plus 6 medium helicopters.	Blocks 2 of 3 routes of advance planned for CCA.	Without helicopters will require 12 hr to open 2 routes, 10 hr to open one.
20 KT surface burst in forest at (coord).	20 hr (this can be at least doubled by placing observed artillery fire on equipment clearing the routes of advance).	Two tank dozers or equivalent per route opened.	Can stop enemy for from 2-3 days with little further expenditure of our effort.	Planned as obstacle on major enemy avenue of approach into unit area.

## 6. Methods of Passage

There are three general courses of action which units in combat may resort to in countering an obstacle. These are: bypassing; disregarding, or forcing-through; and breaching.

*a. Bypassing.* This method is accomplished by going around, over, or under the obstacle. Whether or not an obstacle shall be bypassed will depend upon the location of bypasses, the availability of means for going over or under the obstacle, and the tactical situations.

*b. Disregarding, or Forcing-Through.* This method is a course of action which is resorted to only under situations of extreme emergency and where breaching means are not available and bypasses are not present. Some obstacles cannot be forced-through, such as unfordable rivers, dragon's teeth, and other concrete or steel obstacles; these must

be breached if they cannot be bypassed. Minefields may be forced-through, but the attrition of tanks and personnel must be weighed against the expected tactical gain (FM 20-32).

*c. Breaching.* This method is the approach with which this manual is concerned. Breaching may be hasty or deliberate: hasty breaching implies speed of action with a minimum of detailed reconnaissance or prior planning and the use of any immediately available means; deliberate breaching methods are preferable—particularly in regard to obstacles created by nuclear explosions—wherever time permits detailed reconnaissance, planning, and the bringing forward of special breaching devices from the rear. In modern warfare speed and movement are of paramount importance. It may not always be possible to obtain immediately the detailed reconnaissance data desired, or to transmit it to the commander with the speed necessary to assist him in deciding upon the course of action to take in a given obstacle passage. For this reason the commander must have with his combat element the best available means for breaching any type of obstacle which he is likely to encounter.

## **7. Lanes and Lane Marking**

The lane is the clear route through an obstacle and is normally about 8 yards wide. A double lane is about 16 yards wide. The degree of trafficability required depends upon whether it is to be used by tracked vehicles or wheeled vehicles. Tanks are able to pass through lanes that would stop wheeled vehicles. The unit responsible for breaching an obstacle is also responsible for marking the lanes if the lanes are not obvious to the eye. The techniques for marking lanes through land obstacles are the same as those for marking the lanes through a minefield (FM 20-32).

## **8. Improvement of Manual**

Users of this manual are encouraged to submit recommended changes or comments to improve the manual. Comments should be submitted on DA Form 1598, together with reasons, to insure complete understanding and evaluation. Forward comments to the U. S. Army Engineer Combat Development Agency, Fort Belvoir, Va.



## **CHAPTER 2**

### **TREE BLOWDOWN**

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#### **Section 1. INTRODUCTION**

##### **9. Nature of Obstacle**

In nuclear warfare there will be frequent requirements for breaching tree blowdown obstacles created by both air and surface bursts of nuclear weapons. The frequency and magnitude of these requirements will depend upon the level of use of enemy and friendly nuclear weapons, the extent to which the enemy devotes his effort to deliberate production of a blowdown barrier, and the extent to which the terrain permits ready bypass of blowdown obstacles. When cross-country movement is good in an area, use of nuclear weapons, even in fairly large numbers, does not appear likely to produce extensive contiguous barriers to movement unless a significant proportion of them is devoted to this specific purpose. When cross-country mobility is poor, as is the case in many areas after heavy rains or spring thaws, the blocking of routes by tree blowdown can stop mechanized movements. This effect becomes even more pronounced when surface burst nuclear weapons are used on these routes.

##### **10. Variations in Forests**

There are numerous types of forests found throughout the world. They range from small, second or third growth pine stands to the heavy and almost impenetrable mangrove forests. Nuclear weapons effects on standing timber depend on the type and stage of development of the forest involved. Table II breaks down the various forests into types and gives their major differentiating characteristics.

##### **11. Damage Levels**

There are three levels of damage resulting from a nuclear burst: severe, moderate, and light. There is also "total damage" which is not a level, but is simply and arbitrarily defined as ninety percent or more of tree trunks broken or uprooted. It can be seen that total damage, depending upon the type of forest involved can consist of varying amounts of actual damage: in terms of obstacle production, this can range from very severe to no obstacle at all. As the damage extends from ground zero it

Table II. *Types and Characteristics of Forests*

Type	Identifying characteristics	Average height* of trees	Average tree density per acre*	Average total stem per acre	Tree diameter
I	Improved natural or planted coniferous forest with uniform tree spacing, height, and diameter; uniform dense crown canopy. Trees normally break rather than uproot. Occurs in Western Europe.	40 m	75	3,000 m	Up to 60 cm
II	Unimproved coniferous forest developed under unfavorable growing conditions with random tree spacing, heights, and diameters. Forest floor cluttered with fallen trees; heavy underbrush in clearings. Irregular crown canopy. Trees normally uproot rather than break. Occurs in Western Europe and S. E. Asia.	15 m	260	4,000 m	Up to 50 cm
III	Unimproved coniferous forest developed under favorable growing conditions with random tree spacing and diameters; uneven crown canopy and irregular clearings. In Western Europe fallen trees may clutter forest floor but brush is light. In S.E. Asia may be dense shrub undergrowth.	25 m	200	4,600 m	Up to 1 m
IV	Includes all deciduous forests. Damage in such stands depends upon whether they are in leaf or not (foliated (f) defoliated (d)). There is extensive crown and branch breakage. The stem damage, especially in moist ground is principally by uprooting. Type IV, because of the numerous varieties is further				

	broken down into subtypes.				
IVa(1)	Includes most temperate zone deciduous forests; the shorter open portions of dry season deciduous forests of Northern S.E. Asia; and evergreen oak forests at 1,000 to 2,000 meters elevation in S.E. Asia. Air photos of the evergreen oak may show either a continuous or open canopy. These forests, excluding the evergreen oak are defoliated in winter (temperate zone) or summer (dry season deciduous forests of Northern S.E. Asia).	25 m	200	4,600 m	Up to 1 m
IVa(2)	Includes Teak plantations and the dense tall cloud forests of low elevation. Teak in this type is planted in rows $4\frac{1}{2}$ to 6 meters apart and has continuous canopy. Leafless in dry season. The cloud forests start at 1,000 meters on mountain slopes in S.E. Asia and present a matted tone with rough and irregular texture on aerial photos.	30 m	140	4,300 m	60 cm average
IVb	Includes rain forests of S.E. Asia and the majority of the dry season deciduous forests of Northern S.E. Asia. They are so dense and massive that they may attenuate the blast wave, causing a reduction in blast damage distances. (No data on this aspect is available.) Rain forests present a rough irregular pattern with mottled tone to aerial photos.	30 m (varies up to 60 m in Rain forests, 45 m in dry season deciduous forest for about 10% of trees.)	850	26,000 m	Average 1 m (2 m in up to 10% of Rain forest trees, $1\frac{1}{2}$ m in up to 10% of dry season deciduous forests.)
IVc	Includes cloud forests at high elevations, savannas, and low open forests with relatively small scattered trees. Occurs in Western Europe and S.E. Asia.	10 m	40 (6 to 15 meter spacing)	370 m	Up to 45 cm

See footnote at end of table.

Type	Identifying characteristics	Average height* of trees	Average tree density per acre*	Average total stem per acre	Tree diameter
IVd	Includes rubber plantations with dense overlapping crowns and little underbrush.	12 m	100	1,200 m	Up to 45 cm
Other forest stands in S.E. Asia. (untyped)	<p>1. Bamboo, either in small plantations or in uncontrolled forest areas may present a significant obstacle to foot troops and wheeled vehicles, blown down or standing, depending on density. 15,000 stems per acre have been counted. Such very dense thickets may have to be bypassed. No data is available regarding damage distances.</p> <p>2. Mangrove forests are similar to rubber plantations, but are about 5 times denser. Severe and moderate obstacles would occur at slightly greater distances than Type IVa, but the swampy, constantly wet ground makes tank or vehicle passage rarely, if ever feasible. These forests normally have to be bypassed, except for foot troops who could clear by hand at rates comparable to those in a dense virgin jungle.</p> <p>3. Banana and hemp should present no significant obstacle to foot troops, or tracked and wheeled vehicles, even blown down.</p> <p>4. Palms up to 20 meters high (average 12 meters) and 30 to 45 cm's in diameter, with an average density of about 70 trees per acre, and averaging 1200 meters stem per acre do not produce a severe obstacle. It is estimated from what test data is available that they will produce a moderate obstacle at distances roughly comparable to a Type I forest.</p>				

\*Considers only trees 15 cm or more in diameter.

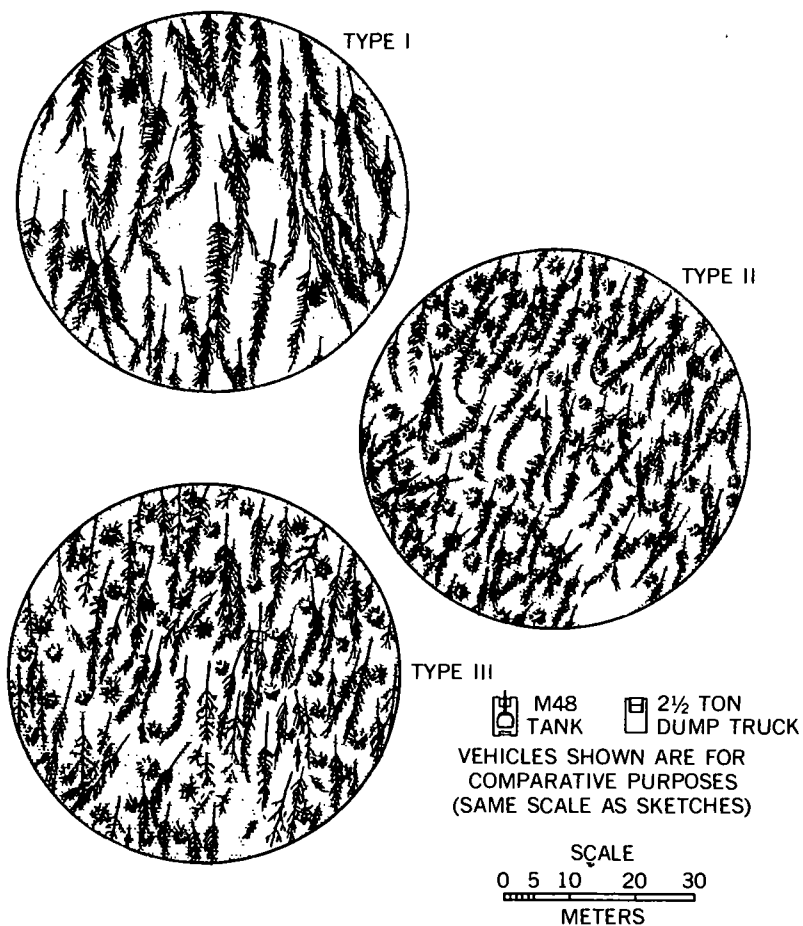
gradually changes from severe to moderate to light to no damage. There are no clear-cut lines or exact boundaries between the different levels; rather, there is an irregular transition from one to the other, making photointerpretation from aerial photographs necessary before even rough boundaries can be determined. The distances to which the three damage levels—severe, moderate, and light—extend depend upon two factors: the extent to which a given percentage of tree uprooting and breakage takes place; and the total amount of tree trunk per acre characteristic of the type forest under consideration. (Total amount of tree trunk is equal to the average tree height multiplied by the number of trees per acre having a diameter of 15 centimeters or more.) The two factors given do not apply, of course, to total damage, because of the percentile definition of the latter. (See paragraph 12 for the distances to which the different levels of damage extend as a result of nuclear air bursts of varying yields.) Since effects vary considerably in the different types of forests, the three levels of damage are taken up separately for coniferous and deciduous forests in the following paragraphs.

*a. Coniferous Forests (Types I, II, III).*

- (1) A severe damage level in a coniferous forest retards foot movement, stops wheeled vehicles, and stops tracked vehicles, or at best, makes their movement difficult. If there is a large amount of tree trunk breakage the resulting stumps trap tanks. An average of 2700 meters of tree trunk down per acre in a coniferous forest results in a severe damage level. This is schematically portrayed in figure 1. The trunks may be broken, or uprooted, depending on the root systems and moisture content of the soil. Type II generally produces more uprooting than breakage. (Wet marshy land, and shallow root systems favor uprooting.) There is very little crown and branch breakage.
- (2) A moderate damage level in coniferous forests is defined as 460 meters of tree trunk down per acre. The uprooted or broken tree trunks do not present a major obstacle to foot troops, vehicles, or tanks. They may occasionally block a road or trail, however, and force a circuitous cross-country route. Figure 2 schematically portrays a moderate damage level in coniferous forests.
- (3) A light damage level does not exist in a coniferous forest.

*b. Deciduous Forests (Type IV).*

- (1) A severe damage level in a deciduous forest retards movement to the same degree as does the same level in a coniferous forest. But because of the almost complete crown and branch breakage, a severe damage level can result from only 2,300 meters of trunk down per acre. This is schematically portrayed in figure 3. There is generally more uprooting than breaking, but again this depends to a degree upon the root systems and



*Figure 1. Severe damage level in coniferous forests.*

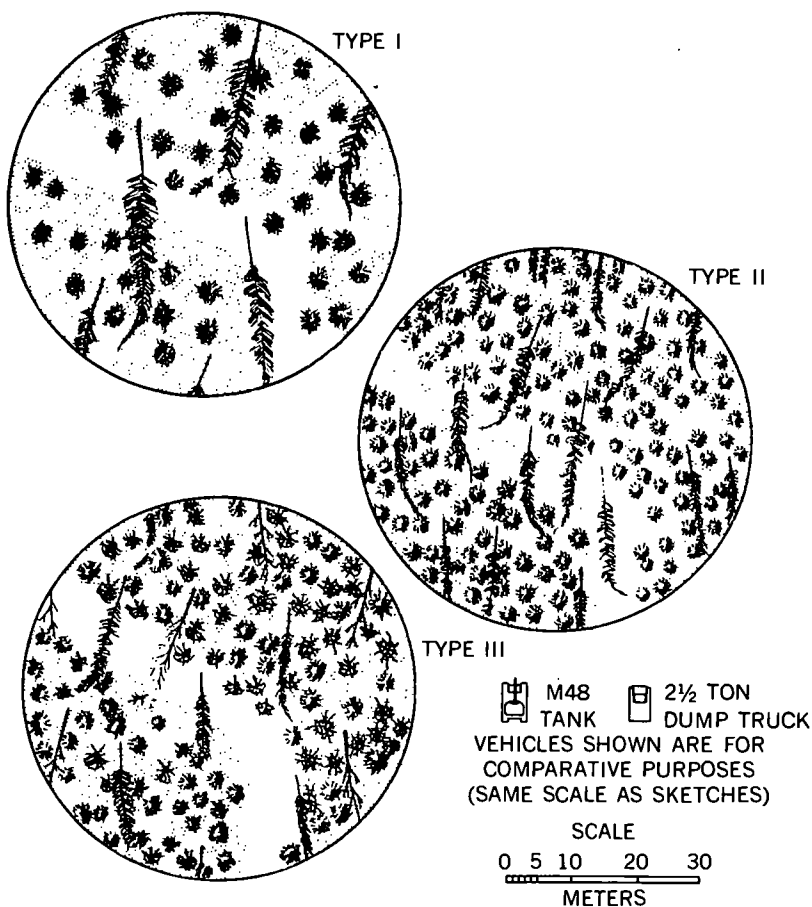
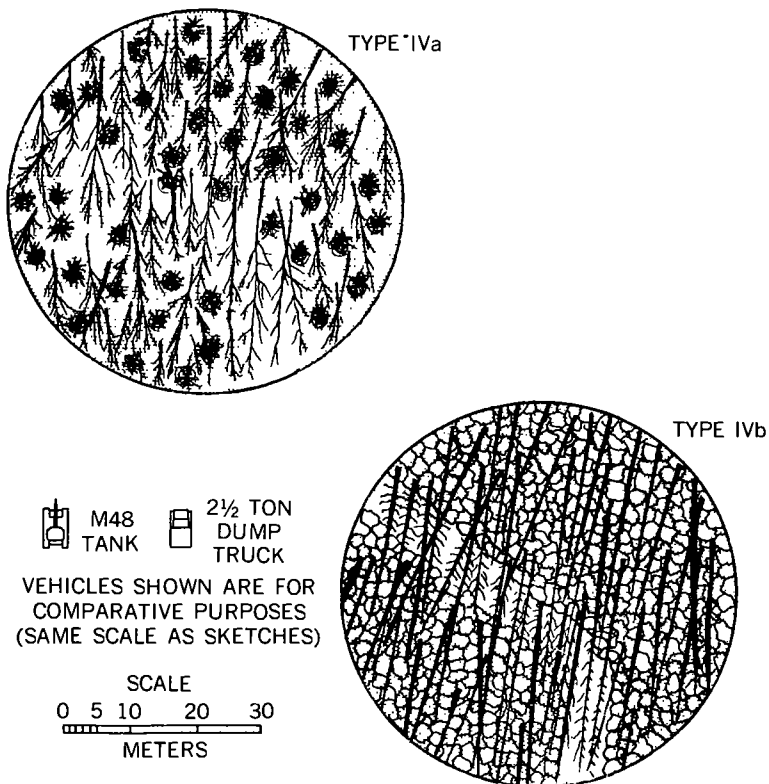
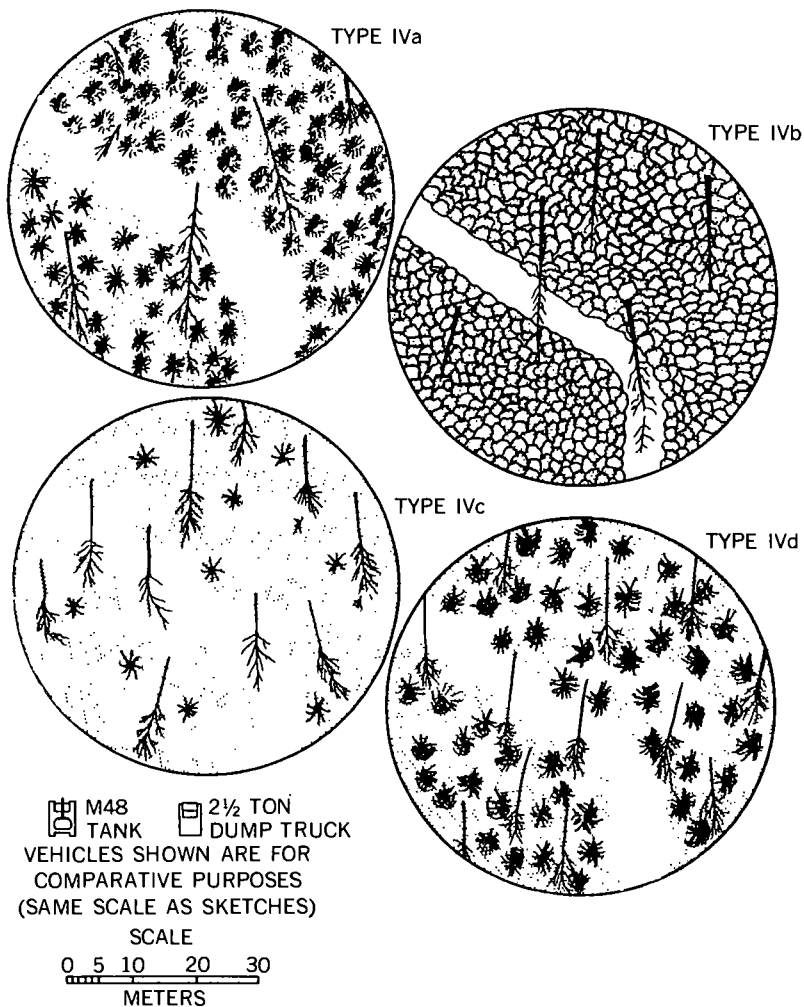


Figure 2. Moderate damage level in coniferous forests.



*Figure 3. Severe damage level in deciduous forests.*





*Figure 4. Moderate damage level in deciduous forests.*

Table III. Radii Distances

Forest type	1 KT			3 KT			10 KT			30 KT		
	L*	M*	S*	L	M	S	L	M	S	L	M	S
I	n/a	380	270	n/a	600	430	n/a	1010	730	n/a	1730	1220
II	n/a	490	375	n/a	770	580	n/a	1270	930	n/a	2100	1500
III	n/a	490	380	n/a	770	600	n/a	1270	1010	n/a	2100	1730
IVa (in leaf)	570	490	380	900	770	600	1600	1270	1010	2600	2100	1730
IVa (without leaves)	570	380	375	900	600	580	1600	1010	0930	2600	1730	1500
IVb (in leaf)	570	490	490	900	770	770	1600	1270	1270	2600	2100	2100
IVb (without leaves)	570	380	380	900	600	600	1600	1010	1010	2600	1730	1730
IVc (in leaf)	570	380	n/a	900	600	n/a	1600	1010	n/a	2600	1730	n/a
IVc (without leaves)	570	375	n/a	900	580	n/a	1600	930	n/a	2600	1500	n/a
IVd	570	490	n/a	900	770	n/a	1600	1270	n/a	2600	2100	n/a

\*L equals Light  
M equals Moderate  
S equals Severe

the moisture content of the soil. Even though there are various subtypes of deciduous forests, one basic set of data for variations in percentage of uprooting or breaking suffices for all. The data can be modified if necessary. (For example, a young and open type IVa forest is more accurately compared to a type IVd forest because of the total meters of tree trunk per acre.) A type IVb forest, undamaged, presents an obstacle in itself hence; the severe damage level figures for this type forest apply only to natural clearings or previously cleared areas, such as roads, trails, or firebreaks. Type IVc and IVd forests do not create a severe damage level as they are neither dense enough nor tall enough to produce the criteria.

- (2) A moderate damage level in a deciduous forest is defined as 230 meters of uprooted or broken tree trunks per acre and is schematically portrayed in figure 4. There is severe crown and branch breakage which presents a major obstacle to foot troops and wheeled vehicles. The moderate damage level

*(In Meters) Low Air Burst*

100 KT			300 KT			1 MT			3 MT			10 MT		
L	M	S	L	M	S	L	M	S	L	M	S	L	M	S
n/a	2800	2000	n/a	4300	3100	n/a	7000	5000	n/a	11000	7100	n/a	17200	11300
n/a	3400	2400	n/a	5200	3700	n/a	8400	5800	n/a	12800	8800	n/a	20300	14000
n/a	3400	2800	n/a	5200	4300	n/a	8400	7000	n/a	12800	11000	n/a	20300	17200
4500	3400	2800	7000	5200	4300	11300	8400	7000	16700	12800	11000	26000	20300	17200
4500	2800	2400	7000	4300	4700	11300	7000	5800	16700	11000	8800	26000	17200	14000
4500	3400	3400	7000	5200	5200	11300	8400	8400	16700	12800	12800	26000	20300	20300
4500	2800	2800	7000	4300	4300	11300	7000	7000	16700	11000	11000	26000	17200	17200
4500	2800	n/a	7000	4300	n/a	11300	7000	n/a	16700	11000	n/a	26000	17200	n/a
4500	2400	n/a	7000	3700	n/a	11300	5800	n/a	16700	8800	n/a	26000	14000	n/a
4500	3400	n/a	7000	5200	n/a	11300	8400	n/a	16700	12800	n/a	26000	20300	n/a

criteria applies only to natural clearings or previously cleared areas when considering a type IVb forest.

- (3) The light damage level in a deciduous forest is defined as fifty percent crown and branch breakage. There may be some tree trunk uprooting and breaking, making it difficult to distinguish accurately between a low degree moderate damage level and a light damage level in certain forests. A light damage level seriously impedes foot troops and wheeled vehicles but does not affect the movement of tanks. A fifty percent breakage in a type IVe forest results in much less of an obstacle than in the type IVa and type IVd forests. On the other hand, a type IVb forest produces a major obstacle when it suffers from a light damage level.

## 12. Damage Distances

Table III gives the radii of the three levels of damage produced in the different type forests from airbursts of varying yield nuclear weapons.

## **Section II. TREE BLOWDOWN CLEARANCE (AIRBURST)**

### **13. Requirements**

The incidence of nuclear targets along major routes for movement of wheeled or tracked vehicles can be expected to be high enough that even with low level use of nuclear weapons there will be tree blowdown obstacles. It may be, however, that a road through the woods will not be blocked to its full width. The numbers of such obstacles along major routes of advance can be expected to vary with the level of use of nuclear weapons. These obstacles will not stop advancing units when good cross-country mobility exists, but it may slow them significantly by forcing them to change direction of advance and search out suitable bypasses. Along secondary routes similar obstacles can be expected, but probably in smaller concentration, as fewer desirable nuclear targets will be located on these routes. Routes used as MSR's for conventional wheeled traffic behind combat units that have bypassed obstacle areas will vary in the ease with which they can be reopened, depending on the level of nuclear weapons use; the extent to which surface bursts are used; and the extent to which terrain permits rapid bypass construction for continued wheeled vehicle use. Even at the lower levels of nuclear weapons use, considerable engineer effort will have to be devoted to either bypassing or breaching blowdown areas before the MSR's are open. Engineer troops and equipment, augmented when required with aircraft, additional troop labor and, if possible, indigenous labor will be employed in such tree blowdown clearance missions. Engineers in the combat zone will lead the assault troops through blowdown areas and those in the rear areas will clear the routes for supply and reinforced movement.

### **14. Planning**

Assuming that thorough prior planning has been accomplished, based on the anticipated or potential obstacle, the available equipment, materials, and troops, final planning is now made based on the actual situation.

### **15. Reconnaissance**

There should be thorough route reconnaissance to permit choice of the easiest possible routes. This includes both foot reconnaissance in the immediate area of blowdown ahead of the equipment, and combined aerial and ground reconnaissance along the entire route planned. The wide range of natural variations in forests, and the great differences in nuclear effects, makes thorough reconnaissance imperative.

### **16. Employment of Units and Equipment**

a. For blowdown from a small (up to 20 KT) tactical nuclear yield in types II, III, IVa and IVd forests, a reinforced engineer platoon, operating two to four different points of advance along a single route to be

cleared, can normally attain the maximum practical rate of tree blow-down clearance.

b. A combat engineer company of an Engineer Combat Battalion, Army, is able to handle three to five such routes, depending on the proximity of the routes and what security requirements are met by other units (coverage of such obstacles by artillery fire can greatly harass clearance parties).

c. If a divisional engineer company must furnish local security for working parties, it may be able to handle only one or two routes.

d. All capabilities depend on augmentation with enough heavy equipment and heavy or medium helicopters to operate at least one helicopter or one piece of heavy equipment at each feasible point of advance.

e. Additional operators must be available to handle supplementary engineer heavy equipment; for extended operations additional maintenance personnel must also be furnished. An adequate supply of pioneering tools must be available. Without the helicopters, usually only one point of advance can be utilized for each route; this will reduce the troop strength that can be utilized profitably.

f. For blowdown resulting from high tactical nuclear yields the routes to be cleared may be of such length that maximum speed and effectiveness in clearance can be had by using as much as a combat engineer company stretched along a single route, with one or more crawler tractors and four to eight medium or heavy helicopters. A type IVb forest, even for low yield weapons, will be much more difficult to clear and may require a combat engineer company or more on each route, if enough clearing equipment is available. Type I and IVc forests normally present a considerably smaller requirement for personnel than for the other types, and unit capabilities will depend primarily on the number of major items of clearing equipment that can be made available to the unit, and that the unit can effectively control and operate.

## **17. Equipment Clearance Data**

a. *Uncleared Areas.* Data on tree blowdown clearance capabilities in uncleared areas is presented in tables IV through VI. The rates given are based on the assumption that personnel with hand and power tools will be working in conjunction with the clearing equipment. Specific requirements may vary from a D8 crawler tractor with a Rome blade working in a type I forest with no additional personnel, to a platoon working in conjunction with an H-37 Helicopter in a type IV forest. The equipment considered is current standard military equipment, standard military equipment modified with adaptable commercial equipment, and current developmental equipment. Since local variations in forest types may be extensive, care should be exercised in using tables IV through VI, to analyze the characteristics of the average type forests, and to make the appropriate allowances for the differences.

*Table IV. Clearance Capabilities of Current Standard Military Equipment*  
(Time in hours for clearing a 6 meter path through 1 kilometer of previously  
uncleared forest)

Forest type	Damage or obstacle	Crawler Tractor D6S; Tank Dozer <sup>1</sup>	Crawler Tractors D7 and TD18; H-34 and H-37 Helicopters <sup>2</sup>	Crawler Tractors D8 and TD24
I	Undamaged and moderate obstacle.....	12	6	5
	Severe obstacle and total damage.....	18	9	7
II	Undamaged and light obstacle <sup>3</sup> .....	22	11	8
III	Moderate obstacle and severe obstacle.....	27	14	11
IVa	Total damage.....	38	19	15
IVb	Undamaged.....	33	17	13
	Light obstacle.....	42	22	17
	Moderate obstacle.....	53	27	22
	Severe obstacle.....	62	31	25
	Total damage (broken).....	130	65	53
	Total damage (uprooted).....	175	87	70
IVc <sup>4</sup>	Undamaged; light and moderate obstacles...	7	3½	3½
IVd	Total damage.....	11	7	5

<sup>1</sup> Figures are for tank not buttoned up. Otherwise multiply by 1.5.

<sup>2</sup> With adequate clearing crews.

<sup>3</sup> Light obstacle here applies only to Type IVa.

<sup>4</sup> Various tree spacings and arrangements may lessen this time.

Radiation transmission factors

Crawler tractors: D6S-0; D7, TD18-0.7; D8, TD24-0.6

Tank dozer buttoned up: 0.05

*Table V. Clearance Capabilities of Current Commercial Equipment (Rome Blades)*  
(Time in hours for clearing a 6 meter path through 1 kilometer of previously  
uncleared forest <sup>1</sup>)

Forest type	Damage or obstacle	Crawler Tractors with Rome Blade:		
		D6S	D7; TD18	D8; TD24
I	Undamaged and moderate obstacle.....	6	3	2½
	Severe obstacle and total damage.....	9	4½	4
II	Undamaged and light obstacle <sup>2</sup> .....	11	5	4½
III	Moderate obstacle and severe obstacle.....	14	7	6
IVa	Total damage.....	19	10	8
IVb	Undamaged.....	16	8½	6½
	Light obstacle.....	21	11	8½
	Moderate obstacle.....	26	14	11

See footnotes at end of table.

Table V. Clearance Capabilities of Current Commercial Equipment (Rome Blades)—Continued

Forest type	Damage or obstacle	Crawler Tractors with Rome Blade:		
		D6S	D7; TD18	D8; TD24
	Severe obstacle.....	30	16	13
	Total damage (broken).....	65	32	27
	Total damage (uprooted).....	87	43	35
IVc, IVd	All.....	4	3	2

<sup>1</sup> When using this table with formula  $T=st\left(1-\frac{d}{hf}\right)$  multiply values given in this table by 1.5.

<sup>2</sup> Various tree spacings and arrangements may lessen this time.

Table VI. Clearance Capabilities of Developmental Military Equipment  
(No QMR for the development of shielding kits has been established.)  
(Time in hours for clearing a 6 meter path through 1 kilometer of previously uncleared forest <sup>1</sup>)

Forest type	Damage or obstacle	Crawler tractors						Combat Engineer vehicle Buttoned up?	
		Shielded cab			Remote controlled				
		D6S	D7, TD18	D8, TD24	D6S	D7, TD18	D8, TD24	No	Yes
I	Undamaged and moderate obstacle.	14	7	6	17	9	7	7	12
	Severe obstacle and total damage.	22	11	9	26	15	11	11	18
II, III, IVa	Undamaged and light obstacle. <sup>2</sup>	26	13	11	33	17	13	13	22
	Moderate and severe obstacle.	32	16	14	41	20	16	16	27
	Total damage.....	47	23	19	54	27	23	23	38
IVb	Undamaged.....	39	20	17	49	24	20	20	33
	Light obstacle.....	52	26	22	65	32	26	26	42
	Moderate obstacle.....	66	32	27	82	41	32	32	53
	Severe obstacle.....	75	37	31	95	48	37	37	62
	Total damage, broken.....	160	80	65	200	100	80	80	130
	Total damage, uprooted..	210	100	87	260	130	100	100	175
IVc <sup>3</sup>	Undamaged; light and moderate obstacle.	8	4	3½	9	5	4	4	7
IVd	Total damage.....	11	7	7	13	9	7	7	11
-									

<sup>1</sup> Use of Rome blade where feasible on shielded equipment will halve rates given in this table (for previously uncleared forests). For previously cleared forests, multiply rates shown in this table by 0.75 and use formula  $T=st\left(1-\frac{d}{hf}\right)$ .

<sup>2</sup> Light obstacles here applies only to Type IVa.

<sup>3</sup> Type IVc may require much less time than shown here, depending upon spacing and arrangement. Transmission factors for shielded equipment against residual radioactivity are estimated between 0.05 and 0.1.

b. *Cleared Areas.* The rates for clearing tree blowdown along previously existing routes in forests depend on the clearance rate for the type forest; the distance the operation occurs from the edge of the previously cleared area; the height of the trees; and the direction of fall of the trees, which is generally assumed to be radial from the center of ground zero (the exception will be those trunks which are affected by the suction phase of the blast wave). Using the above factors, the clearance rates through previously cleared areas such as roadways, fire-breaks, etc, are determined by use of the formula discussed in paragraph 18.

## 18. Clearance Rate Formula

$$T \text{ equals st } \left( 1 - \frac{d}{hf} \right)$$

Where:

T equals the time in hours for blowdown clearance of a path 6 meters wide a distance s meters along a previously cleared road or trail. A negative value of T indicates negligible clearing effort.

s equals the distance in meters along a proposed clearance route for which no appreciable change occurs in the values of parameters d, f, and h.

t equals the time in hours from tables IV through VI required to clear a 1000 meter length of path 6 meters wide through a previously uncleared area subject to tree blowdown. (When considering total damage for type IVb forest use only the trees broken figure.)

d equals the perpendicular distance in meters (in the direction of the blast) from the centerline of the path being cleared to the edge of the previously cleared area (fig. 5). The value of d could reasonably vary from about 3 to 60 meters. Thus, this parameter is of considerable significance and is included in the above equation.

h equals the average height of trees in meters. The variation in the average heights of the forest types discussed is from 10 to 60 meters (table II). Consequently, this parameter is of considerable significance and is included in the above equation.

f equals a factor related to the size of the angle made by the center line of the proposed path to be cleared with a radial line from ground zero. This is related to the number of trees affecting the clearance operation (fig. 5). Table VII gives values of f to be used with either estimated or measured angles, and is an indication of the magnitude of variation for this parameter.





Table VII. Angle Factor

Angle	f
60°-90°	.9
40°-60°	.75
20°-40°	.5
10°-20°	.3
0°-10°	.2

## 19. Examples of Clearance Estimate

Illustrative examples of the use of the clearance rate formula and related tables are given below. These examples are given in the greatest detail, but once an individual is familiar with the procedures and data they may be simplified. The first example is worked with full explanatory notes. The second is worked as an individual familiar with the procedures might work it in brief tabular form. The third is a desirable formula modification to reduce the calculations if the characteristics of an area and the equipment are relatively constant.

*a. Example One.* Route D to B shown in figure 6 has a cleared way 15 meters wide. By using the shoulder and staying as far away from the blowdown as is feasible, the centerline of the path to be cleared is 9 meters from the edge of the cleared area in the direction of ground zero. The forest is type IVa(1). Equipment available is the D7 tractor. In the section from D to C the following lengths are to be cleared:

$s_1$  equals 280 meters of road in the total damage area at an angle of 40 to 60° from a radial line to GZ.

$s_2$  equals 260 meters of road in the total damage area at an angle of 60 to 90° from a radial line to GZ.

$s_3$  equals 200 meters of road in the total damage area at an angle of 20 to 40° from a radial line to GZ.

Time to traverse equals  $st \left( 1 - \frac{d}{hf} \right)$

$t$  equals 19 hr/1000 meters (table IV).

$d$  equals 9 m (see above).

$h$  equals 25 m (see table II for type IVa(1) forest).

$f_1$  equals 0.75 for 40 to 60° (table VII).

$f_2$  equals 0.9 for 60 to 90° (table VII).

$f_3$  equals 0.5 for 20 to 40° (table VII).

$$T_1 \text{ equals } \frac{280 \times 19}{1000} \left( 1 - \frac{9}{25 \times .75} \right) = 5.32 \times 0.520 = 2.8 \text{ hr}$$

$$T_2 \text{ equals } \frac{260 \times 19}{1000} \left( 1 - \frac{9}{25 \times .9} \right) = 4.94 \times 0.600 = 3.0 \text{ hr}$$

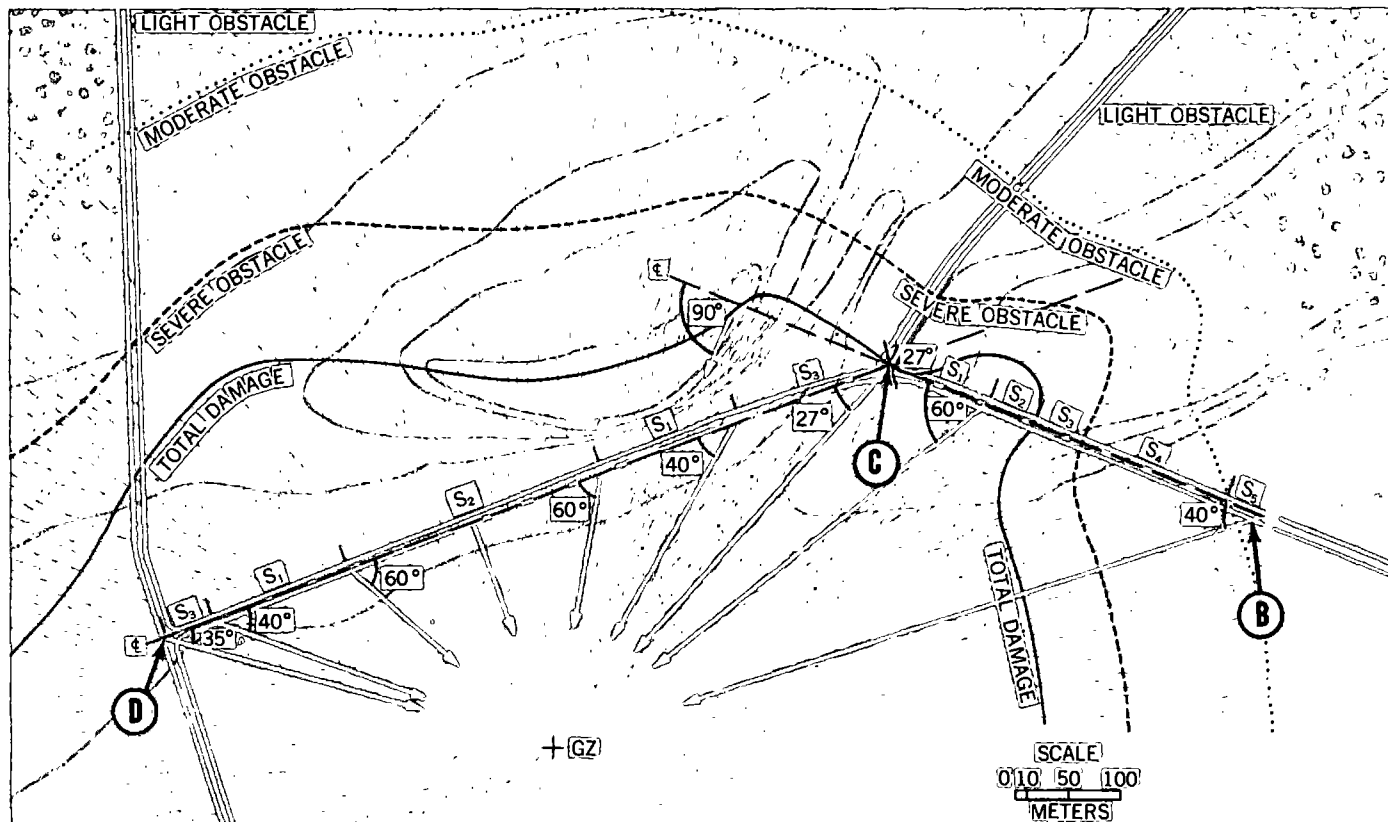


Figure 6. Effects of a low tactical yield low airburst in deciduous forest (in leaf).

$$T_3 \text{ equals } \frac{200 \times 19}{1000} \left( 1 - \frac{9}{25 \times .5} \right) = 3.80 \times 0.280 = 1.1 \text{ hr}$$

$$\text{Total time D to C} = \overline{6.9 \text{ hr}}$$

In the section C to B the following lengths are to be cleared:

$s_1$  equals 100 meters of road in total damage at an angle of 60 to 90° from a radial line to GZ.

$s_2$  equals 50 meters of road in total damage at an angle of 40 to 60° from a radial line to GZ.

$s_3$  equals 50 meters of road in severe obstacle at an angle of 40 to 60° from a radial line to GZ.

$s_4$  equals 150 meters of road in moderate obstacle at an angle of 40 to 60° from a radial line to GZ.

$s_5$  equals 40 meters of road in light obstacle at an angle of 40 to 60° from a radial line to GZ.

$t_1$  equals 19 hr/1000 meters (table IV).

$t_2$  equals 19 hr/1000 meters (table IV).

$t_3$  equals 14 hr/1000 meters (table IV).

$t_4$  equals 14 hr/1000 meters (table IV).

$t_5$  equals 11 hr/1000 meters (table IV).

$d$  equals 9 meters (see above).

$h$  equals 25 meters (see table II for type IVa(1) forest).

$f_1$  equals 0.9 (table VII).

$f_2$  equals 0.75 (table VII).

$f_3$  equals 0.75 (table VII).

$f_4$  equals 0.75 (table VII).

$f_5$  equals 0.75 (table VII).

$$T_1 = \frac{100 \times 19}{1000} \left( 1 - \frac{9}{25 \times .9} \right) = 1.90 \times .600 = 1.1 \text{ hr}$$

$$T_2 = \frac{50 \times 19}{1000} \left( 1 - \frac{9}{25 \times .75} \right) = .95 \times .520 = .5 \text{ hr}$$

$$T_3 = \frac{50 \times 14}{1000} \left( 1 - \frac{9}{25 \times .75} \right) = .70 \times .520 = .4 \text{ hr}$$

$$T_4 = \frac{150 \times 14}{1000} \left( 1 - \frac{9}{25 \times .75} \right) = 2.10 \times .520 = 1.1 \text{ hr}$$

$$T_5 = \frac{40 \times 11}{1000} \left( 1 - \frac{9}{25 \times .75} \right) = .44 \times .520 = .2 \text{ hr}$$

$$\text{Total time C to B} = \overline{3.3 \text{ hr}}$$

$$\text{Total time D to C} = \overline{6.9 \text{ hr}}$$

$$\text{Total time D to B} = \overline{10.2 \text{ hr}}$$

---

*Note.* This time can be reduced by using more effective equipment.

b. *Example Two.* Compute the time taken to clear the road from A to E on figure 7. Equipment available consists of a D8 crawler tractor and two H-34 helicopters. The forest is best described as type IVa(1), but it is immature and the tree heights average only 18 meters, although they are somewhat closer together than in a mature forest. The characteristics of the roadway through the forest are such that the centerline of the path to be cleared will be about 8 meters from the edge of the forest closer to ground zero. The computations are accomplished in tabular form (table VIII), as they would be done by one familiar with such computations. The various symbols and expressions and their use are shown in the preceding example. By having the D8 tractor start at the near edge of the forest, one helicopter at the far edge of the forest, and one about 800 meters in from the far edge of the forest working toward the near edge, a path can be cleared along the road in about 4 hours from the time the equipment can arrive on the site. The D8 alone would have required 9 hours.

Table VIII. *Example of Tabular Computation*

Section to be cleared-----	A to B <sup>1</sup>	B to C	C to D	D to E
Degree of damage-----	Total to severe.	Severe	Moderate	Moderate
Average rate/km (t)				
D8-----	*	11 hr	11 hr	11 hr
H-34-----	*	14 hr	14 hr	14 hr
Distance, centerline to forest edge (d)-----	*	8 m	8 m	8 m
Average tree height (h)-----	*	18 m	18 m	18 m
Angle GZ to roadway-----	*	20-40°	40-60°	20-40°
Angle factor (f)-----	*	.5	.75	.5
Length of section (s)-----	*	700 m	1500 m	1100 m
st { D8-----	*	7.7 hr	16.5 hr	12.1 hr
1000 { H-34-----	*	9.8 hr	21.0 hr	15.4 hr
$\left(1 - \frac{d}{hf}\right)$ -----	*	0.113	0.406	0.113
Time to clear section (T)				
D8-----	*	0.9 hr	6.7 hr	1.4 hr
H-34-----	*	1.1 hr	8.5 hr	1.7 hr

<sup>1</sup> For initial passage this section normally should be bypassed. Could be cleared later if required.

c. *Example Three.* This example assumes a battalion is in Western Europe in an area in which type I is the only forest type. The battalion is assigned only D8 dozers and the average tree height in its area of responsibility is 30 meters. If under certain circumstances it is desirable to use a constant clearance rate for simplicity of calculation it would be best to use a rate of 6 hr/1000 meters for the value of t for all conditions of blowdown (see table IV). Thus for the above mentioned unit and area, the formula could be modified as follows:

$$T \text{ equals } (0.006 \text{ s}) \left(1 - \frac{d}{30f}\right)$$

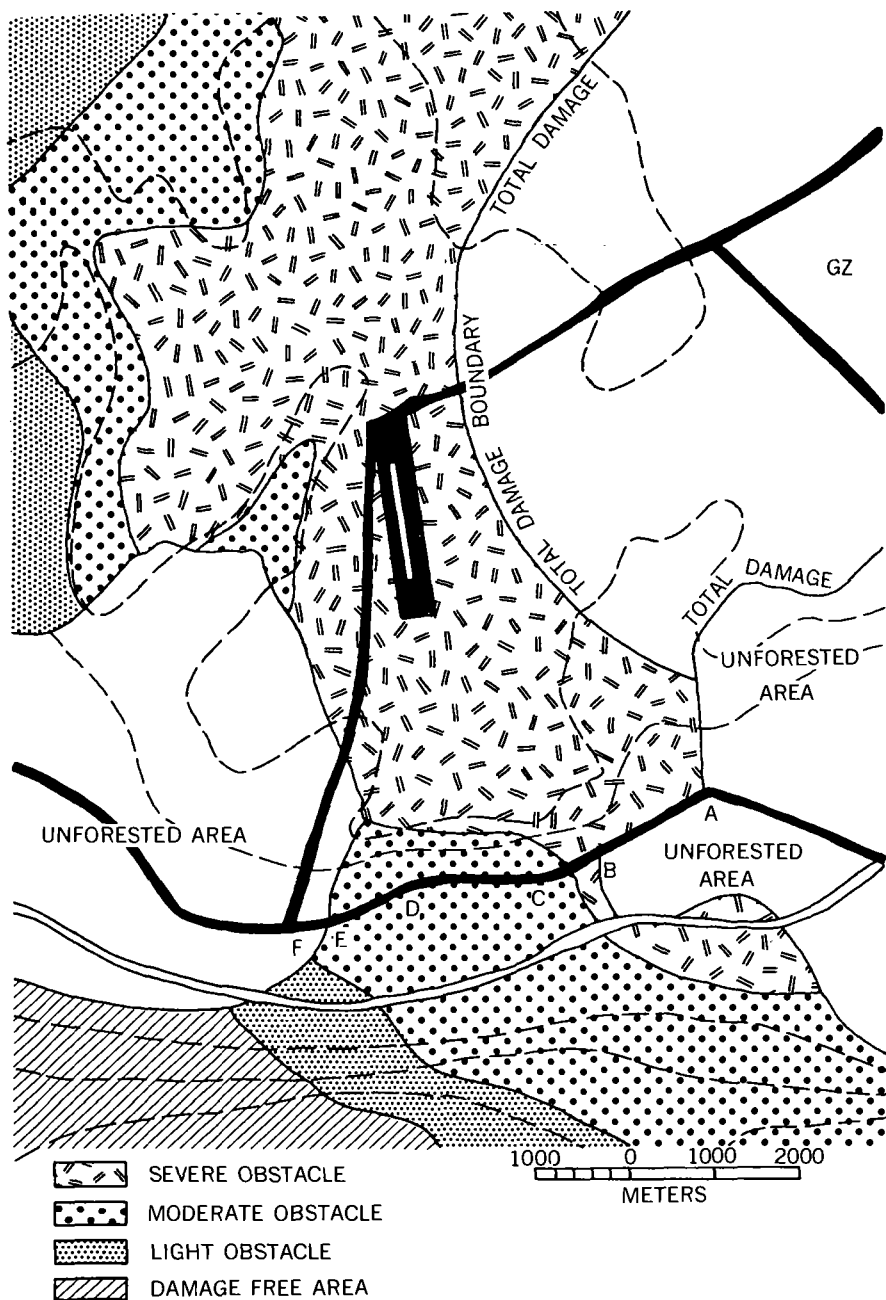


Figure 7. Effects of high yield low air burst in deciduous forest (in leaf).

For a specific mission of road clearance through a forested area in which  $d$  is 8 meters, the formula could be reduced to:

$$T \text{ equals } (0.006 \text{ s}) \left( 1 - \frac{0.267}{f} \right)$$

Consequently, only the applicable clearance distances and values of  $f$  would be required to calculate the clearing time.

## **20. Clearance in Contaminated Areas**

A surface burst nuclear weapon introduces two problems in addition to those produced by an air burst of a comparable yield: the radioactive nuclear crater, and residual radiation which hinders obstacle passage and clearance operations by limiting the time troops can spend in either traversing the obstacle or working to clear it. Blowdown clearance in the presence of radiological contamination is difficult and will involve more time and equipment than would otherwise be required. It is advisable, whenever time and effort can be saved and the mission can be accomplished, to bypass a fallout area. Generally, a surface burst reduces the area over which the tree blowdown effects extend. Table IX gives the radii distances for a surface burst of various yield weapons. For a surface burst to create the same damage produced by an air burst of a given yield, a slightly larger yield weapon is required. An unprotected unit in an affected area cannot await the hours required by survey and plotting procedures to produce fallout dose rate contour maps. When faced by obstacles from tree blowdown, any unit must react rapidly, intelligently, and aggressively. The following paragraphs discuss some of the procedures which will allow units to act promptly and independently.

## **21. Equipment Capabilities**

The basic data on tree blowdown clearance capabilities for equipment when buttoned up or shielded, and for remote control equipment, is given in tables IV through VI.

## **22. Personnel Operating Capabilities**

Personnel operations in a given operation are limited primarily by the maximum permissible radiation dosage established by the command. (Nuclear weapons manuals, TM 23-200, TM 3-225, FM 101-31, and DA PAM 39-1, provide data and procedures facilitating computation of radiation doses, permissible stay times, attenuation factors, and other required information.) In an area having residual radiation in dangerous dose rates, a unit's capability for blowdown clearance depends mainly upon the amount of shielded equipment and equipment operators available. The number of equipment operators and their previous radiation dosage history is critical because high dose rates or previous

Table IX. Radii Distances

Forest type	1 KT			3 KT			10 KT			30 KT		
	L*	M*	S*	L	M	S	L	M	S	L	M	S
I	n/a	320	220	n/a	520	345	n/a	880	600	n/a	1400	1030
II	n/a	420	310	n/a	670	490	n/a	1080	830	n/a	1700	1270
III	n/a	420	320	n/a	670	520	n/a	1080	880	n/a	1700	1400
IVa (in leaf)	490	420	320	780	670	520	1320	1080	880	2130	1700	1400
IVa (without leaves)	490	320	310	780	520	490	1320	880	830	2130	1400	1270
IVb (in leaf)	490	420	420	780	670	670	1320	1080	1080	2130	1700	1700
IVb (without leaves)	490	320	320	780	520	520	1320	880	880	2130	1400	1400
IVc (in leaf)	490	320	n/a	780	520	n/a	1320	880	n/a	2130	1400	n/a
IVc (without leaves)	490	310	n/a	780	490	n/a	1320	830	n/a	2130	1270	n/a
IVd	490	420	n/a	780	670	n/a	1320	1080	n/a	2130	1700	n/a

\*L equals Light  
M equals Moderate  
S equals Severe

radiation exposure permit only short exposure times. For example, for the first 20 hours after a burst in an area of high intensity (3,000 rad per hour at 1 hour) with a maximum permissible dose of 20 rad per day, and with operations beginning 1 hour after the burst, approximately eight operators would be needed for each tank dozer. After the first day the number of operators required decreases rapidly. Stay times for various maximum permissible dosages and radiation intensities can be computed from data in the aforementioned nuclear weapons manuals. When determining total stay time allowance must be made for the time the operator will need to travel from the edge of the residual radiation area to the worksite and out again to arrive at an accurate work time. For example, if this travel is not made in the tank dozer, this additional allowance must be made for the dose received as a result of transferring into and out of the tank dozer.

### 23. Considerations for Work in Contaminated Areas

The following required procedures for operating and manning equipment in radioactive areas usually determine whether or not it is in the best interest of the command to initiate action in areas of intense residual radioactivity.



*(In Meters), Surface Burst*

100 KT			300 KT			1 MT			3 MT			10 MT		
L	M	S	L	M	S	L	M	S	L	M	S	L	M	S
n/a	2270	1700	n/a	3400	2700	n/a	5200	4100	n/a	8000	6200	n/a	12200	9300
n/a	2800	2000	n/a	4100	3000	n/a	6600	4600	n/a	9700	6700	n/a	15000	10000
n/a	2800	2270	n/a	4100	3400	n/a	6600	5200	n/a	9700	8000	n/a	15000	12200
3400	2800	2270	5200	4100	3400	82	6600	5200	12600	9700	8000	19000	15000	12200
3400	2270	2000	5200	3400	3000	82	5200	4600	12600	8000	6700	19000	12200	10000
3400	2800	2800	5200	4100	4100	82	6600	6600	12600	9700	9700	19000	15000	15000
3400	2800	2800	5200	3400	3400	82	5200	5200	12600	8000	8000	19000	12200	12200
3400	2800	n/a	5200	3400	n/a	82	5200	n/a	12600	8000	n/a	19000	12200	n/a
3400	2000	n/a	5200	3000	n/a	82	4600	n/a	12600	6700	n/a	19000	10000	n/a
3400	2800	n/a	5200	4100	n/a	82	6600	n/a	12600	9700	n/a	19000	15000	n/a

a. Several operators are required per piece of equipment operating in areas of high residual radioactivity, the exact number depending upon the number of shifts required. Unless other provisions are made, an operator must take his piece of equipment into the contaminated area, work with it, bring it out, and turn it over to another operator before he has exceeded his allowable dose. This is time consuming. When short shifts are being worked, every effort must be made to keep the equipment "on the job" by using other means, such as helicopters or tanks, to shuttle the operators back and forth. This necessarily involves exposure while transferring from vehicle to vehicle; rapid completion of transfer is thus imperative, since the dose outside a tank dozer is many times greater than inside one.

b. Dust stirred up by helicopters may increase the fallout hazard. To deal with this problem in dry areas, tanks can be used for the shuttle vehicles.

c. The radioactive area should be monitored at all times to determine any change in dose rates. Personnel and equipment leaving the work area should be monitored for radioactivity and decontaminated as required.

d. Shuttle requirements are reduced as the shifts lengthen. They will be eliminated eventually because the equipment must be brought out of the contaminated area in any event for routine maintenance, and the operator can bring it out.

## **24. Operating Procedures**

The general procedures discussed in this paragraph apply to the overall operation. Their use speeds up clearance and obstacle passage in fallout areas. (These same procedures apply when dealing with induced radioactivity from air bursts or from a radiological warfare attack.)

a. *Rapid Aerial Route Reconnaissance.* Aerial route reconnaissance should be initiated as soon as the operation of aircraft over the blowdown area is feasible. The essential purpose is to determine as early as possible the blowdown characteristics and to conduct aerial radiological survey on various routes. This permits prompt determination of where passage can occur, or clearance operations begin, along the routes. The information should be transmitted directly to the units responsible for the passage or clearance. If possible, an engineer officer should be in the aircraft to evaluate the blowdown obstacle. He can facilitate prompt choice of routes to be cleared or traversed and hasten the conversion of reconnaissance information into clearance rates and passage time. Pertinent radiation data along the path traversed, in addition to being transmitted to the units responsible for clearance and passage, should be forwarded in accordance with unit SOP's as raw data for contour plotting.

b. *Initial Ground Actions from Relatively Safe Areas.* When routes through a blowdown area are directed or can be predetermined, ground action can be started to effect clearance or passage before the aerial reconnaissance data is received, providing the following precautions are taken:

- (1) Action should be initiated from a staging area which is outside the area of probable fallout as determined by current Army methods.
- (2) Each work party must possess a reliable radiation monitoring capability.
- (3) Estimates of expected dosages to operation personnel from radiological contamination should be prepared.

## **25. Computations for Clearance Time**

Computations are performed as shown in paragraphs 17 through 19, using the appropriate reduced clearance rates allowed for buttoned-up or shielded equipment. Unprotected personnel will not be allowed to work in conjunction with the equipment. Helicopters and crews cannot be used to make additional starts along the path to be cleared, unless there are areas relatively free of radiation.

## CHAPTER 3

### RUBBLING IN URBAN AREAS

---

#### **26. Nature of Obstacle**

The obstacle created by rubble is essentially a blocking of routes of communication through urban areas with debris and rubble from buildings adjacent to the route. In both nuclear and nonnuclear warfare there will be a requirement for breaching rubble created by the bombing of built-up areas. The mass bombing raids of World War II produced rubble areas comparable in magnitude to those to be expected from low yield nuclear weapons. As in the case of tree blowdown, the frequency and magnitude of rubble clearance will depend upon the level of use of both enemy and friendly bombing, the extent to which the enemy devotes his effort to deliberate production of rubble barriers, and the extent to which the type of construction found in the area and the existing network of streets permit ready bypass.

#### **27. Variations in Urban Areas**

Urban areas differ widely in the types and distribution of buildings they contain. The damage and resulting obstacles produced from any destructive force depend upon these differences. The types of buildings normally found can be classified as: frame, light masonry, and heavy masonry and reinforced concrete.

*a. Frame construction* includes wood frame buildings of all types, thatched huts, and light steel structures covered with corrugated metal or a similar light sheathing, such as one-story steel frame industrial buildings.

*b. Light masonry construction* includes single or multistory residences, apartment buildings, small office buildings, and similar structures constructed of brick, adobe, cinder block, and other light masonry materials.

*c. Heavy masonry and reinforced concrete construction* includes reinforced concrete buildings of all types, multistory monumental wall-bearing buildings, and medium and heavy steel frame buildings.

#### **28. Variations in Damage**

*a. Frame Construction.* The debris from wooden or thatched structures resulting from a damaging force may burn in a mass fire before transit

through the area can even be contemplated. Figure 8 illustrates what could be expected in an area containing light frame construction after suffering both a blast and a fire. (The picture was taken after the roads had been cleared.) In such an event there is little obstacle or clearance problem, except perhaps in terms of damage to pneumatic tires. On the other hand, if personnel are in such an area and attempt to evacuate before the mass fire develops, the unburned debris from wood frame structures will present obstacles to wheeled vehicles and slow the movement of foot troops and tracked vehicles. Unburned debris from frame construction, however, is easily cleared by conventional engineer equipment. Debris from light metal frame structures will consist for the most part of the sheathing or roofing, the building contents, and the building frame. It is possible, although not probable, that the frame as a whole could be moved into a street and present a major obstacle to all types of movement. The sheathing frame and contents of other types of light frame buildings usually consist of components which, when separated from the buildings, break into fragments small enough to present relatively minor obstacles.

b. *Light Masonry Construction.* The debris from light masonry structures is produced by the outer walls and other materials falling into and along the routes of advance. Occasionally roof and floor beams or other structural members will contribute to the obstacle presented. Under normal conditions this debris cannot be expected to burn; however, conventional engineer earthmoving equipment can remove it with relative ease.

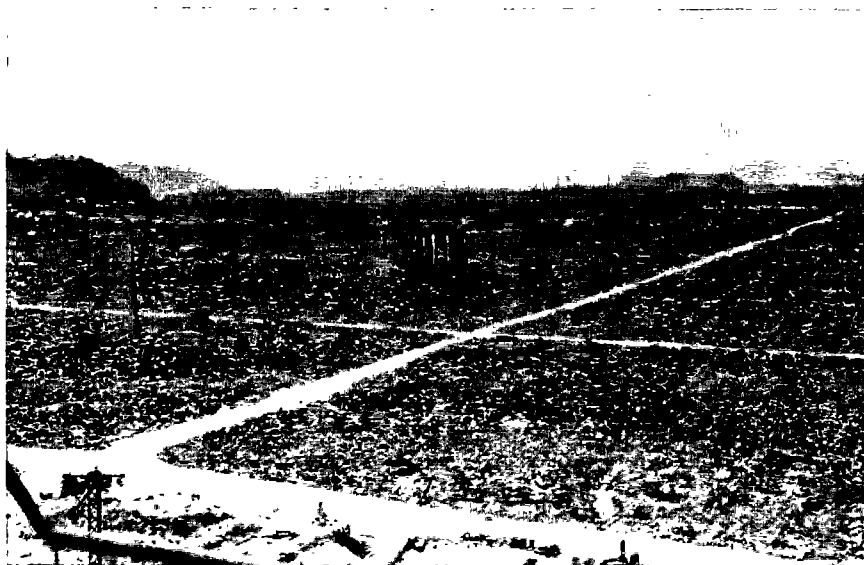


Figure 8. Light frame construction after blast and fire.



*Figure 9. Heavy masonry building severely damaged illustrating necessity for deliberate destruction of standing portions.*

c. *Heavy Masonry and Reinforced Concrete Construction.* When debris from this type of construction falls to block a route it produces a major obstacle that probably will require demolition or steel cutting operations if it cannot be bypassed; the condition of the surrounding area determines which should be done. Portions still standing may require deliberate destruction or shoring to permit safe passage. Figure 9 reveals the rubble resulting from a severely damaged heavy masonry building, although in this figure the rubble has not fallen on the route. Figure 9 also illustrates the necessity for deliberate destruction or shoring. Figure 10 further illustrates the characteristic rubbing of this type of building. If an area containing a large concentration of these heavily constructed buildings has been severely damaged, it is normally advisable to bypass the entire area.

## **29. Unit Capabilities**

Unit capabilities for clearing urban rubble depend primarily on the number of major items of clearing equipment that a unit can obtain and handle effectively. Usually, there will be less opportunity for use of multiple points of advance on the routes to be cleared than when clearing tree blowdown, since helicopters are not as effective in handling rubble as they are in handling trees. When heavy masonry and reinforced concrete rubble must be cleared, the necessity for steel cutting and air compressor tool crews will create increased personnel requirements.



*Figure 10. Severely damaged heavy masonry construction.*

### **30. Equipment Clearance Data**

To be of value, the equipment capabilities given in this chapter must be combined with an estimate based on related experience data or on a reconnaissance of the route to be cleared. When such estimates are not available, table X gives some figures which may be used for frame and light masonry construction. It is important that the figures in table X be recognized for what they are at best—estimates under average conditions, in average areas. The figures may be quite inaccurate for a specific situation, however, and should be used only when no better information is available.

*a. For Frame and Light Masonry Construction.* Clearing rubble produced by both frame buildings and light masonry buildings can be compared to moving broken rock, the equipment rates for which are specified in current engineer manuals.

*b. For Heavy Masonry and Reinforced Concrete Construction.* No standard rates can be established for equipment capabilities in respect to rubble from this type of construction. It is obvious that the rates will be slower than those for light masonry and frame buildings, but how much slower depends on the size of the pieces of rubble, the extent to which these pieces are attached to each other with steel reinforcing, and the ease with which equipment can be maneuvered. Often, several types of equipment will have to be used together, such as dozers, cranes, power

shovels, and cutting torches. When merely creating a passage through the rubble, the work effort is less than in general clearing operations, since the debris can be shoved to one side or bypassed instead of being hauled away.

Table X. Clearance Rates Through Rubble

(For clearing a one kilometer path six meters wide or original road width, whichever is less.)

Type of clearance equipment	Type of construction to be cleared			
	Burned frame <sup>1</sup>	Unburned frame	Light masonry	
			(Tracked vehicles)	(Wheeled vehicles) <sup>2</sup>
Crawler Tractor D6S.....	1/3 hr	2 hrs	3 1/2 hrs	35 hrs
Tank Dozer (Buttoned up or not)...	See D6S			
Crawler Tractor D7; TD18.....	1/3 hr	1 1/2 hrs	2 hrs	20 hrs
Crawler Tractor D8; TD24.....	1/3 hr	1 1/2 hrs	2 hrs	20 hrs

<sup>1</sup> No clearance required for foot troops or tracked vehicles.

<sup>2</sup> These rates are for sufficient clearance for routine traffic.

### 31. Clearing Rate Computations

To insure the most accurate estimates of clearance rates, ground and air reconnaissance, conducted by experienced engineer personnel, are required. Clearance progress depends on the distance to be traveled, the type of rubble to be encountered and the amount of rubble to be removed or pushed aside. Two examples of rate computations are given below. They both apply to the same stretch of road, but one is based on reconnaissance data, the other on the tabulated average capabilities given in table X. The variations in the results should be considered normal, with the more reliable answers resulting from the reconnaissance data.

*a. Based on Reconnaissance.* (One D7 dozer is available. The rates in km/hr are the speeds at which it can move along and through the rubble on given sections of the route.) Reconnaissance reveals the following information:

*Section 1:* This is a 1 km section of road through damaged frame construction. The rubble is burned along 3/4 of it. There is no obstacle to tank traffic along the entire section. At two points, requiring approximately five minutes' dozer effort each, are accumulations of debris which may stop armored personnel carriers. There is much minor debris which must be removed for routine wheeled vehicle traffic, but this can be swept off easily by the dozer moving down the route.

*Section 2:* This is a 2 km section of road through damaged light masonry construction. Tracked vehicles can move through and

around the rubble if 16 major accumulations of rubble are removed by a dozer, requiring an estimated 15 minutes at each. Approximately 6000 cubic yards of debris must be removed before the route is restored to a condition permitting routine movement of wheeled vehicles.

*Computations for clearance for passage by tracked vehicles.*

Section 1:

1 km at 8 km/hr	= .17 hr
2 obstacles at 5 min each	= .17 hr
to clear section 1	= .34 hr (use .4)

Section 2:

2 km at 4 km/hr	= .50 hr
16 rubble piles at 15 min each	= 4.00 hr
to clear section 2	= 4.5 hr
Total = 4.9 hr (use 5)	

*Computations for clearance for routine passage by wheeled vehicles.*

Section 1:

Dozer sweeps off accumulated debris over a 1 km route in 2 passes at 4 km/hr. Dozer travels 3 km, traveling at 8 km/hr on return from 1st pass, which equals  
.62 hr  
2 obstacles at 5 minutes each which equals  
.17 hr  
to clear section 1 = .79 hr (use 1)

Section 2:

6000 cubic yards of rubble at rate of 95 cubic yards/hr requires  
63 dozer hours  
Section 1 requires 1 hr  
Section 2 requires 63 hr  
Total = 64 hours

(In such a case more than 1 dozer would normally be used.)

b. *Based on Table X.* This computation uses the same route and area as the preceding example, but in this case all that is known is that the route is 3 km long, with 1 km going through an area of destroyed frame construction (whether burned or not is unknown) and 2 km's going through an area of light masonry rubble. The same D7 is available.

*Computations for clearance for passage by tracked vehicles.*

Section 1:

Assuming unburned frame construction rubble (conservative)  
from table X the time for a D7 to clear  
= 1.5 hours

Section 2:

2 km at 2½ hr/km (from table X)  
= 5.0 hours  
Total time = 6.5 hours



Section 1:

Same as above from table X  
= 1.5 hours

Section 2:

2 km at 22 hr/km (from table X)  
= 44.0 hours  
Total time = 45.5 hours (use 46)

## **32. Procedures and Techniques**

The same general procedures prescribed for tree blowdown passage and clearance operations apply as well to the passage and clearance of urban rubble. The following subparagraphs discuss some specific considerations peculiar to urban rubbing.

a. Reconnaissance, and study of maps and photographs of the area before it was damaged are highly desirable. This might reveal, for instance, that passage through a railroad right-of-way will require the least clearing effort because the type and location of structures found near such rights-of-way are less likely to produce major obstacles.

b. Visual or photo aerial reconnaissance locates those areas which have burned, areas in which there is relatively little rubble, and areas which contain large accumulations of rubble. Where roads are extensively blocked, it is important to select the easiest and quickest route through or around the area. This is best done by rapid, extensive aerial and, if possible, ground reconnaissance.

c. After a route has been selected, clearance or passage operations should be initiated from as many different points as possible. In some cities it may be possible to move clearing equipment by water into or around damaged areas in order to reach these many points. If waterways do exist, they can be used as alternate routes through rubble areas.

d. Helicopters are not as useful here as in clearing tree blowdown, but they can, within their limited lift capacity, act as a lift device in areas where cranes are not available.

## **33. Rubble Clearance From a Surface Burst Nuclear Weapon**

See paragraphs 20 through 25 for a discussion of the additional problems raised by the residual radiation following a surface nuclear burst. The hazards to be considered and the procedures to be followed in clearing urban rubble from a surface burst are substantially the same as those prescribed for the clearance of tree blowdown from a surface burst. Computations for clearing time are performed as given in paragraph 31, using, where appropriate, the reduced work capabilities specified in table VI for buttoned-up or shielded equipment. Again, obstacle clearance time for urban rubble, in the presence of residual radiation, will be extended considerably.

## CHAPTER 4

### FIRE

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#### 34. Nature of Obstacle

The obstacle created by fire is essentially a blocking of routes of communication by burning fires or by the rubble and debris remaining after the fire burns out. Fire is a constant potential danger in war or peace. It can be caused in numerous ways in all environments containing combustible materials. Fires range from small, easily controlled blazes, which all units are trained and equipped to fight, to mass fires which are largely uncontrollable. This chapter is concerned with the development and characteristics of mass fires which occur during combat from conventional, incendiary, and nuclear effects in urban and rural areas.

#### 35. Mass Fires

Regardless of their cause in source, mass fires fall into one of the two following types.

*a. Conflagrations.* Conflagrations are mass fires which spread in the general direction of the wind and are entirely out of control. Their identifying characteristic is the presence of a fire front—an extended wall of fire—moving to the leeward, preceded by a mass of fireheated, turbid, burning vapors. The extent and destructive power of a conflagration, which continues until there are no more combustible materials are of greater magnitude than that of a firestorm (see below) which burns itself out in a relatively confined area.

*b. Firestorms.* Firestorms are phenomena, the development of which depends upon at least three conditions: usually a minimum area of 1 square mile involved, containing 20 percent or more combustible material; many small blazes must start simultaneously throughout this area; and there must be an absence of a strong ground wind. Given these conditions the temperature of the air rises due to the many small blazes; and the interacting fire winds, augmented by the heat radiation, merge these separate blazes into one pillar, or column of burning gases. The rapid vertical rise of the hot, burning, gaseous pillar causes cooler air to rush into the base of the pillar with a velocity equal to hurricane winds. Figure 11 shown tree damage caused by winds resulting from a firestorm.



*Figure 11. Illustrating hurricane force of ground winds during firestorm.*

### **36. Factors Affecting Rate of Fire Spread**

The factors which determine the rate at which fires spread are numerous and interrelated. Experienced firefighting personnel, familiar with a given locality, can predict with some accuracy the course of a particular fire. Understanding the factors discussed below, however, will enable other personnel to devise a course of action that will be adequate enough to avoid entrapment.

#### *a. Weather Factors.*

- (1) *Humidity.* Normally, the average humidity for the prior 3 weeks determines the moisture content of combustible material at any given time. An average relative humidity above 70 percent in the winter and 75 percent in the summer produces an equilibrium moisture content of more than 15 percent in the potential fuel. A moisture content of 15 percent or higher appreciably hinders the initiation of a vigorous fire. Moisture content is an effective fire retarder only during initial development, and has practically no effect in retarding later fire growth and spread.
- (2) *Precipitation.* Precipitation in the 8 hours preceding inception of a fire, and in the period immediately following inception, is an important factor. Rain during these periods does not affect the ignition potential of protected materials, but it does hinder the spread of the fire. Snow is less effective as a deterrent to the spread of fire than is rain.

- (3) *Wind.* Wind is the weather factor having the greatest influence on the rate of fire spread. With all other factors of fire potential at a minimum, fires of moderate proportions can be controlled by aggressive firefighting action if the wind velocity is no greater than 13 knots per hour. (An exception is the absence of any ground wind which, in conjunction with other conditions, may produce a firestorm, as described in paragraph 35.) As the wind velocity increases from 13 knots per hour to 26 knots per hour, the rate of fire spread increases rapidly; at the latter velocity, even a relatively minor blaze must be considered a serious threat to the downwind area.

*b. Topographic Factors.* In the Northern Hemisphere, fires on slopes facing north have less chance of spreading than those on south and southwest slopes. In the Southern Hemisphere the reverse of this is true. On slopes facing upwind the rate of fire spread can be expected to be greater than on slopes facing downwind. A fire starting at the base of a slope will spread more rapidly than a fire starting at the top. Fires originating in box canyons have a rapid rate of spread. Fires at low elevations have less fire spreading potential than those at higher elevations. In some cases the time of the day has an effect. Because of the difference between day and night wind patterns, the chance of fire spread at higher elevations is greater during the night, whereas for lower elevations it is greater during the daytime. Normally, level terrain hinders the rate of spread, whereas hilly terrain causes a fire to spread rapidly. In some cases, however, the presence of hilly terrain in an urban area can reduce the fire potential by preventing spread from one valley to another. The influence of this factor depends on the individual layout of the given urban area, as well as upon the point of the fires' origin.

*c. Fuel Factors in Urban Areas.*

- (1) *Density.* In an urban area one of the most important factors influencing the start and spread of fire is building density, that is, the ratio of roof area to ground area. The greater the density, the greater the number of individual ignitions. There is also less open area in which to maneuver firefighting equipment. All of the mass fires occurring in World War II took place in areas of high building density. With some possible exceptions, firestorms and conflagrations can be expected primarily in areas having a building density greater than 20 percent.
- (2) *Combustibility of structures.* Another principal factor in the growth of fire is the combustibility of structures. Combustibility is determined mainly by the materials composing a particular structure. Building construction is placed in three major classes: all frame construction; masonry-combustible buildings, that is, having masonry walls but with combustible material in their main structural members, such as roofs and floors; and fire-resistive buildings which are constructed of

materials that will inhibit combustion and withstand all but the most intense fire without serious structural damage. Figure 12 pictures Kobe, Japan after a World War II fire. The city consisted, primarily, of wooden buildings, but what few brick-walled and fire-resistive buildings there were, burned out on the inside. Figure 13 pictures Hamburg, Germany after an incendiary attack. This particular group of buildings was constructed of substantial brick walls. Figure 14 pictures a fire-resistive building in the central business district of Stuttgart, Germany. Incendiary bombs set fire to every building in the district; entering the windows of this particular building, they burned out the interior. (This picture was taken after the building had been restored to some measure of use by the bricking up of the windows.)

- (3) *Size of target area.* The extent of fire damage caused by enemy attack depends not only on the size of the city area but also on the size of the zones within the city capable of sustaining firestorms and conflagrations. The minimum size of the area capable of sustaining a firestorm is uncertain, but a study of the data suggests that it is unlikely to be less than 1 square mile.



*Figure 12. Kobe, Japan after a World War II conflagration.*



*Figure 13. Hamburg, Germany after an incendiary attack in World War II.*

- (4) *Continuity of combustible construction.* Exterior wood construction is a very important factor in fire spread. Sheds, private garages, small storage buildings, and other buildings of various kinds are often entirely built of wood, and hence contribute greatly to fire spread. Continuity of combustible construction is also provided by continuous cornices, porches, fences, awnings, and wooden additions to masonry buildings. Removal of much of this highly combustible construction may be necessary in anticipation of an emergency. In this connection the presence or absence of firebreaks is an important factor. Open spaces such as streets, parks, canals, and occasionally, strategically located fire-resistive buildings, serve as firebreaks. The extent to which streets and other open spaces aid or hinder the spread of fire depends upon their width; the size, height, combustibility, and density of the surrounding buildings; and the wind conditions. Figure 15 illustrates the sometimes questionable value of a firebreak when a mass fire has developed. While average street widths would probably have little or no effect in limiting fire spread in a firestorm, they could act as firebreaks in more limited fires or at the fringes of mass fires. The individual value of firebreaks must be



*Figure 14. Stuttgart, Germany: fire damage to fire-resistive buildings.*



*Figure 15. Mass fire straddles firebreak.*

considered on a relative basis in determining boundaries of zones and in arriving at an overall estimate of the fire potential of the given area.

- (5) *Occupancy combustibility.* Most fires caused by bombing in World War II originated from the combustible contents of the buildings and not from the structures themselves. These small blazes, left uncontrolled, resulted in serious fires.
- (6) *Size of buildings.* For assessment purposes, the size of the buildings (including both ground area and height) must be considered, since this influences the size of the individual fire and ability to fight it. In this connection, excessive reliance must not be placed on sprinklers for control purposes.

*d. Fuel Factors in Rural Areas.* Ground litter, consisting of dry dead exposed branches on the floor of forests, enhances the growth of a fire considerably. Conversely, a fire in a forest with large open areas, a thick canopy of green leaves, and no exposed dead branches or litter will not burn as rapidly or spread as far. In the dry seasons of late summer and fall, heavy stands of cured dry grain crops will ignite quickly and spread rapidly. Due to the lack of heavy fuel in such crop areas, however, these fires will usually burn themselves out in short order.

### **37. Categories of Fire Potential**

There are three possible fire potentials in a given area: critical, dangerous, or low. These determine the probable extent of the fire spread which, in turn, indicates the action a unit or installation can and should take to survive and accomplish its primary mission. The exact determination of fire spread can best be made by personnel experienced in firefighting in a given locality, who are able to base their estimates on intimate knowledge of all the local variables.

*a. Critical.* This is a condition which produces a mass fire. Rapid burning and spotting (the throwing of burning brands) as much as a mile ahead of the fire front are characteristic. Critical potential exists when an adequate supply of heavy fuel is present and dry and windy conditions, such as those normally associated with summer and fall months, prevail.

*b. Dangerous.* This is a condition that produces a continuous, intense fire front that moves rapidly and spots ahead. The dangerous type of fire occurs under dry, relatively windless conditions, or under less dry conditions, but with brisk or strong winds present. Terrain has a considerable effect on the existence of a dangerous fire potential.

*c. Low.* This is a condition that produces an irregular fire pattern, with the fire spread determined by local variations in the fuel structure and marked changes in the terrain. The fire depth is usually small. The low category potential exists when fairly moist conditions and winds of low velocity are present. Under such conditions, thermal radiation is not likely to cause dense initial blazes over large areas.



## 38. Fire Potential from a Nuclear Burst

Fires caused by thermal radiation can be expected in all areas—urban, cultivated, forests, or grasslands—during the particular area's dry season. In wooded areas, when conditions are critical and favor the development of a mass fire, cross-country mobility may be quite hazardous, since woods and cultivated grain crops will burn over large areas. Under these circumstances the fire spread is not easily predicted. Low level use of nuclear weapons under conditions of critical or dangerous fire potential will greatly hinder all movement. Later, the lack of natural cover in the burned off area will affect the security of movement. In some cases, however, where the unburned area presents an obstacle in its natural state, burning may perform a service by clearing formidable or impenetrable growths.

## 39. Characteristic Ignition Patterns from Thermal Radiation

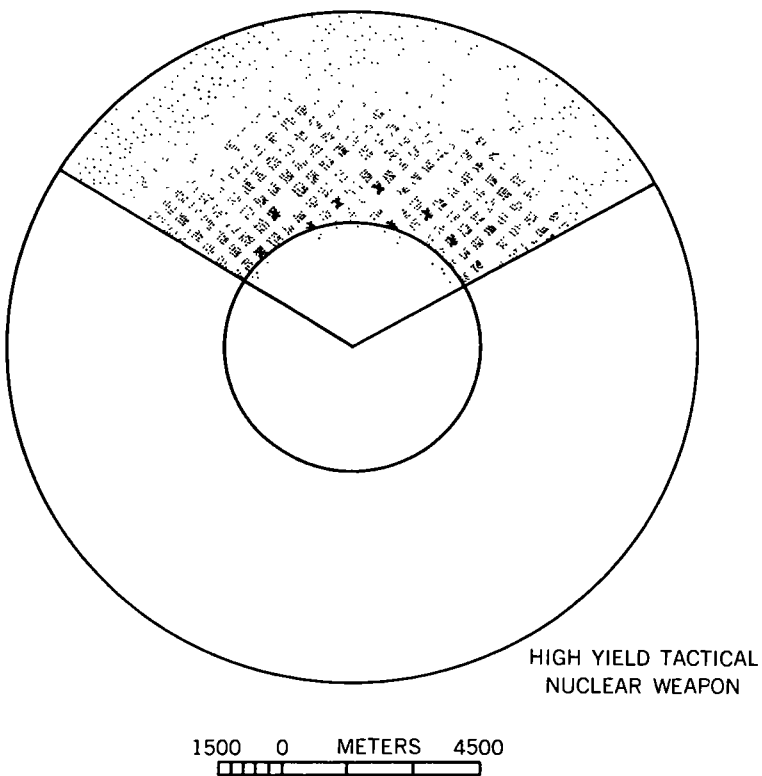
Figures 16 through 21 schematically present variations in the nature of the blazes which occur in urban and rural areas. The blazes in a rural area are limited usually to primary ignitions, whereas the blazes in an urban area are primary and also secondary, that is, those caused by short circuits, upset heating plants, ruptured gas mines, and other causes resulting from the blast damage.

### a. In Urban Areas.

- (1) *Uniform dense ignition pattern* (fig. 16). In urban areas where wood, paper, or dried grass has been used for dwelling construction, widespread dense ignitions occur. The inner area has most of the initial blazes blown out by the blast effect. The central area contains widespread ignition, and the outer ring has sparse blazes with primary ignitions not occurring in buildings, but only in the combustible trash or other materials usually found around and between buildings. Throughout all areas, secondary blazes may occur to the limit of the blast damage.
- (2) *Uniform scattered ignition pattern* (fig. 17). A widespread but less dense pattern of ignition occurs in urban areas where easily ignitable buildings are mixed with nonignitable buildings (such as thatch and mud with brick or masonry); or in areas where easily ignitable materials are used for walls but nonflammable materials are used for roofs (such as thatch walls with tile roofs); or in nonflammable urban areas containing large quantities of ignitable trash. The effects on personnel and equipment in these areas again depend on the fire potential conditions discussed in paragraph 37. Secondary blazes occur throughout the blast damage area.
- (3) *Sparse scattered ignition pattern* (fig. 18). In well-kept urban areas in which nonflammable materials are used for roofs and exterior walls, a sparse scattered initial ignition pattern develops.



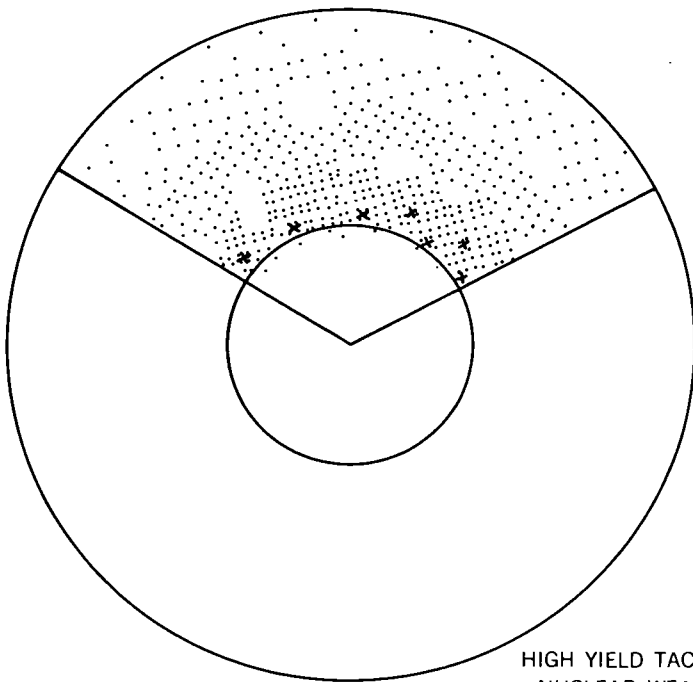
VERY LOW YIELD  
NUCLEAR WEAPON



*Figure 16. Uniform dense ignition pattern in urban areas.*



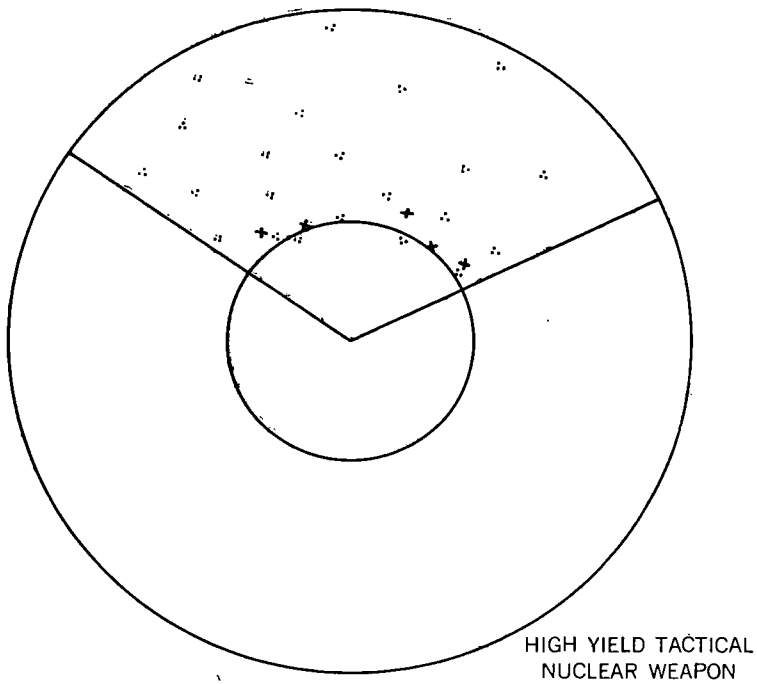
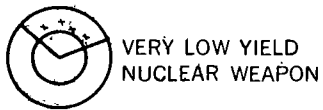
VERY LOW YIELD  
NUCLEAR WEAPON



HIGH YIELD TACTICAL  
NUCLEAR WEAPON

1500 0 METERS 4500

*Figure 17. Uniform scattered ignition pattern in urban areas.*



1500 0 METERS 4500

Figure 18. Sparse scattered ignition pattern in urban areas.

Secondary ignition, however, will occur throughout the blast damage area.

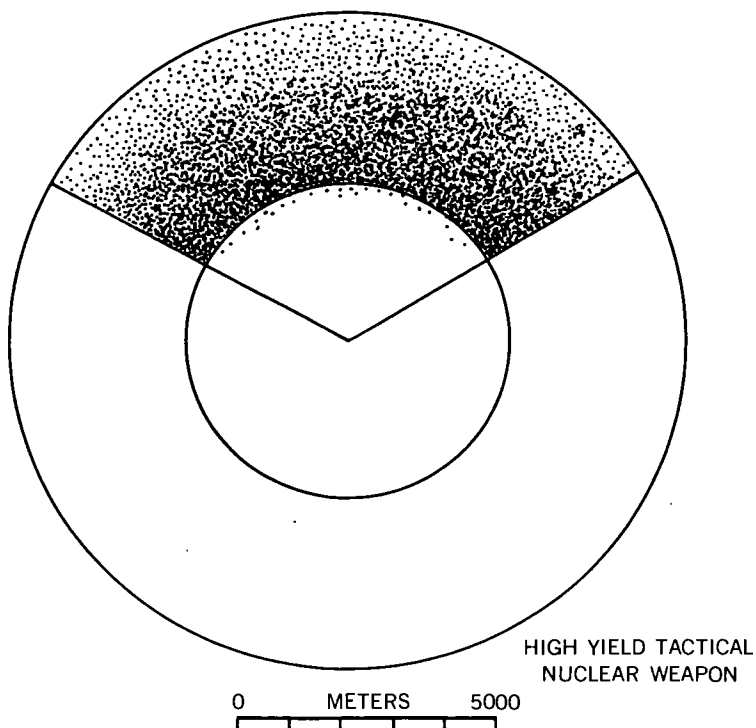
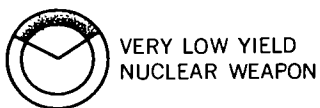
- (4) *No ignition.* In urban areas, in the presence of rain, snow, or high humidity, there may be no initial ignitions. Secondary ignitions, however, may start as a result of blast damage.

*b. In Rural Areas.*

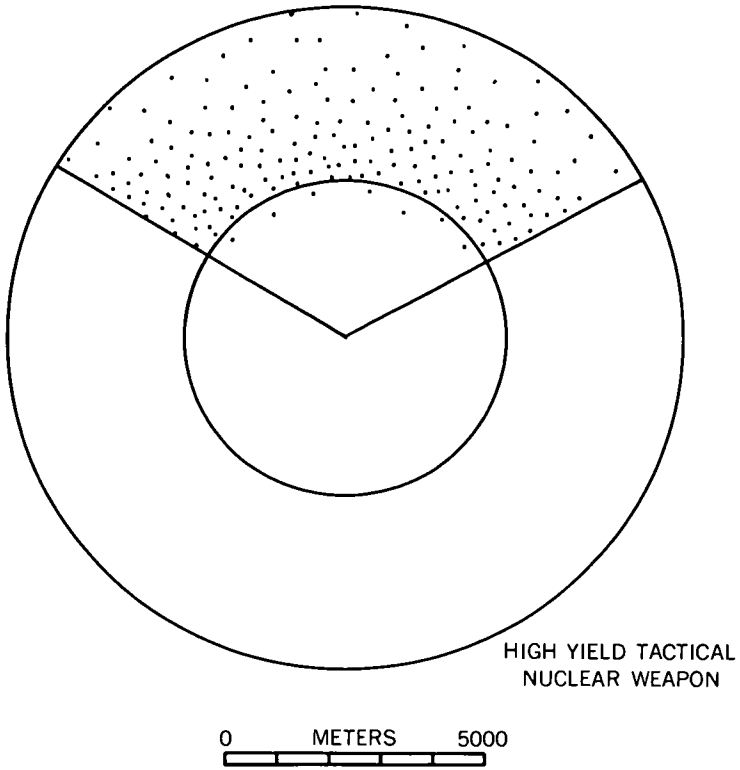
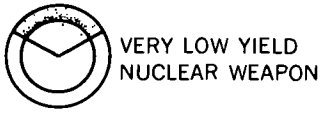
- (1) *Uniform dense ignition pattern* (fig. 19). In dry grassland or cultivated areas with dry grain fields or similar crops, ignition occurs almost instantaneously in an annular area about the burst. Because of the completeness of ignition, personnel in the area will normally become casualties unless they are in clearings, field fortifications, or shelters. Even then deoxygenation of the air and inhalation of hot gases may cause casualties. Unprotected personnel will receive thermal radiation burns when the weapon detonates. Outside this annular area of instantaneous ignitions isolated ignitions will occur. If the fuel is dry enough to burn intensely, the duration of the blaze at a given point will be short. Up to a certain distance from ground zero, the blast wave blows out the initial ignitions. Rekindling, however, can be expected.
- (2) *Uniform scattered ignition pattern* (fig. 20). In dry sparsely wooded grasslands, dry, defoliated forests, and similar areas, a less uniform and dense, but still widely spread, pattern of ignitions will occur. The effects on personnel and equipment in the area depend upon the fire potential conditions discussed in paragraph 37. Certain types of ignitions, such as those in dry punk, resist being blown out by blast winds.
- (3) *Sparse scattered ignition pattern* (fig. 21). In green wooded areas, even in dry weather, ignitions will not normally occur except in clearings or openings; this results in a sparse scattered ignition pattern.
- (4) *No ignition.* In green vegetated areas and forested areas without clearings, it is possible to have no ignitions. This may be the case also in any other type area, under unfavorable weather conditions, such as rain, snow, or high humidity.

#### **40. Fire Potential in Areas of Previous Rubbling and Tree Blowdown**

*a. Rubbling.* Even in areas of highly combustible frame buildings, there may remain large amounts of unignited combustible debris, or rubble, remaining. Primary ignition is the main cause of fire here, with secondary ignitions unlikely. The combustible materials are no longer dried out by the interior heating and are now exposed to the elements; this lowers the fire potential somewhat. On the other hand, combustible materials inside the buildings and previously shielded from thermal radiation, now become exposed and provide an additional source of



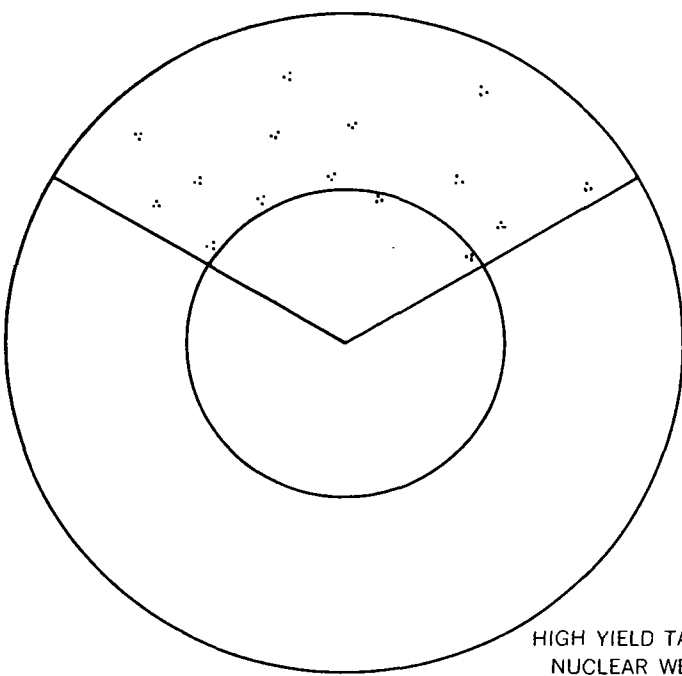
*Figure 19. Uniform dense ignition pattern in rural areas.*



*Figure 20. Uniform scattered ignition pattern in rural areas.*



VERY LOW YIELD  
NUCLEAR WEAPON



HIGH YIELD TACTICAL  
NUCLEAR WEAPON

0 METERS 5000

*Figure 21. Sparse scattered ignition pattern in rural areas.*



primary ignition. The devastated, rubble, and unburned urban areas have fire potential characteristics similar to those of a tree blowdown area.

*b. Tree Blowdown.* In an area of tree blowdown, most of the vegetation is broken or uprooted. With the passage of time this creates an increased fire hazard. There is no longer a protective canopy of leaves to reduce the number of ignitions. The tree stand no longer restricts the entrance of surface winds to the area of dead, highly combustible material. The heavier fuels of the branches and trunks are brought closer to each other and to the lighter fuels on the forest floor. When the humidity is low, almost all of the fuel is dry and highly combustible, instead of being green and growing. In dry periods, blowdown forests may dry out in 2 to 4 weeks.

## **41. Protective Measures**

### *a. Basic Requirements for Protection.*

- (1) It is essential for commanders to know the fire potential of the areas in which their units are operating and the susceptibility of these areas to mass fires. If troops are familiar with the ignition characteristics of the various areas in which they are operating, and if they can move on a few minutes notice, the units can be trained to fight fires, evacuate as appropriate, and take intelligent action to inhibit the development of a fire. But if the units are to take such action, it is necessary for them to know the current fire potential conditions.
- (2) There are many types of installations which, though nominally mobile, cannot move in time to get out of the way of a mass fire. In such cases provision must be made either to protect or abandon that which cannot be moved. Protection might consist of moving the materials or equipment into areas containing a minimum of combustible material, or placing them in trenches between buildings. There are many items which stand a good chance of surviving when dug in and covered with a tarpaulin or loose earth.
- (3) Professional firefighting advice should be available to units throughout the field army and communications zone to permit them to develop effective unit fire defenses. Intelligent firefighting effort, if promptly applied, can limit the spread of fire to the areas damaged by the nuclear blast. An elaborate organization is not needed. Firefighting teams should be assigned to critical immobile logistic units, to certain installations, and to missile units. Headquarters at corps level and above require professional firefighting advice from either an appropriate firefighting unit or the engineer staff.

*b. Under Critical Potential Conditions.* Under critical potential conditions personnel must be evacuated from both the front and the flanks of a fire. Units or installations in areas of uniform dense initial

ignitions, such as those in dry grasslands, or in crowded highly flammable buildings, will probably become casualties regardless of what action they take if they are actually located in the combustible material. If they are not, they must seek shelter or rapidly evacuate the area of ignitions.

*c. Under Dangerous Potential Conditions.* In a dangerous potential condition, aggressive organized action is required to protect personnel and equipment. This situation calls for vigorous and competent firefighting effort, unless an excellent firebreak exists between the area of primary ignition and the area in question. Even then, there is always danger from the fire spotting over the firebreak. Professional firefighting advice and assistance is essential for effective action. In the area of uniform dense ignitions, exposed personnel will become casualties; however, it should be remembered that open foxholes provide some protection from the fire. If there is a large amount of combustible material available, and if it burns long enough, personnel may become casualties unless they are in oxygenated air-retaining shelters. In areas of widespread but scattered ignitions, most units and individuals not otherwise casualties will probably have time to save themselves by taking cover or quickly moving from the burning areas. Control of the fire within the area of ignition from a nuclear burst will be difficult because of the large number of blazes to be controlled, but since it may take as much as an hour or two for a major fire to develop from the many scattered ignitions, there may be time for evacuation between the blazes. In areas of few scattered ignitions, prompt and aggressive action to control smaller local fires may prevent development of a larger regional fire.

*d. Under Low Potential Conditions.* When the fire potential is low, individual action can usually control a fire. The unit or installation is generally able to remain in its position and, with locally available personnel<sup>1</sup> and equipment, control any blazes that occur. Normal aggressive firefighting action is taken to control the spread or destruction. Professional firefighting direction and assistance, while always desirable, are not essential under these conditions. If a fire line develops and passes through a unit area, protection can be found in any clearing, rock outcrop, fortification, or shelter. Tanks and other vehicles should be given enough protection so that they are not ignited by localized fires.

## **42. Firefighting Techniques in Urban Areas**

*a. Preventive Measures.* Wartime firefighting, while a difficult problem requiring the assistance of many persons, is not an insurmountable one. In the center of large urban mass fires, firefighting is a hopeless task. Nevertheless these fires can be attacked on their periphery and in numerous other locations to stop or slow the spread. Also many measures can be taken prior to anticipated attack, which will reduce materially the fire potential. For the most part these are simple acts of common sense, such as:

- (1) Eliminating potential ignition points.
- (2) Painting exterior surfaces to hinder ignition by thermal radiation (tests proved unpainted frame structures burned, whereas the same frame structures, when painted, merely scorched but did not break into flame).
- (3) Removing extraneous wooden features, such as fences, shacks, and decorations.
- (4) Eliminating, as far as possible, secondary ignition points at installations, and when that is not possible, using safety devices and automatic cutoff valves to keep gas, fuel, and electric lines from open flames and hot surfaces.
- (5) Identifying potential mass fire areas and building or locating accordingly.
- (6) Establishing emergency water supply sources.
- (7) Training all personnel to fight numerous small primary and secondary blazes.

*b. Problems Encountered.* After a mass fire has developed, experience has shown that there will never be enough professional firemen and equipment to fight it. Hence, in mass firefighting, the action is one primarily of containment, to prevent further spread if possible. This involves peripheral firefighting and attacking the small isolated blazes. Rubble, overturned equipment, and damaged and destroyed paving will probably preclude the use of conventional equipment. Figure 22 illustrates the barrier formed by damaged equipment. Figure 23 shows the rubble which develops in streets from fires in brick-walled buildings only two to three stories in height. The street is passable for motor vehicles only up to the point from which the picture was taken. Very slight depths of rubble, as little as 20 inches, make a street impassable to ordinary wheeled vehicles. Figure 24 shows a heavy half-tracked vehicle stuck on a pile of rubble. From this position it could not move under its own power and had to be towed out backwards. Figure 25 shows the difficulty a light armored tractor had. It was just able to make its way over a point where the two piles of rubble met. The tractor could not climb either of the piles at the side because the tracks merely churned up the loose rubble. Figure 26 shows the type truck which was found to be best for work in rubble areas. This chassis, with a 4-wheel drive, proved fairly satisfactory because of the generous ground clearance. Nevertheless, it was possible to climb this pile of rubble only by putting snow chains on the tires because otherwise the loose rubble was too readily churned up by the moving wheels.

*c. Lessons.* Lessons learned from urban firefighting experience in World War II provide the following guidance:

- (1) Mutual aid arrangements are not too successful.
- (2) In mass fires there is no possibility of fighting fires except at the fringes.



*Figure 22. Damaged equipment blocking route.*



*Figure 23. Rubble from burned low brick structures.*



*Figure 24. Half-tracked vehicle unable to negotiate rubble filled streets.*



*Figure 25. Light armored tractor attempting to negotiate rubble filled streets.*



*Figure 26. Truck type found best for work in rubble areas.*

- (3) Wartime firefighting is small line work, with the emphasis on fighting fires in the interior of buildings. Little use was made of large streams or curtains of water, and long relays were seldom undertaken.
- (4) Mopping up of fires once they are knocked out by the professional firefighters becomes the responsibility of non-professional individuals.
- (5) In large cities it is necessary to bring all available firefighting forces into operation within 3 hours if they are to be effective.
- (6) Reconnaissance of the area involved in a fire is of crucial importance of effective measures are to be carried out. The reconnaissance should be completed within an hour after ignition. Reconnaissance is facilitated by the use of helicopters.
- (7) Firefighting forces must possess a reliable communications system.
- (8) It is less important to bring great crowds of auxiliary firemen and equipment into fire areas than to have a few resolute men with good equipment.
- (9) Preventive measures have always been more effective than the best organized protection which can be provided.
- (10) Water requirements are about 400 gallons per minute per 100 feet of street frontage.

- (11) Loss of life in buildings was due to suffocation, carbon monoxide poisoning, and heat. In the open, however, these were rarely the causes of death.
- (12) Firebreaks must be at least 100 meters wide to be effective; if possible they should be planted with trees for heat insulation and to act as spark catchers.
- (13) Fire crews must work together in an organization long enough so they can fully understand their part in the overall action.
- (14) Finally, large firefighting forces are not, in themselves, the answer.

### **43. Firefighting Techniques in Rural Areas**

*a. Methods Available.* There are three basic methods of attacking a fire in rural areas: *direct*, *parallel*, and *indirect*. Each is adapted to meet certain conditions of fire behavior. Usually a combination of methods is used, the choice depending on the following:

- (1) Behavior of fire at time of attack.
- (2) Safety of men.
- (3) Topography and natural firebreaks.
- (4) Intensity of wind and influence of other weather factors.
- (5) Chance of crown fire.
- (6) Safety in burning out.
- (7) Type of equipment available.
- (8) Amount of labor required and available.
- (9) Experience and dependability of supervisory and labor personnel.
- (10) Quality of men available to supervise backfiring.

*b. Direct Method.* The direct method of fighting a fire treats the fire as a whole, or its burning edges, directly by wetting, cooling, smothering, or chemically quenching the flame, or by mechanically separating the fire from any unburned fuel. A hot grass fire can be fought successfully with wet sacks and swatters, or by smothering the flame with dirt. Often the spread of a fire can be stopped by applying water directly on the burning material. The direct method may be employed on sections of the fireline that have cooled so that the edge of the fire can be dug out, scraped, pushed into the burned area, or otherwise extinguished. This method eliminates the need for constructing a control line and burning out, since the fire edge is the control line. However, a partly dead fire edge must be carefully inspected and, if necessary, felt with the hand to detect any fire. The control of a dead fire edge is called "cold trailing" and is employed in flash fuels where the fire edge may go out quickly. Experienced firefighters should make maximum use of "cold trailing" when using the direct method, but inexperienced firefighters should encircle all fires by a control line regardless of the apparent deadness of the fire edge. The direct method sometimes

entails the practice of "hotspotting." This is the construction of short sections of a control line to check spread at critical points, at localized flareups, and in case there is a badly spotted and fingered section of the fire edge. The direct method is recommended for the following situations:

- (1) On a smoldering or creeping ground fire.
- (2) During night or early morning hours when burning intensity has slowed and the flames can be beaten out or smothered.
- (3) When the fire is burning against the wind.
- (4) When much fire perimeter has gone out and digging out a few smoldering spots will result in control. This is usually during night or early morning hours.
- (5) Where there are light fuels and the heat is not too intense for men to work safely on the fire edge.

*c. Parallel Method.* This method is used when a fire is too hot, or there is too much smoke to stop the spread by direct attack. A control line is constructed approximately parallel to the fire edge but far enough from it to enable men and equipment to work effectively and safely. The fire is followed as closely as possible unless a saving in the total job of line construction and mopup can be made. The control line should be started at an anchor point, such as a rockslide, road, trail, stream, or clearing, and travel parallel to the fire edge. The distance between the control line and the fire edge will vary with the intensity of the heat and smoke, the location of natural barriers, dangerous fuels, and the fire edge regularity. There should be enough distance to build the line and to safely burn it out. Reconnaissance ahead should be made to determine the shortest, quickest, and safest route for the control line to follow. The parallel method may be best to use under the following conditions:

- (1) Slow to medium fast running fires.
- (2) When using plows, dozers, or other mechanized equipment.
- (3) Where there are numerous spot fires.
- (4) Where the control line can be shortened by cutting across fingers.
- (5) On steep slopes below the fire to avoid undercut fire lines.
- (6) On areas where the material can be fired as it lies and can burn out quickly without special danger of crown fires.
- (7) Where natural barriers may be used for fire lines.
- (8) Where resistance to control is less, by locating the control lines away from the fire edge.

*d. Indirect Method.* The indirect method of fighting a fire consists of selecting a location and preparing a fire control line a considerable distance in advance of the fire path (usually more than 100 feet) and burning out the intervening areas. Such a method may be used to stop the spread of crown fires, or large hot fast running ground fires. Whenever practical, preconstructed firebreaks, streams, roads, trails,



fields, or other natural barriers should be used as anchor points for the control line. The area to be backfired in the indirect method is wider than in the parallel method and allows a choice in timing the setting of the backfire. This method of fighting fire requires maximum skill and must be directed by thoroughly experienced men. The indirect method should be used—

- (1) On large crown fires.
- (2) On fast running ground fires where it is not safe to work crews except along natural or artificial barriers.
- (3) Where natural or preplanned barriers are present.
- (4) In extremely steep or rugged topography where change of slope will favor control.

*e. Use of Aircraft.* Aircraft are used primarily for—

- (1) Reconnaissance, mapping, and photography of the fire perimeter and adjacent control areas.
- (2) Transportation of firefighters to the fire; placing them over the fire area where they may parachute from fixed wing planes or jump, or be lowered by winch from helicopters.
- (3) The delivery of firefighting equipment and facilities by cargo drops or direct to air terminals.
- (4) Bulk dropping (cascading) of water or chemicals from fixed wing air tankers or helitankers.
- (5) In the direct method of attack, the support of ground attack forces by knocking down and cooling hotspots so the ground crew may attack directly; laying retardants to stop the advance of a fire so ground forces may construct control lines; laying hose lines for pumper operations, thus checking the advance of a fire until ground forces arrive.

## **44. Equipment**

*a. Conventional.* There are many types of conventional firefighting equipment. The most common in use by the U. S. armed forces are—

- (1) Hand fire extinguishers which contain water, antifreeze solutions, foam solutions, vaporizing liquids, or inert gases. These agents are propelled by hand operated pumps, internally generated pressure produced by a chemical reaction, compressed air, or compressed inert gases. These extinguishers are usually referred to as the first aid firefighting apparatus, that is, they are employed immediately in an attempt to extinguish or control a fire until the organized or regular firefighting force arrives on the scene.
- (2) Class 500 trailer mounted pumpers which provide a complete unit designed as an auxiliary item of firefighting equipment.
- (3) Class 530 B firefighting trucks which are provided only for installations having an installed water supply system or other

reliable water source capable of maintaining a water flow equal to pumping capacity.

- (4) Class 1500 fire trucks which are intended primarily to combat fires involving guided and ballistic missiles and missile fuel storage facilities in a theater of operations. This truck has a pump capable of delivering 1,000 gpm at 150 pounds or 500 gpm at 300 pounds. It carries 1,000 gallons of foam liquid. For fires involving a larger missile, such as the Redstone, there is a 2,000 gallon tank trailer to be used and pulled by the truck. This provides 3,000 gallons of uninterrupted flow of water when required.
- (5) Class 100 trailer mounted units which are designed to provide fire protection and personnel decontamination at a NIKE installation.

*b. Emergency.* Assuming that in time of emergency or disaster the water supply systems will not be available for fighting fire, an emergency pipe system, known as the Ames Pipe System, has been developed. This system allows access to whatever water sources are available, such as ponds, streams, lakes, reservoirs, swimming pools, and similar facilities, and can be run for any necessary distance. It requires only one or more of the pumps described below to act as boosters in the system. In addition, conventional equipment can be used as boosters if higher pressures are required; or conversely, the emergency system may be employed merely as a water source for the conventional pumpers if the normal water supply system is disrupted. This emergency system is of great value. It comes in easy to handle 20-foot lengths with simple couplings, and can be put into operation by a minimum of inexperienced personnel quickly and without need of special tools or equipment. One thousand feet of pipe with two booster pumps can be put into operation in 3½ minutes by troops who have never handled the system before. The pumps to be used with the Ames Pipe System are cylindrical in construction and have a bell and spigot for quick coupling to the pipe. They are submersible and can pump water from practically any source where there is at least 18 inches of water over the suction end to prevent whirlpooling and cavitation. These pumps are generally 40 to 60 hp, 1,500 gpm at 120 foot head, 440 volt, 3 wire, 3 phase, 60 cycle, and can be powered by any generator of sufficient capacity. In addition, there is a lightweight trailer mounted generator equipped to carry one of these pumps and two lengths of flexible suction hose. This hose is for the preliminary connection between the Ames pipe and the submerged pump to allow for the initial surge and fishtailing of the pump when first put into operation. To complete this system there is various accessory equipment for 90° turns and manifolds supplying multiple hose connections, or for connections between emergency systems and conventional pumpers. In some situations it may be physically impossible to utilize the Ames pipe as described above. An alternate method may then be employed to supply water quickly to an

inaccessible area. Helicopters can lower the submersible pumps into the water source. Attached to the pumps are 8-inch lightweight rubber hoses which are fabricated in 500 foot lengths and arranged in flaking boxes that play out when lifted by the aircraft. In this manner any number of lengths of hose can be employed, depending upon the distance from the source of water supply to the fire. When the two techniques are combined there is almost an unlimited capability; and when the combination of techniques is employed in conjunction with conventional firefighting equipment, effective firefighting is possible in almost all situations.

*c. Protective Clothing.*

- (1) *Firefighting suit.* An expendable aluminized suit for protection of personnel has great application in mass firefighting. It can be stored in quantities for use in anticipated mass fires where large numbers of personnel are required for close firefighting. The suit is worn over the normal clothing.
- (2) *Protective masks.* Two types of protective masks are worn by firefighters. One is for the purification of air when there is enough oxygen in the atmosphere to support life (at least 16 percent). The second is worn when there is not enough oxygen to support life or when the atmosphere contains a high concentration of toxic gas or toxic liquid and solid particles, such as is probably the case inside a burning building.
- (3) *Fireman's hood.* When close range firefighting is required there is available a fireman's hood that has a fiberglass fabric outer shield, a neoprene coated fiberglass fabric inner liner, a wool knit liner, and a plexiglas visual face insert.

## **45. Passage Procedures**

Routes of communication blocked by mass fires in urban or rural areas must be bypassed if possible. If not possible, continuous reconnaissance must be made to insure that routes are opened as soon as possible after the fire has burned out sufficiently to permit passage. The rubble and debris left as a result of mass fires are cleared, if necessary, in the same manner as described in chapter 3.

## CHAPTER 5

### CRATERS

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#### 46. Nature of Obstacle

The obstacle created by cratering is essentially a roadblock which, if created on routes of communication that preclude bypassing, requires considerable engineer effort to reduce. When a nuclear burst occurs under, on, or close to the surface of the earth, the resulting nuclear crater becomes an integral part of any obstacle produced by the explosion. In many cases the crater may be the primary desired effect.

#### 47. Formation

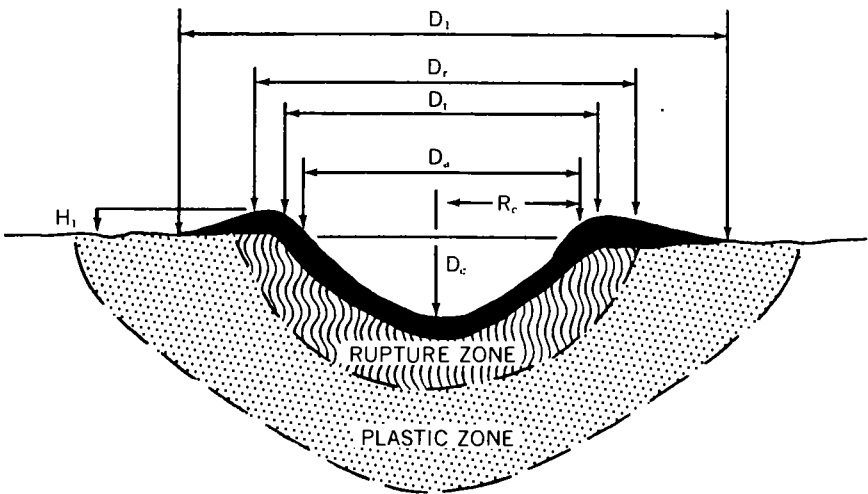
A large quantity of material (soil and rock) is vaporized by the extremely high temperatures of the fire ball. This vaporized material is sucked by the ascending air currents accompanying the rising fireball and eventually condenses in the characteristic mushroom cloud. In addition, the pressure produced by the rapid expansion of the hot gas bubble displaces material by pushing, throwing, and scouring. Because of the outward motion, very little of this displaced material falls back into the crater. A considerable amount, however, is deposited around the edges, forming an irregular and rough "lip."

#### 48. Factors Affecting Size of Crater

Figure 27 illustrates, schematically, an idealized crater. There are many factors, however, contributing to the exact conditions that can be expected. The depth of burst, the yield of the weapon, the geological characteristics of the earth, the character and moisture content of the rocks and soils, and the absence or presence of a water table all determine the final characteristics of the crater and the problems encountered in its passage.

a. *Depth of Burst.* The deeper the burst, the deeper the crater and the greater the grade of the slopes. As the depth of burst decreases the depth of the crater decreases, the diameter increases, and the grade of the slopes decreases.

b. *Yield.* The yield of the weapon determines the dimensions of the crater. Curves showing the variations in diameters and depths of the craters formed by varying yields from a contact surface burst in dry soil



- $D_l$     EQUALS THE DIAMETER OF LIP
- $D_r$     EQUALS THE DIAMETER OF RUPTURE ZONE
- $D_t$     EQUALS THE DIAMETER OF TRUE CRATER
- $D_a$     EQUALS THE DIAMETER OF "APPARENT" CRATER
- $H_l$     EQUALS THE HEIGHT OF LIP
- $R_c$     EQUALS THE RADIUS OF "APPARENT" CRATER
- $D_c$     EQUALS THE DEPTH OF "APPARENT" CRATER

*Figure 27. Idealized crater.*

## NOTE:

The curves give the values of apparent crater diameter and depth as a function of weapon yield for a contact surface burst in dry soil. Average values of soil factors to be used as multipliers for estimating crater dimensions in other types of soil are as follows:

	diameter	depth
Hard rock (granite or sandstone).....	0.8	0.8
Saturated soil.....	1.7	0.7

## EXAMPLE:

Given: A 20 KT contact burst over a sandy loam soil where the water table is within a few feet of the surface.

Find: the crater dimensions.

Solution: From the curves the crater diameter and depth in dry soil are 340 feet and 53 feet respectively. By applying the soil factors listed above for saturated soil, the estimated (approximate) crater dimensions for a 20 KT surface burst over saturated soil are as follows:

Apparent crater diameter ( $D_a$ ) =  $340 \times 1.7 = 580$  ft.  
 Apparent crater depth ( $D_c$ ) =  $53 \times 0.7 = 37$  ft.  
 Diameter of rupture zone =  $1.5 (D_a) = 1.5 \times 580 = 870$  ft.  
 Height of lip =  $0.25 (D_c) = 0.25 \times 37 = 9$  ft.

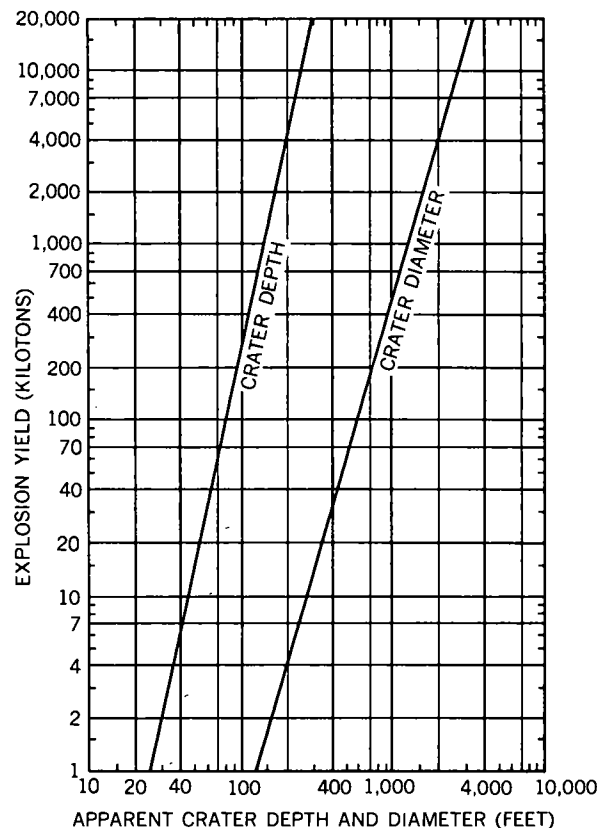


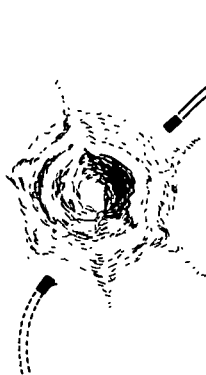
Figure 28. Crater depths and diameters for contact surface bursts in dry soil.



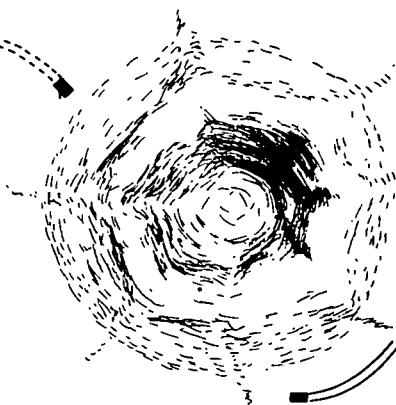
1 KT (SIDE VIEW)



10 KT (SIDE VIEW)



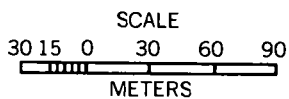
1 KT (TOP VIEW)



10 KT (TOP VIEW)



100 KT (SIDE VIEW)



*Figure 29. Schematically portrayed craters from varying yield surface bursts.*

appear in figure 28. Figure 29 shows schematically craters formed from varying yield surface bursts.

*c. Rock and Soil Characteristics.* As can be seen from the correction factors for varying soil types in figure 28, crater dimensions vary as the soil conditions vary. Exact data is available in TM 23-200 and FM 101-31. Generally speaking, however, in rock, such as granite or hard sandstone, the dimensions are less than in dry soil.

*d. Water Factor.* In soil saturated with water the diameter and initial depth are greater than in dry soil. (The final depth of a crater in wet soil is less, due to the slumping back of wet materials and the seepage of water carrying loose soil.) If a high water table is involved the crater will fill the water to the level of the table. In coastal areas, or on islands, seawalls may be destroyed and the sea water may be expected to rapidly fill the entire crater.

## **49. Obstacle Characteristics**

*a. Radioactivity.* Initially, a nuclear crater is highly radioactive in its immediate vicinity—3,000 rad or more per hour at 1 hour after burst. This radioactivity extends to greater soil depths in and around the crater than it does in areas subject to radioactive fallout only. This is an important factor if decontamination operations are contemplated in order to hasten passage, since greater amounts of contaminated material must be removed to achieve the desired attenuation. In addition to the immediate radiation area, fallout will occur in the surrounding area, the extent and direction depending on the yield of the weapon and the wind direction. This makes the crater and its surrounding area an obstacle to unprotected personnel. Even a 1 KT weapon denies the area of the crater to exposed personnel for days after the burst. Land reclamation by decontamination of the crater lip area will hasten the start of passage operations, but, entry time, which is based on allowable dose rates, is a command decision.

*b. Condition of the Soil.* In the absence of a high water table, the soil in and around the crater is finely pulverized. The presence of water will result in muddy and sloppy conditions, depending on the amount of water. This soil condition will not normally deter tracked vehicles, but wheeled vehicles will be impeded until engineering effort has made an area passable. It has been determined that Corps of Engineer heavy equipment can operate satisfactorily in this type material.

*c. Lip.* The crater lip is a physical obstacle to wheeled vehicles. Tracked vehicles may be able to negotiate portions under favorable soil conditions prior to any engineer effort.

*d. Slopes.* The grade of the slopes of a nuclear crater depends on the depth of burst and the weapon yield. It is estimated, for a contact surface burst, that a 1 KT will produce an average slope of 30 percent (steeper at the rim and flattening out down toward the center). As the



yield increases this slope average decreases. As the depth of burst increases the slope increases.

## **50. Passage Procedures**

Passage through the crater itself should not be attempted unless there is no alternative and unless such passage is the only way to accomplish the mission. Normally a temporary hasty route can be created around the rim under favorable soil conditions. Assuming that passage is necessary and that the dose rate is at a permissible level, either through natural decay, land reclamation procedures or the use of shielded equipment and protective devices for personnel, suggested methods are given below.

a. Tracked earthmoving equipment, performing normal earth-moving operations, level the lip area and create a maneuverable work area. If the soil is very dry and highly pulverized, dust palliatives should be used often. Pressured water sprinkling trucks have been used to advantage. The steeper grade at the rim of the crater is then cut to allow passage into the crater. Under favorable soil conditions and after a satisfactory grade has been achieved at the rim, tracked vehicles can negotiate the crater floor and slopes with little difficulty.

b. When the initial breakthrough has been made, equipment works from both sides of the crater, increasing the rate of operation. Hasty expedient roads are built down the slopes and across the floor (TM 5-337). If time permits and material is available the route is improved by building plank or corduroy roads. Metal track expedients, as discussed in TM 5-337, may be used effectively if soil conditions permit and if engineering efforts have made the rim passable. If time does not permit or if materials are not available, heavy equipment and winches or block and tackle equipment could aid wheeled vehicles in their passage through the crater if they experience difficulty in climbing the slopes. Foot troops do not have difficulty in passing, except in climbing the far slope where it might be necessary to employ haul ropes.

c. In water bearing soil, suitable fill material may be required. In this case the lip material might be moved into place with little effort. Use of metal track in similar wet and boggy soil with little bearing is described in TM 5-337. In the presence of a high water table or if surface water has partially filled the crater, passage is impractical until it is possible for unshielded personnel to perform extensive engineering work.

d. When dimensions of the crater and field conditions permit, a Bailey bridge could be used advantageously to gap the crater.

## **CHAPTER 6**

### **NATURAL OBSTACLES**

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#### **51. Introduction**

A natural obstacle is any terrain feature that stops, delays, or diverts movement of personnel or vehicles. Examples of such obstacles of interest to the military are: swamps, mud, snow, sand, short gaps, inland water barriers, and steep slopes. See FM 30-10 for a detailed description of these terrain features and FM 31-10 for a discussion of their military significance.

#### **52. Swamps**

a. Swamps are areas of wet, spongy land, sometimes covered by shallow water, characterized by unstable soil conditions, and varying in size from less than one acre to hundreds of square miles. Swamps are found at all elevations and in all latitudes, and are variously named—bog, marsh, morass, quagmire, fen, or muskeg. It is dangerous to generalize about swamps as there are such variations in their formation. Detailed descriptions of swampy lands in general are found in FM 30-10 and TM 5-260. Jungle swamps are covered in FM 31-30, and the swampy areas peculiar to arctic regions (muskeg) are discussed in TM 5-560, FM 31-71, and FM 31-70.

b. Because it is generally conceded to be impractical to attempt the passage of large and continuous swamps, they are considered to be effective military obstacles and are seldom defended. This fact gives tremendous tactical and strategic value to a successful and unexpected swamp crossing.

c. When a swamp is to be crossed the crossing should take place at the narrowest point requiring the least ground reinforcement. Many swampy stretches can be made comparatively trafficable within a relatively short time if they are not torn up in advance by attempted forced passage before the required engineer work is completed. If passage is forced, restoration of a passable route is extremely difficult. Engineers and their equipment have trouble moving through the stalled and mired vehicles. The entire route is often completely closed. This results in serious traffic tie-ups and dangerous bunching of vehicles, lasting many hours and possibly days, and presenting a tempting nuclear target.

d. There are numerous expediciencies that can be employed for clearing a passage through a swamp. The choice depends upon the type swamp and its peculiar condition.

- (1) Corduroy roads will often suffice to pass certain types of small swamps. They require constant maintenance, however, and through continuous use such roads may gradually sink and require several layers of corduroy or similar material before the passage is completed. Corduroy roads slow movement. Wheeled vehicular travel on this type of road is strenuous; equipment, especially sensitive instruments, suffer from the incessant pounding. Techniques and procedures for building and maintaining corduroy roads are found in TM 5-337.
- (2) Variations of corduroy construction that have been used successfully in passing swamps include plank roads, fascine corduroy, plank tread, log-plank and log-tread roads, army track, chespaling mat, bamboo mats, and metal landing mats; or expedient temporary surface using any available material such as sand bags, wet sand, treadway decking from floating bridges, rocks, rubble, brick, canvas, burlap, trees, and brush. These all are described in detail in TM 5-337.
- (3) In swamps having shallow water and a relatively stable base it may be feasible to construct rock filled causeways, providing the fill material is available. See TM 5-260 for details of construction.
- (4) In swamps with a water depth of three feet or more and light vegetation at the surface, Navy pontoon cubes present a practical solution. See TM 5-250 and TM 5-360 for employment and details of construction. Wherever swamps are too deep, bridges must be used. Even in deep swamps and marshes there often will exist small islands or fingers and hummocks of firm terrain to which bridging can be anchored. TM 5-260 contains information pertaining to the types of bridges that have proved successful in crossing certain swampy areas.
- (5) If a swamp area is narrow enough its crossing can be facilitated by using the AVLB (Armored Vehicle Launched Bridge) (par. 56b).

### **53. Mud**

a. Mud presents an obstacle to movement similar to that presented by a swamp. It differs in two respects, however, which make it less of a problem: it can occur without the additional obstructions characteristic of a swamp; and it is a relatively temporary condition, being associated usually with the local rainy season. Self propelled wheeled vehicles with standard tires have very low mud mobility unless supplementary traction and flotation devices are used. High traction tire chains and low tire inflation pressures will help. Track laying vehicles

are superior to wheeled vehicles in traversing muddy areas, and their mobility can be improved still further by the addition of extended end connectors, grousers, and other such devices. Amphibian vehicles with their low ground pressure tires have a relatively high degree of mud mobility. Winches, tramways, and cableways can be used to haul materiel and mired light vehicles across muddy terrain. Their use, however, is limited to relatively narrow muddy areas, within easy range of the cable lengths (TM 5-270).

b. When the terrain is beyond the mud mobility of vehicles or when the muddy area has become ditched, rutted, and impassable, landing mats are an excellent expedient (TM 5-337). Material such as grasses and logs or brush should be used if available. Placed between the mud and the landing mats, it prevents mud from seeping too rapidly through the mats. Satisfactory roads following the same techniques suggested for crossing swamps can be built in highly plastic mud using many types of portable materials: corrugated metal, aluminum or steel treadways, plywood treadways, portable trackway, wood plank, and wire mesh. If nothing else is available, ordinary small shrubs, grasses, reeds, and other such vegetation provides a surprising degree of traction, even in deep mud.

## **54. Snow**

a. Heavy snowfalls affect the mobility of ground troops whether they are moving cross-country or traveling on hard surface roads. Wheeled vehicles cannot travel satisfactorily when the depth of uncompacted snow exceeds 12 inches. Most tracked vehicles are stopped by a depth of 25 to 30 inches. Snow on ice covered slopes affects the ability of vehicles to traverse snow-covered surfaces, and snow of sufficient depth in such terrain can stop all mechanized movement except that of specialized oversnow vehicles, which can normally negotiate all snow except the deepest loose drifts.

b. The basic properties of snow; its behavior under various conditions; and its effect on military operations are fully covered in FM 31-70 and TM 5-560.

c. For details on the procedures and techniques in the clearance and compaction of snow, in order to effect passage, see TM 5-506.

## **55. Sand**

a. *Beach Sand.* The sandy terrain peculiar to the foreshore of a beach area will present an obstacle to wheeled vehicles, especially those with dual tires. Tracked vehicles are relatively unaffected by this type of terrain. Landing mats and treadways can be used to advantage in moving wheeled vehicles until they reach the firm coastal terrain. See FM 31-25 for driving and recovery methods employed in sandy conditions.

b. *Sand Bars.* Sand bars are sometimes encountered at shallow depths as barriers to construction of floating bridges in initial river crossing operations, or adjacent to beaches in amphibious landing operations. They are easily breached by the CEV or waterproofed bulldozers; in the absence of this type of equipment, it is often possible to clear a passage with shovels and other available pioneer tools. Explosives are used to advantage in breaching sand bars; the details of this means are covered in FM 5-25.

c. *Desert Sands.* The nature of desert terrain makes vehicular movement relatively simple. There may be local movement problems but in most cases these present no major obstacle to military operations. The minor obstacles associated with sandy deserts include wadies, sand dunes, and sand hillocks. A description of these obstacles and methods for breaching them are found in FM 31-25.

## **56. Narrow Gaps**

a. Narrow gaps may consist of narrow streams, antitank ditches, canals, ravines, gullies, washouts, gorges, arroyos, wadies, railroad cuts, and other similar terrain features. These gaps are obstacles to wheeled vehicles, and when they exceed 5 meters in width are effective obstacles for tracked vehicular movement.

b. The AVLB is a most effective method for crossing such gaps and can be used for any width up to 18 meters. See TM 5-216 for a description of the operational characteristics of the AVLB and FM 5-135 for its employment.

c. Components of the light tactical raft set, M4T6, and the class 60 bridge set can be used to provide fixed bridging capable of crossing vehicles, troops, and equipment over narrow gaps. See TM 5-210 for types and classes.

d. A CEV can provide a passage across narrow gaps quickly and simply by filling the gap, using standard bulldozing techniques. An approach ramp may be dozed through the side of the larger gaps using the displaced material as an embankment across the bottom.

e. Depending upon soil or revetment conditions, handtools may be used to break down the sides of the obstacles, or to provide material for filling it. Work with handtools is generally necessary to make passable any crossing provided by explosive means (FM 5-25).

## **57. Inland Water Barriers**

a. Rivers are considered to be major military obstacles and their crossings are covered in detail in FM 31-60.

b. Very large rivers (over 305 meters in width), estuaries, large bays, lakes, and inland seas present specialized crossing problems which have much in common with shore-to-shore amphibious operations. See FM 31-12 for the passage of such water barriers.

c. See TM 5-210 for techniques and procedures in crossing tidal estuaries and inundated areas.

## 58. Steep Slopes and Escarpments

*a. Steep Slopes.* The degree of steepness required to stop vehicles varies with the type of vehicles involved. Both wheeled and tracked vehicles are able to ascend and descend slopes as steep as 60 percent, and negotiate sharp turns, providing soil conditions are normal. When the ground is slippery with mud, snow, or ice, they are hampered. This disadvantage may be partially overcome by using grousers. When there is sufficient traction, prime movers with loads in tow can be driven down or up most grades. But, when the ground becomes too slippery and the grade steep, all vehicles must be lowered or raised by block and tackle or winches (see TM's 5-725 and 5-270 for techniques and procedures). For the details of operations in steep and hilly terrain see FM 31-72.

*b. Escarpments.* Escarpments over 2 meters in height are formidable obstacles to both personnel and vehicles. They may be bridged by earth ramps pushed up by dozer blades, or they may be ramped with steel treadways. If the situation warrants it and if the bank is not too high, the AVLB may be used to advantage. If the escarpment is of soft material, it often can be reduced by dozer blades, and a passage forced. If the escarpment is of hard rock, explosives and demolitions or direct artillery fire are required to shatter it, with bulldozers then creating a crossing for vehicles. See FM 5-25 for details on the use of explosives and demolitions in breaching hard rock escarpments.

## CHAPTER 7

### ARTIFICIAL OBSTACLES

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#### 59. Introduction

Artificial obstacles are those obstacles built by man for the express purpose of stopping, impeding, or canalizing enemy military movement. They include works of demolition and construction, such as demolished bridges, abatis, wire entanglements, and steel and concrete structures. See FM 5-15 for a detailed description of these obstacles and FM 31-10 for a discussion of their military significance.

#### 60. Log and Wood Obstacles

a. Log obstacles may be destroyed and pushed aside even though they consist of large enmeshed tree trunks wired together and supported by vertical steel beams. The CEV, tank dozer, and standard bulldozer all are suitable for the purpose.

b. An abatis can be attacked successfully by a CEV in either of two ways: the dozer may be used to destroy the abatis by direct application of power; or the power of the vehicles may be applied to cable which is attached to the abatis to pull it out. By either method the objective is to destroy the obstacle along a lane sufficiently wide for passage of vehicles. The bulldozer, and tank dozer, may be used in the same manner as the CEV.

#### 61. Barbed Wire

a. *Means for Surmounting.* Using canvas mats, chicken wire, planks, or any other suitable materials, foot troops can surmount barbed wire obstacles if antipersonnel mines are not present. Such mats are used as follows:

- (1) Chicken wire or canvas is wound around an open rectangular frame (approximately  $1\frac{1}{2}$  meters long and  $1\frac{1}{4}$  meters wide) made of 1-x 3-inch lumber. Two men carry the loaded frame to the crossing point. One man then places the material over the wire by flopping the frame end over end and walking on the material.
- (2) To place hardware cloth, two lengths are wired together with a  $1\frac{1}{2}$  mm overlap, giving a total width of  $1\frac{1}{2}$  meters. When used

to cross barbed wire it is rolled up to a pole so that the ends of the pole extend  $1\frac{1}{2}$  mm beyond the mesh on both ends. Both men stand on the free end of the roll to hold it down and toss the roll over the entanglement. Chicken wire or canvas also may be laid in this way.

- (3) A cyclone fence is heavier than chicken wire or canvas and three men are required to place a 12-meter roll. A 2-meter width is rolled on a pole and placed in the same manner as is the hardware cloth.
- (4) Galvanized mesh is placed in the same manner as the cyclone fence, but since it is comparatively light in weight, one man can easily carry a 9-meter roll. It is more elastic, and, therefore, more difficult to unroll and throw.
- (5) Issue wire cutters may be used to cut a lane through a deep entanglement, but this takes time. One man can cut a 1-meter lane through a 12-meter fence made of concertinas and high wire in approximately 4 minutes under ideal conditions. Wire cutters should be carried when placing the chicken wire or the canvas rolls to cut occasional high wires.

*b. Removal by Vehicles.*

- (1) In the latter phases of a breaching operation, not under fire, entire sections of wire entanglements can be removed with a rope or cable attached to tanks or trucks, or by vehicular winch cables.
- (2) Sections of wire also may be removed by dragging a length of wire attached to two tanks. In emergencies, tanks can be used to crush wire entanglements, however, this is not recommended as the wire is very likely to become snarled in the drive sprockets and tracks.
- (3) When using a  $2\frac{1}{2}$ -ton truck with winch, the truck should start at the end of the entanglement facing down-fence. The winch cable is unwound and placed over the center of the fence along the section to be removed. The chain on the end of the cable is fastened around the middle of a log about 6 meters long which is placed on the ground at the far end of the fence section and perpendicular to it. The truck then winds in the cable pulling all the pickets and wire in one mass. Using this method, a truck can pull out an entanglement 12 meters deep and  $30\frac{1}{2}$  meters long in beach sand at the rate of 6 linear meters per minute. When removing wire entanglements whose pickets are firmly embedded in the ground, it may be necessary to pass the cable under the wires of the last 9 meters of the fence before attaching the chain to the log. This will prevent the log from riding over the firmly driven pickets. Such a fence can be removed at about  $1\frac{1}{2}$  linear meters per minute. Shallow entanglements can be cleared readily by driving the truck close to the fence and facing



it at right angles. The winch cable is placed under all wires of the fence, brought back over the fence, hooked to the truck, and wound in.

- (4) A CEV or a bulldozer or tank bulldozer can clear wire rapidly by pushing it out of place with the blade. The vehicles should start work parallel to a deep fence, gradually turning perpendicular to it, until the wire is bunched in the center, reducing the depth to about 4 meters. The wire can then be pushed into a single pile. To prevent the wire from becoming entangled in the tracks and sprockets of the vehicle, the operator should not pile up too much wire at one pass. It is best to place a man on each side of the dozer to immediately remove any wire caught in the tracks. In beach sand, against wooden post fences driven 50 cm into the ground, bulldozers can clear 12 meter deep entanglements at the rate of 2 linear meters of fence per minute. Steel angle-iron pickets driven into hard ground slows up removal operations.
- (5) A combat engineer vehicle, by mechanical action alone, provides the speediest means of removal for sizeable quantities of barbed wire in areas where armor protection is required. If the situation permits, the winch on the CEV, which is much stronger than that of a 2½-ton truck can be used to pull out wire. With this method there is no danger of the wire fouling the tracks of the vehicle. The boom may also be used to remove large bunches of wire or other objects that are not readily pushed or dragged.

## **62. Small Concrete and Rock Obstacles**

The CEV is capable of pushing aside most small concrete and rock obstacles in order to create lanes for the passage of troops and vehicles. The bulldozer and tank dozer have similar capabilities. Obstacles of this type which are too heavy to be pushed aside can be bridged over by earth pushed into position by the dozer blade.

## **63. Steel Obstacles**

Steel rails and similar obstacles may be pushed aside and broken by the weight and impact of the CEV. Bulldozers and tank dozers can also push aside tetrahedrons and hedgehogs and can ramp over curved-rail obstacles that cannot be moved. In the latter phases of a breaching operation, individual steel obstacles can be pulled aside with rope or cable attached to tanks or trucks, or with the winch cable of vehicles, as well as cut into easily-removed pieces by acetylene torches.

## **64. Walls**

Small masonry or concrete walls may be shattered and crumbled by the dozer blade on the CEV. Thick walls of low or medium height may

be bridged with earth ramps pushed up by the dozer blades on the CEV or bulldozer. In addition walls can be ramped with steel treadways. Personnel can cross walls by scaling, using folding ladders, or by ramping with hand carried stiles and ramps.

## **65. Demolished Bridges**

Demolished bridges rarely constitute an obstacle to an offensive operation except so far as they impede construction of a new bridge at the same site. If the degree of damage to the bridge is slight, it is usually quicker and cheaper in labor and in materials to remove the damaged portions of the old bridge and use the same approaches, abutments, and substructure. If, on the other hand, the damage to the bridge is great, it will be quicker and less consuming of labor and materials to build a completely new bridge. When it is decided to use a demolished bridge site in the construction of a new one, CEV's and bulldozers are used to remove debris, either by pushing it aside with the dozer blade, or by towing it aside with cable. For emergency repair and passage of a demolished bridge see TM 5-260. See TM 5-216 for the employment of the AVLB to expedite passage over a weakened bridge.

## **66. Fortified Positions**

Mechanical means are usually ineffective for the reduction of permanent fortifications on any scale. A CEV and tank bulldozer are effective, however, for the removal of accessory obstacles, such as dragons teeth. This equipment is used primarily in clearing away the rubble and debris resulting from explosive demolition of permanent fortifications (FM 5-25). Bulldozers and CEV's can be used to block embrasures and entrances of captured fortifications by bulldozing earth into these entrances as a substitute for demolishing the fortification itself.

## **67. Antiairborne Obstacles**

In airborne operations extensive obstacles placed on the landing fields or landing strips must be attacked first by demolition parties, dropped or landed early in the operations (FM 5-25). Mechanical equipment can be employed in the removal of such obstacles only after it is possible to land such equipment and place it in operation. The speed required to insure success in airborne operations, and the greater capabilities for removal possessed by mechanical equipment in comparison to demolition parties, make it imperative that at least a few items of mechanical equipment, such as bulldozers be landed at the earliest possible moment in order to clear landing fields for the rapid reinforcement of the already landed combat elements. Full exploitation must be made of all locally available sources.

## **68. Underwater and Beach Obstacles**

Equipment for and methods of passing obstacles on dry land, described elsewhere in this chapter, generally apply also to beach obstacles above the water's edge. Equipment such as a CEV or tank bulldozer can be used against obstacles in shallow water. Underwater obstacles can usually be passed by landing the assaulting foot troops on the beach in rubber boats. These boats can pass over most underwater obstacles, thus providing local protection for clearing parties. Obstacles then can be cleared without subjecting the clearing personnel to fire from shore.

## **69. Floating Obstacles**

These types of obstacles may be attacked by destroying the anchorage of the boom, cable, or net with a CEV or bulldozer. It is generally preferable to sever one anchorage only, allowing the obstacle to float or be hauled downstream along the opposite bank where it will be out of the way. If the obstacle may be removed merely by sinking in place, the flotation elements can be punctured with handtools by a working party in a utility boat.

## GLOSSARY

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*Air burst*—The explosion of a nuclear weapon at such a height that the expanding ball of fire does not touch the earth's surface when the luminosity is at a maximum (in the second pulse). A *typical air burst* is one for which the height of burst is such as may be expected to cause maximum blast destruction in an average city.

*Backfire*—A controlled fire set in front of an advancing fire front to burn and meet the advancing fire.

*Ball of fire (or fireball)*—The luminous sphere of hot gases which forms a few millionths of a second after a nuclear (or atomic) explosion and immediately starts to expand and cool. The exterior of the ball of fire is initially sharply defined by the luminous shock front (in air) and later by the limits of the hot gases themselves.

*Blast wave*—A pressure pulse of air, accompanied by winds, propagated continuously from an explosion. (See *Shock wave*.)

*Burning out*—The controlled burning of an area in order to remove fuel for an advancing fire.

*Coniferous forest*—Forest consisting of trees of an order (pinales) of trees and shrubs, mostly evergreens, including those of the pine family (Pinaceae), bearing true cones, and those of the yew family (Taxaceae), having a berrylike fruit.

*Contact surface burst*—(See *Surface burst*.)

*Contamination*—The deposit of radioactive material on the surfaces of structures, areas, objects, or personnel, following a nuclear (or atomic) explosion. This material generally consists of fallout in which fission products and other bomb debris have become incorporated with particles of dirt, etc. Contamination can also arrive from the radioactivity induced in certain substances by the action of bomb neutrons. (See *Decontamination*, *Fallout*, *Induced radioactivity*.)

*Control line*—This is a line constructed in front of a fire front. It utilizes natural points such as rivers, and is tied together by these points. From the control line back firing starts.

*Decay (or radioactive decay)*—The decrease in activity of any radioactive material with the passage of time, due to the spontaneous emission from the atomic nuclei of either alpha or beta particles, sometimes accompanied by gamma radiation.

*Deciduous forest*—Forest consisting of trees whose leaves fall off at maturity or during certain seasons.

*Decontamination*—The reduction or removal of contaminating radioactive material from a structure, area, object, or person. Decontamination may be accomplished by (1) treating the surface so as to remove or decrease the contamination; (2) letting the material stand so that the radioactivity is decreased as a result of natural decay; and (3) covering the contamination so as to attenuate the radiation emitted. Radioactive material removed in process (1) must be disposed of by burial on land or at sea, or in other suitable ways.

*Dose*—A (total or accumulated) quantity of ionizing (or nuclear) radiation. The term dose is often used in the sense of the *exposure dose*, expressed in roentgens, which is a measure of the total amount of ionization that the quantity of radiation could produce in air. This should be distinguished from the *absorbed dose*, given in rems or rads, which represents the energy absorbed from the radiation per gram of specified body tissue.

- Dose rate**—As a general rule, the amount of ionizing (or nuclear) radiation to which an individual would be exposed per unit of time. It is usually expressed as roentgens per hour or in multiples or submultiples of these units such as milliroentgens per hour. The dose rate is commonly used to indicate the level of radioactivity in a contaminated area.
- Fallout**—The process or phenomenon of the fall back to the earth's surface of particles contaminated with radioactive material from the atomic cloud. The term is also applied in a collective sense to the contaminated particulate matter itself.
- Fireball**—(See *Ball of fire*.)
- Firestorm**—Stationary mass fire, generally in built-up urban areas, generating strong, inrushing winds from all sides, which keep the fires from spreading while adding fresh oxygen to increase their intensity.
- Ground zero**—The point on the surface of land or water vertically below or above the center of a burst of a nuclear weapon; frequently abbreviated to GZ. For a burst over or under water, the term *surface zero* should preferably be used.
- Height of burst**—The height above the earth's surface at which a bomb is detonated in the air. The *optimum height of burst* for a particular target (or area) is that at which it is estimated a weapon of a specified energy yield will produce a certain desired effect over the maximum possible area.
- Induced radioactivity**—Radioactivity produced in certain materials as a result of nuclear reaction, particularly the capture of neutrons, which are accompanied by the formation of unstable (radioactive) nuclei. The activity induced by neutrons from a nuclear explosion in materials containing the elements sodium, manganese, silicon, or aluminum may be significant.
- Maximum permissible exposure (or mpe)**—The total amount of radiation exposure which it is believed a normal person may receive day-by-day without any harmful effects becoming evident during his lifetime.
- Rad**—A unit of absorbed dose of radiation; it represents the absorption of 100 ergs of nuclear radiation per gram of the absorbing material or tissue.
- Residual nuclear radiation**—Nuclear radiation, chiefly beta particles and gamma rays, which persists for sometime following a nuclear explosion. The radiation is emitted mainly by the fission products and other bomb residues in the fallout, and to some extent by earth and water constituents, and other materials, in which radioactivity has been induced by the capture of neutrons.
- Residual number**—This is the decimal fraction of the potential dose which would be received if the countermeasure is used. The potential dose multiplied by the residual number of the countermeasure gives the dose to personnel when the countermeasure is used.
- Rome blade**—An angle dozer blade especially made for tree clearance. It features a sharp "stinger" and a curved sharpened leading edge.
- Shock wave**—A continuously propagated pressure pulse (or wave) in the surrounding medium which may be air, water, or earth, initiated by the expansion of the hot gases produced in an explosion. A shock wave in air is generally referred to as a blast wave, because it is similar to (and is accompanied by) strong, but transient, winds. The duration of a shock (or blast) wave is distinguished by two phases. First there is the *positive (or compression) phase* during which the pressure rises very sharply to a value that is higher than ambient and then decreases rapidly to the ambient pressure. The duration of the positive phase increases and the maximum (peak) pressure decreases with increasing distance from an explosion of given energy yield. In the second phase, the *negative (or suction) phase*, the pressure falls below ambient and then returns to the ambient value. The duration of the negative phase is approximately constant throughout the blast wave history and may be several times the duration of the positive phase. Deviations from the ambient pressure during the negative phase are never large and they decrease with increasing distance from the explosion.

*Subsurface burst*—(See *Underground burst*.)

*Suction phase*—(See *Shock wave*.)

*Surface burst*—The explosion of a nuclear weapon at the surface of the land or water or at a height above the surface less than the radius of the fireball at maximum luminosity (in the second thermal pulse). An explosion in which the bomb is detonated actually on the surface is called a *contact surface burst* or a *true surface burst*.

*Thermal radiation*—Electromagnetic radiation emitted from the ball of fire as a consequence of its very high temperature; it consists essentially of ultraviolet, visible, and infrared radiations. In the early stages, when the temperature of the fireball is extremely high, the ultraviolet radiation predominates; in the second pulse, the temperatures are lower and most of the thermal radiation lies in the visible and infrared regions of the spectrum.

*Underground burst*—The explosion of a nuclear weapon with its center beneath the surface of the ground.

*Yield*—The total effective energy released in a nuclear explosion. It is usually expressed in terms of the equivalent tonnage of TNT required to produce the same energy release in an explosion. The total energy yield is manifested as nuclear radiation, thermal radiation, and shock (and blast) energy, the actual distribution being dependent upon the medium in which the explosion occurs, primarily, and also upon the type of weapon and the time after detonation.

## APPENDIX REFERENCES

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DA Pam 39-1	Nuclear Weapons Employment.
39-3	The Effects of Nuclear Weapons.
108-1	Index of Motion Pictures, Film Strips, Slides, and Phono-Recordings.
310-series	Indexes Pertaining to Administration, Training, Maintenance, and Supply.
750-1	Preventive Maintenance Guide for Commanders.

### 2. Field Manuals

FM 3-5	Chemical, Biological, and Radiological Operations.
5-1	Engineer Troop Organizations and Operations.
5-15	Field Fortifications.
5-20	Camouflage, Basic Principles and Field Camouflage.
5-25	Explosives and Demolitions.
5-26	Employment of Atomic Demolition Munition (ADM) (U).
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5-35	Engineer's Reference and Logistical Data.
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5-461	Engineer Handtools.
5-725	Rigging.
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## INDEX

	Paragraphs	Page
Abatis.....	60	77
Adobe construction.....	27b	33
Aerial photography.....	11, 15, 32b	18, 7, 39
Aerial radiological survey.....	23	30
Aerial reconnaissance.....	15, 23, 32b	18, 30, 39
Air burst.....	13	18
Aircraft, use of in firefighting.....	43e	63
Alternate routes.....	5b	4
Ames Pipe System.....	44	63
Amphibian vehicles.....	53	73
Antiairborne obstacles.....	67	80
Antitank ditches.....	56	75
Apartment buildings.....	27b	33
Armored vehicle launched bridge.....	56, 58, 65	75, 76, 80
Army track.....	52d	73
Arroyos.....	56	79
Artificial obstacles.....	59-69	77
Assignments, work.....	5c	4
AVLB. (See Armored vehicle launched bridge.)		
Bailey bridge for passage of craters.....	50	71
Bamboo mats.....	52d	73
Barbed wire.....	61	77
Bays.....	57	75
Beach obstacles.....	68	81
Blowdown:		
Clearance from air burst.....	13-19	18
Clearance from surface burst.....	20-25	29
Clearance rate formula.....	18	22
Frequency.....	9, 13	7, 18
In coniferous forests.....	11a	11
In deciduous forests.....	11b	11
Bog.....	52	72
Breaching.....	6c	6
Brick construction.....	27b	33
Bridges, demolished.....	65	80
Bridging in swamps.....	52d	73
Building combustibility.....	36c	42
Building density.....	36c	42
Building types.....	27	33
Built-up areas, rubble.....	26-33	33
Bypassing.....	6a	5

	Paragraphs	Page
Cableways .....	53	73
Camouflage discipline .....	5e	5
Canals .....	56	75
Canvas mats .....	61	77
Capabilities of personnel in contaminated areas .....	22, 23	29, 39
Capabilities of units:		
Blowdown .....	16	18
Contaminated areas .....	22, 33	29, 39
Rubble .....	29	35
Causeways, rock filled .....	52d	73
Changes, recommended .....	8	6
Chespalng mats .....	52d	73
Chicken wire .....	61	77
Cinder block construction .....	27b	33
Class 60 bridge set .....	56	75
Clearance estimate .....	19	24
Clearance rate formula in blowdown .....	18	22
Clearance rates:		
Blowdown .....	17, 18	19, 22
Contaminated areas .....	25, 33	32, 39
Rubble .....	30, 31	36, 37
Clothing, firefighting .....	44	63
Combustible buildings .....	36c	42
Commercial equipment .....	17	19
Computation for clearing rate in rubble .....	31	37
Concrete construction .....	27c, 28c	33, 35
Concrete obstacles .....	62	79
Conflagrations .....	35a	40
Coniferous forests, damage .....	11a	11
Contaminated areas:		
Blowdown clearance .....	23, 24	30, 32
Equipment capabilities (tables IV-VI) .....	33	39
Personnel capabilities .....	22	29
Rubble clearance .....	33	39
Controlled demolition .....	5e	5
Conventional firefighting equipment .....	44a	63
Corduroy roads .....	52d	73
Corrugated metal .....	53	73
Craters:		
Formation .....	47	66
Passage .....	50	71
Size .....	48	66
Critical fire potential .....	37, 41b	46, 57
Cross-country mobility .....	13	18
Cube, Navy pontoon .....	52d	73
Cuts, railroad .....	56	75
Cyclone fence .....	61	77
Damage distances in blowdown:		
Air burst .....	12	17
Surface burst .....	20	29
Damage levels:		
Coniferous forests .....	11a	11
Deciduous forests .....	11b	11

	Paragraphs	Page
Damage to buildings from blast:		
Frame construction.....	28a	33
Heavy masonry construction.....	28c	35
Light masonry construction.....	28b	34
Reinforced concrete construction.....	28c	35
Dangerous fire potential.....	37, 41c	46, 56
Deciduous forests, damage.....	11b	11
Defiles.....	4b	3
Demolition, controlled.....	5e	5
Density of buildings.....	36c	42
Developmental military equipment.....	17	19
Direct attack in firefighting.....	43b	61
Disregarding.....	6b	5
Dunes.....	55	74
Dust raised by earthmoving equipment.....	23	30
Emergency firefighting equipment.....	44b	64
Employment:		
Engineer combat battalion in blowdown clearance.....	16	18
Engineer platoon in blowdown clearance.....	16	18
Equipment in contaminated areas.....	23	30
Units.....	16	18
Equipment, firefighting:		
Conventional.....	44a	63
Emergency.....	44b	64
Equipment, shielded (tables IV-VI).....	21, 50	29, 71
Equipment assignments.....	5c	4
Equipment capabilities in contaminated areas (tables IV-VI).....	17, 21	19, 29
Equipment clearance rates in rubble.....	30	36
Equipment employment in contaminated areas.....	23	30
Escarments.....	58	76
Estuaries.....	57	75
Expedients roads.....	53	73
Expedients temporary surfaces.....	52d	73
Extinguishers, hand.....	44a	63
Factors in successful passage.....	5c	4
Fallout.....	49	70
Fascine courduroy.....	52d	73
Fen.....	52	72
Fire.....	34-45	40
Fire extinguisher, hand.....	44a	63
Fire potential.....	37, 40	46, 51
Fire spread.....	36	41
Fire trucks.....	44a	63
Firebreaks.....	5e, 36c, 42c	5, 42, 57
Firefighting equipment:		
Conventional.....	44a	63
Emergency.....	44b	64
Firefighting teams.....	41a	55
Firefighting techniques:		
Rural areas.....	43	61
Urban areas.....	42	56
Firestorms.....	35b	40

	Paragraphs	Page
Floating obstacles.....	69	81
Flotation devices.....	53	73
Forced passage.....	6b	5
Forests:		
Characteristics.....	10	7
Coniferous.....	11a	11
Damage.....	11	7
Deciduous.....	11b	11
Susceptability to fires.....	36d	46
Types.....	10, 11	7
Fortified positions.....	66	8
Frame construction.....	27a	33
Damage.....	28a	33
Fuel factors in rate of fire spread:		
Rural areas.....	36d	46
Urban areas.....	36c	42
Galvanized mesh.....	61	77
Gaps.....	56	75
Gorges.....	56	75
Ground reconnaissance.....	15	18
Gullies.....	56	75
Handtools.....	15	18
Hardware cloth.....	61	77
Heavy equipment.....	16	18
Heavy masonry construction, damage.....	27c, 28c	33, 35
Helicopters.....	16, 23, 25, 44b	18, 30, 32, 65
Hillocks.....	55	74
Hood, fireman's.....	44c(3)	65
Humidity as a weather factor in fire spread.....	36a	41
Indirect attack in firefighting.....	43c	62
Inland seas.....	57	75
Inland water barriers.....	57	75
Inundated areas.....	57	75
Labor assignments.....	5c	4
Lakes.....	57	75
Landing mats.....	52d, 53	73, 73
Lanes.....	7	6
Light damage level in deciduous forests.....	11b(3)	17
Light masonry construction.....	27b, 28b	33, 34
Light tactical raft set.....	56	75
Lip of crater.....	47, 49	66, 70
Log obstacles.....	60	77
Log plank roads.....	52d	73
Log tread roads.....	52d	73
Low fire potential.....	37, 41d	46, 56
M4T6.....	56	75
Marking lanes.....	7	6
Marsh.....	52	72
Masks, firefighting.....	44c	65

	Paragraphs	Page
Masonry construction:		
Damage.....	28b, 28c	34, 35
Heavy.....	27c	33
Light.....	27b	33
Mass fires.....	35	40
Metal landing mats.....	52d	73
Methods for passage.....	6	5
Moderate damage levels:		
Coniferous forests.....	11a(2)	11
Deciduous forests.....	11b(2)	11
Morass.....	52	72
Mud.....	53	73
Muskeg.....	52	72
Natural obstacles.....	51-58	72
Navy pontoon cubes.....	52d	73
Nuclear crater. (See Crater.)		
Office buildings.....	27b	33
Operator employment in contaminated areas.....	23	30
Parallel attack in firefighting.....	43c	62
Passage methods.....	6	5
Passage through crater.....	50	71
Photo aerial reconnaissance.....	•11, 15, 32b	7, 18, 39
Plank roads.....	52d	73
Plank treads.....	52d	73
Planning.....	5, 14	3, 18
Pontoon cubes, Navy.....	52d	73
Power tools.....	17	19
Precipitation as a weather factor in fire spread.....	36a	41
Preventive measures taken against fire.....	41, 42a	55, 56
Protective firefighting clothing.....	44c	65
Pumpers, trailer-mounted.....	44a	63
Quagmires.....	52	72
Radiation dosage.....	22	29
Radioactive nuclear crater. (See Crater.)		
Radioactivity in craters.....	49	70
Rain as a weather factor in fire spread.....	36a	41
Ravines.....	56	75
Recommended changes.....	8	6
Reconnaissance.....	5, 15, 23, 30, 31a, 32a, 42c, 44	3, 18, 30, 36, 37, 39, 57, 63
References.....	3, app.	2, 85
Reinforced concrete construction.....	27c	33
Damage.....	28c	35
Residual radiation.....	20, 33	29, 39
Rivers, large.....	57	75
Rock and soil characteristics affecting crater dimensions.....	48	66
Rock filled causeways.....	52d	73
Rock obstacles.....	62	79
Rome blade.....	17	19

	Paragraphs	Page
Rubble:		
Computation for clearing rate .....	31	37
Frequency .....	26	33
From fire .....	42b, 45	57, 65
Procedures and techniques for clearing .....	32	39
Rural fire fuels .....	36d	46
Sand .....	55	74
Seas, inland .....	57	75
Security at work sites .....	16	18
Severe damage in:		
Coniferous forest .....	11a(1)	11
Deciduous forest .....	11b(1)	11
Shielded equipment (tables IV-VI) .....	21, 50	29, 71
Shifts in contaminated areas .....	23	30
Shore-to-shore amphibious operations .....	57	75
Slopes .....	58	76
Snow .....	54	74
Snow as fire retardant .....	36a	41
Standard military equipment, clearance rates .....	17	19
Steel frame buildings, heavy .....	27c	33
Steel frame industrial buildings .....	27a	33
Steel obstacles .....	63	79
Steel structures, light .....	27a	33
Surface burst .....	33, 46	39, 66
Swamps .....	52	72
Tank dozer in clearing operations .....	22	29
Thatched huts .....	27a	33
Thermal radiation .....	38, 39	47
Tidal estuaries .....	57	75
Tools:		
Hand .....	17	19
Power .....	17	19
Topographic factors in rate of fire spread .....	36b	42
Total damage in forests .....	11	7
Total tree trunk per acre .....	11	7
Trailer-mounted pumps .....	44	63
Tramways .....	53	73
Treadways .....	53	73
Tree blowdown. (See Blowdown.)		
Tree trunk per acre .....	11	7
Turnouts .....	4b	3
Underwater obstacles .....	68	80
Unit capabilities:		
Clearing blowdown .....	16	18
Clearing rubble .....	29	35
In contaminated areas .....	22	29
Urban area variations .....	27	33
Urban fire fuels .....	36c	42
Wadies .....	55, 56	74, 75
Wall-bearing buildings .....	27c	33
Walls .....	64	79
Washouts .....	56	75

	Paragraphs	Page
Water:		
As it affects crater dimensions.....	48	66
As it affects crater passage.....	50	71
Weather factors in rate of fire spread.....	36a	41
Winches.....	53	73
Wind as weather factor in rate of fire spread.....	36a	41
Wire cutters.....	61	77
Wire entanglements.....	61	77
Woodframe buildings.....	27a	33

BY ORDER OF THE SECRETARY OF THE ARMY:

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28