

UNCLASSIFIED

AD NUMBER

AD449936

LIMITATION CHANGES

TO:

Approved for public release; distribution is unlimited. Document partially illegible.

FROM:

Distribution authorized to U.S. Gov't. agencies and their contractors; Specific Authority; 20 DEC 1999. Other requests shall be referred to Air Force Research and Development Command, Project Rand, Washington, DC 20330. Document partially illegible.

AUTHORITY

Defense Threat Reduction Agency ltr., dtd April 6, 2000, signed by Chief Freedom of Information Act/Privacy Act Division

THIS PAGE IS UNCLASSIFIED

UNCLASSIFIED

AD NUMBER

AD449936

CLASSIFICATION CHANGES

TO: UNCLASSIFIED

FROM: CONFIDENTIAL

LIMITATION CHANGES

TO:

Distribution authorized to U.S. Gov't. agencies and their contractors; Specific Authority; 20 DEC 1999. Other requests shall be referred to Air Force Research and Development Command, Project Rand, Washington, DC 20330. Document partially illegible.

FROM:

Distribution authorized to DoD only; Test and Evaluation; 13 MAR 1955. Other requests shall be referred to Air Force Research and Development Command, Project Rand, Washington, DC 20330. Document partially illegible.

AUTHORITY

31 Mar 1967, DoDD 5200.10 gp-4; 20 Dec 1999, AFRDC per DTIC Form 55

THIS PAGE IS UNCLASSIFIED

19991012133

(1)

U. S. AIR FORCE
PROJECT RAND
RESEARCH MEMORANDUM

449936

AD NO.

DDC FILE COPY

(6) PREDICTION OF CRATER DIMENSIONS
FOR THE TEAPOT UNDERGROUND TEST,
(10) by J. E. Hill
and
J. J. Gilvarry .
(14) Rept. no. RM-1449 ✓ 320
(11) 13 Mar 1955,

This material contains information affecting the national defense of the United States within the meaning of the espionage laws, Title 18 U.S.C. Secs. 793 and 794, the transmission or the revelation of which in any manner to an unauthorized person is prohibited by law.

Assigned to _____

(B)

This is a working paper. Because it may be expanded, modified, or withdrawn at any time, permission to quote or reproduce must be obtained from RAND. The views, conclusions, and recommendations expressed herein do not necessarily reflect the official views or policies of the United States Air Force.

DISTRIBUTION RESTRICTIONS

Reproduced From
Best Available Copy

DDC
RECEIVED
OCT 23 1964
REGISTERED
DDC-IRA A

(5)

The RAND Corporation
1200 MAIN ST. • SANTA MONICA, CALIFORNIA

FOR OFFICIAL USE ONLY

449936

NOTICE: When government or other drawings, specifications or other data are used for any purpose other than in connection with a definitely related government procurement operation, the U. S. Government thereby incurs no responsibility, nor any obligation whatsoever; and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use or sell any patented invention that may in any way be related thereto.

Ref-1449
3-31-55
-2-

ABSTRACT

Crater dimensions which may be anticipated for the underground explosion of a 1.2-KT nuclear device as part of the TEAPOT nuclear test series are discussed. Estimates are made on the basis of available crater measurements at the Nevada Test Site and appropriate scaling procedures. A value approximately half way between estimated upper and lower limits of 210 and 167 feet for the crater radius, or about 190 feet, is given. Other characteristic dimensions are estimated such as the diameter at the top of the lip, the height of the lip above the original surface, and the depths measured from the top of the lip or from the original surface.

INTRODUCTION

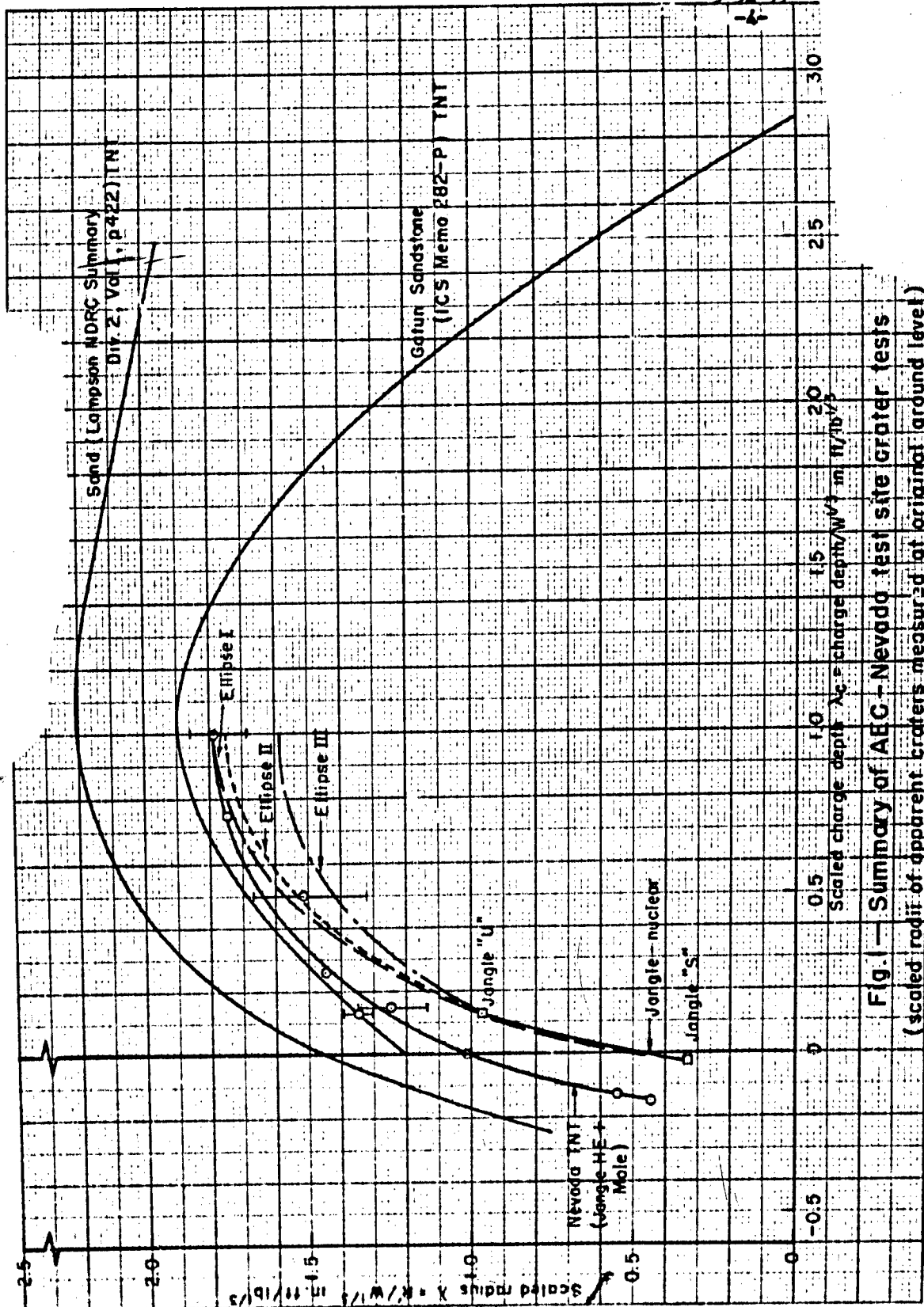
As a part of the "TEAFOT" nuclear test series, an underground explosion of a 1.2 KT nuclear device at a scaled depth of $0.5 \text{ ft}/\text{lb}^{\frac{1}{3}}$ (actual depth - 67 ft.) is planned. Consequently, it is of interest to estimate the crater dimensions which may be anticipated on the basis of available crater measurements at the Nevada Test Site and appropriate scaling procedures.

COMPARISON OF TNT AND NUCLEAR TEST CRATERS OBSERVED AT THE NEVADA TEST SITE

Table I summarizes the data on the apparent crater radii for both high explosive and nuclear craters observed at the Nevada Test Site. (1)(2)(3) The corresponding scaled radii and scaled charge depths are also given.

The average scaled radius ($\bar{r} = R^1/W^{\frac{1}{3}}$) for each scaled charge depth ($r_c = \text{charge depth}/W^{\frac{1}{3}}$) is plotted as a circle in Figure 1. Where several values of \bar{r} were available for a given value of r_c , the range of variation is indicated by vertical bars. Also shown for comparison are Lampson's (4) curve for TNT craters in sand and the Isthmian Canal Studies (5) curve for TNT exploded in sandstone.

It will be noticed that the two latter curves have their maximum values of \bar{r} for a value of r_c near unity and that the Nevada TNT data are consistent with a maximum at $r_c = 1$.



Sand (Lampson MDRG Summary
Div 2, Vol 1, 2422) TNT

Gofun Sandstone
(ICS Memo 282-P) TNT

Fig. 1 - Summary of AEC-Nevada test site crater tests
(scaled radii of apparent craters measured at original ground level)

TABLE I

SUMMARY OF DATA ON APPARENT CRATER RADII AT THE
ORIGINAL GROUND SURFACE FOR THE AEC NEVADA TEST SITE

Identification of Round	Weight of Charge W(lbs.)	$W^{\frac{1}{3}}$ (lbs.) ^{$\frac{1}{3}$}	Crater Radius R' (feet)	Scaled Charge Depth $\frac{R'}{C}$ (ft/lbs. ^{$\frac{1}{3}$})	Scaled Radius $\frac{R'}{C}$ (ft/lbs. ^{$\frac{1}{3}$})
Jangle HE-4 (TNT)	2560	13.68	6.1	-0.15	0.45
Mole 207 (")	256	6.35	3.5	-0.13	0.55
" 206 (")	256	6.35	6.4	0.00	1.01
" 205 (")	256	6.35	8.8	0.13	1.39
" 403 (")	256	6.35	8.33	0.13	1.31
					av. 1.35
Jangle HE-1 (")	2560	13.68	18.5	0.15	1.35
" HE-2 (")	40000	34.20	39.0	0.15	1.14
					av. 1.25
Mole 204 (")	256	6.35	9.2	0.26	1.45
" 405 (")	256	6.35	9.18	0.26	1.45
" 203 (")	256	6.35	8.4	0.50	1.32
" 406 (")	256	6.35	10.0	0.50	1.58
					av. 1.52
" 401 (")	256	6.35	10.58	0.50	1.67
Jangle HE-3 (")	2560	13.68	20.5	0.50	1.50
Mole 402 (")	256	6.35	11.08	0.75	1.75
" 202 (")	256	6.35	11.5	1.00	1.81
" 212 (")	256	6.35	10.7	1.00	1.69
					av. 1.79
" 404 (")	256	6.35	11.78	1.00	1.86
Jangle "S" (Nuclear)	2.4×10^6	134	45	-0.0261	0.336
" "U" (")	2.4×10^6	134	129	0.127	0.963

An attempt was made to fit a parabola of the form

$$(\bar{r}_c - \bar{r}_{co})^2 = -4p(\bar{r} - \bar{r}_0) \quad (1)$$

to the Nevada TNT data, but it was found that no set of values for the parameters \bar{r}_{co} , \bar{r}_0 and p gave a good fit to the data over the whole range of \bar{r}_c . However, a good fit to the Nevada TNT data was obtained with an ellipse of the form

$$\frac{(\bar{r}_c - \bar{r}_{co})^2}{a^2} + \frac{(\bar{r} - \bar{r}_0)^2}{b^2} = 1 \quad (2)$$

with the following values of the parameters \bar{r}_{co} , \bar{r}_0 , a and b :

$$\begin{aligned} \bar{r}_{co} &= 1 \\ \bar{r}_0 &= 0.2597 \\ a &= 1.1420 \\ b &= 1.5303 \end{aligned}$$

This ellipse is the solid curve drawn through the Nevada TNT data in Figure 1. The constants were chosen so that the curve passes through the three points $(-0.15, 0.45)$, $(0.15, 1.3)$ and $(1, 1.79)$ and has a maximum at $\bar{r}_0 = 1$.

The Jangle "S" and "U" data are indicated as squares, in Figure 1, for comparison with the Nevada TNT data. It is seen that the "scaled radius" of the apparent crater at the original surface, for Jangle "S", is 0.36 of that for the Nevada TNT curve, at the same scaled charge depth. For the Jangle "U" crater this ratio is 0.76. The increase of the cratering efficiency of the nuclear explosions relative to TNT, as the "scaled charge depth" is increased,

makes the prediction of the TEAPOI "ESS" crater dimensions dependent on some kind of extrapolation, of a curve connecting the Jangle "S" and "U" points, to a value of $r_c = 0.5 \text{ ft/lb}^{\frac{1}{3}}$. The good fit of an ellipse to the Nevada Proving Ground TNT data suggests that an ellipse might also be used to extrapolate the nuclear r vs. r_c curve. However, the fact that only two measured points on the nuclear crater curve are available, means that there are not sufficient points to determine a unique ellipse through the Jangle "S" and "U" points; i.e., there are not enough measurements to determine the four parameters in Equation (2) above. The similarity between the Isthmian Canal Studies TNT curve for Gatun Sandstone, the Nevada TNT and Lampson's curve for Sand suggests that the nuclear curve for Nevada soil conditions may also have its maximum near $r_c = 1$. Even if it is assumed that $r_{co} = 1$, an additional assumption is necessary to determine a unique ellipse of the form of Equation (2) through the Jangle "S" and "U" points.

The fact that the initial temperatures and pressures in nuclear explosions are much higher than for chemical explosions suggests that the nuclear explosion would never reach as high a cratering efficiency as TNT, even at the optimum charge depth. For example, in air, the fraction of the energy released in a nuclear explosion which appears as mechanical blast energy is never as large as for TNT explosions because a much larger fraction of the energy is radiated away as heat and light and also the air is left at a higher temperature behind the shock front because of the higher temperatures and pressures in the shock front.

Consequently, it appears likely that the maximum value of r for the Nevada TNT curve, i.e., $r = 1.79 \text{ ft/lb}^{\frac{1}{3}}$, should represent an upper limit to the Nevada nuclear scaled crater radius for r_c near unity.

If an ellipse of the form of Equation (2) is made to pass through the Jangle "S" and "U" points and have a maximum at $r = 1.79 \text{ ft/lb}^{\frac{1}{3}}$ and $r_0 = 1$, then the constants in Equation (2) for the Nevada nuclear scaled radius curve are:

$$\begin{aligned} r_{\infty} &= 1 \\ r_0 &= -0.08168 \\ a &= 1.0521 \\ b &= 1.8717 \end{aligned}$$

The curve, drawn through the Jangle "S" and "U" points and labeled No. 1 in Figure 1, is a graph of the above ellipse and yields a value of $r = 1.56_5 \text{ ft/lb}^{\frac{1}{3}}$ for $r_0 = 0.5$. This is equivalent to an apparent crater radius, at the original ground level, of about 210 feet as an upper limit for a 1.2 KT nuclear explosion, burst at a depth of 67 feet.

Since the nuclear scaled radius is 0.76 of the scaled TNT radius at a scaled charge depth of $0.127 \text{ ft/lb}^{\frac{1}{3}}$, any guess for this ratio, at $r_0 = 1$, in the range from ~ 0.8 to 1.00 would appear to be reasonable. Two additional ellipses through the Jangle "S" and "U" points are shown in Figure 1, as numbers II and III, in order to examine the sensitivity of the TRAPOT "ESS" prediction to different but, perhaps, equally justifiable extrapolations of the Jangle crater data. The constants for these ellipses are:

Ellipse II

$$\begin{aligned} r_{\infty} &= 1 \\ r_0 &= 0 \\ a &= 1.045_5 \\ b &= 1.750 \end{aligned}$$

Ellipse III

$$\begin{aligned} r_{\infty} &= 1 \\ r_0 &= 0.2597 \\ a &= 1.028 \\ b &= 1.332_5 \end{aligned}$$

The corresponding maximum values of r at $r_0 = 1$ are 1.75 and 1.59 ft/lb^f, and the ratios of these scaled radii to that from the Nevada TNT curve at $r_0 = 1$, are 0.98 and 0.89 respectively. The use of curves II and III to estimate the apparent radius for the TRAPOT "ESS" crater gives 206 and 191 feet, respectively, and together with the estimate of 210 feet from Ellipse I give an indication of the range of uncertainty which results from the unavoidable ambiguities in extrapolating the meager nuclear crater data.

It should be emphasized that many other factors also contribute to the uncertainty in such a prediction. Among these are the experimental uncertainties in both the nuclear and TNT curves due to the variations in crater dimensions, commonly encountered in repeated experiments under supposedly identical conditions; the assumption that the nuclear and TNT curves have their maxima at $r_0 = 1$; and the use of an ellipse to extrapolate the nuclear curve, simply because an ellipse is a good fit to the available Nevada TNT data. The lack of reproducibility of crater data is commonly as much as 20 or 30 percent. The contribution which the possible lack of validity of the various assumptions makes to the uncertainty in the predicted radius is difficult to assess, but it could be as large as that due to the experimental uncertainties.

Doll⁽⁶⁾ has predicted an apparent radius for the TRAPOT "ESS" crater of 188 feet. Sachs and Swift⁽³⁾ arrive at a slightly smaller value of 173 feet. The detailed procedures used by these workers to make their estimates are not available, but Ref. 3 indicates that Doll used all the available cratering data and assumptions concerning the "mechanical efficiency" to be assigned to the TRAPOT "ESS" device. The lower value predicted by Sachs and Swift is based on the observation that in some series of TNT tests, in which the charge

weight was varied over a large range but the "scaled charge depth" was held constant, the "scaled crater radii" decreased with increasing charge weight. This effect was attributed to a change in soil characteristics with increased depth of charge.

While some series of TNT craters, such as the UET rounds 312, 315 and 318⁽³⁾ show this effect, other series such as the Mole rounds 203, 401 and 406 and Jangle HE-3 with a scaled depth of $0.5 \text{ ft/lb}^{\frac{1}{3}}$ do not (See Table I.) For the latter series the average scaled radius for the three Mole rounds (256 lbs. TNT) was $1.52 \text{ ft/lb}^{\frac{1}{3}}$, while the same quantity for Jangle HE-3 (2560 lbs. TNT) was 1.50 in good agreement with the smaller Mole craters.

Considering the small number of rounds in any one such series among the Nevada TNT tests and the rather large scatter normally encountered in cratering experiments, the effect can hardly be accepted as established. In fact, such considerations as these resulted in the decision to plot the average values of r_c for each "scaled charge depth" to obtain the Nevada TNT curve shown in Figure 1.

Further, if the "scaled radius" taken from the ellipse fitted to the Nevada TNT data at $r_c = 0.5$ is reduced by 0.76 (i.e., $r_c(\text{Jangle "U"})/r_c(\text{TNT}) = 0.76$ for $r_c = 0.127$) and scaled by the "cube root" law, a value of 167 feet would be predicted for the TRAPOT "ESS" radius. In other words, the assumption that the cratering efficiency of nuclear explosions relative to TNT does not increase for "scaled charge depths" greater than $0.127 \text{ ft/lb}^{\frac{1}{3}}$ gives a radius only slightly smaller than that predicted by Sachs and Swift and would appear to be a lower limit.

A value half way between the upper and lower limits or 188 feet is the same as that given by Doll and agrees well with the value of 191 feet predicted by Ellipse III through the Jangle nuclear points. See Figure 1.

From a prediction for the diameter of the TEAPOT "ESS" apparent crater at the original ground surface D' , it is possible to arrive at estimates for other characteristic dimensions such as the diameter at the top of the lip, D , the height of the lip above the original surface, h , and the depths measured from the top of the lip, d , or from the original surface, d' .

A value of D can be estimated from D' by noting that for both the Jangle "S" and "U" craters the ratio D/D' was very nearly 1.165, and by assuming that it will be similar for TEAPOT "ESS". Having D , the modified Baldwin empirical relations⁽⁷⁾⁽⁸⁾ may be used to predict h and d and then $d' = d - h$. The modified Baldwin relations connecting h and D , and D and d are:

$$\log h = -2.125 + 1.542 \log D - 0.097(\log D)^2 \quad (3)$$

and

$$\log D = 0.843 + 0.6917 \log d + 0.1083(\log d)^2 \quad (4)$$

respectively.

The resulting estimates for all the crater dimensions are summarized in Table II.

TABLE II

SUMMARY OF VARIOUS PREDICTIONS OF THE TEAPOT "ESS" APPARENT CRATER DIMENSIONS. (1.2 KT EXPLODED AT A DEPTH OF 67 FEET AT THE AEC NEVADA PROVING GROUND.)

Method of Extrapolation	Diameter at Original Surface D' (feet)	Diameter at Top of Lip D (feet)	Height of Lip h (feet)	Depth from Top of Lip d (feet)	Depth from Original Surface d' (feet)
I Ellipse I (Figure 1)	420	490	21	106	85
II Ellipse II (Figure 1)	412	480	20.5	104.5	84
III Ellipse III (Figure 1)	382	445	19	98	79
IV Using Scaled Radius from TNT Curve $\times 0.76$ for $\lambda_0 = 0.5$	334	390	16	87	71

The dimensions obtained for the TEAPOT "ESS" apparent crater by extrapolating the Jangle data with Ellipse III in Figure 1 (Number III in Table II) are probably as good an estimate as can be made with available data, i.e., about half way in between fairly reasonable upper and lower limits.

When the results of the TEAPOT "ESS" test are known, it will be possible to choose a unique ellipse through the nuclear points, in Figure 1, if the assumption of a maximum λ at $\lambda_0 = 1$ is retained, i.e., if λ_{00} is taken equal to unity in Equation (2). While there is no theoretical reason for choosing an ellipse to fit the data, it appears to be a good fit in the region

RM-1449
3-31-55
-13-

$-0.15 < \alpha < 1$ for the Nevada TNT data and provides a convenient means for interpolating between the experimental points on a graph such as Figure 1. Even a modest extrapolation of such a curve through the region between $\alpha = 0.5$ to $\alpha = 1$ would probably not result in large errors of prediction but examination of the Lampson curve for sand (Figure 1) should indicate caution in extrapolating beyond the maximum. Extrapolation to higher "scaled heights of burst" above the ground would be even more risky.

Also, the fact that four experimental points would suffice to uniquely determine an ellipse should not be used to argue against more nuclear cratering experiments. The rather large scatter in crater data indicates that additional data might well make considerable improvement in the best average curve.

In conclusion the authors wish to acknowledge the helpful discussions with H. L. Brode concerning the relative cratering efficiencies of nuclear and chemical explosives.

REFERENCES

1. Vaile, F. B. Jr., First Interim Report - Small Explosion Tests Phase I of Project Mole, Stanford Research Institute, AFSWP-288, Jan. 1953. (SECRET-RESTRICTED DATA).
2. Swift, L. M. and Sachs, D. C., Second Interim Report - Small Explosion Tests - Phase II of Project Mole, Stanford Research Institute, AFSWP-289, May 1954. (SECRET-RESTRICTED DATA).
3. Sachs, D. C. and Swift, L. M., Third Interim Report - Small Explosion Tests - Phase II-B of Project Mole, Stanford Research Institute, AFSWP-290, Dec. 1954. (SECRET-RESTRICTED DATA).
4. Lamson, C. W., Explosions in Earth, Chapter 3 of Summary Technical Report of NDRG, Div. 2 Vol. 1. Effects of Impact and Explosion, 1946. (CONFIDENTIAL).
5. Darling, James A., Crater and Slope Tests, Department of Operation and Maintenance - Special Engineering Division, I.C.S. Memo 282-P, June 8, 1954.
6. Doll, E. B., Crater Radius Estimate for Teapot ESS. Technical Memorandum TDWET-54-50, AFSWP, Oct. 15, 1954. (SECRET).
7. Baldwin, R. B., The Face of the Moon, University of Chicago Press, 1948.
8. Hill, J. E. and Gilvarry, J. J., Crater Formation by Explosions, The RAND Corporation, (To be published soon.) (SECRET-RESTRICTED DATA).



Defense Threat Reduction Agency

45045 Aviation Drive
Dulles, VA 20166-7517

APR 6 2000

This is in response to your Freedom of Information Act (FOIA) request dated September 24, 1999, to the Defense Technical Information Center (DTIC). DTIC forwarded your request to the Directorate for Freedom of Information and Security Review (DFOISR) who subsequently forwarded the request to the Defense Threat Reduction Agency (DTRA) for action. Your FOIA request was received at DTRA on November 9, 1999, and assigned DTRA FOIA Case Number 00-032. You requested a copy of the following document:

AD Number 449936
Title: Prediction of Crater Dimensions for the Teapot
Underground Test
Authors: Hill, J.E., Gilvarry, J.J.
Pagination: 12
Report Date: March 1955
Report Number: RM1449

A thorough security review of the document revealed it could be released in its entirety.

There are no fees assessable for this request.

Should you have any questions concerning this case please contact me (703) 325-1205.

Sincerely,

Sandy Ford
Chief, Freedom of Information Act/
Privacy Act Division

Enclosure:
As stated