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RESTORATION OF RUNWAYS FOLLOWING ATTACK

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The object of this paper is to determine suitable planning criteria for the restoration of runways obstructed directly or indirectly by an attack with weapons of .5, 1, 2 and 10 MT yield range, burst on the surface and aimed at the base complex. The runway obstructions are chiefly the result of cratering effects but residual radioactivity does present significant impediment to the undertaking of the necessary repairs.

The criteria to be defined are:

1. Runway obstructions and the probable distance from GZ at which they occur.
2. Productive rates of equipment suitable for runway restoration.

The areas where runway obstructions can occur are:

1. The crater proper.
2. The crater lip, i.e., the area surrounding the crater over which the earth scooped out of the crater comes to rest in compact layers of varying thickness.
3. The missile area over which loose gravel, pebbles, boulders and broken pieces of surface structures, highways, etc. originally in the crater area are thrown out in sufficient amount, density or mass to prevent or endanger landing or take off.

Within the crater proper structures or runways will be either pulverized or broken up beyond repair. There are many uncertainties regarding the crater parameters and the scaling of same. These stem from our lack of understanding of the crater mechanism and from the scarcity of test data. This subject has been discussed frequently and it need not be repeated here.

For a 1 KT surface burst in dry soil the radius has been estimated to vary approximately from 40 to 60 feet, depending on the exact height of burst. These radii apply to Nevada type of soil, dry and soft rock, but saturated soil, wet clay, etc., may boost them as much as 50% and hard rock reduce them as much as 30%. The commonly accepted cube root scaling factor for the crater radius is well substantiated. For the purpose of this study 50 ft seems a reasonable estimate for the crater radius of a 1 KT surface burst given average operational burst height and dry soil conditions.

The depth and volume of a surface burst crater is more difficult to estimate.The evidence is less reliable and the applicable scaling factor is not substantiated by a sufficient range of tests. For our purpose, the significance of these uncertainties lies in their effect on the lip geometry which to a major extent is a function of the crater parameters.

The width of the lip measured radially from the crater edge to an extreme point where the thrown out material is down to a negligible thickness is estimated to be equal to the crater radius. The JANGLE test data confirm this estimte but the JANGLE S lip (the only test of a surface burst crater in dry soil) presents a very irregular contour with rather deep indentation and, therefore, a quite uneven density of throwout in the outer annulus of the lip. At JANGLE S, however, the stated width of the lip, i.e. one crater radius, encompasses all these irregularities.

Moreover, the lips of all test craters, at the Nevada or the Pacific Test Sites, show a characteristic profile. The greater part of the throw-out is accumulated in a high mound surrounding the crater edge with a fairly sharp down slope outward followed by a gradual decline to the outer periphery of the lip. It is in this latter area that the irregularities occur. The radial width of the annulus covered by the high part of the lip ranges from .35 to .50 of the total width of the lip. For the sake of simplicity, conservatism, and for lack of better evidence, we will assume that the high mound annulus ends at a point from GZ 1.5 times the crater radius and that the lip distances scale according to the cube root of the yield. This gives the following distances from GZ for the yields under consideration:

Yield	Crater Radius, in ft.	1/2 Lip Radius, in ft.	Lip Radius in ft.
1 KT	50	75	100
.5 MT	400	600	800
1 MT	500	750	1000
2 MT	630	945	1260
10 MT	1075	1615	2150

On the basis of both test data and analysis of runway slab response, one can also assume with a good degree of reliability that no structural damage to the runway surface or sub-surface will occur at the half lip point. In fact structural damage is doubtful even at points closer in,* the probability of this damage at any point within the lip area being less with large yields than with small yields as long as the point of burst remains at the surface or higher.

* (i.e. at points under the high part of the lip, as indicated by the JANGLE S data.)

An estimate of the distribution of the throwout material over the lip area is now necessary. The total lip volume was estimated to be one-quarter of the crater volume at JANGLE S and one-sixth at JANGLE U. For lack of better evidence the lip geometry of JANGLE S will be assumed to be typical. Moreover, a re-examination of the data shows that for the JANGLE S case three-quarters of the lip volume is in the inner-half and one-quarter in the outer half. The evidence is poor and the fraction of the lip volume attributed to the outer half where the characteristic irregularities occur is, if anything, on the high side.

The volume of the crater is a function of its profile, radius and depth. According to RAND P-801 (Hill and Gilvarry) the volume scales roughly according to yield (within a range of $\left(\frac{W}{W}\right)^{1}$ to $\left(\frac{W}{W}\right)^{1.1}$) for both methods of scaling discussed in that document and for the range of yields under consideration here. AFSWP Capabilities, on the other hand, state that the radius scales according to the cube root, the depth according to the fourth root, and that the crater profile is a paraboloid. The volume scale factor is then $\left(\frac{W_1}{W_o}\right)^{11/12}$.

The JANGLE S volume was estimated at 1825 cubic yards for a radius of 45 feet and a depth of 21 feet. According to the AFSWP formula, however, the volume should be 2500 cubic yards. If, on the other hand, the crater profile is taken to be a cone, then the volume is only 1700 cubic yards. The best way out of this dilemna is to assume that the 1825 cubic yards was actually measured on the site and that this volume can be corrected to account for the difference in radius. The volume of a 50 foot radius crater is then

2250 cubic yards of which 560 cubic yards is deposited on the lip, 420 on the inner half and 140 on the outer half.

In the following table the estimated volume of the lip has been scaled according to the factors indicated in the preceding paragraphs and the height of the lip at the half point has been computed assuming an even distribution of the throwout material over the outer half and a progressive decline to zero thickness at the outer edge. The indicated heights at the one-half points should of course be somewhat increased, in order to account for uneven distribution of the material. However, the deliberate boosting of the fraction of lip material over the outer half should compensate the effects of irregular contours.

Yield	Scaling Factor $\frac{W_1}{W_o}$			Scaling Factor $\left(\frac{W_1}{W_o}\right)^{11/12}$		
	Volume of Lip in Cu.Yd.		Height of Lip at 1/2 Point, in ft.	Volume of Lip in Cu.Yd.		Height of Lip at 1/2 Point, in ft.
	Inner Half	Outer Half		Inner Half	Outer Half	
1 KT	420	140		420	140	
.5 MT	210,000	70,000	2.2	124,000	41,000	1.3
1 MT	420,000	140,000	2.8	240,000	80,000	1.6
2 MT	840,000	280,000	3.5	450,000	150,000	2.0
10 MT	4,200,000	1,400,000	6.0	1,950,000	650,000	2.8

The estimate of the missile area or annulus beyond the lip is more complicated and more tentative. To be consistent with our assumption as to the character and dimensions of the lip, we must also assume that the area of the annulus will be free from deposits of soil except for the thin radial streamers of soil blown over from the lip by the wind following the shock. The material covering the annulus will, therefore, consist of the rubble of boulders and pebbles originally incorporated in the soil mass of the crater and of the broken pieces of concrete or masonry structures or pavement originally located in the crater area. Whether structures are within the crater area is a matter of chance but there is a high probability that the typical marine and glacial soils over which most of ZI SAC Bases are built will provide the necessary projectile materials. However, the trajectory of this material is a function of external ballistics and does not scale with the weapon yield. We can therefore assume that from any scaled distance within the outer crater ring the trajectory of a projectile of constant mass remains constant, and that the radial width, measured from the crater edge, of the area over which the projectiles come to rest will also remain constant.

Unfortunately, we have practically no data allowing reliable estimates of the density of rubble and of its trajectory characteristics in the case of a surface shot. On the basis of the results of the JANGLE U test where a variety of slabs and structures were built within the crater area, the trajectories and density of material expected from the breakup of a continuous slab over the crater area of a 32 KT exploded at the same scaled depth as JANGLE U were computed as follows (WT 375):

Range from GZ	Number of Missiles per 100 Sq. Ft.		
	.8 to 2.8" dia.	2.8" to 6.4" dia.	6.4" to 30" diam.
1700' (1300')	300	2	1
2200' (1900')	70	3	1
2700' (2300')	-	1	<1
3200' (2900')			<<1

(The range number in parenthesis is range distance less crater radius)

However, the volume of boulders suitable for projectiles is considerably less than the mass of a continuous slab. Moreover the trajectory is a function of the angle of initial momentum which should be on the average much nearer the optimum (45°) in the case of an underground burst than of a surface burst. Considering all the uncertainties we hazard the guess that the maximum radial distance measured from the crater edge to the limit of significant rubble coverage can be approximated as 1500 feet.

Assuming the crater radius to be half the outer lip radius we get the following dimensions of the missile annulus:

Yield MT	Radius of Outer Periphery of Lip	Radius of Outer Periphery of Missile Annulus	Net Radial Width of Missile Annulus
.5	800'	400' + 1500 = 1900'	1100'
1	1000'	500' + 1500 = 2000'	1000'
2	1260'	630' + 1500 = 2130'	870'
10	2150'	1075' + 1500 = 2575'	425'

The lip and missile areas are near enough the point of burst to be subject to fallout beginning almost immediately after the burst and with the major portion of the activity being deposited within one hour after burst. Moreover, the level of radioactivity will be of the order of 5,000 to 10,000 r per hour (measured one hour after burst) irrespective of the yield within the range considered. These assumptions are relatively well substantiated by the test data. The rate of decay, however, is more uncertain but for purpose of planning the standard $T^{-1.2}$ rate is a satisfactory assumption applicable to the conditions obtaining after the major portion of fallout is deposited. Under these conditions the shielding required to protect the human operators of the necessary motorized equipment should therefore provide a reduction factor of at least 100 if emergency plans are directed toward beginning restoration activities as promptly as possible after the attack.

It is believed that the design of shields providing a reduction factor of 100 can be achieved without adversely affecting the operating efficiency of the equipment described below. In any case the sheer weight of the shield does not appear to be a limiting factor.

In summary one can conclude that the restoration of obstructed runways in the near vicinity of craters will consist of sweeping loose gravel, debris, rubble or boulders, or of removing compact layers of earth, or both. Only the first operation, sweeping, appears necessary beyond the outer edge of the crater lip, i.e. two crater radii from GZ. The density and character of the rubble to be swept aside are a function of the soil composition of the crater and of the structure which happens to be within the crater. They are therefore highly unpredictable. Within the outer half of the lip, earth moving to a varying extent must precede sweeping.

It is obvious that the actual line of demarcation where the earth moving operation becomes necessary cannot be defined with any precision. Moreover where obstruction becomes interdiction is a matter of equipment and time rather than definition.

The overall job of clearance calls for a number of specialized and motorized equipment working in various combinations for most efficient results.

All of this equipment must be provided with specially designed lead cabs capable of shielding the operator. The dimensions of these cabs are 3' x 3' x 7' and follow the specifications computed by T. E. Harris in RM-1624. The reduction factor is 100, the weight is 2 tons and the cost is estimated at $4500. Lead glass windows inserted in the lead walls provide the operator with the necessary field of vision. As an alternative we checked the cost of remote control and television equipment to permit the equipment operator to drive the equipment from a point outside the radioactive area. This would cost more than $20,000 per unit of construction equipment.

The standard construction equipment listed below requires only minor modification to carry the weight of lead cab. This involves the substitution of slightly stronger tires and bracing of the equipment frame.

A team or unit of three pieces of equipment, i.e. one 150 HP motor grader costing $20,500, one power sweeper costing $10,000 and one bulldozer costing $23,000 will remove and sweep clean rubble, debris, and compact dust layers up to a maximum thickness of 6 inches. The cost of the equipment includes strengthening for cabs installation but excludes the cost of the cab itself. The motor grader is equipped with a 12 foot grading blade as well as an 8 foot bulldozer blade in order to facilitate removal of boulders. The working capacity of the unit is 8000 square yards of runway surface per hour.

For surfaces covered with compact dust or earth layers, more than 6" thick, the clearance operation will require two working units. The first consists of four motorized scrapers, each costing $35,000, plus one bulldozer costing $23,000. These costs exclude the lead cabs. The working capacity of this unit is 400 cubic yards per hour. The first operation is then followed by the same sweeping clearance described in the previous paragraph.