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A Heuristic Examination of Scaling

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Lawrence Livermore National Laboratory

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A HEURISTIC EXAMINATION OF SCALING

(Title: Unclassified)

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A HEURISTIC EXAMINATION OF SCALING

Abstract

This study investigates the scaling of dimensions of craters formed by nuclear explosive sources as well as the problem of making consistent estimates of other geonuclear effects including maximum base surge radius, vented fraction of the gamma emitting radionuclides appearing in close-in fallout, and main cloud dimensions. Input to the proposed scaling method includes the Froude number as determined by the depth of burial and the mound surface velocity at vent time, and the pressure in the cavity at vent time. These inputs are provided from long-running cratering-mechanics numerical calculations. Illustrations are given of the use of the method for 1 Mt and 200 kt cratering events.

Introduction

Engineering scaling laws have been a convenient way of estimating crater dimensions when given the yield of the explosive, its depth of burial, and the medium. The fact that simple yield scaling of crater dimensions violates the required similarity conditions has been discussed by Chabai.[1] However, that work did not contain an estimate of the error introduced in the prediction of crater dimensions by the lack of satisfaction of the similarity conditions. Montan[2] suggested that nuclear crater dimensions scale with the inverse of the Froude number.* This suggestion was largely ignored by those making cratering (code) calculations, and probably with some justification, in that the proposed method for prescribing the surface velocity of the mound was valid for optimally buried shots in dry rock. The dilemma for the more general case is illustrated as follows. Based on surface velocity information, and using the depth of burial (DOB) as the characteristic length, the Froude number (Fr) for the Sedan spall mechanism is about 1.0, the Froude number at vent time (Fr_{t_v}) (based on extrapolated surface velocity data at ~3.2 seconds) is ~2.0, and the Froude number for the farthermost projectile is about 11 (see Ref. 3). Hence, depending on time selected for specification of the Froude number, there can be at least a factor-of-ten spread in the Froude number for a given experiment. It is because of this ambiguity that the suggestion of Montan has so far been ignored.

Dissatisfaction with simple yield scaling of crater dimensions has been held for sometime by several members of K-Division. For example, Crowley[4] has shown that SOC-TENSOR solutions cube root scale as long as the energy sources are in the same unlayered material, the same cube-root-scaled emplacement depth is used, and gravity

*The Froude number is defined as the ratio of the inertial forces to the gravitational forces, or v^2/gL, where L is a characteristic length of the system, g is the acceleration of gravity, and v is the velocity of the fluid.

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is ignored. The analysis shows that when constant value of gravity is included, the solutions no longer scale. The errors associated with the use of the various proposed simple yield scaling laws for crater dimensions are still not adequately quantified today.

This present study began as a search for a "better" basis for scaling; it has resulted in finding a means of using physical-variables calculated by TENSOR at estimated time of vent to predict a consistent set of effect-variables, including: apparent crater dimensions, base surge maximum radius in a neutral atmosphere, vented fraction appearing in the close-in fallout pattern, and vented energy. From vented energy, one can use methods already known (or being developed) to predict (a) air blast over pressure from the gas vent as a function of range for a homogeneous, isotropic atmosphere, and (b) main cloud dimensions. The study is heuristic in nature; it is nonrigorous in many places, and there are a few intuitive leaps. Nonetheless, it is possible to find several interesting empirical correlations that appear to have promise in predicting geonuclear effects from cratering detonations.

The key to this study is that the kinetic energy of the mound material and the energy available to do work in the cavity gas, both evaluated at vent time (t_v), constitute the only two sources of energy for cratering at that time. Late in the mound development, when its behavior is quasi-hydrodynamic, the free surface velocity is simply related to the mean velocity of a conical zone (see Fig. 1). Under these conditions, as we will see, the only variables that need to be evaluated by physics code calculations (TENSOR) or by actual measurement are surface velocity of the mound at t_v and the cavity pressure at t_v. However, the prediction of crater depth also requires the specification of an empirically determined bulking factor to which the depth predictions are sensitive (particularly at low yield). This fact has been recognized by Terhune in the process of performing many cratering calculations.

In developing the correlations presented, we use measured values of the mound surface velocity (at surface zero) at vent time, L = DOB to calculate Froude number, and estimated values of $\ln (p_c/p_0)$ derived from gas-vent air blast over pressure records for a few events. (Note: p_c is the cavity pressure and p_0 is the atmospheric pressure.) Methods developed by Montan (1968) were used to estimate $\ln (p_c/p_0)$ from gas vent air blast signatures. It may well be that this is the most reliable means of measuring late time cavity pressures in cratering shots available today.[5]

It is probably pertinent for background purposes to cite some of the types of physical systems that have been found to Froude scale.

1. The steady state flow of water on an inclined channel with skin friction has been studied by Jeffreys (1925). By integrating the law of conservation of momentum, he showed that steady state solutions satisfy the relation,

$$\frac{u_1^2}{g D_w} = \frac{\sin a}{k} = Fr$$

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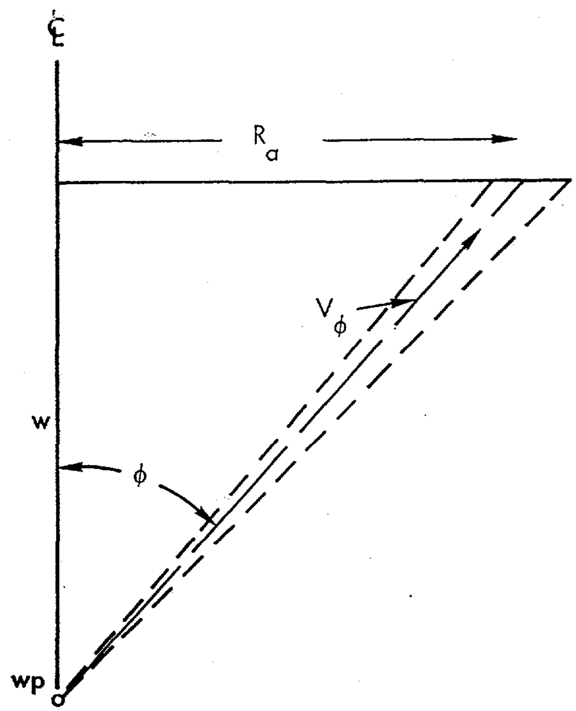

Fig. 1. Geometrical definition of variables used in Eqs. (1) and (2).

where u_1 is the velocity of the fluid at the free surface, g is the acceleration of gravity, D_w is the depth of water, k is the coefficient of skin friction, and "a" is the angle of inclination of the channel from the horizontal. This theoretical result was shown to hold for a number of hydraulic laboratory tests.

2. The collapse of cylindrical columns of heavy fluid into a fluid environment of lesser density has been found to Froude scale in the laboratory.[6] The Navy used such laboratory experiments together with Froude scaling to make predictions of base surge dimensions for the CROSSROADS Baker shot.

3. A method for "calculating" crater dimensions was summarized by the Soviet investigator G. I. Pokrovskiy.[7] The basic equation underlying this method can be written as follows (Ref. to Fig. 1). If it is required that a crater of radius R_a be made, then the kinetic energy that the center of mass of the conical zone (centered on ϕ) must acquire in order to escape the crater is

$$\frac{v_\phi^2}{2} = \frac{g\,w}{3} \cos^2 \phi \qquad (1)$$

where v_ϕ is the velocity the center of gravity of this zone must acquire through all cratering mechanisms (whatever they are), g is the acceleration of gravity, w is the depth of emplacement, and the angle ϕ given by ton^{-1} (R_a/w). Thus, the reported Soviet success at estimating crater dimensions depends on Froude scaling, since we may define from Eq. (1) a Froude number Fr (ϕ), such that,

$$Fr(\phi) = \frac{2}{3} \cos^2 \phi \qquad (2)$$

and w is the characteristic length to be used in the scaling.

Froude Scaling of Crater Dimensions

As previously discussed in the introduction, we now explore relationships or correlations that exist between crater dimensions within the context of Froude scaling at vent time, using the variable $\ln (p_c/p_0)$ to characterize the available work from the cavity gas and D, the depth of burial, as the characteristic length. The surface velocity data used in this work is taken largely from Toman.[8]

Figure 2 shows the ratio of the apparent crater radius (R_a) to emplacement depth (D) as a function of the reciprocal of the Froude number at vent time (calculated from free surface velocity at surface zero), for the following events: Danny Boy, Scooter, Schooner, Cabriolet, Sedan, and Sulky (for which the retarc mound radius is shown). It is to be noted that for Fr between 7.0 and 2.5, the apparent crater radius equal to 1.1 D approximates the data very well, and for Fr less than 2.5 the mound or crater radius is equal to 0.95 D. The evidence suggests that this correlation of $1/Fr$ to R_a/D

*A neutral atmosphere is defined as one in which the dry adiabatic process lapse rate is equal to the environmental lapse rate.

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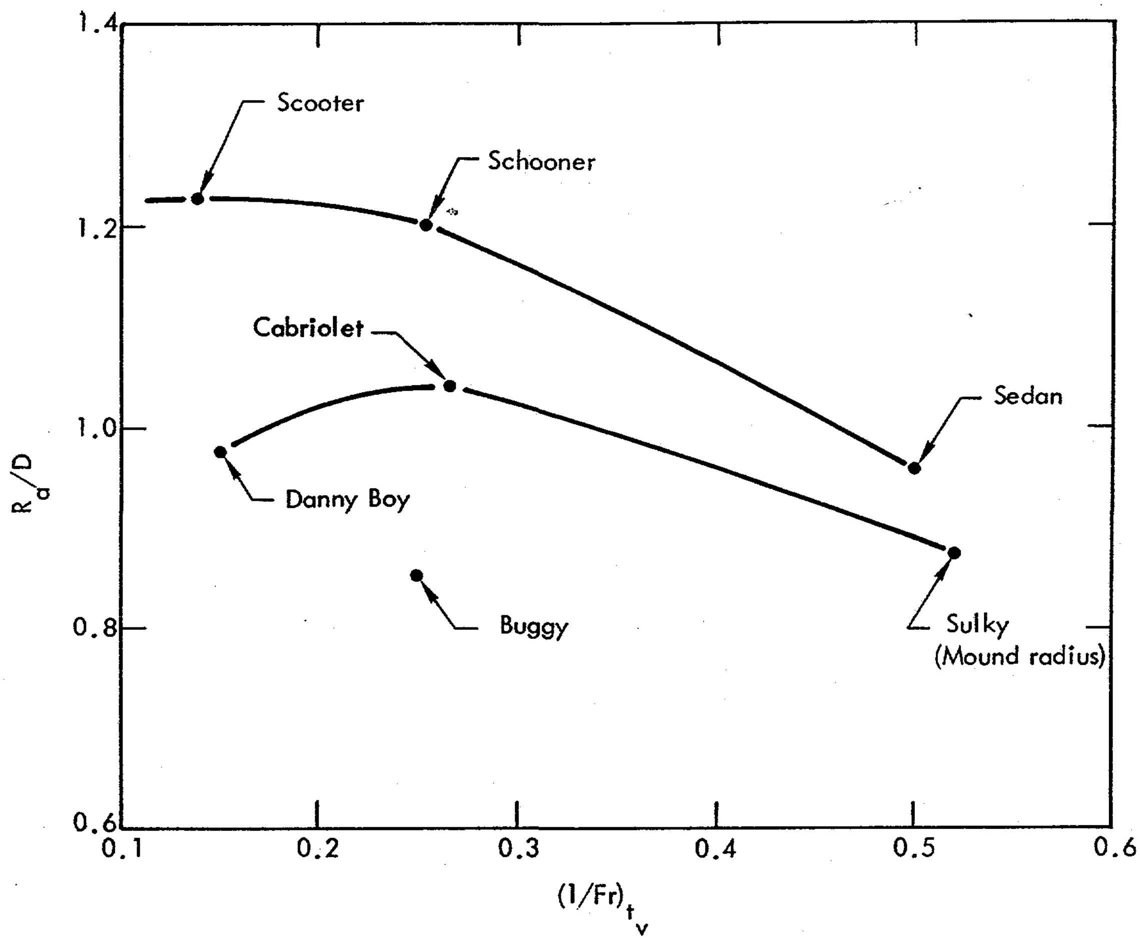

Fig. 2. Ratio of apparent crater radius (R_a) to emplacement depth (D) as a function of the reciprocal of the Froude number (1/Fr) at vent time for selected events.

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may be of considerable predictive value. It should be noted that the value of R_a/D is relatively insensitive to $1/Fr$.

Figure 3 shows the data on the ratio of the depth of apparent crater (D_a) to the DOB (D) as a function of the reciprocal of the Froude number evaluated at vent time for the previously named events. These two variables by themselves do not appear to be well correlated. This scatter suggests, possibly, a missing variable; we shall, for the moment, hypothesize that the missing variable characterizes the energy available to do work in the cavity gas at vent time.

At the suggestion of this author, Montan has reexamined the gas venting air blast pulse as recorded on Sedan, Cabriolet, Buggy, and Schooner in order to estimate the energy vented to the atmosphere. The following table shows the results of these estimates as well as the $\ln(p_c/p_0)$ and $p_c(t_v)$ that can be calculated from the equation published by Montan[9] for the vented energy.

Table 1. Estimates of energy vented to atmosphere, $\ln(p_c/p_0)$ and $p_c(t_v)$ for selected events.

Event	Energy vented to Atmosphere (kt)	$\ln(p_c/p_0)$	p_c (bars) at t_v	
Sedan	2.5	2.0	$7.4\ p_0$	
Cabriolet	3.6×10^{-6}	10^{-4}	p_0	
Buggy	1.0×10^{-5}	10^{-3}	$1.001\ p_0$	
Schooner	0.3	0.69	$2.0\ p_0$	
Danny Boy			$\sim 1.0\ p_0$	Previous estimate Knox (1966)
Sulky			$<1.0\ p_0$	Previous estimate Knox (1966)

The plotting of these $\ln(p_c/p_0)$ values in Fig. 3 has been done. An examination of this array of ln values in two dimensions (D_a/D, $1/Fr$) offers no immediate suggestion of a meaningful correlation. Hence, we will next attempt to correct these data points for the effects of bulking and/or compaction, where actual data exists.

The data shown in Fig. 4 has been corrected for bulking and compaction: Danny Boy for a 30 percent bulking, Sulky for 50 percent bulking, and Sedan for 40 percent compaction contribution to the crater. A straight line drawn through Danny Boy, Buggy, and Sulky joins events of $\ln(p_c/p_0) = 0$. If we ignore Cabriolet because of layering effects, then Schooner and Sedan values of $\ln(p_c/p_0)$ form an organized pattern with regard to Danny Boy and Sulky in two-dimensional space of (D_a/D, $1/Fr$). Buggy has been ignored in the development of the (D_a/D) correlations because of the effects of layering. Layering has the effect of shifting the velocity vector $\tilde{v}_\phi$ away from the angle ϕ. Hence, this above evidence and correlation, however crudely displayed in Fig. 4, suggests that to predict D_a, $1/Fr$, $\ln(p_c/p_0)$, and the bulking or compaction must be known. The first two may be predictable by means of long-running TENSOR calculations; the bulking factor, so far, has been values by means of an "engineering judgment."

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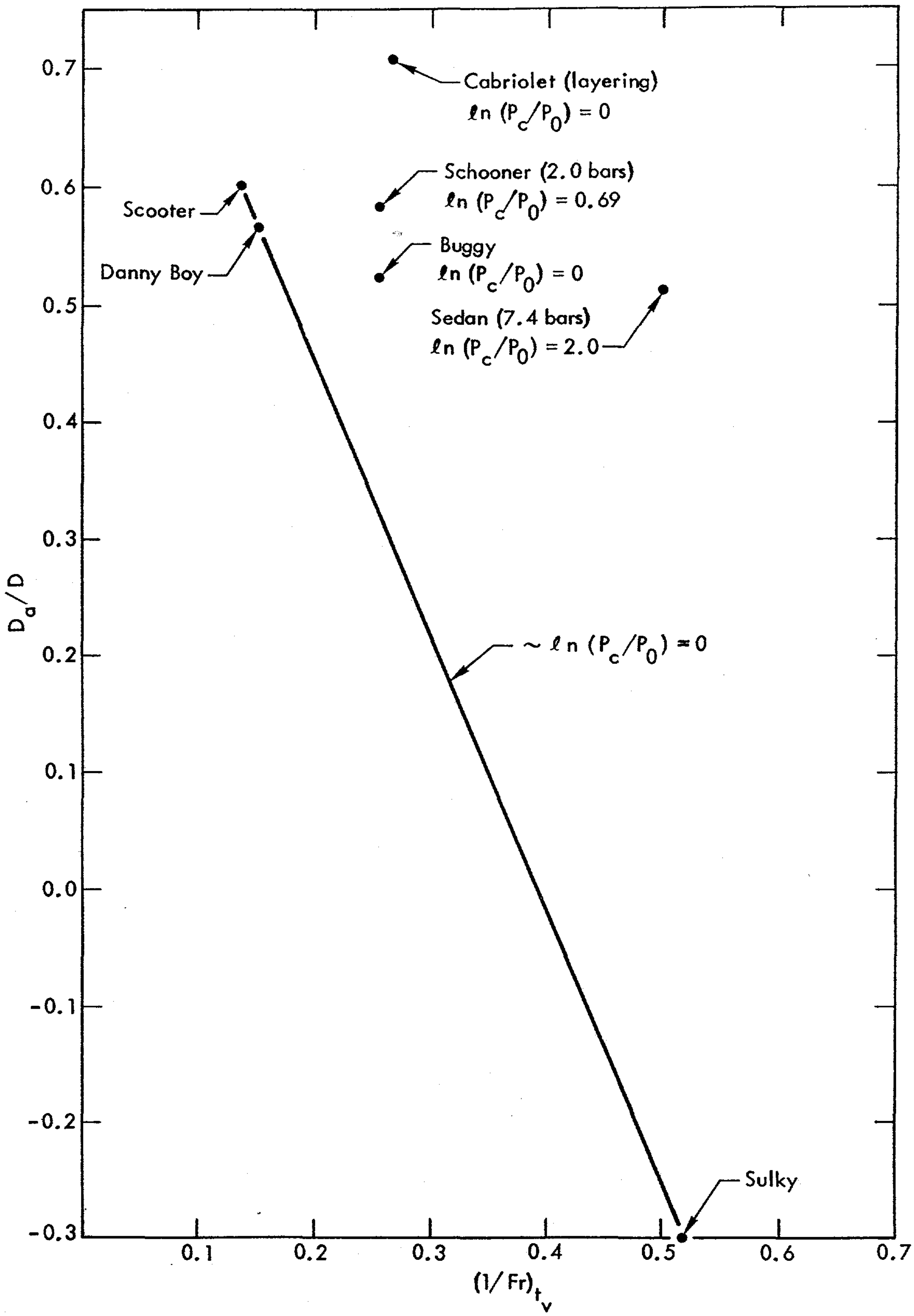

Fig. 3. Ratio of D_a to D as a function of i/Fr at vent time for selected events without any correction for bulking or compaction.

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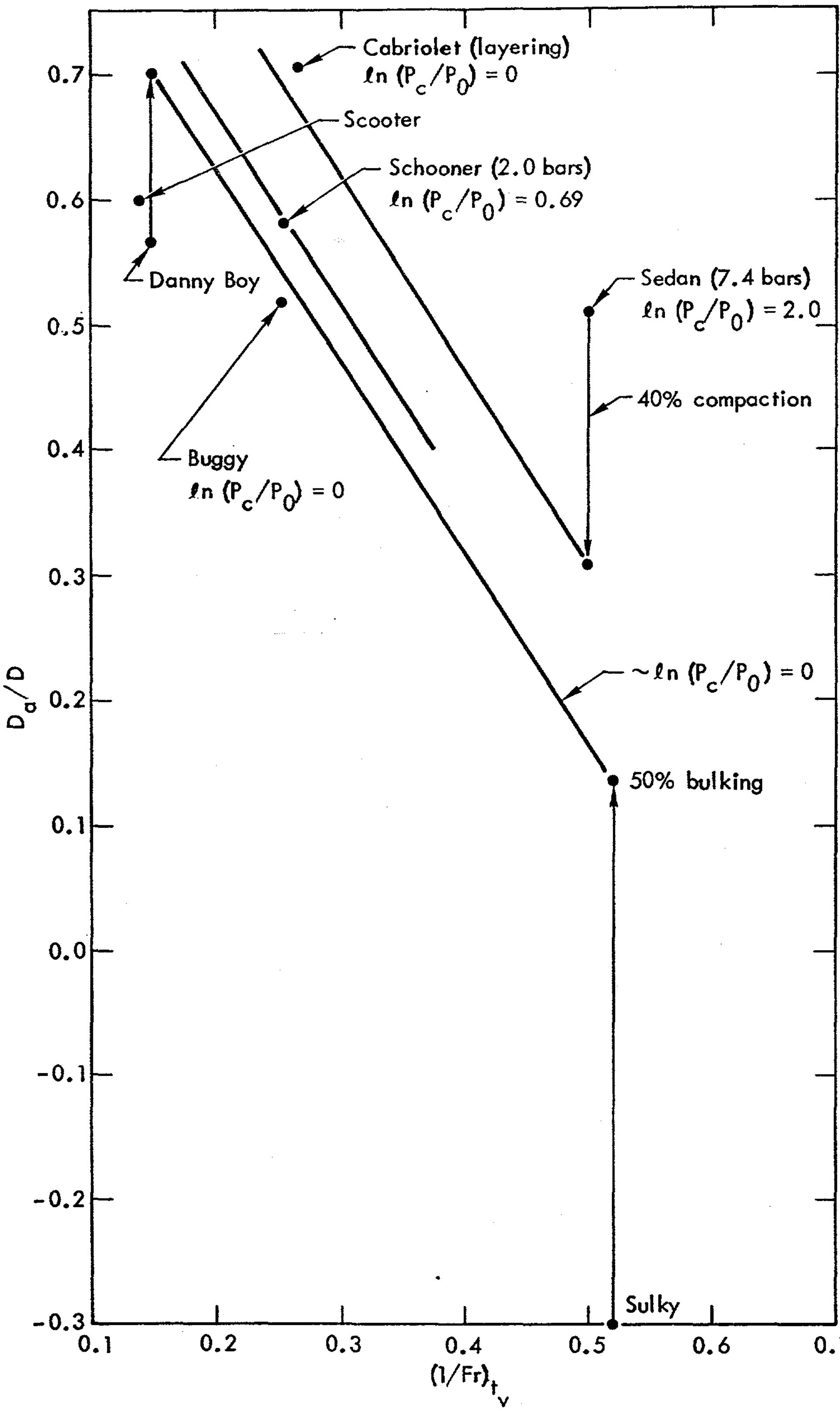

Fig. 4. Same as Fig. 3, except data corrected for bulking and compaction.

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Figure 5 shows a data presentation of R_a/D versus the reciprical of the Froude number wherein isolines of equal values of ln (p_c/p_0) are constructed. This figure represents the next level of sophistication over Fig. 2 in regard to developing an empirical relationship of practical predictive value. The pattern that emerges is consistent with all existing nuclear data; its validity should be tested on forthcoming experiments or conceivably through calculation. To illustrate this latter point the author has plotted the predicted value of R_a from the 1 Mt Canal basalt calculation (as prepared by Terhune, 1969) on the previously constructed ln (p_c/p_0) isolines. It appears that (TENSOR) calculations could be used to extend and partially verify the relationships herein presented involving Froude scaling. It may very well be that the mysteries of gradually changing exponents of the yield—in simple yield scaling—can be avoided with Froude scaling. The results in Fig. 5 show a consistent pattern from 0.5 kt to 1 Mt that avoids this difficulty.

Froude Scaling of Base Surge Radius

The maximum base surge radius (R_b) corrected to a neutral atmosphere according to the prescription of Knox and Rohrer,[10] is tabulated in Table 2. This correction to a neutral atmosphere is, in the author's opinion, required in order to obtain a homogeneous set of data in regard to R_b.

Table 2. Maximum base surge radius corrected to neutral atmosphere, with ratio of maximum base surge radius to twice the apparent crater radius.

Event	Base surge radius (meters) (neutral atmosphere)	$2R_a$ (meters)	$R_b/2R_a$
Sulky	70	48	1.45
Cabriolet	630	110	5.7
Danny Boy	400	66	6.06
Sedan	4000	370	10.8
Schooner	4900[a]	260	19.0
Teapot ESS	2460	89	27.5

[a]Schooner was the only nuclear shot for which a correction for a neutral atmosphere was required.

Figure 6 shows the variable $R_b/2R_a$ as a function of the "equivalent Froude number" (to be defined) and the cube root scaled depth of burial. For a given experiment the equivalent Froude number (Fr') is that value of Fr corresponding to the experimental value of D_a/D if ln (p_c/p_0) were zero; it is found from the empirical correlation shown in Fig. 4. In regard to Fig. 4, it should be mentioned that (a) we have only estimated the Froude number for Teapot ESS, (b) Scooter data has been included on this figure despite the fact its inclusion may make the data set non-homogeneous, and (c) the fact that $R_b/2R_a$ is observed to be zero for surface bursts has been used in instructing the curves.

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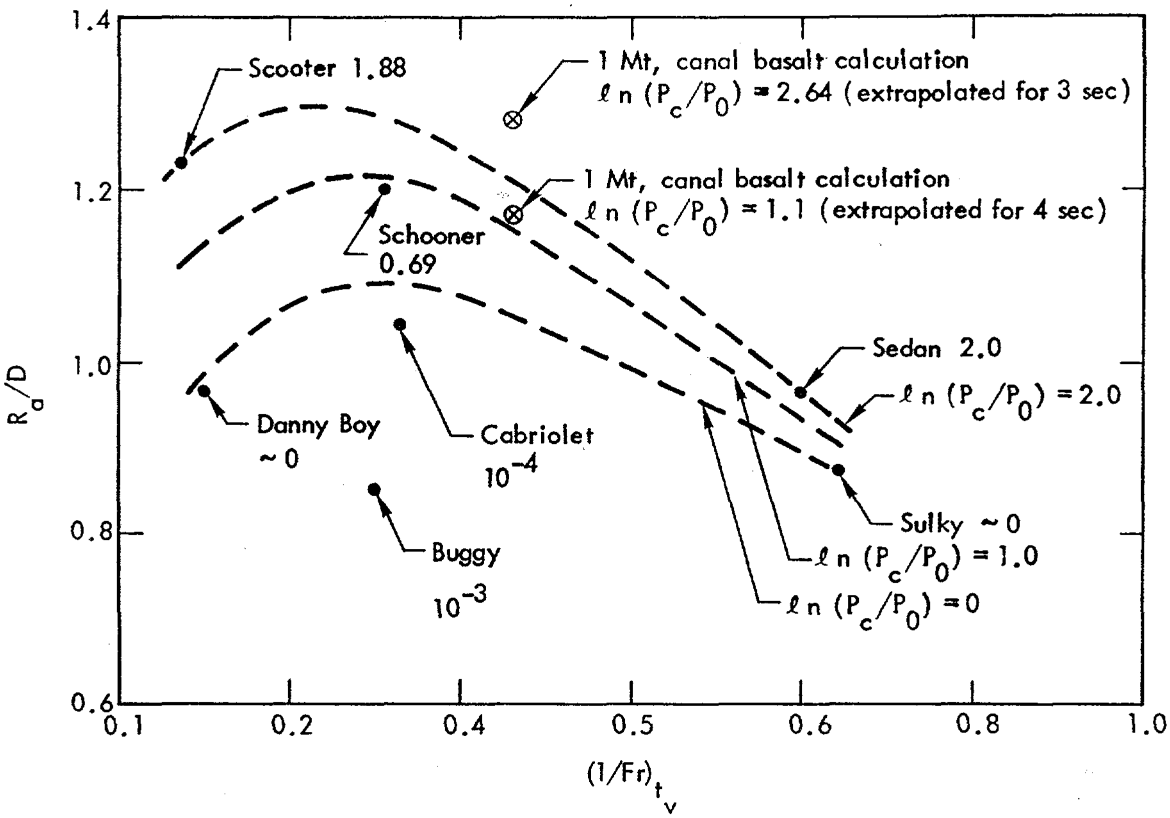

Fig. 5. R_a/D versus $1/Fr$ showing isolines for equal values of $\ln (p_c/p_0)$.

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An inspection of Figs. 6 or 7 indicates that when the variable $R_b/2R_a$ is plotted in two dimensions as a function of the equivalent Froude number and the cube root scaled depth of burial that a potentially useful pattern emerges. The fact that none of the so-plotted points are in conflict with one another suggests that this empirical correlation may have predictive value.

In this section we have restricted the discussion to a means of estimating the stabilized base surge radius. Experimental data analyzed by Knox and Rohrer[10] indicated that for a given scaled DOB and shot material the base surge height in a neutral atmosphere scaled with the 0.2 power of the energy yield of the explosive. Experience gathered since 1963 indicates that if there is an atmospheric inversion within about a factor of two of height of that indicated by the 0.2 scaling, then the final base surge height corresponds closely with the inversion base. Dynamic base surge measurements performed on Schooner (to be reported later in another report) provide evidence that the base surge is a gravity flow phenomenon at early times. However, when the radial growth is completed, there probably is a residual buoyancy in the cloud that provides the lift necessary for the cloud to rise in the near adiabatic layer beneath the inversion to the inversion base.

Fraction of Gamma Emitting Radioactivity in the Close-in Fallout Field

The fraction of the gamma emitting radioactivity that appears in the close-in fallout field for several shots (Sedan 0.10, Teapot ESS, Jangle U, Neptune, Jangle S, Danny Boy and Blanca) has been previously published by the author. (The percentage of vented energy (F_c) data for the more recent shots: Cabriolet, Buggy, and Schooner is classified; since this data is used, this paper is likewise classified. Further, the classified F_c value of 0.18 for Sedan has also been used.)

Figure 8 shows a simple empirical correlation between F_c and the scaled base surge radius in a neutral atmosphere. Froude scaling enters into the determination of F_c only through estimates of R_b. The sequence of graphs contained in this paper appear to offer a means of predicting F_c in a manner that is consistent with predictions of crater dimensions, cavity pressure at vent time, and base surge radius.

Concluding Remarks

It is suggested that (a) the empirical correlations presented here have predictive value, (b) a method of making a consistent set of effect predictions for a cratering shot seems to be emerging, and (c) the scheme should be tested preshot on forthcoming events when design TENSOR calculations are available. The author believes that the predictive curves could be "firmed up" by an appropriate set of TENSOR calculations. Examples of the design and planning use of the relationship are given in the appendices.

With the present information concerning the 1 Mt Canal Basalt (1 percent H_2O) TENSOR problem, the author estimates that crater radius is 1170 ft, depth is about 450 ft, the base surge radius (neutral atmosphere) is 23,400 ft, F_c is 12 percent vented

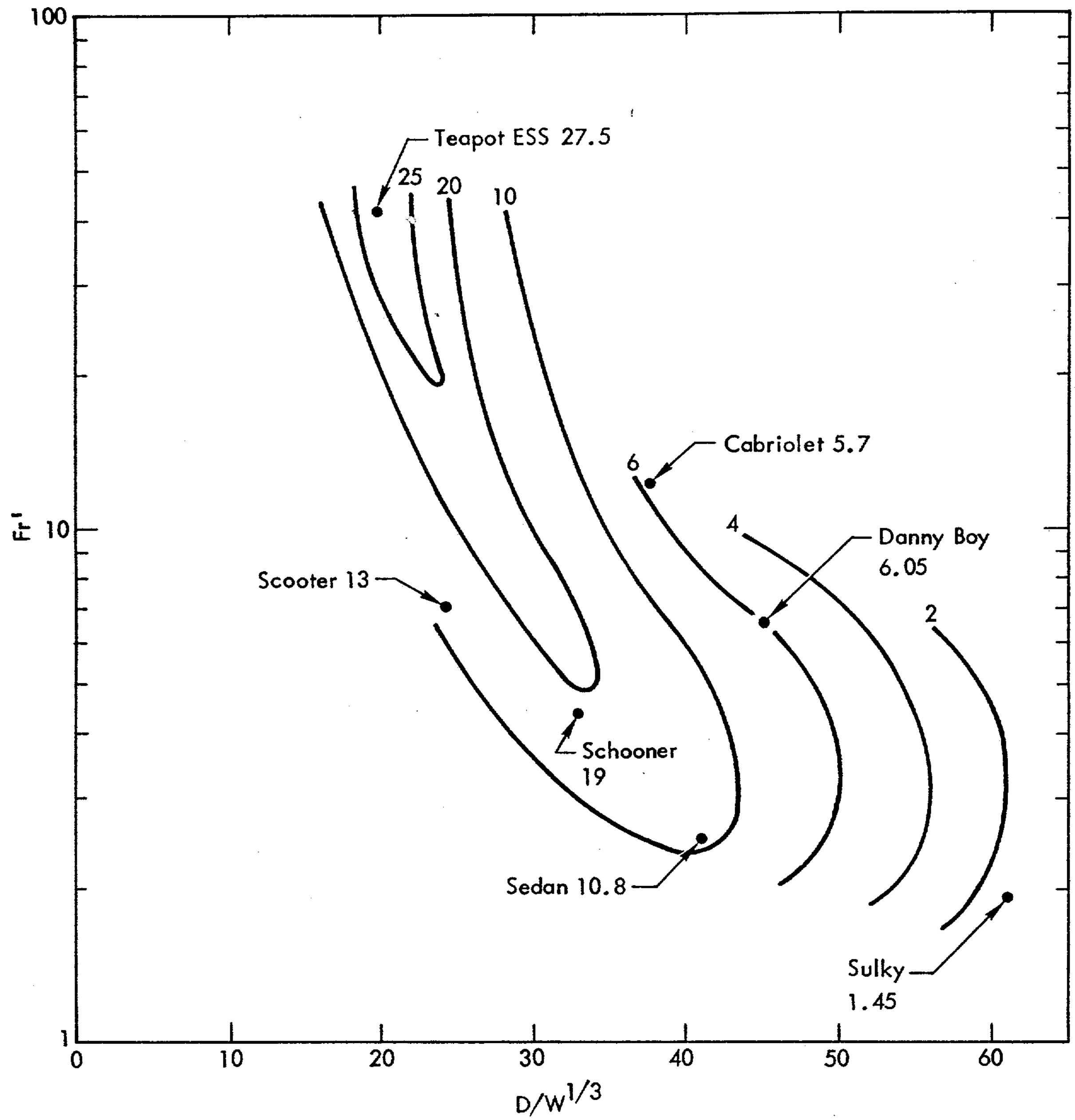

Fig. 6. $R_b/2R_a$ plotted in two dimensions as a function of the equivalent Froude number and the cube root scaled depth of burial (semi-log representation).

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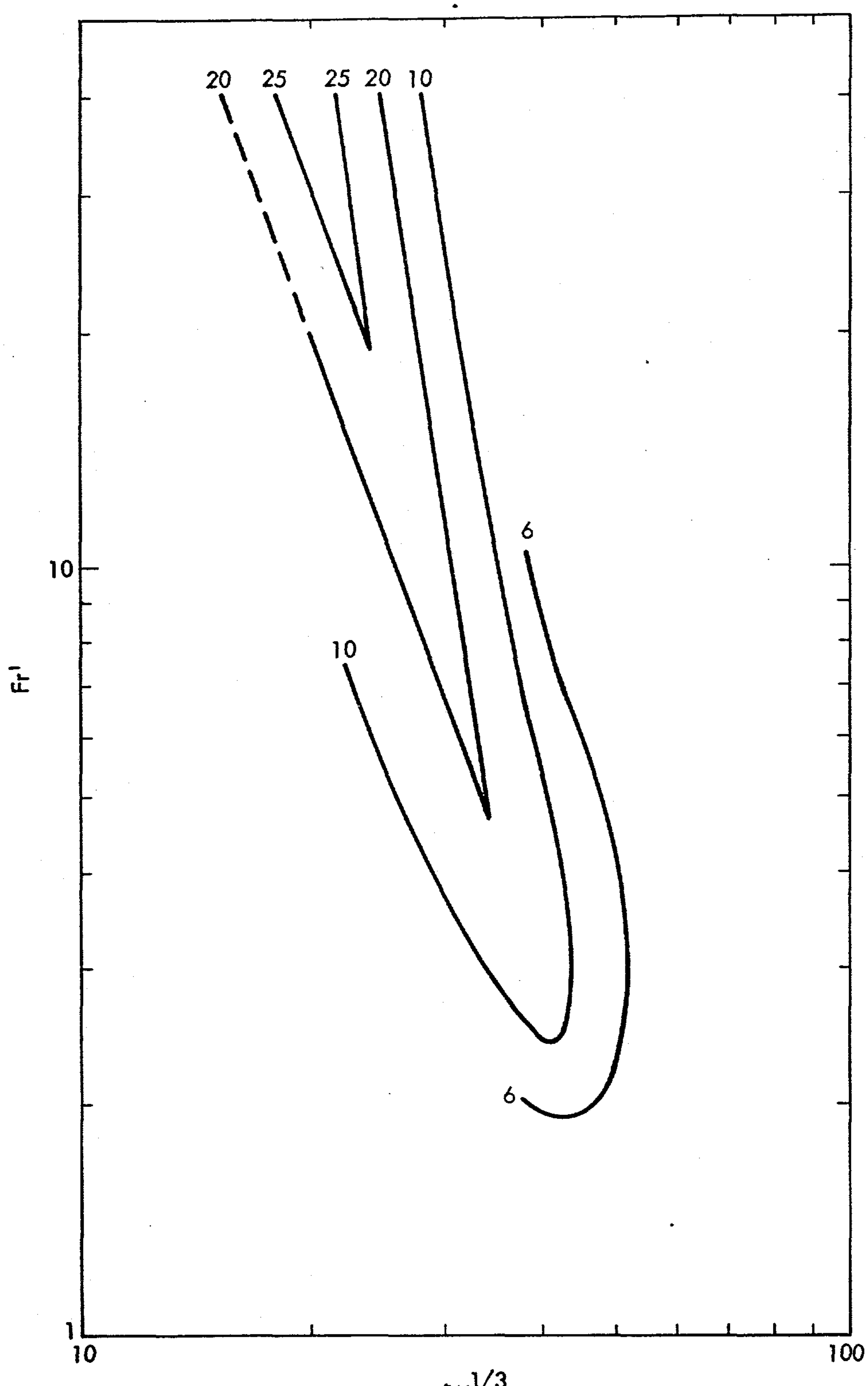

Fig. 7. $R_b/2R_a$ plotted in two dimensions as a function of the equivalent Froude number and cube root scaled depth of burial (log-log representation).

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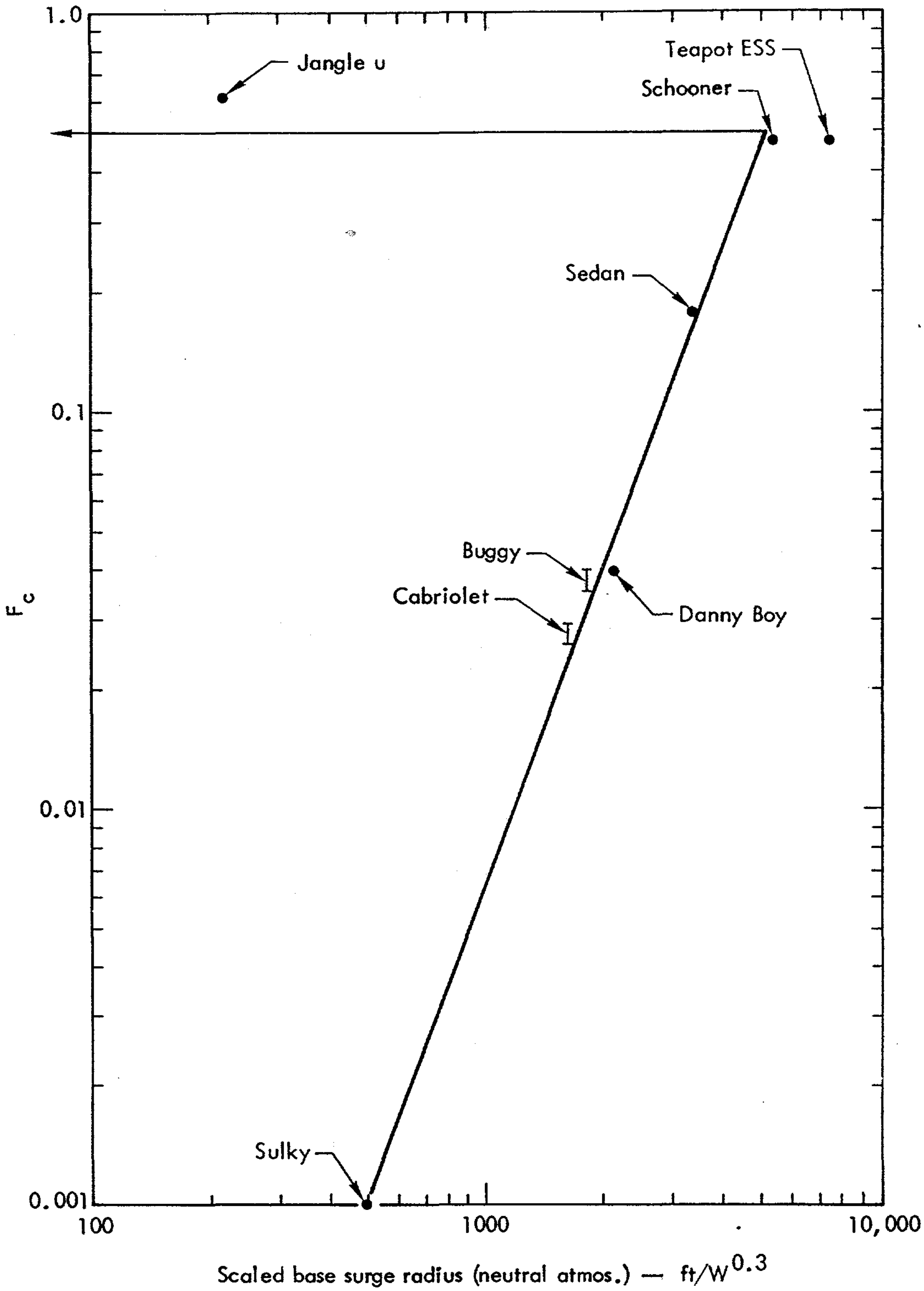

Fig. 8. Empirical correlation between F_c and the scaled base surge radius in a neutral atmosphere.

energy to air blast (gas vent) 14 kt, height of main cloud is 35,000 ft, and main cloud radius is 8000 ft.

In regard to Sturtevant, if the design TENSOR calculations indicate an equivalent Froude number of about 2 to 2.4, a shallow crater should form of depth 85 to 170 ft, radius 760 to 850 ft, base surge radius (neutral atmosphere) of 9100 to 13,600 ft, and an F_c of about 5 to 10 percent. When design TENSOR calculations are completed, the above estimates should be revised, and the main cloud and air blast effects included when $p_c(t_v)$ is available.

APPENDIX A

Design Useage 1

One possible use of the relationships described is to generate a consistent set of crater dimensions, cloud dimensions, air blast predictions, and vented fraction from a given design TENSOR calculation. The logic flow chart (or steps) are shown in Fig. A-1. It is assumed that the input from TENSOR is free surface velocity over surface velocity over surface zero and the cavity pressure at vent time, or else reasonable estimates of the same prepared from "long running" TENSOR calculations. One such problem that we may use for an illustration of the method is the 1 Mt (DOB = 1000 ft) for Canal basalt (1 percent water by weight). Tables A-1 and A-2 summarize the input and the results of the method.

Table A-1. Input at 3 seconds from TENSOR.

Velocity (m/sec)	100
p_c	29.1
Cavity volume	
Estimated to double by 6 seconds	

We estimate that (a) vent time is about 6 to 7 seconds, that (b) $p_c(t_v) = 14.0$ bars (adiabatic expansion with $\gamma = 1.05$), and that (c) velocity of free surface (central mound) ~100 m/sec.

Table A-2. Estimates for 1 Mt $\left[Fr^{-1} = 0.33\ (0.25)\ \ln (p_c/p_0) = 2.64\right]$.

	$\frac{1}{Fr} = 0.33$	$\frac{1}{Fr} = 0.25$	Remarks
R_a/D	1.14	1.20	
R_a	1240	1340	(From Fig. 5)
D_a/D	0.62	0.74	Assuming no bulking
D_a (ft)	580	710	Assuming 10% bulking
$R_b/2R_a$	20	20	
R_b	49,600	53,600	
SR_b (ft)	6,240	6,740	
F_c (%)	50	50	
Vented energy (kt)	33	33	
Main cloud height 38,000 ft			p. 36 Glasstone (1962)
Main cloud height 9,000 ft			p. 36 Glasstone (1962)

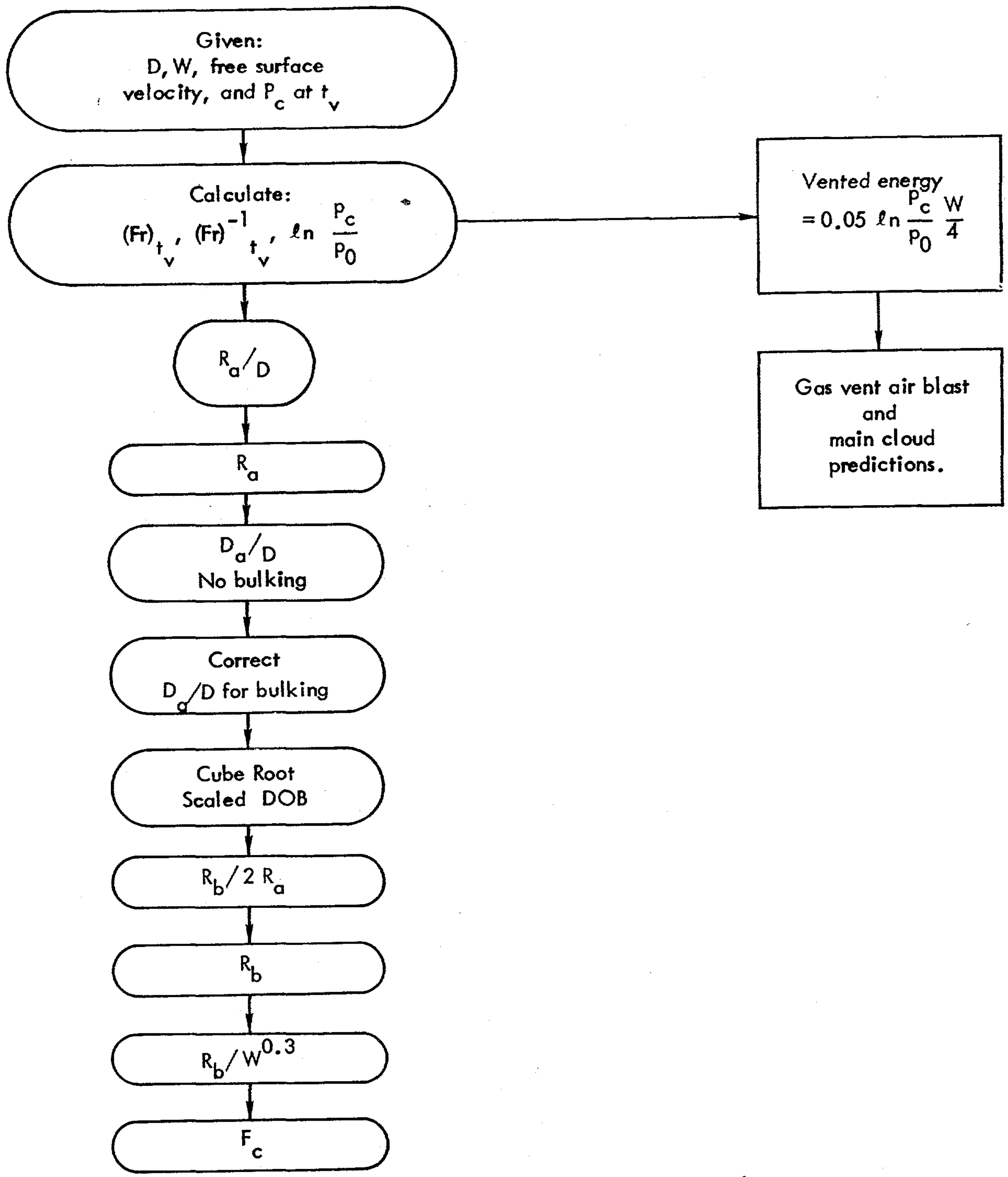

Fig. A-1. Logic flow chart for design usage (TENSOR available).

This TENSOR problem, at the time of writing this report, has been run to 3 seconds. It should be noted that we have extrapolated the mound growth in time in order to estimate the cavity pressure at the approximate time-of-vent of 6 sec. The Froude number was not so extrapolated; we shall now attempt this in order to ascertain the sensitivity of the above effects estimates to the Froude number.

In this regard, it is reasonable to expect that the reciprocal of the Froude number, as determined by SZ velocity, would be about 0.25 at 6 sec in the previously cited TENSOR calculation. If we repeat the calculations for $1/Fr = 0.25$, we obtain the results shown in the second column of Table A-2. It is clear that crater dimensions and other variables of interest are relatively insensitive to changes in the Froude number, in the vicinity of $Fr = 3$ to 4, and $\ln (p_c/p_0) \simeq 2$.

It is of interest to estimate the sensitivity of the prediction method to ending time of the TENSOR problem. We now have data from the 1 Mt Canal Basalt TENSOR problem that indicates that at 4 seconds the near-surface mound velocity is 100 m/sec (as before); however, the cavity pressure is 11.5 bars. An extrapolation of this cavity pressure to 6 seconds indicates at cavity pressure (at 6 sec) of about 3 bars, or $\ln (p_c/p_0) = 1.1$. Table A-3 shows the predicted variables with this input. In comparing Table A-3 to A-2, it is clear that the predicted base surge radius, F_c, and vented energy are very sensitive to the estimate of p_c at vent time. Long-running TENSOR problems appear to be a requirement in order to estimate R_b, F_c and main cloud dimensions.

Table A-3. Estimates for 1 Mt $\left[Fr^{-1} = 0.33 \ \ln (p_c/p_0) = 1.1\right]$.

	$Fr^{-1} = 0.33$	Remarks
R_a/D	1.17	Fig. 5
R_a (ft)	1,170	
D_a/D	0.5	Assuming no bulking
D_a (ft)	450	Assuming 10 percent bulking
$R_b/2R_a$	10	
P_b	23,400	
SR_b	2,950	
F_c (%)	12	
Vented energy (kt)	14	
Main cloud height (ft)	~35,000	
Main cloud radius (ft)	~8,000	

APPENDIX B

Planning Usage

Another use of the relationships contained in this paper is in estimating the crater dimensions, cloud dimensions, and vented fractions of a planned event, before any TENSOR calculation of a design nature have been performed. The steps for doing this are shown in Fig. B-1. The results for two different DOB's for Sturtevant are summarized in Tables B-1 and B-2.

Given W = 200 kt, D = 800 ft, SDOB = 136 ft or 41 m. Try: $D_a/D = 0.3$, or $D_a = 240$ ft, $\ln(p_c/p_0) = 0$.

Table B-1. Results for pre-TENSOR-calculation estimate for Sturtevant with DOB of 800 ft.

	No bulking	10% bulking	Remarks
D_a/D	0.3	0.375	(Assumed value)
$1/Fr$	0.41	0.36	
$R_b/2R_a$	10	12	
R_a/D	0.99	1.03	(From Fig. 5)
R_a (ft)	790	823	
R_b (ft)	15,800	19,700	
SR_b (ft)	3,220	4,040	
F_c (%)	16	27	

Disclaimer: During planning stage, both of the above are equally probable. A particular option is valid only after a design TENSOR calculation verifies the assumed Froude number (equivalent).

Given: 200 kt, D = 850 ft, SDOB = 145 ft (44.5 m). Assume 10 percent bulking. Assuming $\ln(p_c/p_0)$.

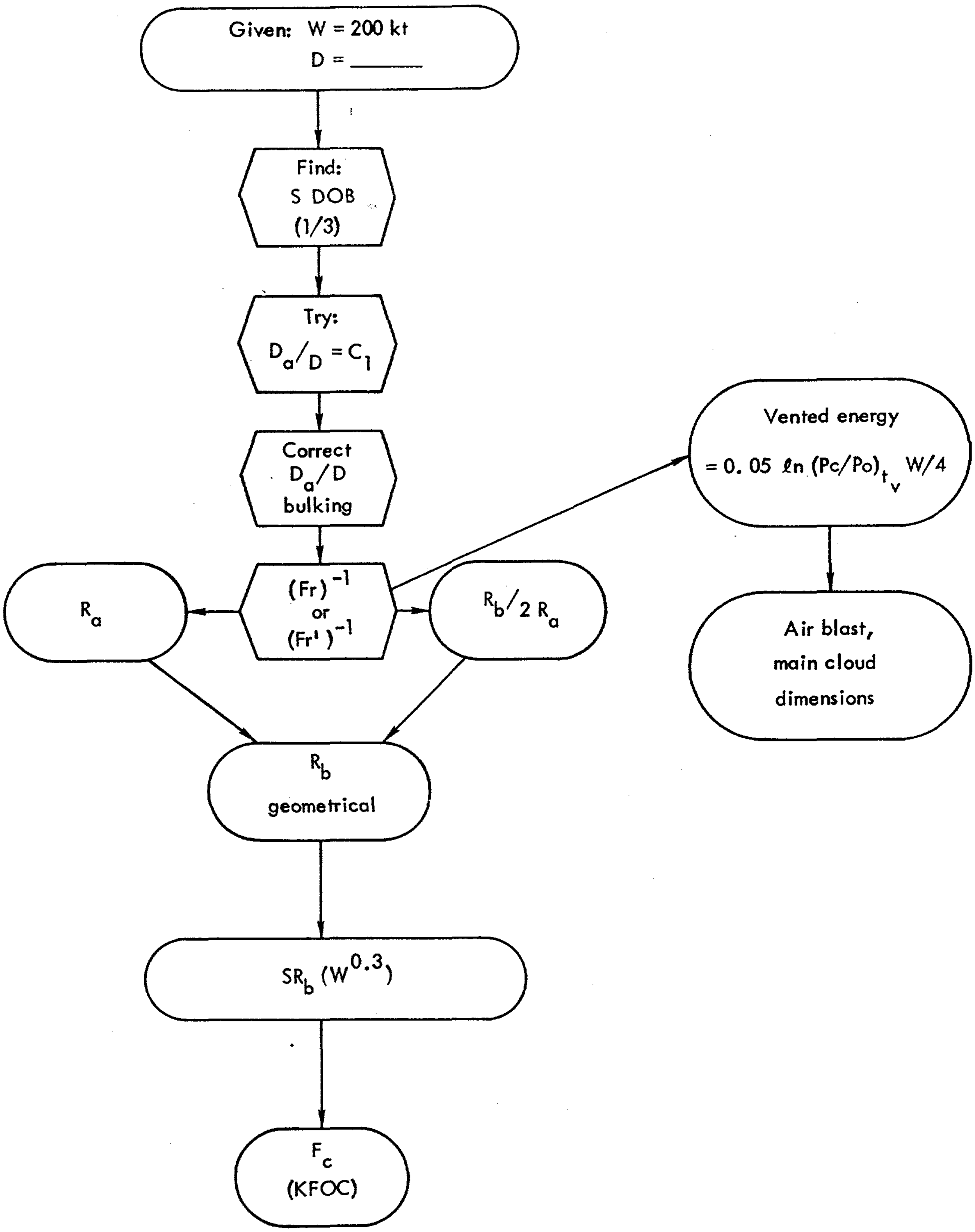

Fig. B-1. Logic flow chart for estimation of crater and cloud dimensions and vented fractions for planned events (TENSOR not available).

Table B-2. Results for pre-TENSOR-calculation estimate for Sturtevant with DOB of 850 ft.

Try No. 1		Try No. 2	
D_a/D	0.2	D_a/D	0.1
D_a	170	D_a	85
D_a/D	0.278, when corrected for bulking	D_a/D	0.19, corrected for bulking
1/Fr	1.42	1/Fr	0.48
Fr	2.38	Fr	2.08
$R_b/2R_a$	8	$R_b/2R_a$	6
R_a	850	R_a	765
R_b (ft)	13,600	R_b (ft)	9,150
SR_b (ft)	2,780	SR_b (ft)	1,870
F_c (%)	10	F_c(%)	3.5

[redacted]

REFERENCES

1. A. J. Chabai, "On Scaling Dimensions of Craters Produced by Buried Explosives," J. Geophys. Res., 70, pp. 5075-5098 (1965).
2. D. N. Montan, private communication (1968).
3. D. N. Montan, private communication (1969).
4. B. K. Crowley, work in progress (1969).
5. C. E. Chapin, private communication (1969).
6. E. Swift, Liquid Model Studies of the Base Surge, U. S. Naval Ordanance Laboratory, White Oak, Md., Rept. NOLTR-62-191 (1962).
7. J. Pokrovskiy, Explosion, Lawrence Radiation Laboratory, Livermore, Rept. UCRL-Trans-10140 (1967).
8. J. Toman, Summary of Results of Cratering Experiments, Lawrence Radiation Laboratory, Livermore, Rept. UCRL-71456 (1969).
9. D. N. Montan, Source of Air Blast from an Underground Explosion, Lawrence Radiation Laboratory, Livermore, Rept. UCRL-71202 (Summary)(1968).
10. J. B. Knox and R. Rohrer, "Base Surge Analysis," Project Pre-Buggy Final Report, USAEC Rept. PNE-304 (1963).

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