DEPARTMENT OF DEFENSE
OFFICE OF FREEDOM OF INFORMATION
1155 DEFENSE PENTAGON
WASHINGTON, DC 20301-1155

NOV 15 2007

Ref: 03-F-1599
DTRA FOIA Case
Numbers 00-082
01-334

Mr. John Greenewald, Jr.

Dear Mr. Greenewald:

This is in response to your December 6, 1996 Freedom of Information Act (FOIA) request to the Defense Technical Information Center (DTIC), which was transferred to the Defense Threat Reduction Agency (DTRA). Because the record that you requested potentially concerns weapons of mass destruction or could be related to homeland security, DTRA forwarded it to this Office for review on June 5, 2003. The enclosed document is responsive to your request, for the document, "AD 341071, Fireball Yields (U)". Additionally an information sheet provided by the Department of Energy (DOE) is also enclosed.

Mr. Jeffrey A. Zarkin, Director, Document Declassification Division, Office of Classified and Controlled Information Review, Office of Security, Department of Energy, and Ms. Sandy Ford, Deputy, Freedom of Information Act / Privacy Act Officer, Defense Threat Reduction Agency, have determined that the release of portions of this document must be denied pursuant to 5 USC § 552(b) (3), which applies to information specifically exempted by a statute establishing particular criteria for withholding. In this instance, the statute is 42 USC 2162(a) which provides withholding of Restricted Data under the Atomic Energy Act of 1954, as amended. Accordingly, this information is denied pursuant to 5 USC § 552 (b)(3).

If you are dissatisfied with this action you may submit an appeal to this Office, by writing to James Hogan, Chief, Policy, Appeals and Litigation Branch, Office of Freedom of Information, 1155 Defense Pentagon, Washington, D.C. 20301-1155. Your appeal letter should be postmarked within 60 calendar days of the date of this letter and should cite case number 03-F-1599. Inasmuch as this completes the processing of your request, I am closing your file in this Office. There are no fees associated with this response.

Sincerely,

Paul J Jacobsmeyer

for Will Kammer
Chief

Enclosures:
As stated

Enclosure 2

SAA 200138730000
01SA20C000018-BH

Information for Requester

Pursuant to Title 10, Code of Federal Regulations, section 1004.6 (10 CFR 1004.6), the Office of Nuclear and National Security Information (ONNSI) in the Department of Energy (DOE) has completed its review of the document responsive to your request. This document, located in the files of the Defense Threat Reduction Agency, contains classified information; therefore, it is provided to you with deletions.

Title 5, United States Code, section 552(b)(3) (5 U.S.C. 552(b)(3)) (exemption 3), exempts from disclosure information "specifically exempted from disclosure by statute (other than section 552(b) of this title), provided that such statute (A) requires that the matters be withheld from the public in such a manner as to leave no discretion on the issue, or (B) establishes particular criteria for withholding or refers to particular types of matters to be withheld . . . ." The Atomic Energy Act (AEA) of 1954, as amended, 42 U.S.C. 2011 et seq., is an exemption 3 statute. Sections 141-146 of this Act (42 U.S.C. 2161-2166) prohibit the disclosure of information concerning atomic energy defense programs that is classified as Restricted Data (RD) pursuant to the AEA. The portions deleted from the subject document pursuant to exemption 3 contain information about weapon design that has been classified as RD. Disclosure of the exempt data could jeopardize the common defense and the security of the nation.

To the extent permitted by law, the DOE, pursuant to 10 CFR 1004.1, will make available records it is authorized to withhold under the Freedom of Information Act (FOIA) whenever it determines that such disclosure is in the public interest. With respect to the information withheld from disclosure pursuant to exemption 3, the DOE has no further discretion under the FOIA or DOE regulations to release information currently and properly classified pursuant to the AEA.

Pursuant to 10 CFR 1004.6(d), Mr. Finn K. Neilsen, Acting Director, ONNSI, is the official responsible for the denial of the DOE classified information.

Pursuant to 10 CFR 1004.8, the denial of a FOIA request may be appealed, in writing, within 30 days after receipt of a letter denying any portion of the request, to the Director, Office of Hearings and Appeals, Department of Energy, 1000 Independence Avenue, SW., Washington, D.C. 20585. The written appeal, including envelope, must clearly indicate that a Freedom of Information appeal is being made, and the appeal must contain all other elements required by 10 CFR 1004.8. If other agencies have denied information within this response, DOE will coordinate the appeal with those agencies. Judicial review will thereafter be available to you in the District of Columbia or in the district where: (1) you reside, (2) you have your principal place of business, or (3) the Department's records are situated.

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AD341071

SAC200157030000

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Fireball Yields (U)

LOS ALAMOS NATIONAL LAB NM

17 AUG 1959

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AD 341071L

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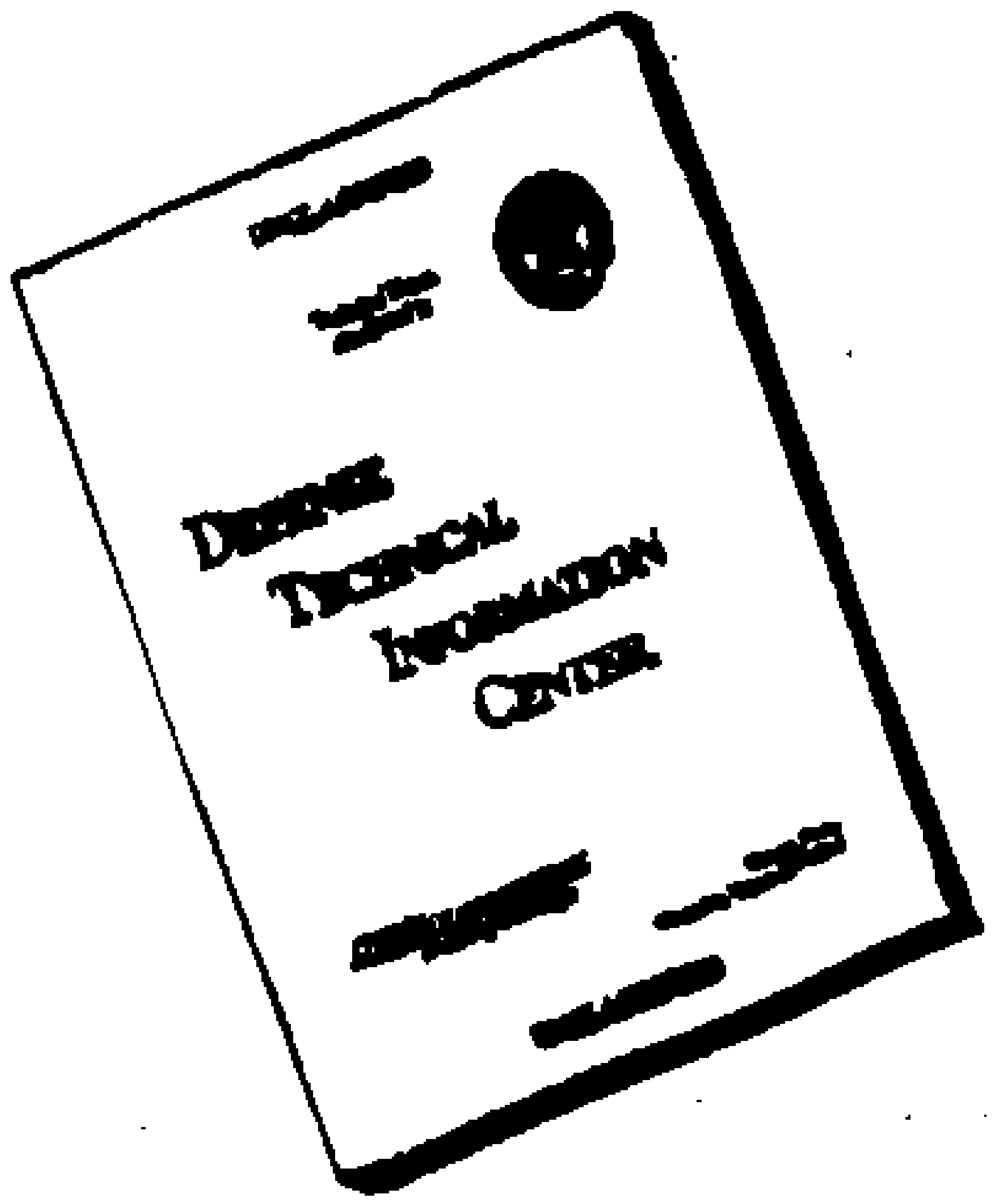

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ATOMIC ENERGY ACT 1954

Report to the Scientific Director

FIREBALL YIELDS

By

J. F. Mallaney, L. N. Blumberg, R. D. Cowan,
L. Gatz, H. Hoerlin, and T. L. Jordan, Jr.

Los Alamos Scientific Laboratory
Los Alamos, New Mexico

August 27, 1959

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~~ATOMIC ENERGY ACT 1954~~

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DEPARTMENT OF ENERGY DECLASSIFICATION REVIEW

1ST REVIEW-DATE: 01/26/2001	DETERMINATION [CIRCLE NUMBER(S)]
AUTHORITY: ☐AOC ☒ADC ☐ADD	1. CLASSIFICATION RETAINED
NAME:	2. CLASSIFICATION CHANGED TO:
2ND REVIEW-DATE:	3. CONTAINS NO DOE CLASSIFIED INFO
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NAME:	5. CLASSIFICATION CANCELLED
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	7. OTHER (SPECIFY): DOE INFO CRD

ABSTRACT

The yields for the Los Alamos Scientific Laboratory shots of Operation Redwing have been calculated from fireball diameter–time data using several related methods. The yield numbers obtained from these calculations are presented in the following table, and a yield is recommended for each shot.

FIREBALL YIELDS IN KILOTONS

Shot	Differential method II	Mach-number scaling	EG&G ϕ^5 method*	Recommended fireball yield
Lacrosse	42.0 ± 2.9	41.9	43.9 ± 2.2	42.0 ± 2.0
Cherokee			4200 ± 220	4000 ± 400
Erie	14.2 ± 1.0	15.8	13.9 ± 0.8	15.0 ± 1.0
Flathead	346 ± 24	361	360 ± 18	365 ± 15
Blackfoot	7.44 ± 0.65	8.2	8.3 ± 0.4	8.0 ± 0.5
Osage	1.73 ± 0.12	1.83	1.6 ± 0.1	1.7 ± 0.1
Dakota	1050 ± 70	1050	1000 ± 50	1100 ± 80
Navajo	4500 ± 320	4570	4430 ± 220	4500 ± 200
Huron	252 ± 17	258	252 ± 13	250 ± 15
	Differential method I	Integral method I		
Seminole	12	14	≥8 ≤15 ± 2	12 ± 2.5

*Obtained by Edgerton, Germeshausen, & Grier, Inc., and reported in EG&G Report 1677.

ACKNOWLEDGMENTS

The assistance at the Pacific Proving Ground of the following members of the Los Alamos Scientific Laboratory Theoretical Division is gratefully acknowledged: D. H. Bradford, J. J. Devaney, P. E. Harper, C. E. Kasak, Jr., and A. M. Lockett III. Yield computation was done at Los Alamos with the assistance of Nancy D. Brown, Roslyn E. Eisenberg, and Nancy M. Waddell.

CONTENTS

ILLUSTRATIONS

DOE b(3)

released here, withheld in Two pages (P.7-8)

FIREBALL YIELDS

Yields have been calculated for the 10 Los Alamos Scientific Laboratory (LASL) shots of Operation Redwing from fireball radius-time data. These data were obtained by Edgerton, Germeshausen, & Grier, Inc. (EG&G) with high-speed motion-picture photography. Zero-frame time was determined by comparing the fireball diameters obtained from the motion-picture film with the diameter-time curve given by the Rapatronic pictures.

The principal method used to calculate yield for Operation Redwing was the method of Bethe and Fuchs,[1] in the form called "differential method II," developed by Blumberg.[2] In this method, which uses the IBM 704 computer, the yield E is given by

$$E = \frac{4\pi}{3} R^3 \rho \left(\frac{dR}{dt}\right)^2 \frac{\gamma}{2(\gamma-1)} \frac{1}{f(R)} \tag{1}$$

where R is the shock radius at time t, ρ is the ambient density of air, γ is the ratio of specific heats within the fireball, and

$$f(R) = \frac{1 + 3\,(R_0/R)^3 \ln (R/\bar{R})}{\left[1 + (R_0/R)^3\right]^2} \tag{2}$$

Equation 2 is the mass term in which the constant R_0 is the radius of that sphere of ambient air which weighs the same as the excess mass, and $\bar{R}$ is the logarithmically averaged distance of the mass from the center of the explosion. This method of treating mass assumes that it is distributed with spherical symmetry about the center of the explosion. However, the actual distribution of the mass, particularly in large shots with big shields, is far removed from spherical symmetry.

The calculation of yield developed by Blumberg[2] includes a method of estimating values of $\bar{R}$ and R_0 to be used in the mass term (Eq. 2) by varying $\bar{R}$ and R_0 until the yield over a large range of the shock radius R becomes most nearly constant. As noted on page 21 of reference 2, the amount of mass given by this procedure does not always agree with the amount of mass known to be present in a simple situation such as an explosion of an airdropped spherically symmetric weapon.

For a surface shot the radius of the hemispherical fireball was measured. The radius-time data were used in the various expressions for yield, and the yield thus obtained was multiplied by one-half to take into account the effect of the surface.

At Eniwetok, in the absence of computing-machine facilities, a desk calculator was employed to figure the yields and a simplified method (called "differential method I") based on Eq. 1 was used. In this method the fireball radius R was plotted vs time, as given by EG&G, and the velocity dR/dt was determined graphically. The reciprocal of the quantity $(\gamma-1)/\gamma$ in Eq. 1 had been determined empirically as a function of Mach number of the shock wave through use of the known radiochemical yield of certain airdrop bursts in previous operations. A plot of the curve used is presented as Fig. 1. Yields at various times in the fireball growth were determined by substituting in Eq. 1 the fireball radius R at the time t, the velocity dR/dt determined graphically, the quantity f(R) obtained after calculating R_0 and $\bar{R}$, and the quantity $(\gamma-1)/\gamma$ from Fig. 1 corresponding to the Mach number [dR/dt]/c, where c is the velocity of sound in ambient atmospheric air.

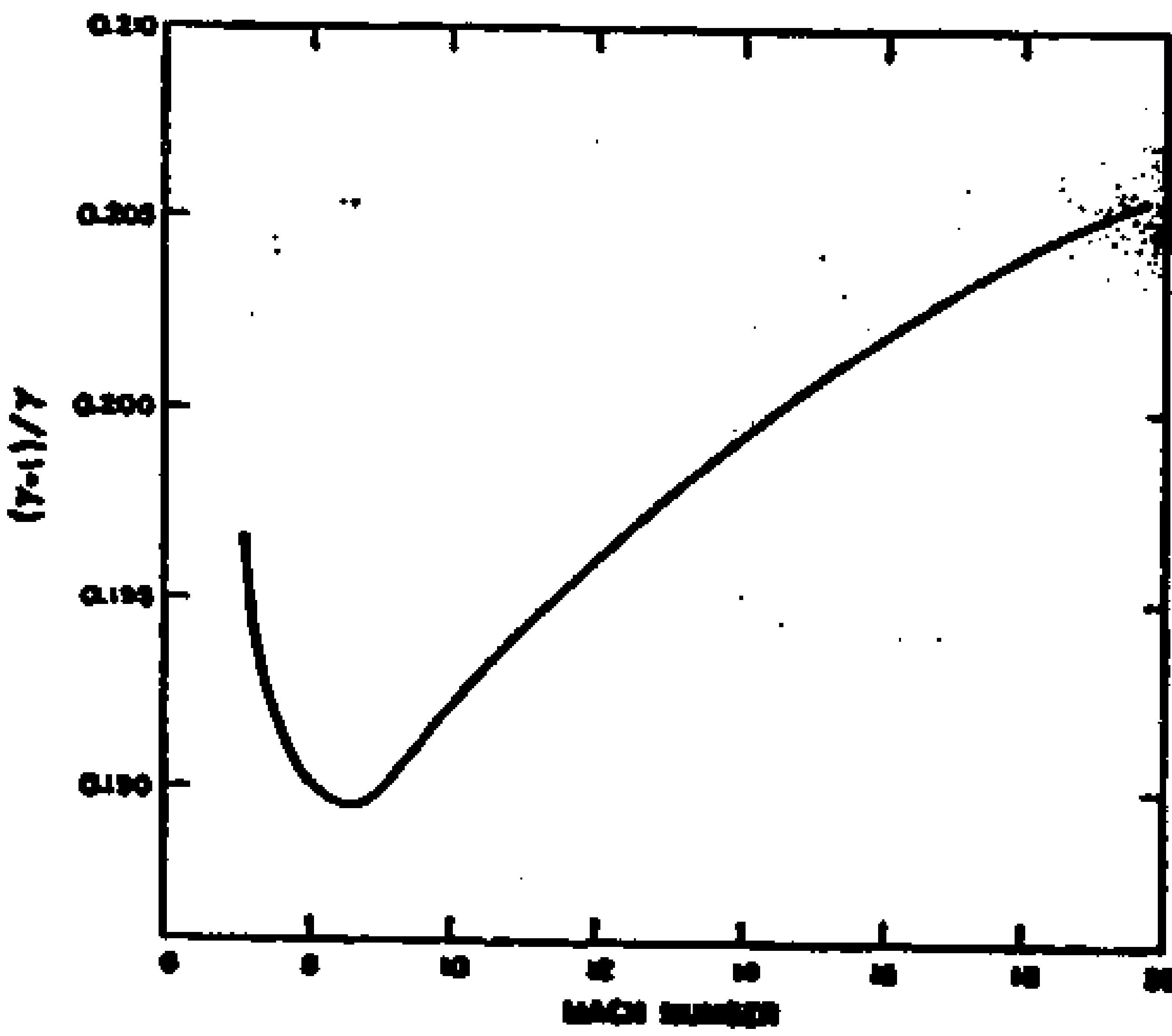

Fig. 1—Empirical $(\gamma-1)/\gamma$ vs Mach number of shock wave.

A second method[3] used in the field (called "integral method I") was developed early in 1954, and, although it was developed independently, it is essentially the method described by Fuchs in Eq. 34 of reference 1. In this method the yield E in kilotons is given by the expression:

$$E = 4.16 \times 10^{-4} \rho \left(\frac{R^5}{t^2}\right) F\left(\frac{R}{R_0}, \frac{R_1}{R}\right) \qquad (3)$$

where ρ = ambient air density (g/liter)

R = fireball radius (meters) at time t

t = time (msec)

$$F\left(\frac{R}{R_0}, \frac{R_1}{R}\right) = \frac{25}{4Z^5} \left\{\int_0^Z \frac{(Z^3+1)\,dZ}{[Z^3 + 3\ln(ZR_0/R)]^{1/2}}\right\}^2$$

$$Z = \frac{R}{R_0}$$

R_0 and $\bar{R}$ have the same meaning as before.

The integral involved in this method was calculated numerically before the operation using the IBM 701 computer at Los Alamos. Tables were prepared giving F as a function of Z for various values of the ratio $R_s/\bar{R}$. The lower limit of integration was taken to be a small nonzero value. The method described in reference 1 differs slightly from integral method I, which was developed without knowledge of Fuchs's previous work.[1]

The principal use of differential method I and integral method I was to give a preliminary yield with consideration of mass for field use. The only yield figures given in this report obtained by using these methods are for Seminole shot.

An additional method used in obtaining yields is Mach-number scaling, developed by Porzel,[4] Grier,[5] and others. In this method, used principally to provide continuity with past operations and to provide a check, the radius R of the fireball is determined at a Mach-number

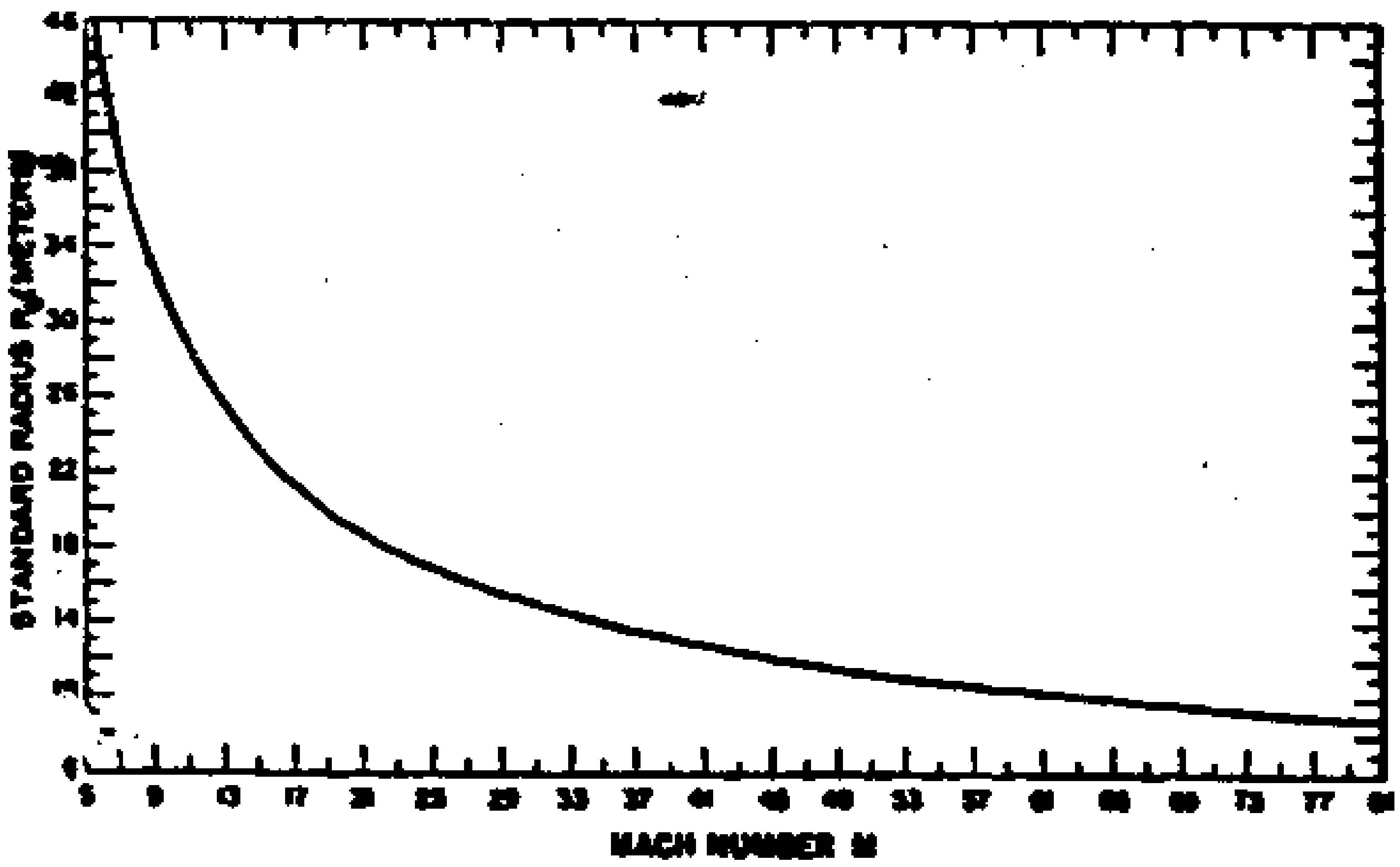

Fig. 2—Radius vs Mach number for standard 1-kt shot. Atmospheric pressure is 1000 mb.

$M = (dR/dt)/c$. The yield is then obtained by scaling to a shot of known radiochemical yield W_0 through the relation

$$\frac{W}{W_0} = \frac{P}{P_0}\left(\frac{R}{R_0}\right)^3_{\text{same } M}$$

where P is the ambient atmospheric pressure and the subscript zero refers to the shot of known yield. To make scaling easier, R_0 (meters) vs M was determined for $W_0 = 1$ kt and pressure $P_0 = 1000$ mb. Figure 2 is a plot of R_0 vs M obtained by F. B. Porzel, D. F. Seacord, Jr., and E. G. Snyder,[6] using results of IBM Problem M reduced to 1 kt and the observed radii and radiochemical yields of several shots, also reduced to 1 kt.

The method used by EG&G to determine yield is the familiar ϕ^5 method used since Operation Ranger. The yield (W) in kilotons is given by

$$W = 1.272 \times 10^{-9} \rho \phi^5$$

where ρ = ambient air density (g/liter)

$\phi = D/t^{0.4}$

D = fireball diameter (meters)

t = time (msec)

DOE b(3)

1 [redacted]

[redacted]-time data were obtained from nine Eastman high-speed cameras, three each on Runit, Piiraai, and Parry. The Piiraai and Runit stations were on opposite sides of the fireball and saw approximately the same profile of the fireball. Because of construction in the foreground, there was some difficulty in establishing the positions of the bottom of the fireball at early times; this is particularly true for the Runit films, which were obtained from cameras at low elevation. The initial field readings of the films gave average radii about 1 per cent lower at a given time than did the final readings because of difference in assignment of the ground position; as a consequence the yields reported in the field were about 3 per cent lower than those reported here.

The effect of the mass of shields, pipes, etc., on fireball growth was apparent. The horizontal radius of the fireball was slightly greater than the vertical radius. Also, the cross section of the fireball as seen from Parry Island was slightly smaller than the cross section seen from Piiraai and Runit. The hypothetical mass given by the procedure of differential method II indicated that 88,200 lb was appropriate.

The yields obtained are

Differential method II	42.0 ± 2.0 kt
Mach-number scaling	41.3 kt
EG&G ϕ^5 method[7]	43.9 ± 2.2 kt
Recommended fireball yield	42.0 ± 2.0 kt

The meteorological data are

Pressure	1008.0 mb
Temperature	27.2°C
Air density	1.157 g/liter

2 [redacted]

DOE b(3)

Four photographic stations had been set up by EG&G to obtain data, but, since the actual position of the burst was a great distance from the predicted position, three of the four stations did not see the fireball, and the fourth station (1519 on Bokolyaadas Island) obtained off-center pictures in two cameras. These two cameras were a 35-mm Fastax running at about 900 frames per second and containing film No. 33,264 and a 16-mm Fastax running at about 2000 frames per second and containing film No. 33,263. Owing to the difference between the actual and the intended burst positions, the images of the fireball were displaced from the center of the frame, and it was necessary to take into account the lens distortion existing for this off-axis positioning.

The distance between the airburst and station 1519 is not known exactly; as a result, a small uncertainty must be associated with the magnification factors of the two cameras. An estimate[5] of this uncertainty was made in the field, and it was found to be ±1 per cent in magnification factor and ±5 per cent in yield. The magnification factors calculated by EG&G[8] are based on the burst position (I), as follows:

*Marshall Islands dates and times are used throughout this report.

N 185,450 ft
E 96,300 ft
Z 4320 ft

A slightly different burst point was obtained by a Los Alamos survey of the data. This burst position (II) has the following coordinates:

N 185,100 ft
E 96,200 ft
Z 4320 ft

Magnification factors were also calculated for burst position II. Fireball diameters obtained using the latter magnification factors were about 1 per cent smaller than those obtained by EG&G, and the yield was about 5 per cent less.

In view of the uncertainties introduced by lens distortion and lack of knowledge of exact burst position and meteorological conditions, it was considered meaningless to use methods of calculating yield other than the ϕ^5 method. The yields obtained are

EG&G ϕ^5 method[10] (burst position I)	4.18 ± 0.21 Mt
EG&G ϕ^5 method (burst position II)	4.0 ± 0.3 Mt
Recommended fireball yield	4.0 ± 0.4 Mt

The air density at burst point was estimated to be 1.04 g/liter.

[redacted] A moderate amount of mass in the form of shields and cab construction was associated with this shot. DOE b(3)

Twelve films from high-speed Eastman cameras were obtained for this shot, three each from Runit, Mack, Piirai, and Parry. Although the films from Runit were badly fogged by radiation, they gave images that could be read. The films from the Runit and Parry stations, which saw approximately the same fireball profile, gave radii somewhat larger than those from Mack and Piirai islands. In differential method II, the data from all 12 films were used. In the ϕ^5 method, EG&G used data from nine films, omitting the data from the Parry station.

The mass-estimating procedure indicated that a hypothetical mass of 33,500 lb should be used in the calculation.

The yields obtained are

Differential method II	14.2 ± 1.0 kt
Mach-number scaling	15.8 kt
EG&G ϕ^5 method[11]	15.9 ± 0.8 kt
Recommended fireball yield	15.0 ± 1.0 kt

Meteorological data are

Pressure	999.4 mb
Temperature	28.5°C
Air density	1.151 g/liter

[redacted] the device was shielded by being placed within a large tank of water, as shown in Fig. 3. The tank was a 50-ft-diameter cylinder filled to a depth of 25 ft. The device was placed in an air-filled chamber within the tank. The total weight of water was 2,900,000 lb.

Ten films were obtained to give data on the size of the fireball as a function of time. Three Eastman high-speed cameras were located at each of three stations: Parry, Engebi, and Mack, and one camera was operated at Bogallua.

The pictures (Figs. 4 to 6) showed an irregularly-expanding mass of material, with no

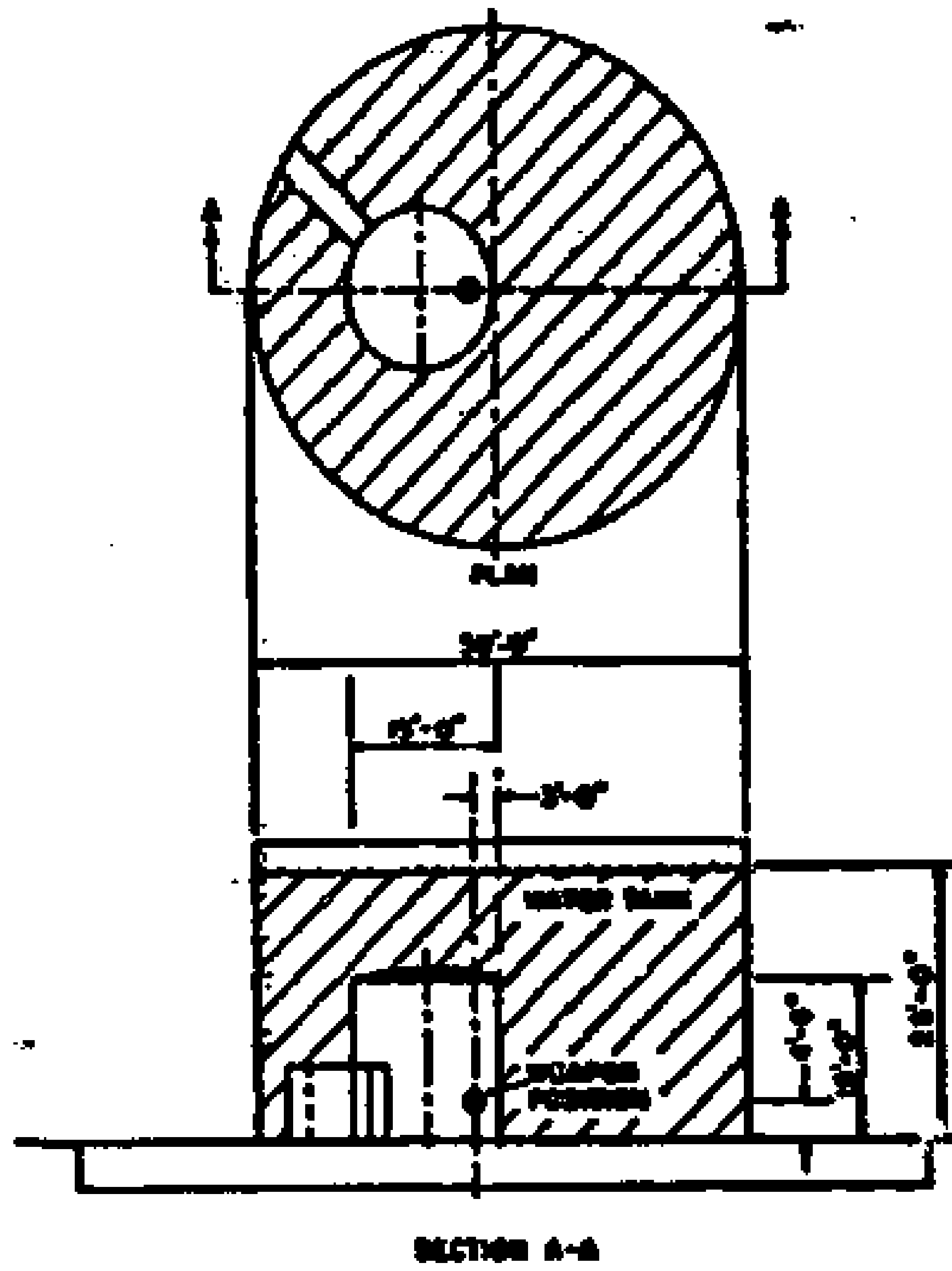

Fig. 3—Water-tank shield for Seminole shot. The passageway to the weapon chamber was filled with water at shot time. Total weight of water was 2,900,000 lb.

clear-cut shock wave emerging. In the field, EG&G examined[12] one film from each of the four stations. The diameter of a half-circle having the same area as the irregular cross section of the fireball was determined by EG&G; these diameters as a function of time are the bases of the yield numbers given in this report.

At a later time the pictures on all 10 films were reexamined[12] by EG&G with the purpose of measuring the diameter of the roughly semicircular portion beneath the irregularly shaped material, and not the dimension of the total disturbed material. The diameters given through this reexamination were somewhat smaller than those given in the field. On the basis of this reexamination, EG&G concludes that the shot Seminole yield was not less than 8 kt.

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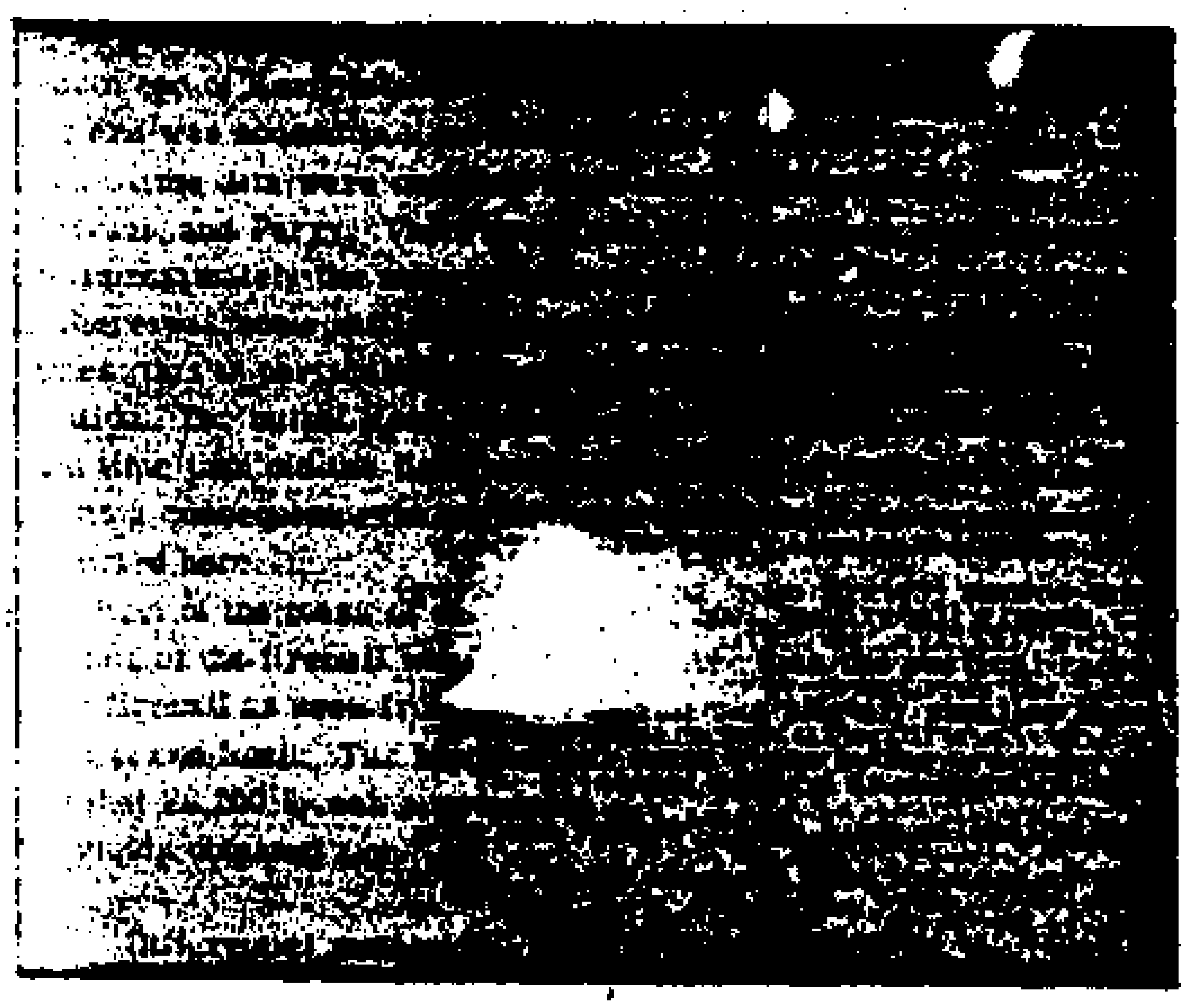

Fig. 4—Seminole fireball at 2.84 msec as seen from Mack tower.

Fig. 5—Seminole fireball at 14.7 msec as seen from the photostation on Engebi.

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Fig. 6—Seminole fireball at 16.9 m ... as seen from Mack tower.

Using the diameter-time data obtained in the field, yields were calculated by differential method I and by the integral method. Various amounts of mass were included in the mass term. The following tabulation gives the mass considered and the yield obtained.

Excess mass, lb	Yield, kt	
	Differential method I	Integral method I
2,570,000	12.2 ± 1.7	12.7
3,130,000	12.1 ± 1.4	14.2
3,350,000	12.0 ± 1.3	14.4

The moderately good consistency of the numbers in ... tabulation has led to the conclusion that a fireball yield of 13 kt with 20 per cent probab... ...er can be given on the basis of the field measurement of the dimension of the irregularly ...ged material.

The yields obtained are

Differential method I	12 kt
Integral method	14 kt
EG&G method[11]	≥[illegible] t
EG&G method[13]	≤15 ± 2 kt
Recommended fireball yield	13 ± 2.5 kt

The meteorological data are

Pressure	1010.5 mb
Temperature	30.9°C
Air density	1.145 g/liter

5 [redacted] b(3)

[redacted] No large amount of shielding was used on this shot.

Seven films giving radius-time data were obtained for this shot. There were three Eastman films from Aomoen, one Fastax film from Chieerete, and two Eastman films and one Fastax film from Enyu. The pictures showed the fireball to be symmetric, with no jets or bulges other than the small protuberance on top which is characteristic of large-yield barge shots.

The hypothetical mass given by the estimating procedure was 84,500 lb; the yield calculated using this mass was 376 kt. On the basis[3] of experience (Fig. 7) using differential method

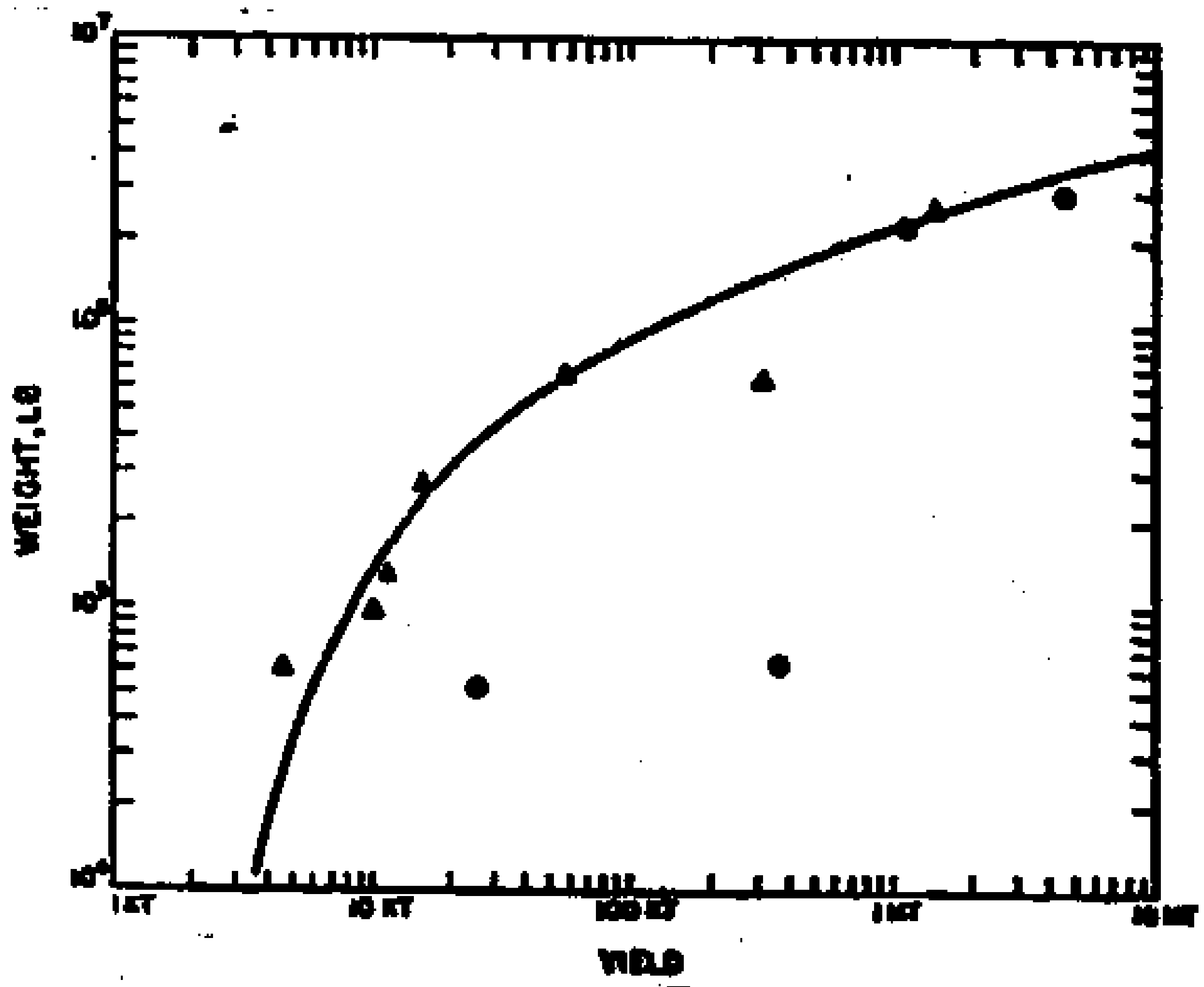

Fig. 7 —Hypothetical mass vs yield for barge shots. ▲, computed mass, Operation Hardtack; ●, computed mass, Operation Redwing.

II on barge shots in Operation Hardtack, this hypothetical mass appeared to be unreasonably small; Operation Hardtack experience indicated that 1,700,000 lb should be used. The yield calculation with this larger hypothetical mass gave a slightly lower number, which was believed to be more reliable.

The yields obtained are

Differential method II	366 ± 24 kt
Mach-number scaling	361 kt
EG&G ϕ^1 method[15]	360 ± 18 kt
Recommended fireball yield	365 ± 15 kt

The meteorological data (surface) are

Pressure	1012.9 mb
Temperature	27.8°C
Air density	1.16 g/liter

DOE b(3)

6 [redacted] Test equipment and cab construction provided some nearby mass to perturb the fireball.

Nine films were obtained for this shot, three each from Mack, Parry, and Piirnai. In using the ϕ^5 method, EG&G disregarded two of the three films from Parry. In using differential method II, these two films were included. Comparison of the resulting average radius vs time curve obtained with that given by EG&G (reference 16, page 8) shows that inclusion of these two films did not substantially change the average radius.

The pictures of the fireball showed some evidence of the presence of mass. The hypothetical mass indicated by the calculation was 75,700 lb. This amount, on the basis of experience with other tower shots of about this yield, seems high, thus making the differential method II yield somewhat low.

The yields obtained are

Differential method II	7.64 ± 0.65 kt
Mach-number scaling	8.2 kt
EG&G ϕ^5 method[16]	8.3 ± 0.4 kt
Recommended fireball yield	8.0 ± 0.5 kt

The meteorological data are

Pressure	1005.6 mb
Temperature	28.7°C
Air density	1.156 g/liter

DOE b(3)

7 [redacted]

The position coordinates of the burst are

N	102,833 ± 20 ft
E	128,669 ± 20 ft
Altitude	685 ± 20 ft

Radius-time data were obtained from six Eastman high-speed cameras, two each on Rujit and Piirnai and one each on Mack and Parry. In addition, two Rapatronic cameras produced pictures. [redacted] the mass-estimating procedure of differential method II indicated that the hypothetical mass to be used in the calculation was about 10,300 lb. This discrepancy indicates the need of the word "hypothetical."

DOE b(3)

For Osage, EG&G used a modified form of the ϕ^5 method in which scaling was done to small shots (~1 kt) of known radiochemical yield. The quantity ϕ did not become constant for Osage.

The yields obtained are

Differential method II	1.78 ± 0.12 kt
Mach-number scaling	1.82 kt
EG&G modified ϕ^5 method[11]	1.6 ± 0.1 kt
Recommended fireball yield	1.7 ± 0.1 kt

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The meteorological data are

Pressure	987 mb
Temperature	26.8°C
Air density	1.134 g/liter

8 [redacted]

Radius-time data were obtained from nine films. There were three Eastman high-speed cameras at Aomoen, two Eastmans and one 35-mm Fastax at Rujoru, and two Eastmans and one Fastax at Chieerete. The pictures showed the fireball to be symmetric, with no bulges or jets other than for the small disturbance on top.

The hypothetical mass given by the calculation was 2,250,000 lb, in good agreement with the curve used for Operation Hardtack barge shots. Recalculations were made with other mass distributions differing by several hundred thousand pounds, but the yield changed by only 1 per cent.

The yields obtained are

Differential method II	1.05 ± 0.07 Mt
Mach-number scaling	1.05 Mt
EG&G ϕ^5 method[15]	1.09 ± 0.05 Mt
Recommended fireball yield	1.1 ± 0.05 Mt

Meteorological data are

Pressure	1009.1 mb
Temperature	27.8°C
Air density	1.158 g/liter

9 [redacted]

Six films were used to give radius-time data. There were two Eastman cameras at Aomoen and two Eastmans, one Mitchell, and one Fastax at Chieerete. The fireball appeared to be symmetrical, with no bulges or jets, other than the small point on top.

The hypothetical mass given by the calculation was 2,890,000 lb. This amount is in good agreement with Operation Hardtack barge experience (Fig. 7).

The yields obtained are

Differential method II	4.58 ± 0.32 Mt
Mach-number scaling	4.57 Mt
EG&G ϕ^5 method[15]	4.41 ± 0.22 Mt
Recommended fireball yield	4.5 ± 0.3 Mt

Meteorological data are

Pressure	1010.2 mb
Temperature	27.3°C
Air density	1.159 g/liter

18 [redacted] There was no massive shielding or other structure near the weapon. Films giving radius-time data were obtained from one Mitchell and three Eastman cameras at Mack and a like number at Piiraal. The fireball showed no bulges or jets and appeared to be symmetrical.

The hypothetical mass indicated by the calculation was 52,000 lb, and the yield associated with this mass is 264 kt. Based on experience with large shots in Operation Hardtack (Fig. 7), this hypothetical mass seems small; a hypothetical mass of 1,400,000 lb would be consistent. Using this larger mass, the yield was calculated to be about 4 per cent less.

The yields obtained are

Differential method II	252 ± 17 kt
Mach-number scaling	258 kt
EG&G ϕ^3 method[20]	252 ± 13 kt
Recommended fireball yield	250 ± 15 kt

The meteorological data are

Pressure	1007.0 mb
Temperature	27.4°C
Air density	1.154 g/liter

APPENDIX RECOMMENDED FIREBALL AND RADIOCHEMICAL YIELDS

The recommended fireball and radiochemical yields for the shots of Operation Redwing are presented for comparison in the following table. The radiochemical yields are not necessarily final, and they may be modified in forthcoming reports.

Shot	Fireball yield, kt	Radiochemical yield, kt
Lacrosse	42.0 ± 2.0	37.5 ± 2.0
Cherokee	4000 ± 400	
Erie	15.0 ± 1.0	14.0 ± 0.5
Seminole	13 ± 2.5	13.7 ± 1.5
Flathead	365 ± 15	360 ± 40
Blackfoot	8.0 ± 0.5	8.2 ± 0.4
Osage	1.7 ± 0.1	1.72 ± 0.09
Dakota	1100 ± 50	1060 ± 70
Navajo	4500 ± 300	
Huron	250 ± 15	230 ± 13

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