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They also represent burst in a homogeneous sea-level atmosphere with standard ambient pressure P_o = 14.7 psi, density ρ_o = .00129 gm/cc, and temperature T_o = 273.2 °Kelvin.

Any other yield or ambient conditions are achieved by multiplying all distances by $(W/\pi)^{1/3}$ and all times by $(W/\pi)^{1/3}\tau^{-1/2}$ where W is the yield in megatons, π is the ratio of ambient pressure (P_a) to standard pressure (P_o), and τ is the ratio of ambient temperature (T_a) to standard temperature (T_o). Under this scaling the various pressure ratios will be the same, but pressures must be multiplied by π, velocities (Mach numbers) by $\tau^{1/2}$ and temperatures by τ^1.

Figure 1. is a plot of peak overpressure in atmospheres (14.7 psi) versus range in kilofeet.

Figure 2. is a similar plot of the peak dynamic pressure ($1/2\ \rho u^2$) in atmospheres versus range in kilofeet. It should be noted that the usual Hugoniot relation for an ideal gas of $\gamma = 1.4$, viz. $Q_s = \frac{5}{2}\ \frac{\Delta P_s^2}{7P_o + \Delta P_s}$ is valid only for small pressures (ΔP_s <3 atmos), and that for higher pressures the peak dynamic pressures are greater than this (characteristic of a smaller γ).

Figure 3. is a plot of particle velocity (u_s) and shock velocity (U_s) in units of ambient sonic velocity, i.e., a plot of particle and shock Mach numbers. Also plotted is the shock density (ρ_s) in units of ambient density (ρ_o) versus range in kilofeet.

Figures 4 - 21 are plots of overpressure (ΔP) in atmos, dynamic pressure (Q) in atmos, particle Mach number (U), density ratio (ρ), and temperature ratio

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U. S AIR FORCE

PROJECT RAND

RESEARCH MEMORANDUM

CLOSE-IN H-BOMB EFFECTS (U)

H. L. Brode

RM-1583-1

ASTIA Document Number AD 144275

Revised 3 February 1956 Copy No. 192

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CLOSE-IN H-BOMB EFFECTS

I. INTRODUCTION

Recent concern with the chances of survival for relatively invulnerable structures and with the design of protective structures has led us to consider the damage due to blast, thermal, and nuclear radiations from an H-bomb in regions of greater intensity than have been previously considered important to military effects. Some aspects of the nuclear explosion remain unchanged in quality and merely increase in intensity as one moves closer to the bomb burst. Other phenomena, however, change their character sufficiently to warrant a special re-evaluation.

For example the nature of nuclear radiations may be expected to be somewhat different. The mean energy, and so the penetrating power and biological effectiveness of neutrons and gamma rays will be increased, and at the same time the rate and direction of dose delivery will be altered. Also in this close-in region the type of weapon and the details of its nucleonics will be of even greater concern. In addition we may expect large hydrodynamic effects on these doses.

In these close-in regions one may expect quite different thermal radiations. Not only will the frequency and time distributions of radiative flux be quite different than that at large distances but here any point will also be engulfed in the superheated air of the fireball itself.

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Here, too, the nature of the blast wave is changed. Such quantities as positive phase duration or total impulses cannot enjoy the same significance that they do at larger distances. Aside from complications due to interaction with radiative processes and the break-down of the ideal gas assumption for air, we encounter radically different time and space histories of the blast parameters. Pressure pulses are exceedingly rapid in both rise and decay and have much greater dynamic effects. Here also we encounter hypersonic flow problems. On the other hand non-ideal surface effects may be reduced. (Strong shocks tend to be less influenced by local irregularities.) It is conceivable that precursor phenomena may not have as large an influence on the blast waves. Although the interactions between the various weapon effects is strongest in this close-in region, and although the details of bomb physics and bomb design are of greater significance here, the general nature of the free-field blast wave may still be adequately well described by a simple hydrodynamic model (using initial conditions compatible with the earlier radiative effects). The next section contains the results of detailed computations on such a model.

II. BLAST

At present measurements in the region of high levels of pressure are scanty and restricted to indirect or simple peak value measures such as fireball growth photography, time-of-arrival data and ball-crusher or beer-can type gauges. The very nature of this region has heretofore precluded extensive measurements and consequently no details of dynamic effects and time histories of pressure pulses are available from tests. For this reason, the curves offered in this section cannot be claimed to be verified in detail.

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However, whenever comparisons with test results are available their satisfactory agreement with these theoretical solutions speaks well for the reliability of both the theory and the data.

However, the important question as to how well the results of these calculations predict blast loading from a nuclear bomb explosion cannot be answered with any certainty at present. The following qualitative evaluation may be useful, however:

1.) In general a strong shock is less influenced by thermal gradients or variable conditions in the medium through which it propagates. For this reason one could expect sharper rises and cleaner shocks in this close-in region.

2.) Since strong shocks are characterized by very sharp rise and decay in both time and space the influence of multiple shocks and disturbances in the after-flow, due to local interferences and reflections, is minimized in problems of structural response.

3.) On the other hand, in the close-in regions the blast has not always developed far enough from its earliest stages to have washed out the influences of multiple bomb shock and initial radiation transport effects. Neglect of this is in general not serious, but in very special instances may mean overlooking a sudden increase in the main shock strength by as much as 20 per cent.

4.) Surface phenomena such as the thermal precursor should be of minor influence for any height of burst at these high levels of blast, since here the blast arrives before the bulk of the thermal radiation is received.

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5.) The hypersonic flow at shock and particle speeds of many Mach may also lead to peculiar loading problems, locally.

The curves presented are the result of numerical integration of the partial differential equations of gas motion. The calculational detail includes the use of a careful fit to the equation of state for air and an entirely general treatment of the gas dynamics (no restricting similarity assumptions, for instance).

In particular the curves presented here stem from a calculation whose initial conditions characterize a point source. Calculations also have been carried out which start from an isothermal sphere approximating the effect of radiation diffusion on the early stages of a nuclear bomb explosion. The essential character of the subsequent blast wave in these latter calculations matches that of the point-source calculation. In detail, however, the isothermal-sphere calculations are encumbered by the presence of multiple minor shocks and rarefactions. For this reason it was felt that the point-source case was more appropriate from the standpoint of simplicity and generality and for ease in scaling and analytical fitting.

The results of these calculations which include the equation of state of air do not differ from the previous ideal-gas calculations in the lower pressure regions (ΔP_s <3 atmos) but they show some marked differences in dynamic pressures, densities and temperatures in the higher pressure regions.

The general methods employed in these calculations are similar to those described in an article by this author which appeared in the Journal of Applied Physics[1] (June 1955) and which covers the ideal-gas computations.

All the curves are scaled to a two megaton free-air burst, with the intent that they should be used as representative of a one megaton surface burst.

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[1] H. L. Brode, J. of Appl. Phys. 26 766-775 (June 1955).

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Figure 3. is a plot of particle velocity (u_s) and shock velocity (U_s) in units of ambient sonic velocity, i.e., a plot of particle and shock Mach numbers. Also plotted is the shock density (ρ_s) in units of ambient density (ρ_o) versus range in kilofeet.

Figures 4 - 21 are plots of overpressure (ΔP) in atmos, dynamic pressure (Q) in atmos, particle Mach number (U), density ratio (ρ), and temperature ratio

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($\Theta = T/T_o$) versus time in seconds at various distances from the burst.

Figure 22. is a plot of various parameters versus the shock overpressure (ΔP_s) in atmos. Definition of these parameters is as follows:

Q_s = shock dynamic pressure ($1/2\ \rho_s U_s^2$)

t_s = time of arrival of shock (sec)

D_P^+ = duration of pressure positive phase (sec)

D_Q^+ = duration of dynamic-pressure positive phase (sec)

Δ_P^s = duration of the right-triangular pulse having the same initial slope as the true pressure pulse (sec)

Δ_Q^s = duration of the right-triangular dynamic-pressure pulse having the same initial slope as the true dynamic pressure pulse (sec)

α = exponent coefficient for early part of pressure pulse fitted by the form $\Delta P = \Delta P_s\ \epsilon^{-\alpha t}$

β = exponent coefficient for early part of dynamic-pressure pulse fitted by the form $Q = Q_s\ \epsilon^{-\beta t}$

Figures 23 - 26 show some of the blast parameters as a function of of radius for various times in the course of the explosion.

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Figure 1

Peak Overpressure vs Distance from a 1 MT Surface Burst

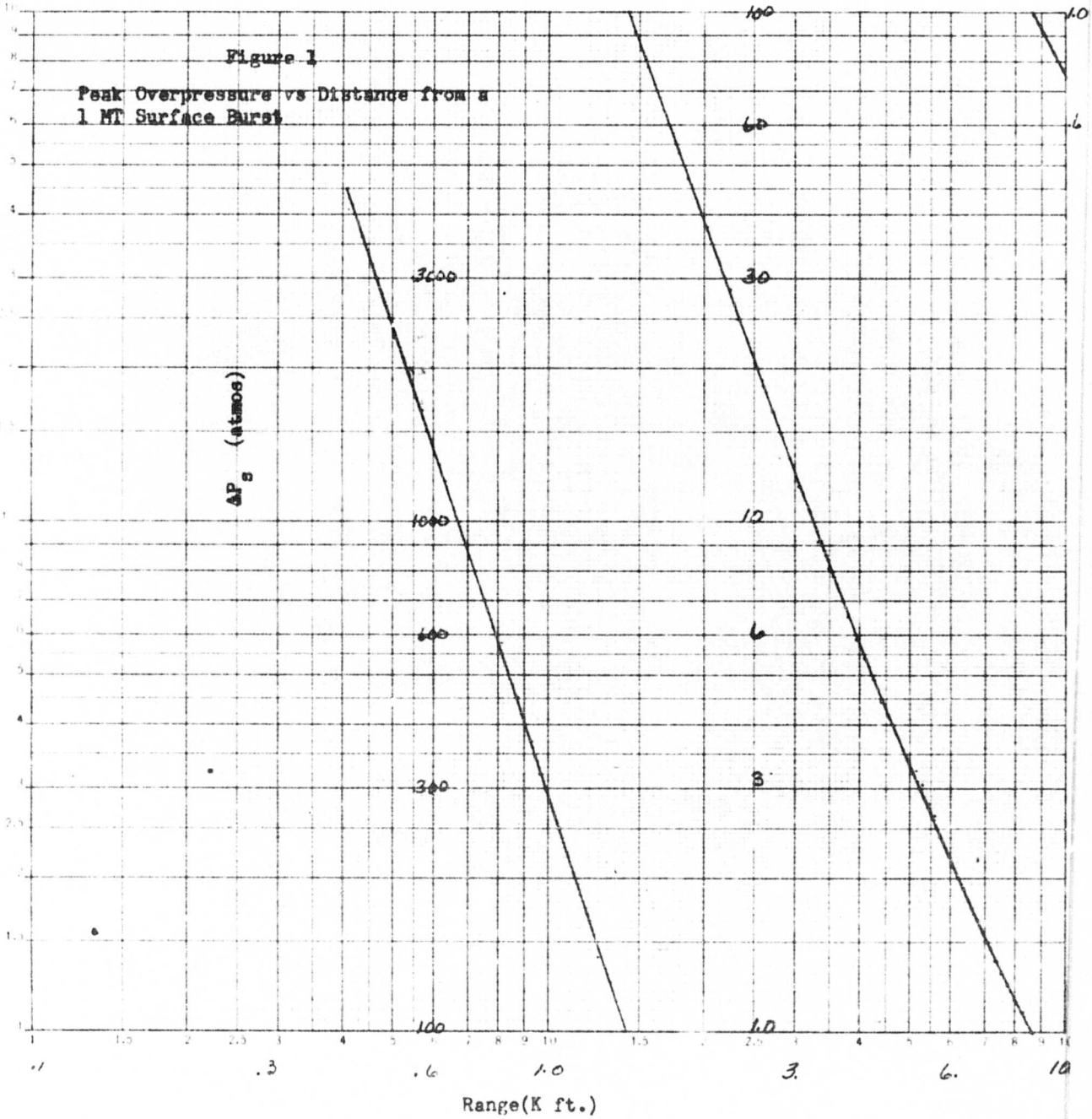
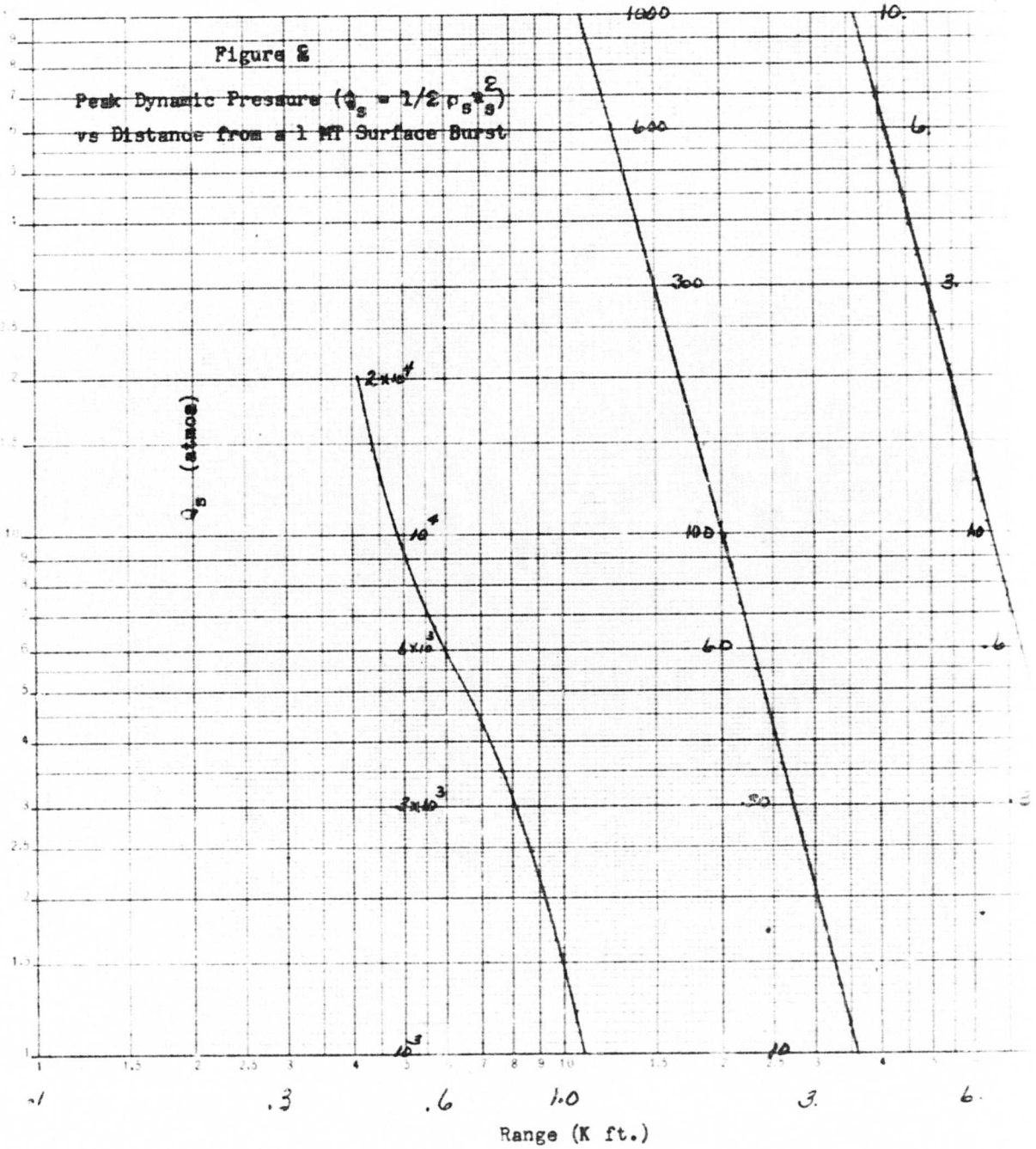


Figure 8

Peak Dynamic Pressure ($q_s = 1/2\,\rho_s v_s^2$)
vs Distance from a 1 MT Surface Burst



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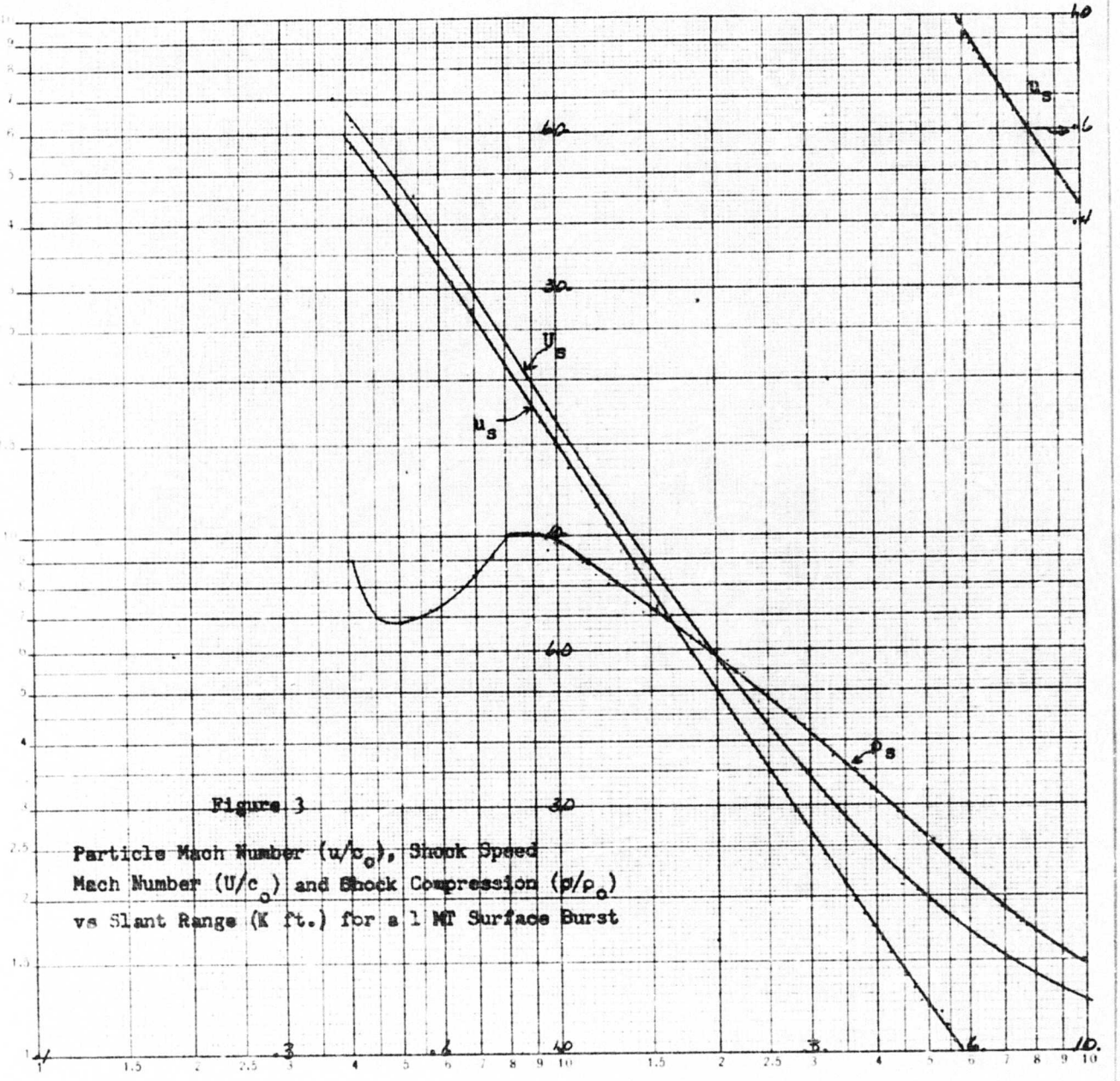

Figure 3

Particle Mach Number (u/c_o), Shock Speed Mach Number (U/c_o) and Shock Compression (ρ/ρ_o) vs Slant Range (K ft.) for a 1 MT Surface Burst

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Figure 4

Blast Parameters as Functions of Time at 695 Feet from a 1 MT Surface Burst

ΔP_s = 900 atmos.

$Q_s = 4.39 \times 10^{3}$ atmos.

t_s = .00807 sec.

$T_s = \theta_s T_o = 1.37 \times 10^{4}$ °K

ρ_s = 8.40

$v_s = u_s c_o = 8.97 \times 10^{4}$ feet/sec.

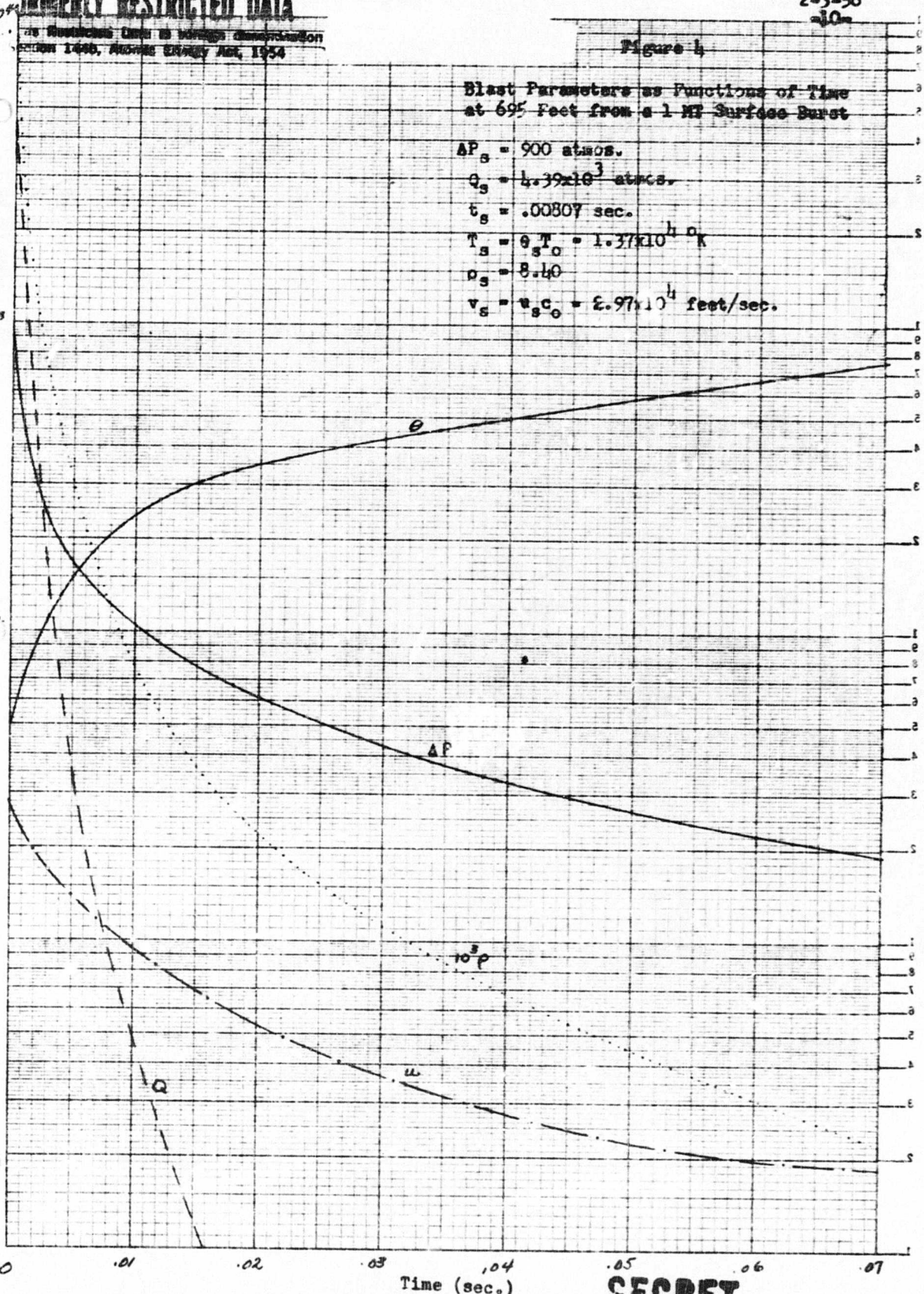

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Figure 5

Blast Parameters as Functions of Time at 755 feet from a 1 MT Surface Burst

ΔP_s = 699 atmos.
$Q_s = 3.51 \times 10^3$ atmos.
t_s = .00992 sec.
$T_s = \theta_s T_\theta = 1.09 \times 10^4$ °K
ρ_s = 9.11
$v_s = u_s \phi_0 = 2.55 \times 10^4$ feet/sec.

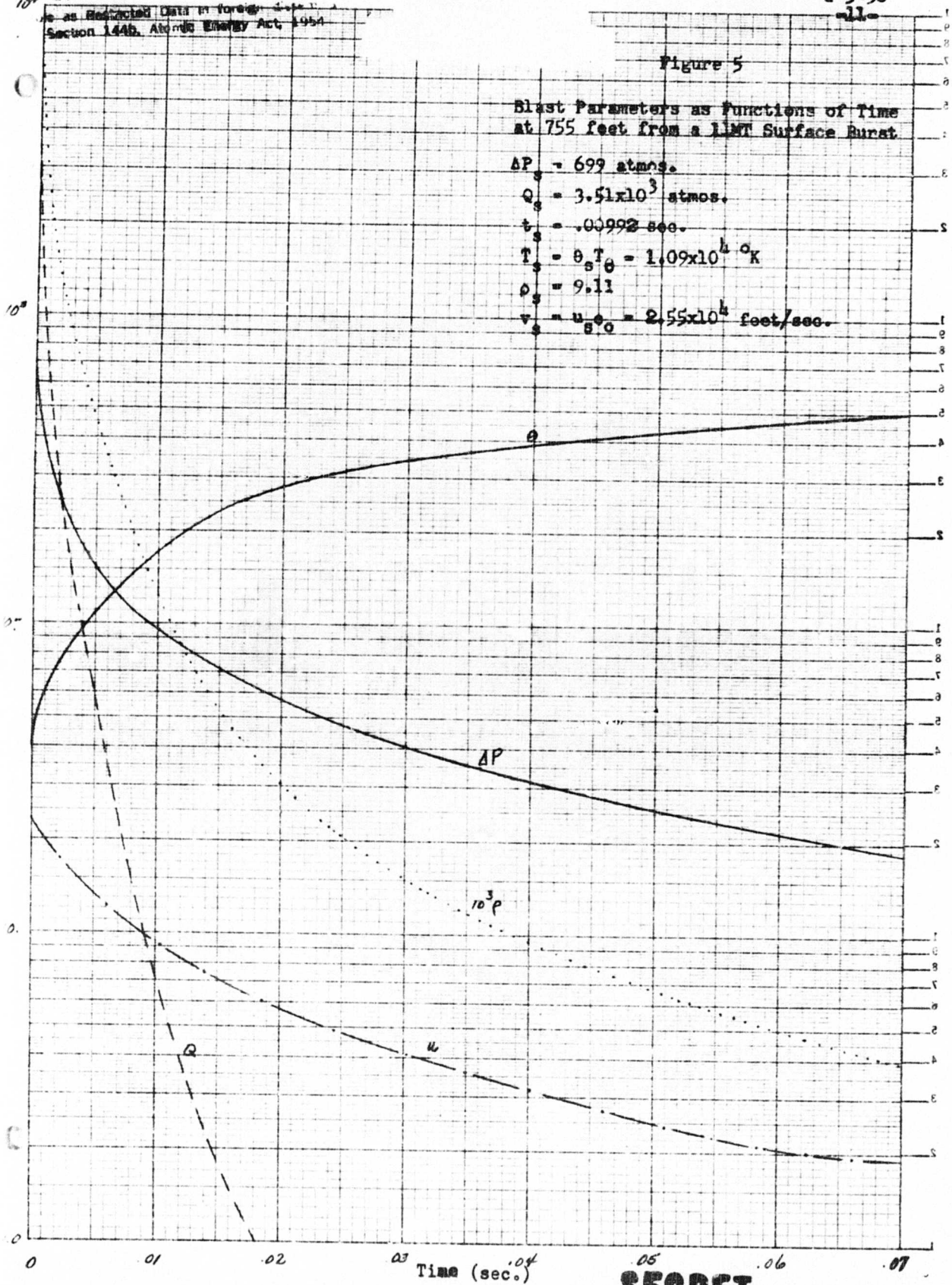

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Figure 6

Blast Parameters as Functions of Time at 874 feet from a 1 MT Surface Burst

ΔP_s = 452 atmos.
Q_s = 2.47x10^3 atmos.
t_s = .0114 sec.
$T_s = \theta_s T_o$ = 7.79x10^3 °K
ρ_s = 10.1
$v_s = u_s c_o$ = 2.03x10^4 feet/sec.

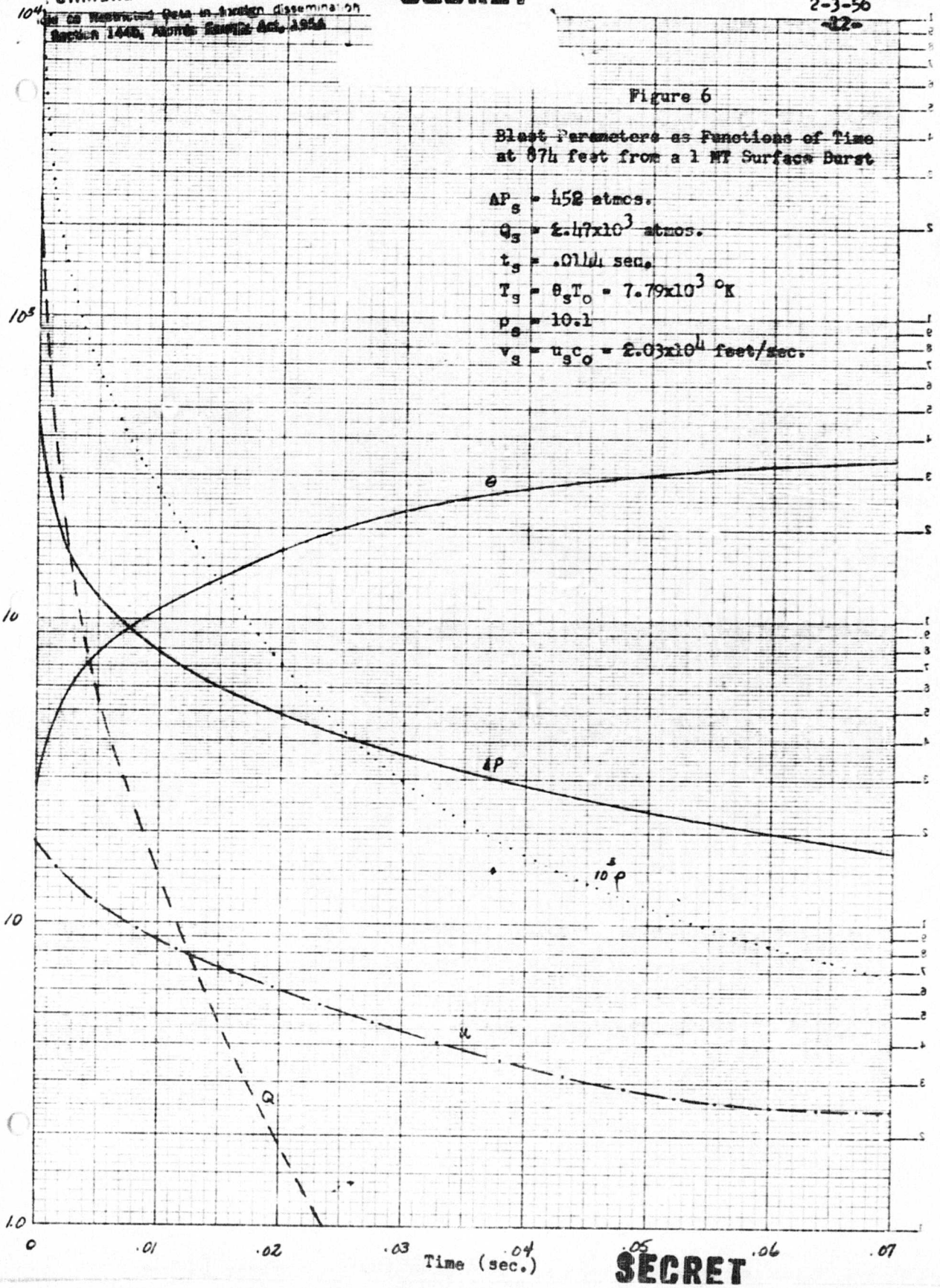

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Figure 7

Blast Parameters as Functions of Time
at 994 feet from a 1 MT Surface Burst

ΔP_s = 297 atmos.
$Q_s = 1.55 \times 10^3$ atmos.
t_s = .0200 sec.
$T_s = \theta_s T_o = 6.19 \times 10^3$ °K
ρ_s = 9.67
$v_s = u_s c_o = 1.64 \times 10^4$ feet/sec.

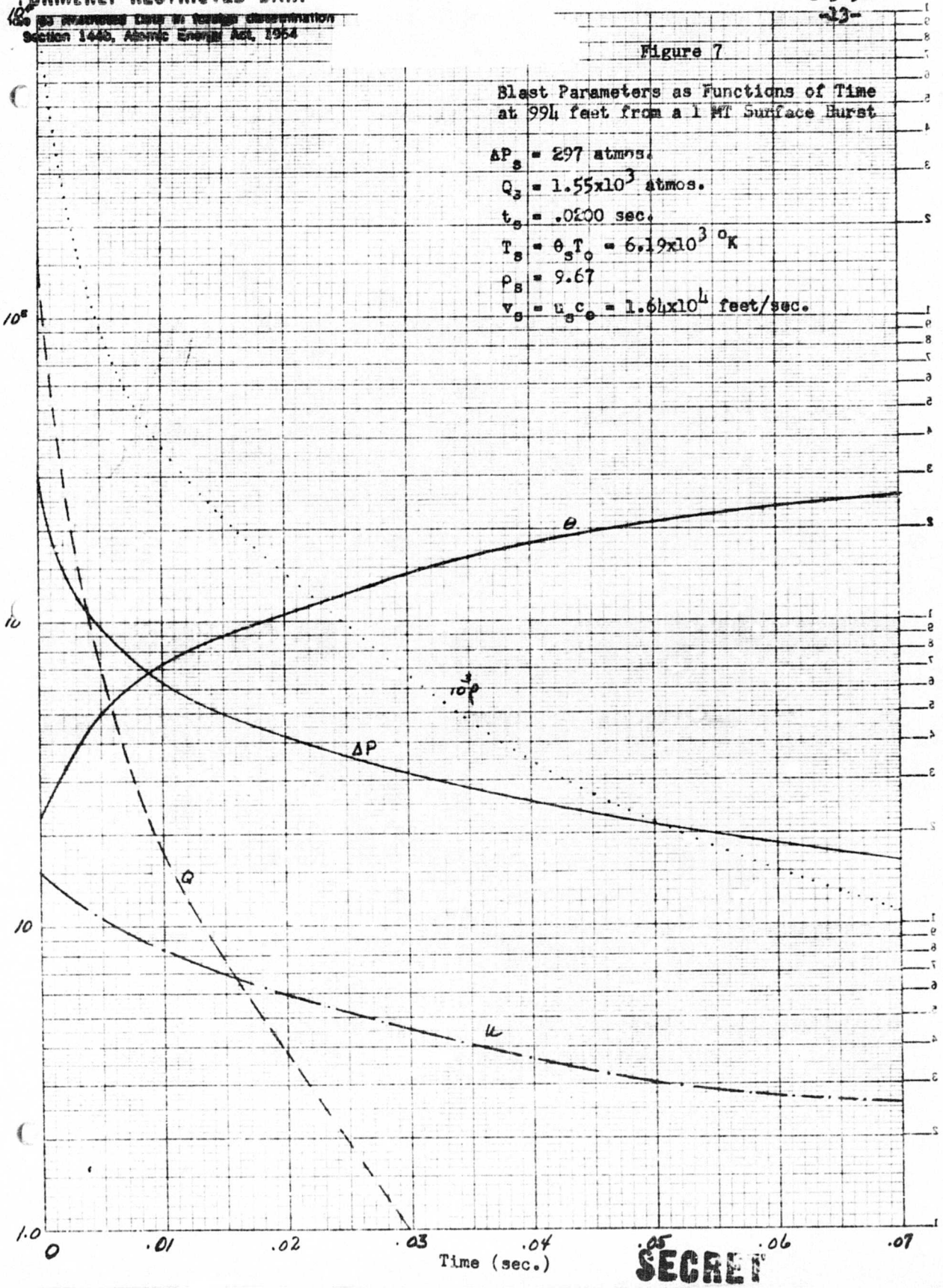

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Figure 8

Blast Parameters as Functions of Time
at 1120 feet From a 1 MT Surface Burst

ΔP_s = 203 atmos.
Q_s = 912 atmos.
t_s = .0273 sec.
$r_s = \alpha_s r_o = 5.86 \times 10^{3} \alpha_s$
ρ_s = 5.24
$v_s = u_s c_o = 1.31 \times 10^{3}$ feet/sec.

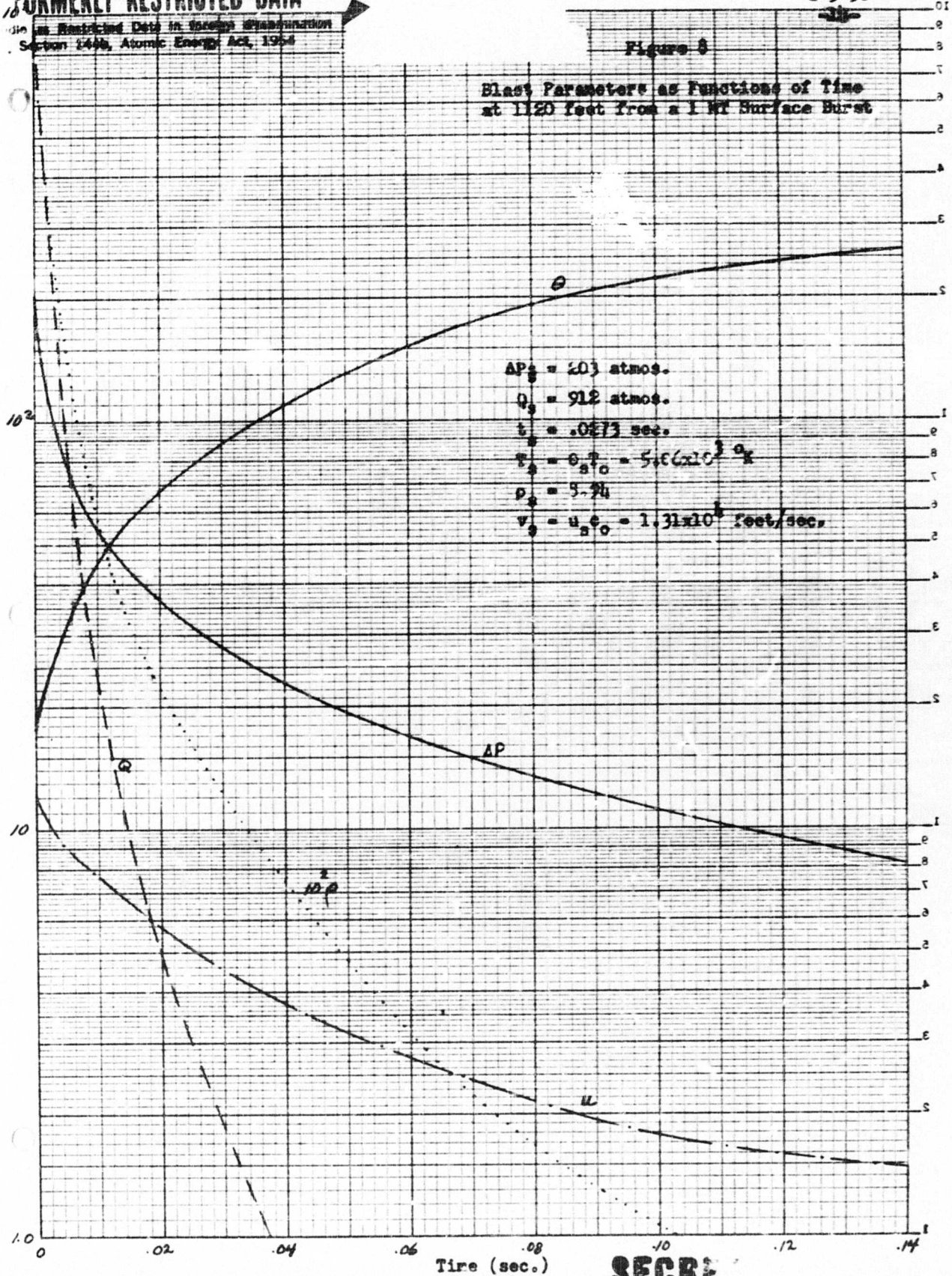

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Figure 9

Blast Parameters as Functions of Time
at 1395 feet from a 1 MT Surface Burst

ΔP_s = 99.9 atmos.

Q_s = 385 atmos.

t_s = .0479 sec.

$T_s = \theta_s T_0 = 3.61 \times 10^3$ °K

ρ_s = 7.36

$v_s = u_s c_0 = 9.40 \times 10^3$ feet/sec.

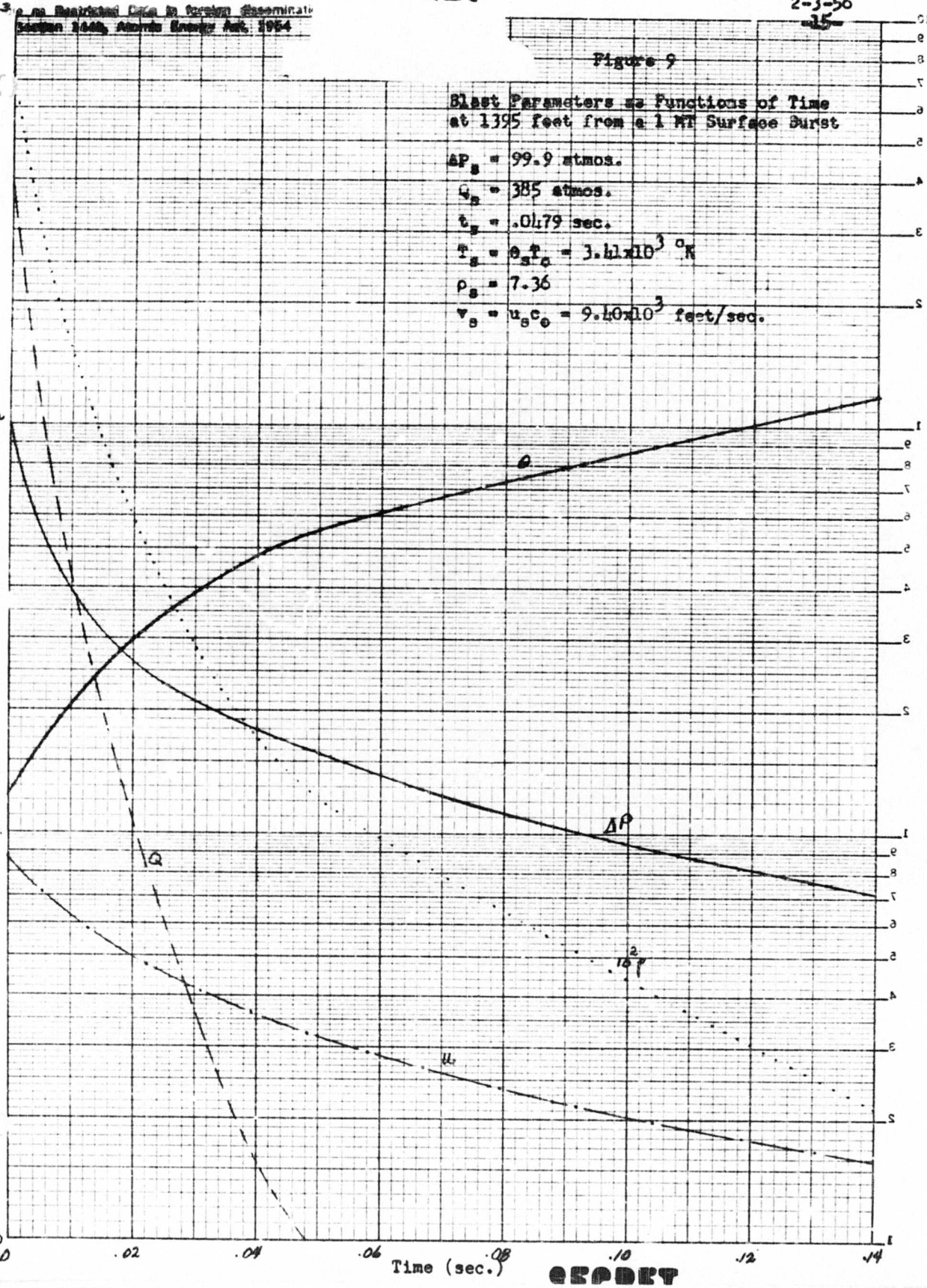

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Figure 10

Blast Parameters as Functions of Time
at 1661 feet from a 1 MT Surface Burst

ΔP_s = 69.9 atmos.

u_s = 22.7 atmos.

t_s = .0699 sec.

$T_s = \theta_s T_o = 2.66 \times 10^3$ °K

ρ_s = 6.86

$v_s = u_s c_o = 7.47 \times 10^3$ feet/sec.

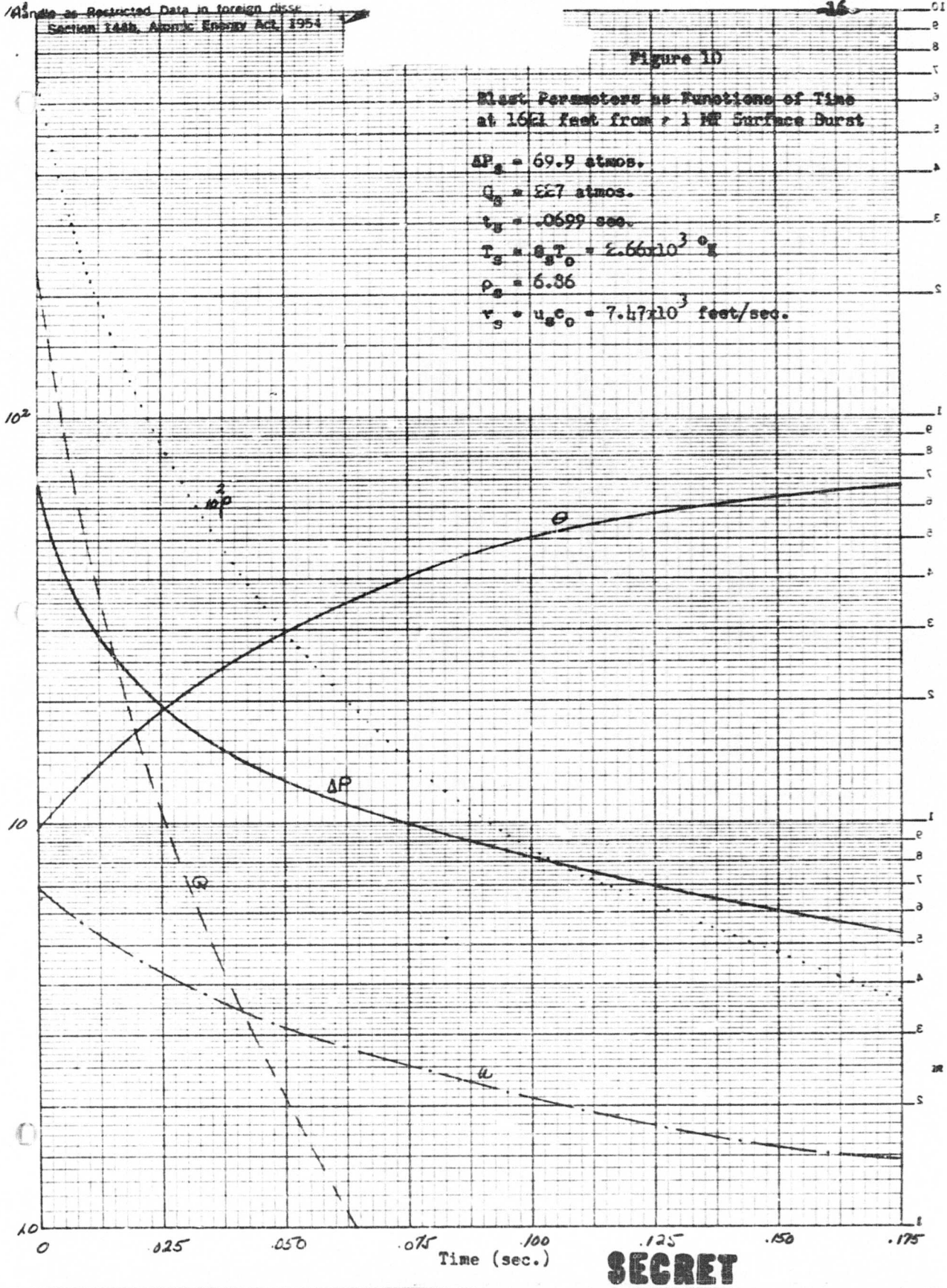

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Figure 11

Blast Parameters as Functions of Time
at 1782 feet from a 1 MT Surface Burst

ΔP_s = 52.7 atmos.

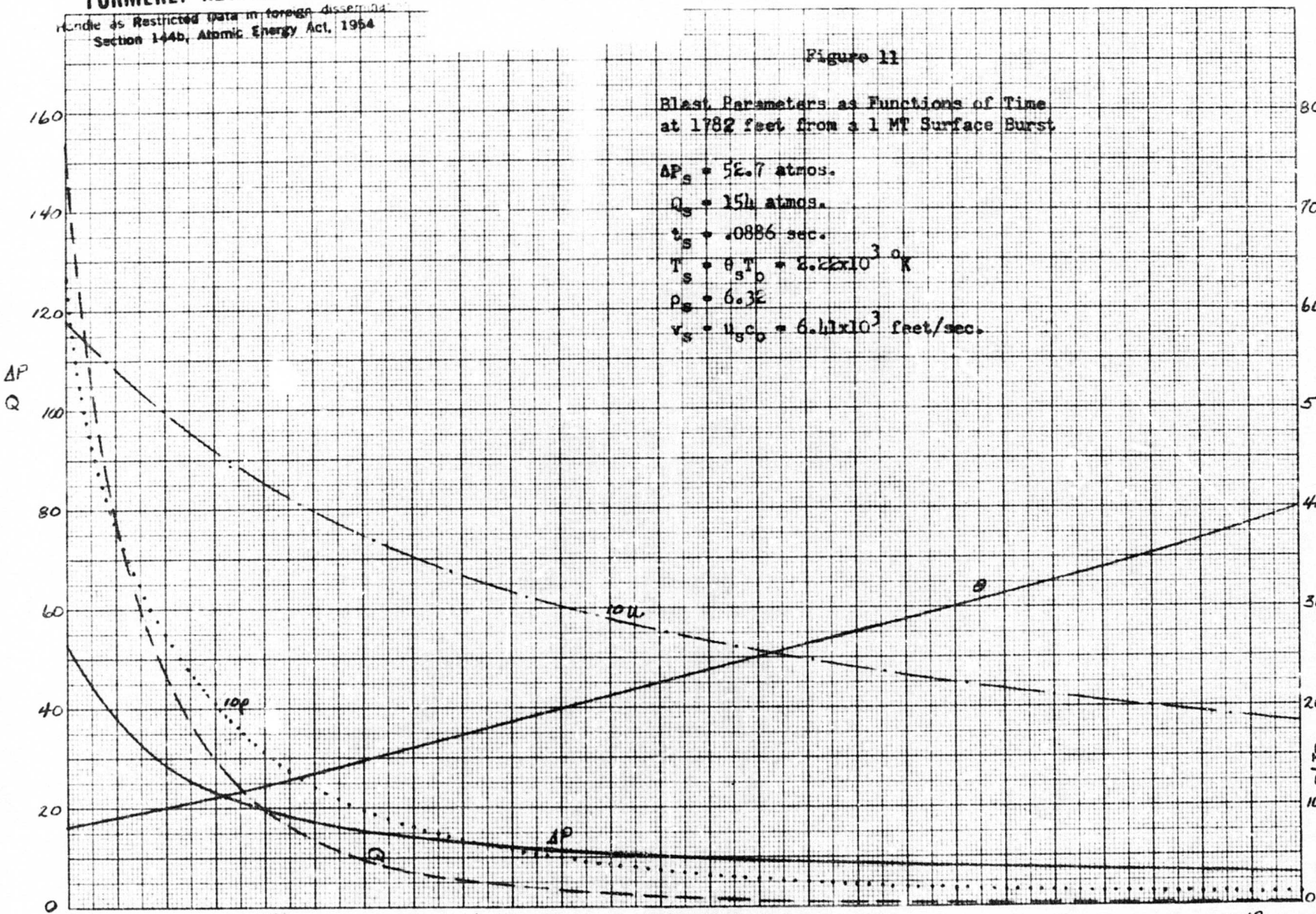
Q_s = 154 atmos.

t_s = .0886 sec.

$T_s = \theta_s T_o = 2.22 \times 10^3$ °K

ρ_s = 6.3%

$v_s = u_s c_o = 6.41 \times 10^3$ feet/sec.



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Blast Parameters as Functions of Time at 2178 feet from a 1 MT Surface Burst

ΔP_s = 30.6 atmos.

Q_s = 72.8 atmos.

t_s = .1hh sec.

$T_s = \theta_s T_o = 1.56 \times 10^3$ °K

ρ_s = 5.h2

$v_s = u_s c_o = 4.76 \times 10^3$ feet/sec.

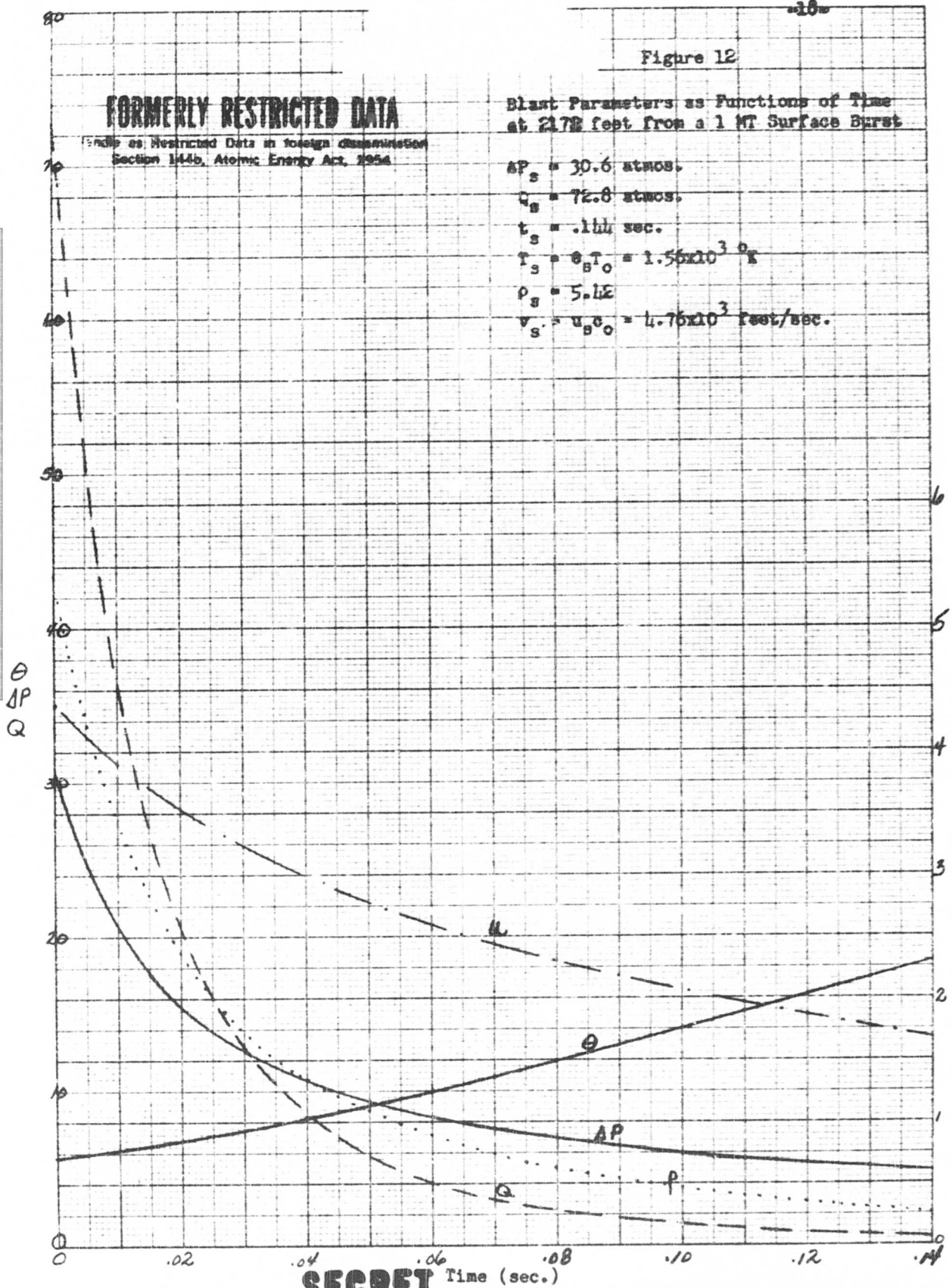

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Figure 13

Blast Parameters as Functions of Time
at 2508 feet from a 1 MT Surface Burst

ΔP_s = 20.7 atmos.
Q_s = 11.4 atmos.
t_s = .205 sec.
$T_s = 1.19 \times 10^3\ ^\circ K = \theta_s T_o$
ρ_s = 4.91
$v_s = u_s c_o = 3.77 \times 10^3$ feet/sec.

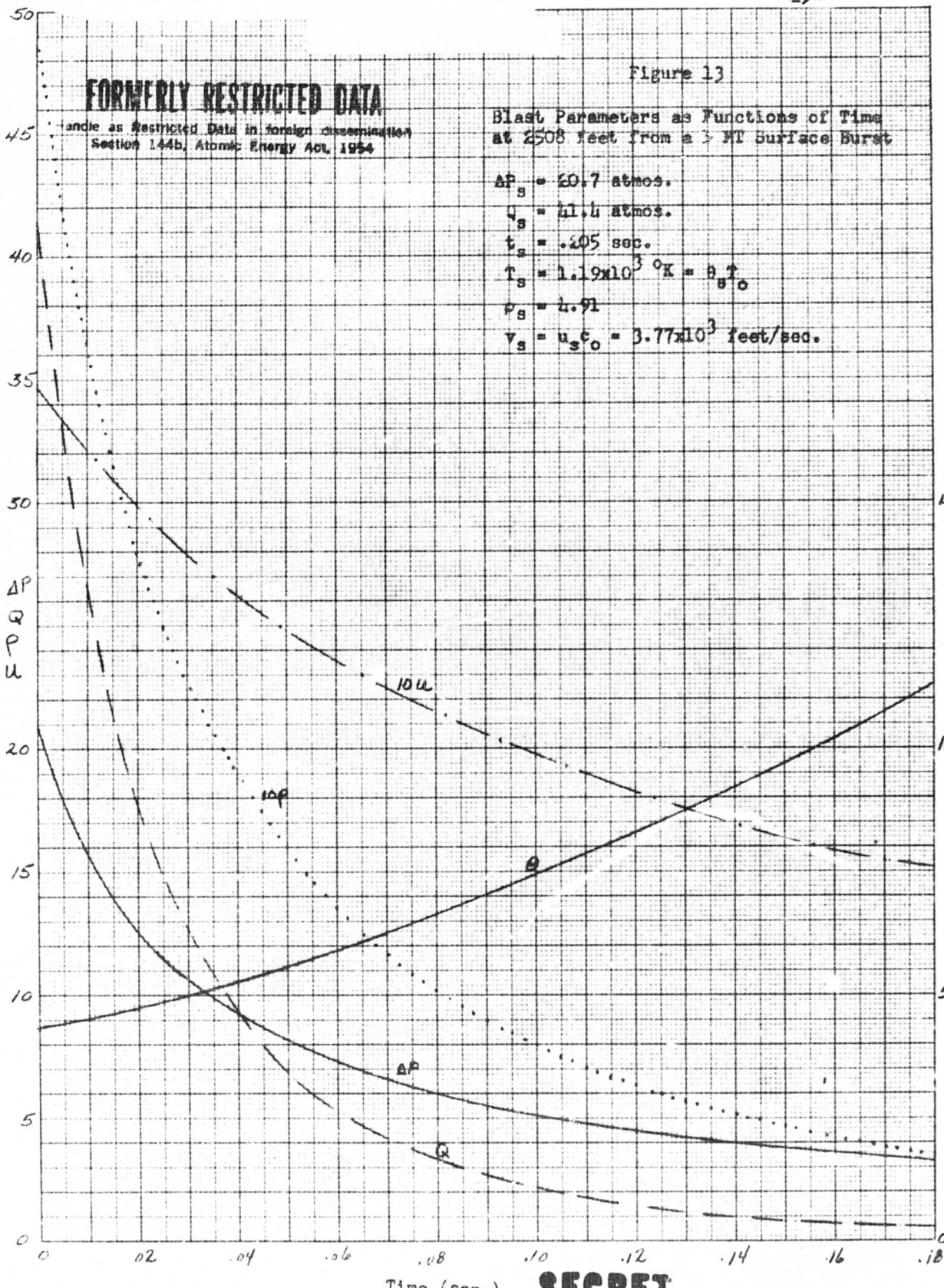

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Figure 14

Blast Parameters as Functions of Time
at 2816 feet from a 1 MT Surface Burst

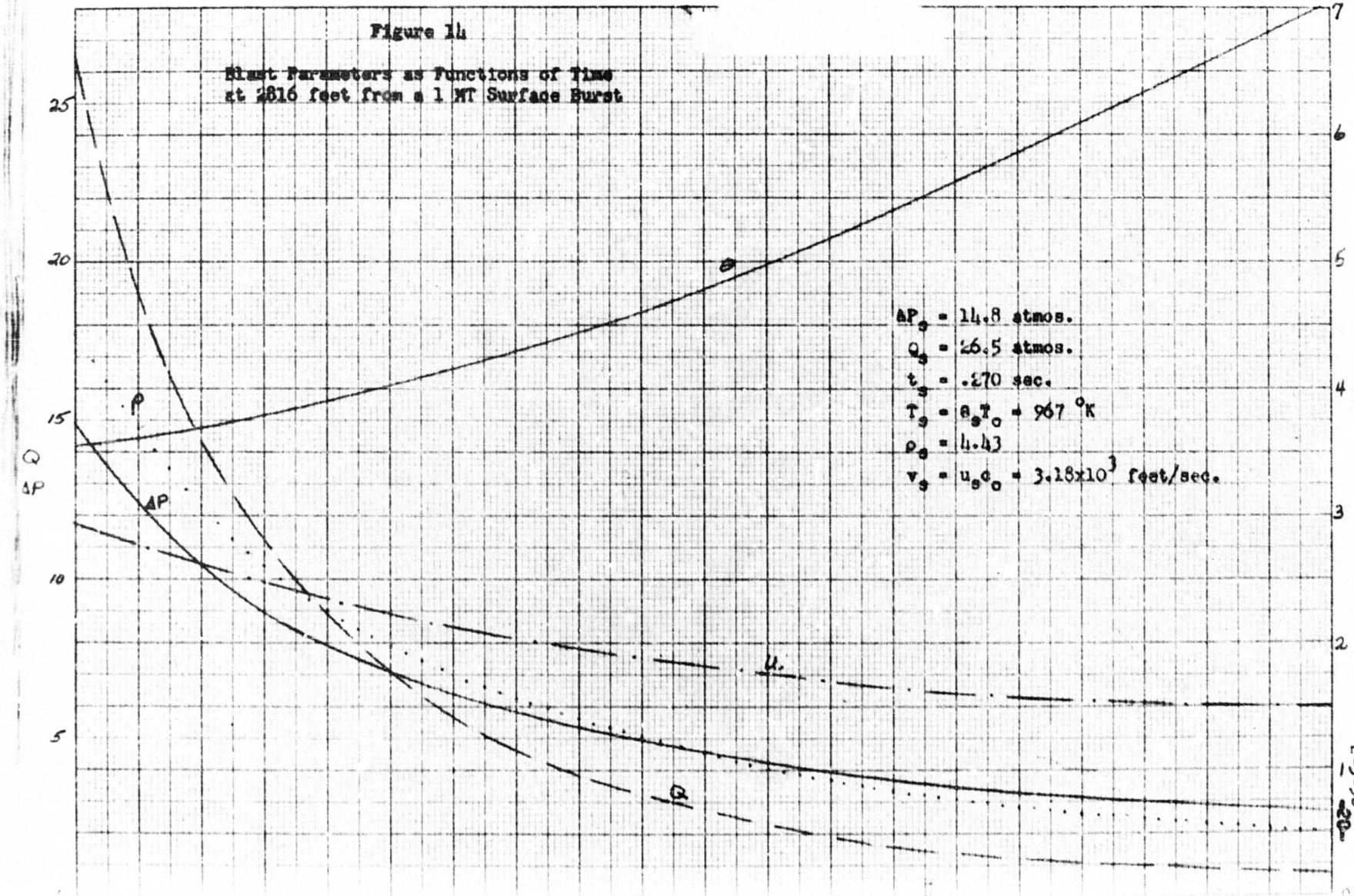

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Figure 15

Blast Parameters as Functions of Time
at 3183 feet from a 1 MT Surface Burst

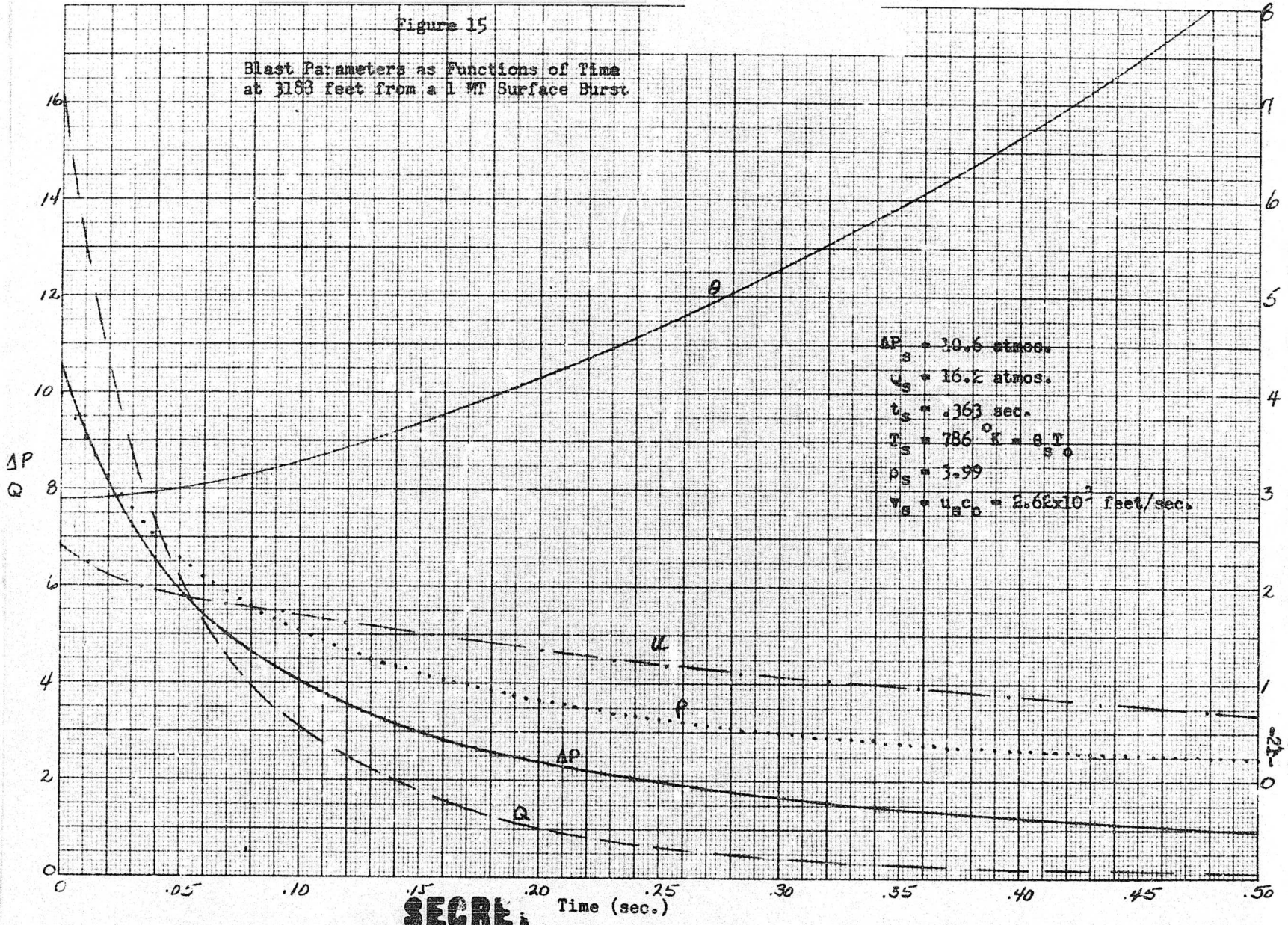

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Figure 16

Blast Parameters as Functions of Time
at 3636 feet from a 1 MT Surface Burst

ΔP_s = 7.34 atmos.
Q_s = 9.46 atmos.
t_s = .494 sec.
$T_s = \theta_s T_o$ = 644 °K
ρ_s = 3.58
$v_s = u_s c_o$ = 2.13x10^3 feet/sec.

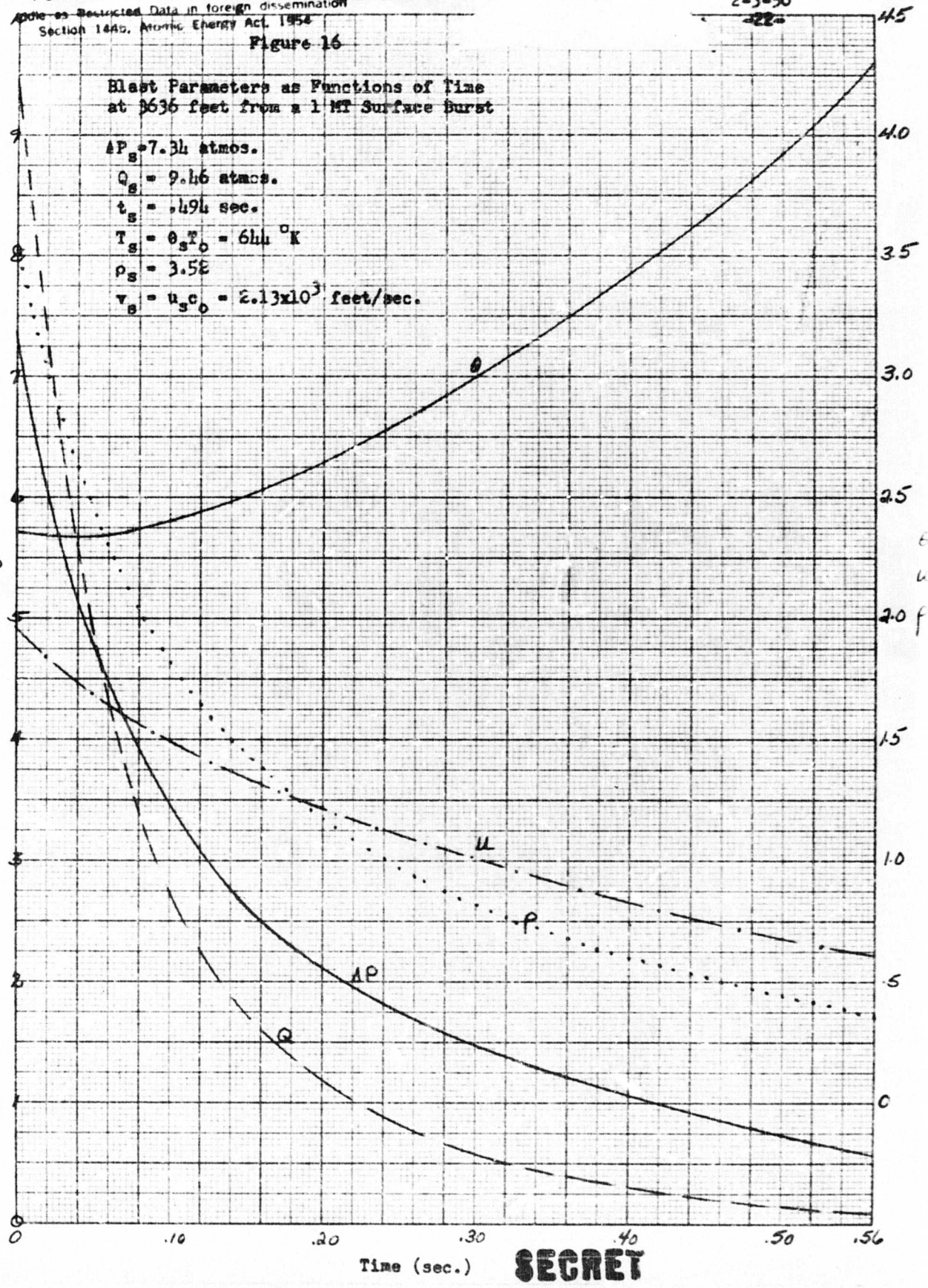

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Figure 17

Blast Parameters as Functions of Time
at ~~1611~~ feet from a 1 MT Surface Burst

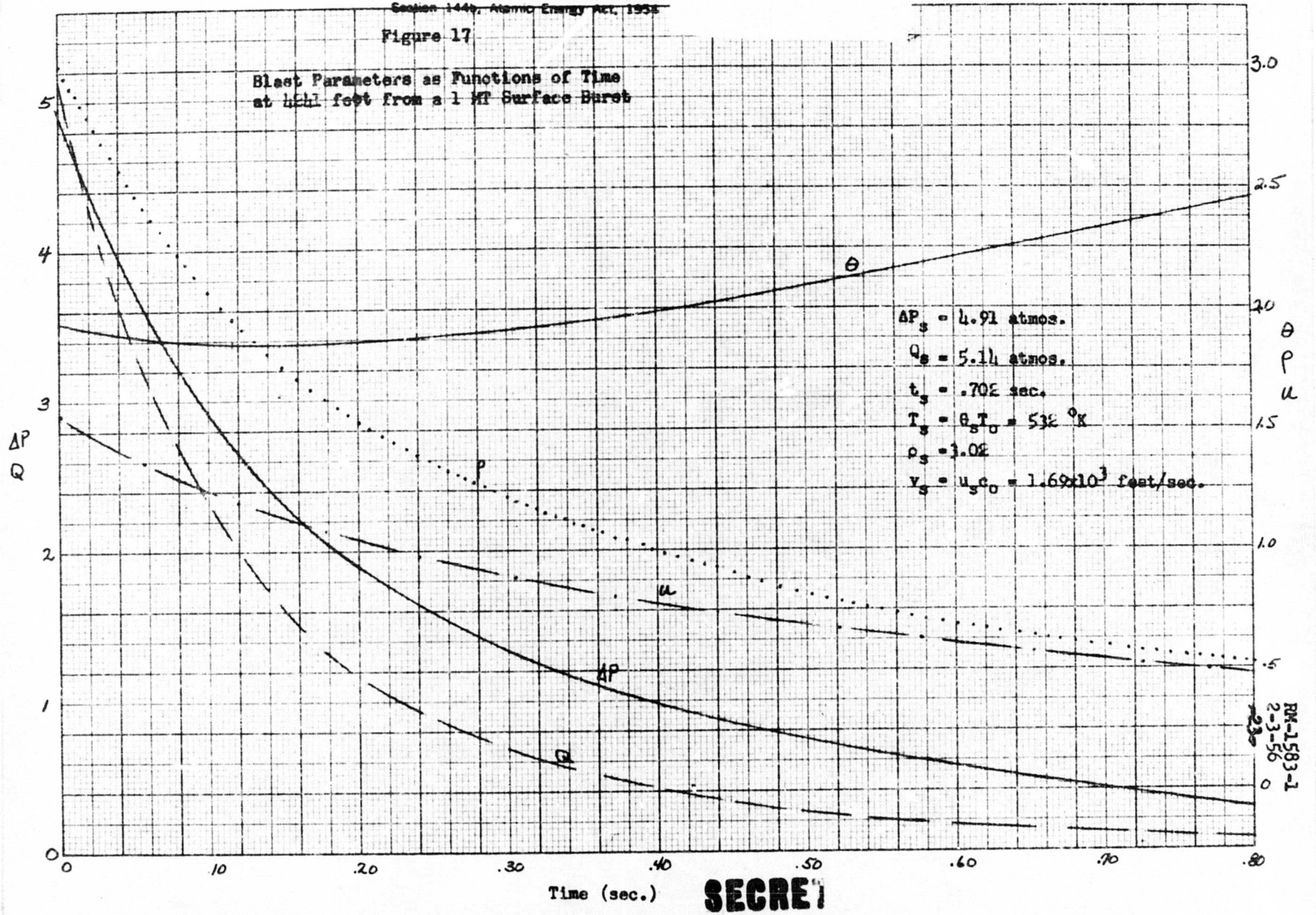

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Figure 18

Blast Parameters as Functions of Time
at 5302 feet from a 1 MT Surface Burst

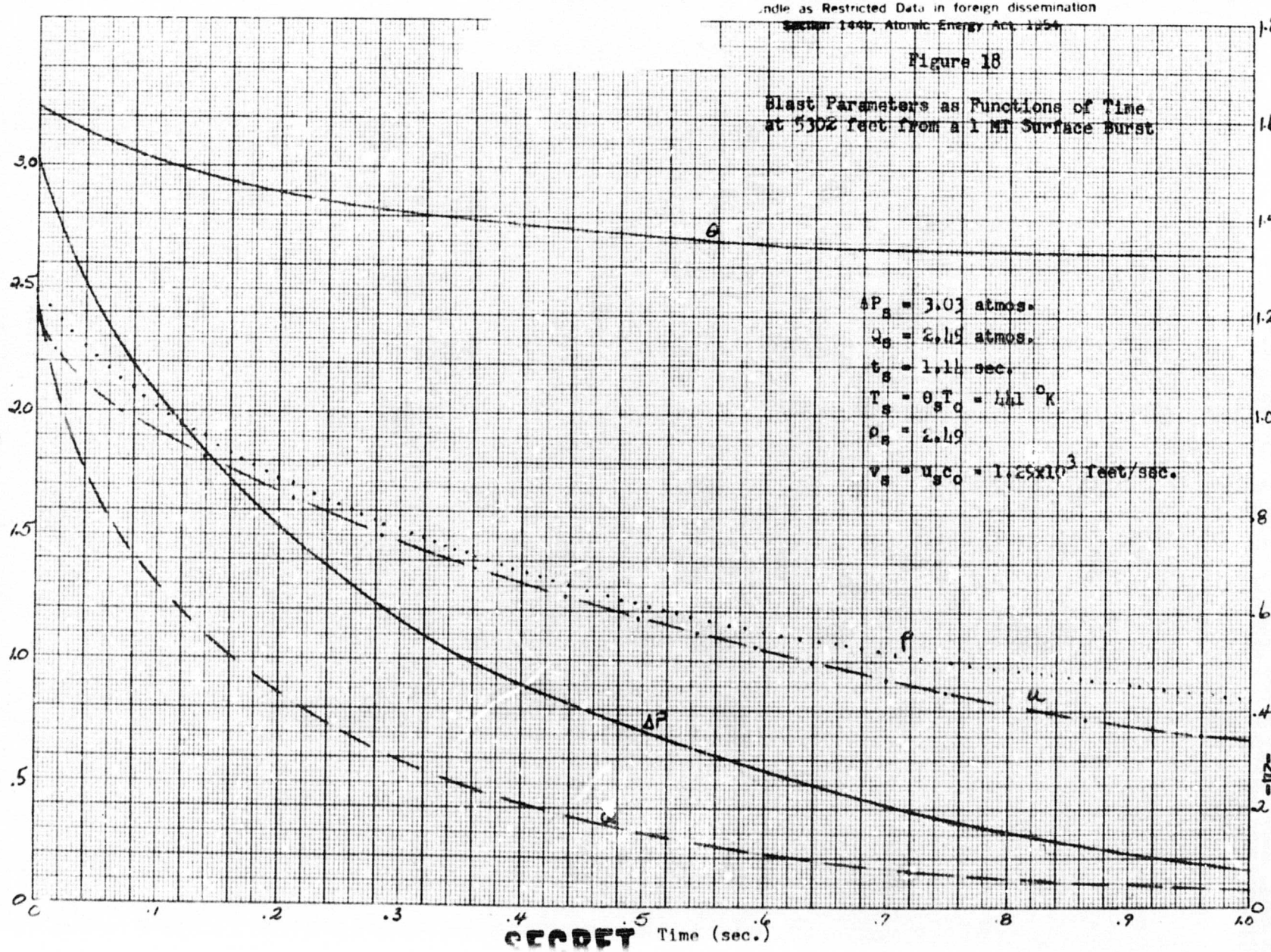

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Figure 19

Blast Parameters as Functions of Time
at 6197 feet from a 1 MT Surface Burst

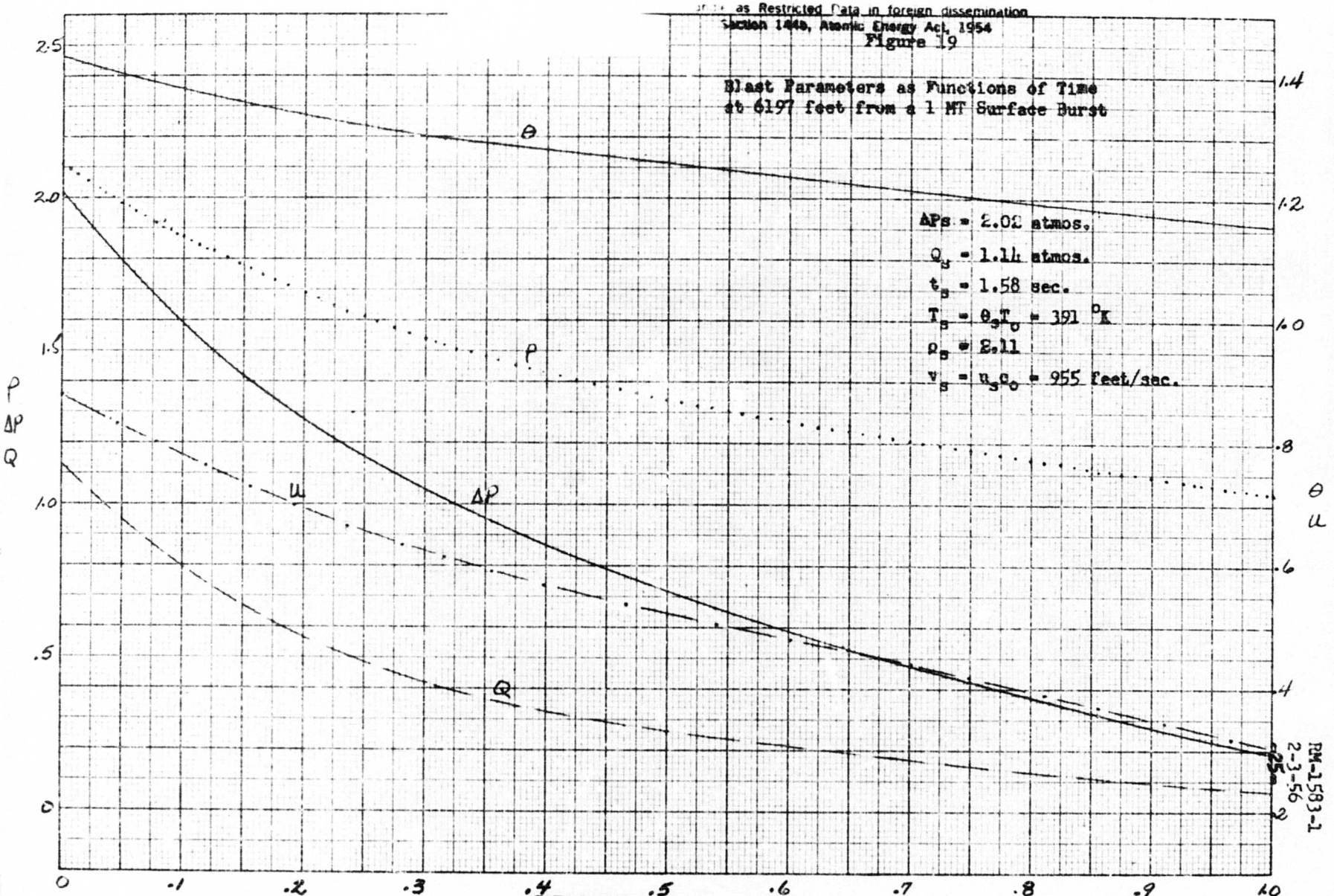

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Figure 20

Blast Parameters as Functions of Time
at 8704 feet from a 1 MT Surface Burst

ΔP_s = .987 atmos.
q_s = .314 atmos.
t_s = 1.05 sec.
$T_s = a_s T_o$ = 336 °K
ρ_s = 1.61
$v_s = u_s c_o$ = 573 feet/sec.

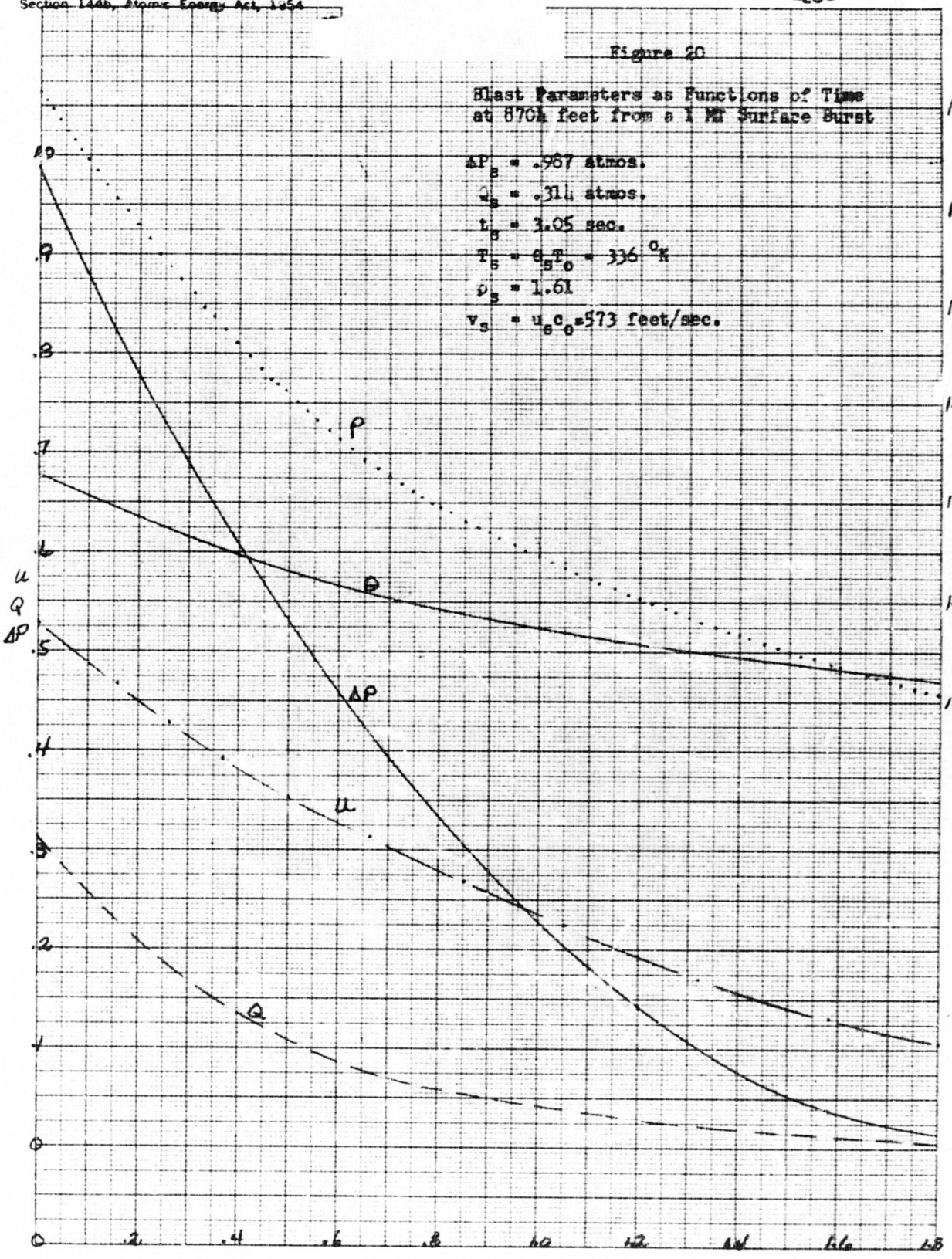

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Figure 21

Blast Parameters as Functions of Time
at 15589 feet from a 1 MT Surface Burst

ΔP_s = 0.497 atmos.
Q_s = 0.0898 atmos.
t_s = 5.68 sec.
$T_s = \theta_s T_o$ = 307°K
ρ_s = 1.33
$v_s = u_s c_o$ = 338 feet/sec.

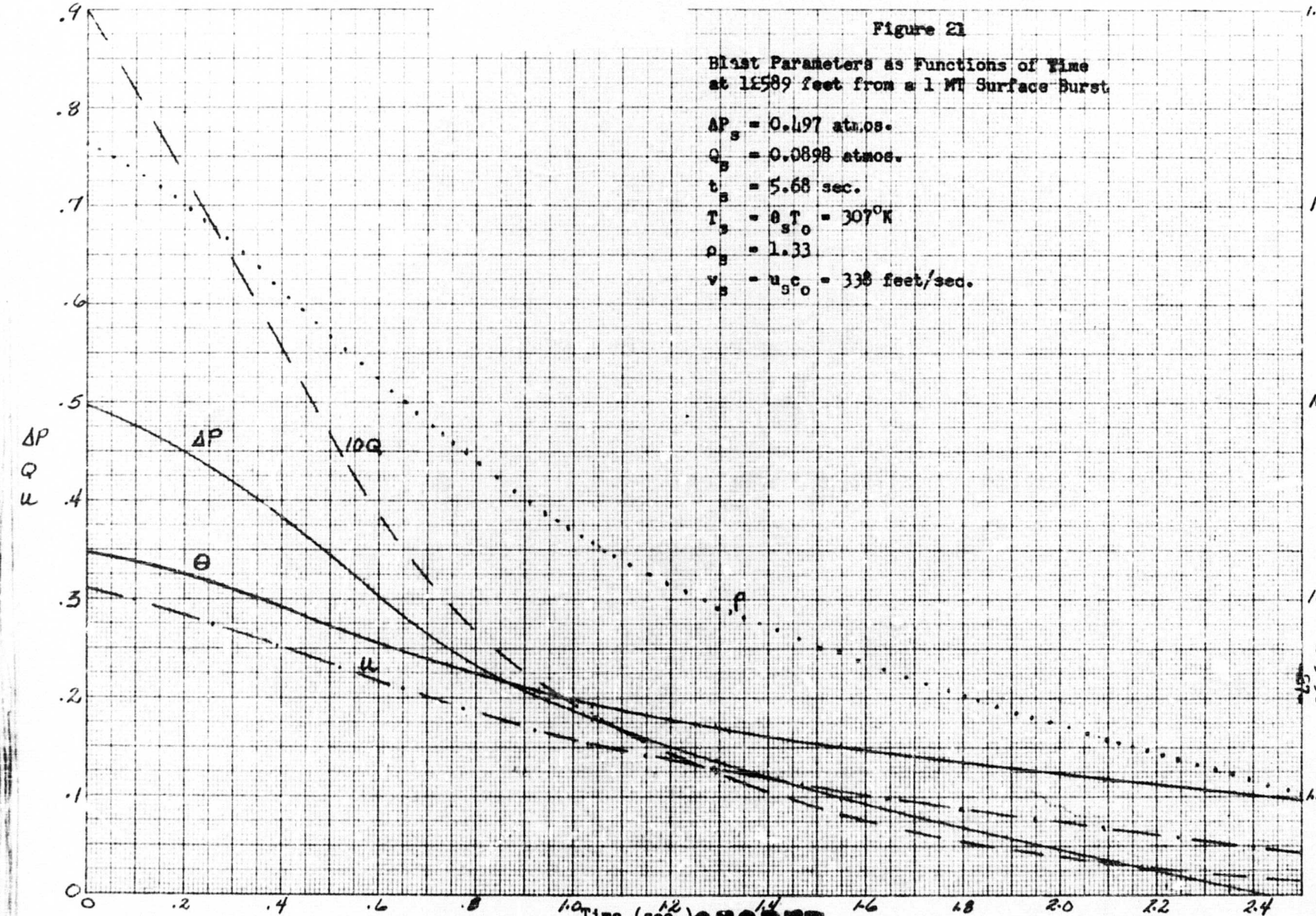

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Figure 23

Various Parameters versus Shock Overpressure

(see text, page 5)

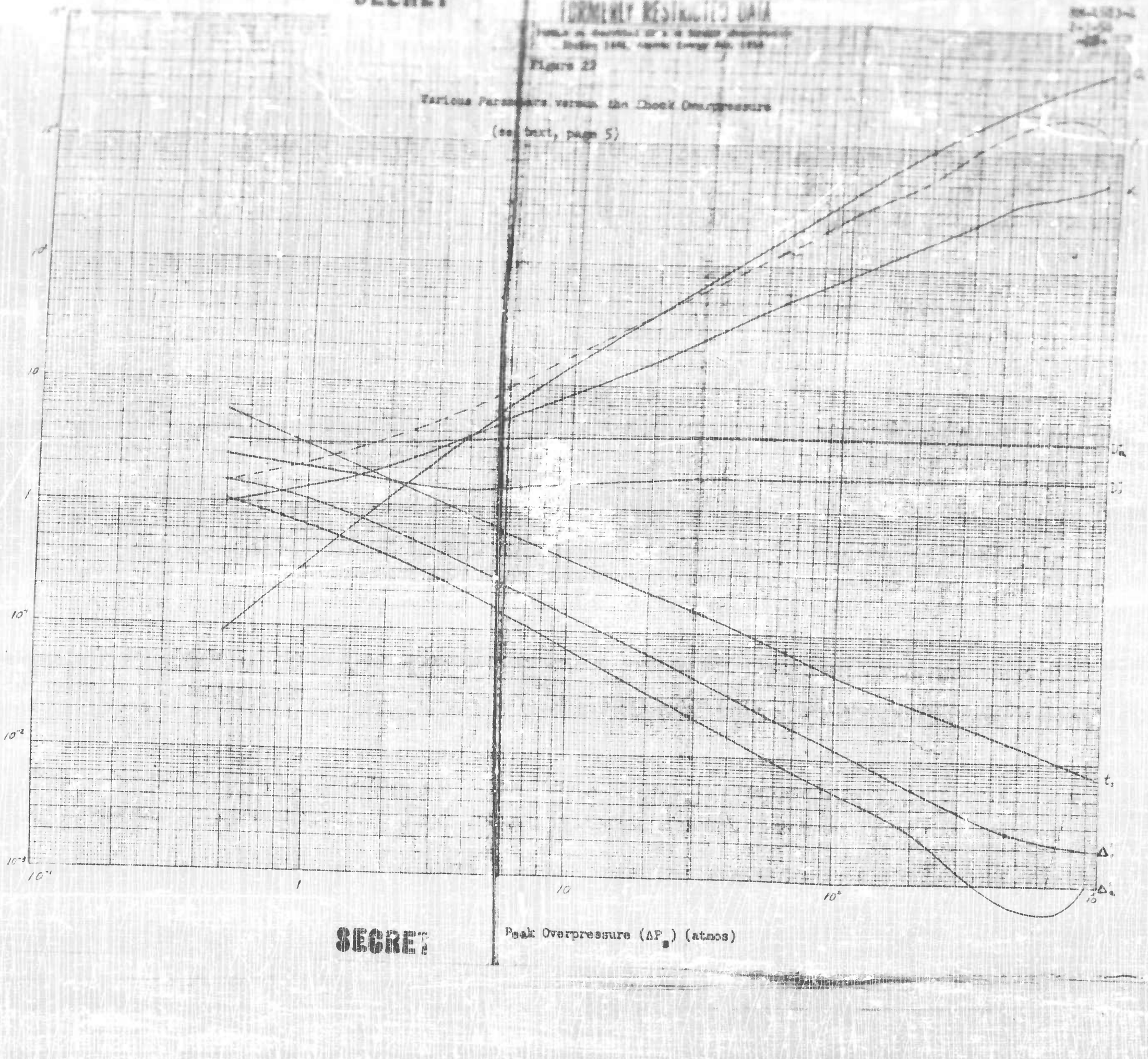

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FIGURE 23

$\Delta p_1 = 900$ atmos.

$Q_s = 4.39 \times 10^{-3}$ atmos.

$p_s = 8.2$ atmos

$\theta_s = \frac{50.3}{8.2} = 2.17 \times 10^{4}$ °R/ft.

$u_s = 27.3 = 3.27 \times 10^{4}$ feet/sec.

θ

Δp

ω^2

ω

u

Q

ω^2

ω

u

Q

Δp

θ

10^3

10^2

10

1

0 .1 .2 .3 .4 .5 .6 .7

Radius (X ft.)

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Figure 6c

Blast Parameters as a Function of Radius
at 0.0699 sec. from a 1 MT Surface Burst

ΔP_o = 6.9 atmos.

q_s = 2.2 atmos.

$P_s = 0.86\, P_o$

$U_s = 5.79 = \frac{2}{\gamma+1}\frac{a_o^2}{v_o}$

$u_s = 6.87 = \frac{24}{C_o}$ Feet/sec.

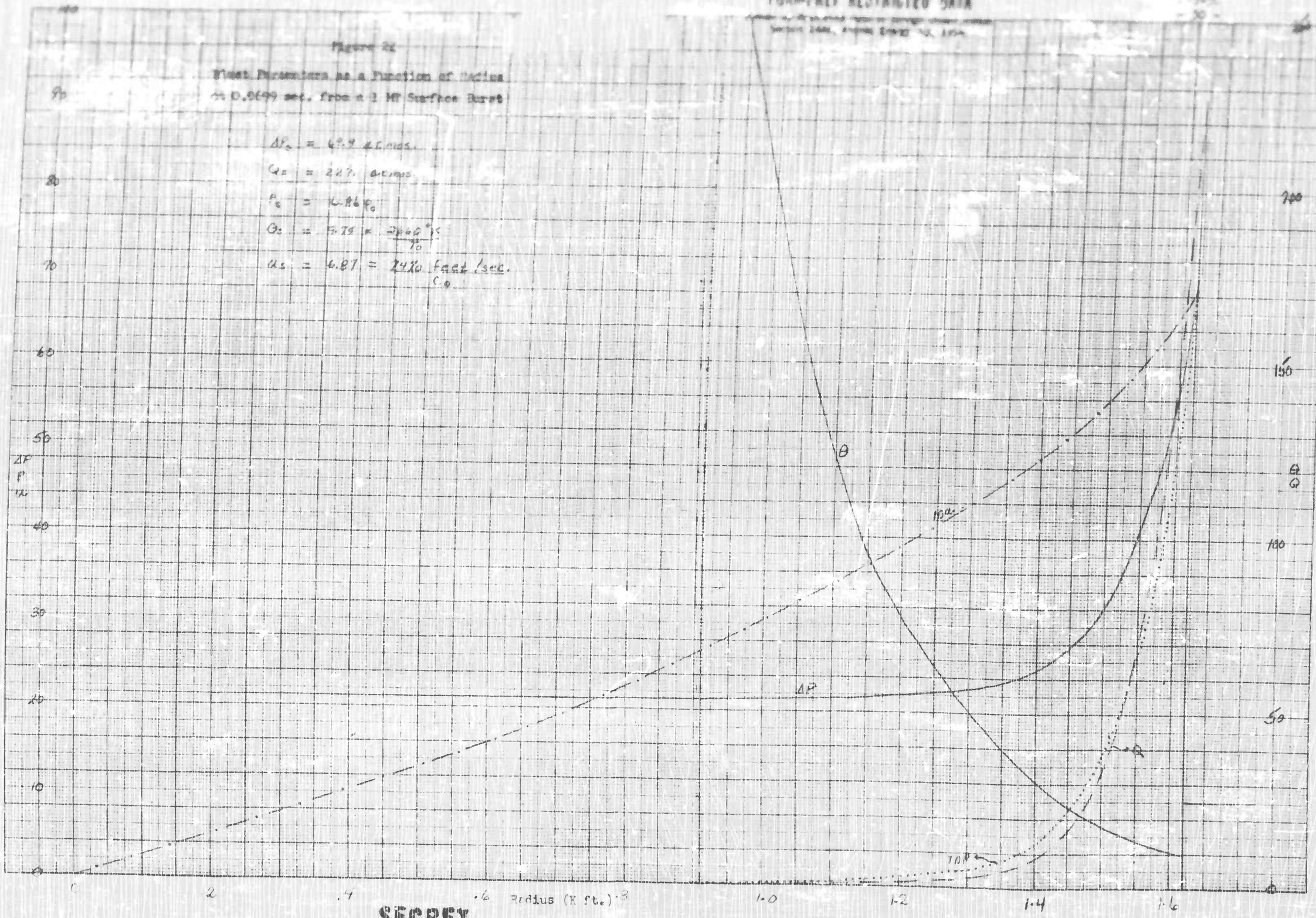

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Figure 33

Blast Parameters as a Function of Radius
at 0.275 sec. from a 1.37 Surface Burst

P_o = 20.7 atm.

i_o = 41.4 atm-sec.

P_s = 4.91 P_o

t_s = 4.36 = $1.72 \frac{T_s}{T_o}$ °K.

U_s = 3.47 = $2.72 \frac{C_s}{C_o}$ Feet/sec.

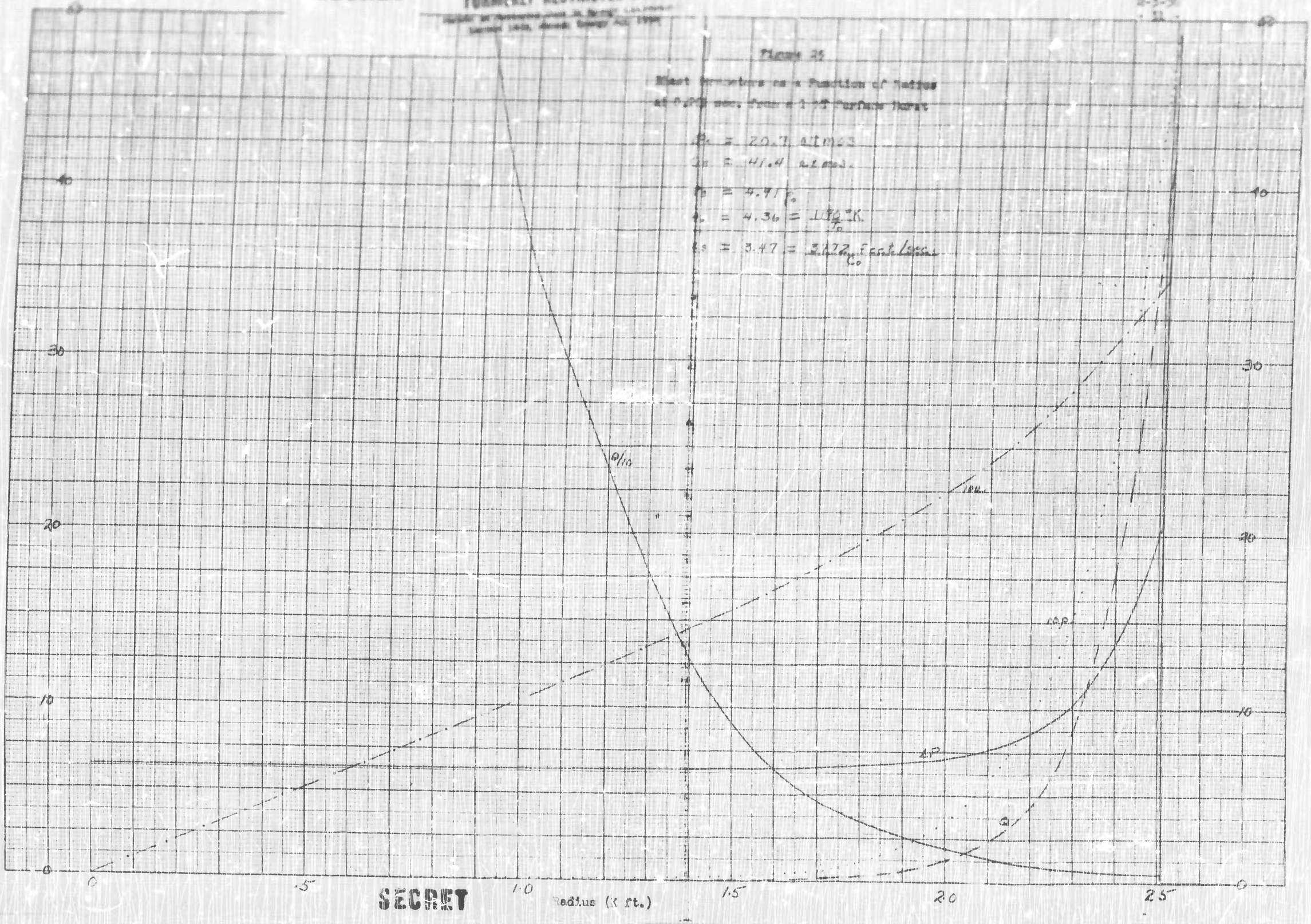

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Figure 16

Blast Parameters as a Function of Radius at 0.49 sec. from a 1 MT Surface Burst

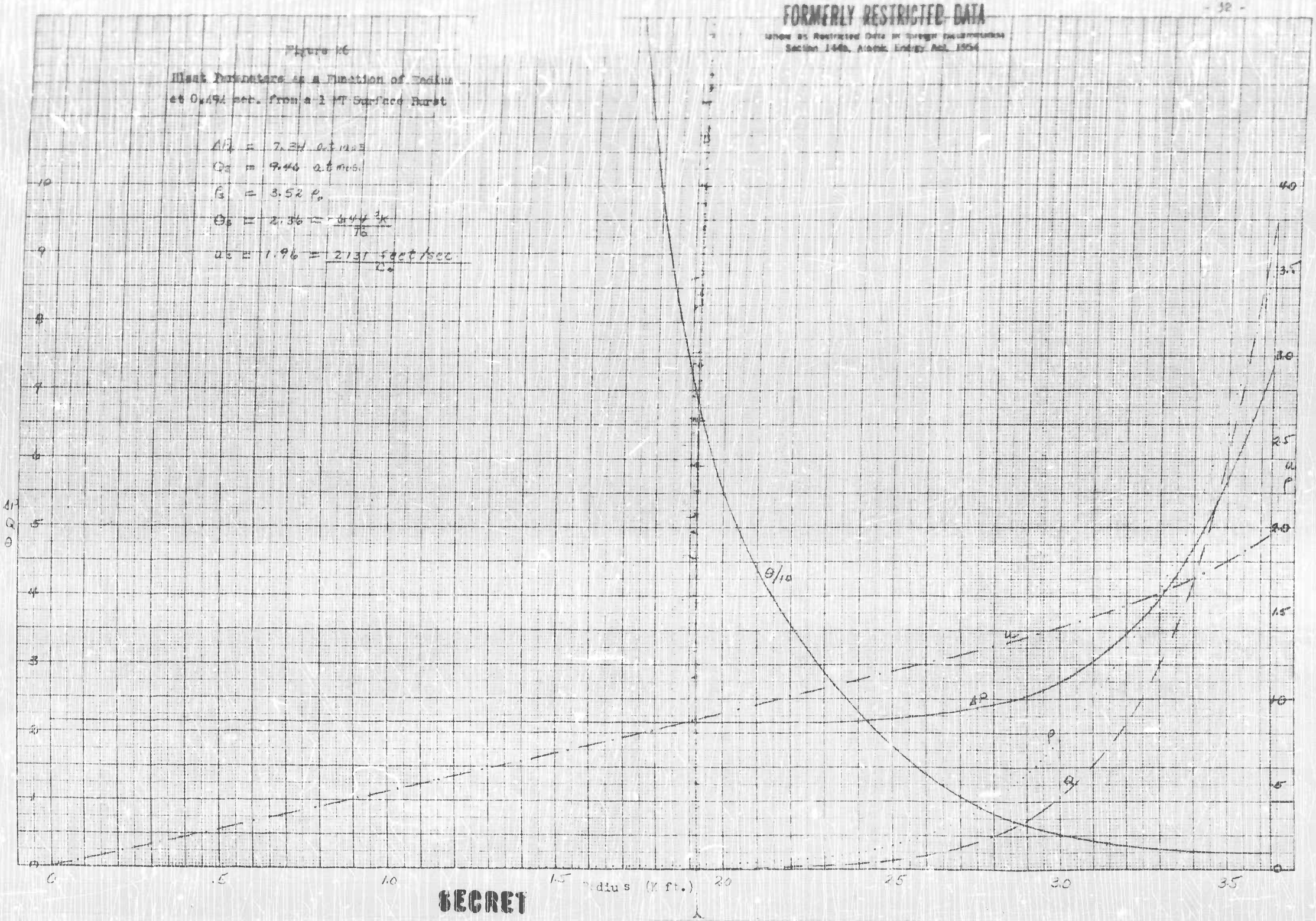
$\Delta P_1 = 2.34$ atmos

$Q_1 = 9.44$ atmos.

$\rho_1 = 3.52\ \rho_0$

$\Theta_1 = 2.36 = \frac{\text{duration}}{T_0}$

$u_1 = 1.96 = \frac{2131 \text{ feet/sec}}{C_0}$



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SUPPLEMENT TO RM-1583-1

CLOSE-IN H-BOMB EFFECTS

The following figures (Figure 27 and Figure 28) together with the data below represent the relations between the overpressure impulse, the dynamic impulse, the peak overpressure and the distance from a one MT surface burst. The impulses are defined as follows:

$$I_p^+ = \int_{t_s}^{D_p^+} \Delta P \, dt \qquad \text{(atmos - sec.)}$$

$$I_Q^+ = \frac{1}{2} \int_{t_s}^{D_u^+} \rho u^2 \, dt \qquad \text{(atmos - sec.)}$$

ΔP (atmos)	I_p^+	I_Q^+	R(kft)
900	7.84	2.53	.695
699	7.41	2.47	.755
452	6.55	2.27	.874
297	5.81	2.09	994
203	5.30	1.94	1.120
99.9	4.43	1.76	1.395
69.9	3.84	1.61	1.62
52.7	3.51	1.51	1.78
30.6	2.84	1.32	2.17
20.7	2.37	1.22	2.51
14.8	2.07	1.12	2.82
10.6	1.75	1.03	3.19
7.34	1.46	0.913	3.64
4.91	1.18	0.768	4.24
3.03	0.960	0.549	5.30
2.02	0.834	0.372	6.20
0.987	0.617	0.152	8.70
0.497	0.460	0.0607	12.59

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Fig. 27

Positive Impulses as a Function of Peak Overpressure for a 1 MT Surface Burst

Positive Impulses as a Function of the Distance from a 1 MT Surface Burst

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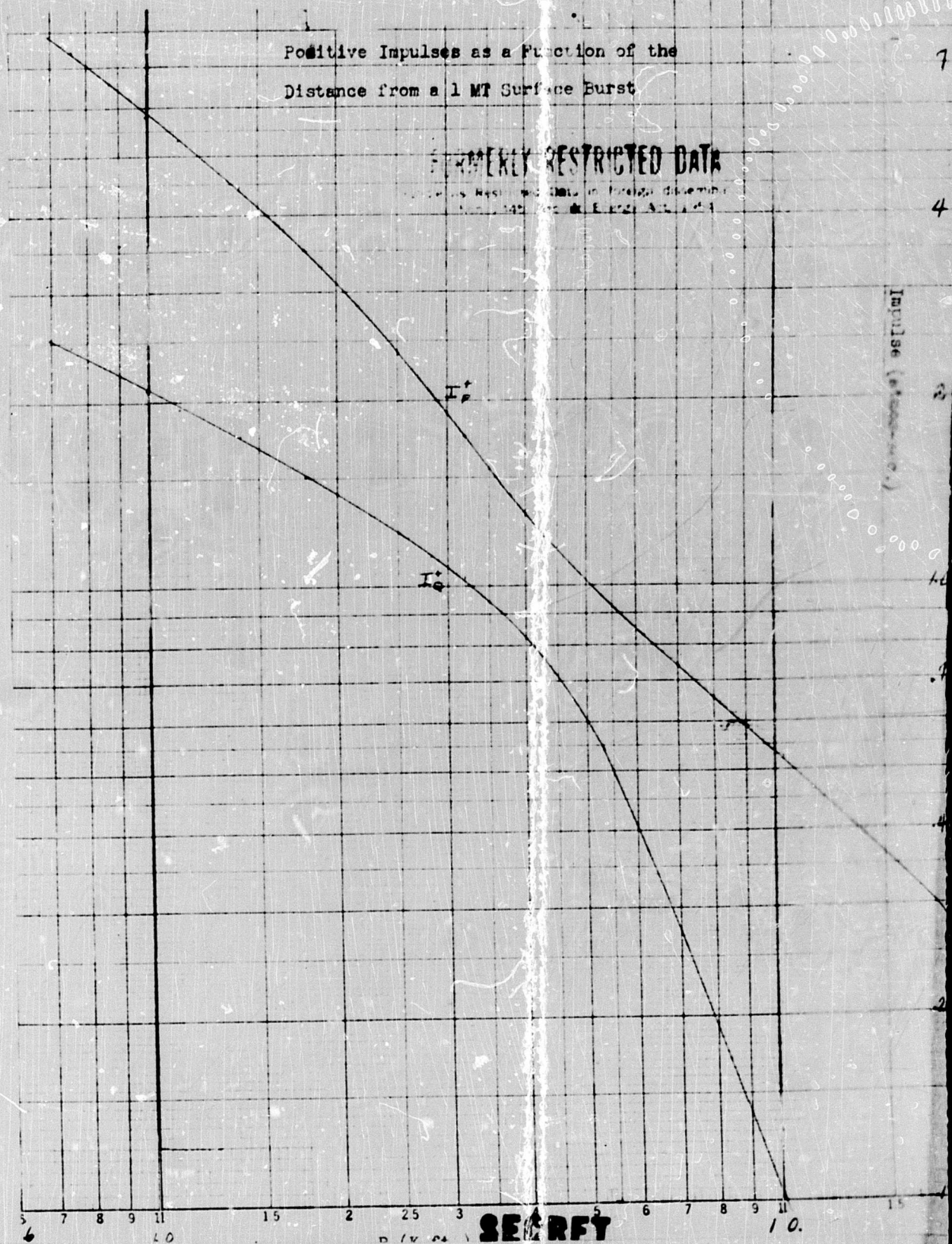

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