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Photo-Optical Studies of Nuclear Airblast
Operations BUFFALO (1956) and ANTLER (1957)

Volume 3 Part 1
A Compilation of Photo-Optical Airblast Data
Scaled and Unscaled

Prepared by

R B Harvey

H B Lutz

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Volume 3 Part 1
A Compilation of Photo-Optical Airblast Data Scaled and Unscaled

Prepared by

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PHOTO-OPTICAL STUDIES OF NUCLEAR AIRBLAST

OPERATIONS BUFFALO (1956) AND ANTLER (1957)

VOL III PART 1

A COMPILATION OF PHOTO-OPTICAL AIRBLAST DATA

SCALED AND UNSCALED

BY

R B HARVEY AND H B LUTZ

ABSTRACT

Observed values of the free air shock, the shock near ground level, the precursor and the triple point have been tabulated as a function of shock radius. Values, scaled to 1 kt and to a standard atmosphere have been tabulated for comparison.

Scaled tabulations have been assembled and averaged for the seven rounds of the two operations Antler and Buffalo.

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ACKNOWLEDGEMENT

Grateful acknowledgement is made to the UK for the opportunity to cooperate in making blast measurements on Operations Buffalo and Antler, and for the data from frequency modulated tape and other records.

The authors are grateful for financial assistance to carry out these studies from the Ballistic Research Laboratory of the Aberdeen Proving Ground, USA, and to the DRES for office and support facilities during the course of the work.

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FORWORD

PHOTO-OPTICAL STUDIES OF NUCLEAR AIRBLAST OPERATIONS (1956) AND ANTLER (1957)

Operations Buffalo and Antler were the code names of two series of nuclear trials carried out in 1956 and 1957 by the UK Atomic Weapons Research Establishment (AWRE) at Maralinga, Australia. Canada was invited to participate in the measurement of peak shock overpressures of the blast wave using a photo-optical technique, and the results were reported to the UK in the period 1956-9. A review of the photographic data has been prompted by substantial progress in the understanding of blast wave propagation, and by a more general review and compilation of UK and USA data into a set of "best values" for the parameters. The photographic data have been reviewed and compared with UK gauge measurements. The results are reported in a series of papers under the general heading "Photo-Optical Studies of Nuclear Airblast - Operations Buffalo (1956) and Antler (1957)".

The publications are grouped into four volumes. Volume I describes the calculations of the free air shock and of the shock near the surface of the ground for Operation Buffalo and for Operation Antler. The results are compared and combined in a scaled form, and some observations are made on the precursor.

Volume II provides data from a more detailed observation of the precursor and of a related phenomenon, the massive dust clouds raised by the shock as it moves outward from the explosion along the ground.

Volume III provides tables of values of the time-of-arrival and of the peak overpressures as a function of radius out from the point-of-burst. These are presented in unscaled form, and scaled to 1 kt and to

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a standard atmosphere (14.7 psi) and temperature (15°C). Data are similarly presented (scaled and unscaled), for the locus of the triple point and for the time-of-arrival of the precursor.

Volume IV provides data on the gamma values (density versus exposure) of the original films as well as some information on copying of the originals to provide duplicate negatives and prints. A second report provides the results of measurements of the frame-to-frame intervals of the films.

Volume V provides a listing of the motion picture films including available technical data. A classification was devised to list the films, and a variety of tracings, tabulations an graphs made during the original analyses (1956-9). This is included in the report.

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PHOTO-OPTICAL STUDIES OF NUCLEAR AIRBLAST

OPERATIONS BUFFALO (1956) AND ANTLER (1957)

Vol I Part 1 - "The Measurement of Free Air Shock Overpressures - Buffalo" by R B Harvey. August 1984

Part 2 - "The Measurement of Free Air Shock Overpressures - Antler" by R B Harvey. September 1984

Part 3 - "A Comparison of Free Air Pressure Measurements for Buffalo and Antler" by R B Harvey. November 1984

Part 4 - "Some Comparisons of Blast Data from Gauges and Photo-Optical Records". A paper prepared for TTCP TLG-3. June 1984

Vol II Part 1 - "Some Notes on the Precursor" by R B Harvey and H B Lutz. February 1985

Part 2 - "The Development of the Dust Cloud from Nuclear Explosions" by H B Lutz and R B Harvey. June 1985

Part 3 - "The Formation of Dust Clouds from Nuclear Explosions" by R B Harvey and H B Lutz. April 1986

Part 4 - "Some Measurements of the Time-History of Dust Clouds" by R B Harvey and H B Lutz. October 1986

Vol III Part 1 - "A Compilation of Photo-Optical Airblast Data - Scaled and Unscaled" by R B Harvey and H B Lutz. May 1985

Vol IV Part 1 - "Copying of Photo-Optical Films and Measurements of Film Density" by R B Harvey and M L Fach. May 1984

Part 2 - "Measurements of Elapsed Time" by R B Harvey and H B Lutz. November 1984

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Vol V Part 1 - "A Listing of Films, Tracings, Graphs and Tabulations" by R B Harvey. December 1984

Part 2 - "A Listing of Films, Tracings, Graphs and Tabulations, Section 5 - Tabulations" by R B Harvey. December 1984

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DEFINITIONS

Free Air Shock - the incident shock wave expanding out from the point-of-burst in that region where it is not affected by reflection or formation of the Mach stem. This direction is usually along a radial line upward from burst.

Ground level shock - the shock moving out close to the surface of the ground from Ground Zero as centre. Close to Ground Zero it may be the incident shock, which become the Mach stem after fusion of the incident and reflected shocks.

Ground Zero (GZ) - the point on the surface of the ground directly below the point-of burst. All ground level shock distances (radii) are measured from Ground Zero unless otherwise stated.

Slant range - The distance from the point-of-burst of the explosion (above the ground) to any point on the ground surface. Whenever this measurement is used it is designated as "slant range".

Overpressures of the shock are calculated on a basis of a standard atmosphere (14.7 psi) at the trial site. A correction (usually 1-2%), is required to convert overpressure to psi on a basis of the ambient pressure at the time of the trial.

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PHOTO-OPTICAL STUDIES OF NUCLEAR AIRBLAST OPERATIONS BUFFALO (1956) AND ANTLER (1957)

VOL III PART 1

A COMPILATION OF PHOTO-OPTICAL AIRBLAST DATA[1] SCALED AND UNSCALED

By

R.B. Harvey and H.B. Lutz

1. INTRODUCTION

The data in the following paper were obtained from the seven events or rounds of Operations Buffalo and Antler using a Photo-optical (PO) technique. This method makes use of a high speed motion picture record of the advancing shock front, from which a plot of (shock) radius versus time can be constructed, and the peak overpressure of the shock front can be calculated by the Rankine-Hugoniot equation. Elapsed time from frame-to-frame of the film, was measured with an error less than 0.1% by a chronographic device, and distance or shock radius was obtained by photogrammetric methods. Each film frame yields a measurement of radius of the shock and time, and these are fitted to an equation from which the velocity of the shock and the corresponding overpressure can be calculated[2]. A full description is given in Reference 1. The data have been taken from the original reports on Operation Buffalo and Operation Antler. See References 2 and 3. Some recalculation was carried out for purposes of checking the earlier work, and overpressures were combined with values of positive duration (from

---

1 The data in these notes have been prepared in response to an action from a meeting on nuclear airblast held at the Defence Research Establishment Suffield, 21, 22 January, 1985.

2 The overpressures under the heading of "Original Data" (e.g. Table 3.1.1, column 3) are calculated on a basis of a standard atmosphere (14.7 psi).

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UK records) to obtain estimates of positive pressure impulse. See Reference 4.

The purpose of the present paper is to summarize the original data into tabular and graphical form. Comparative tables have been calculated in which the data are scaled to a yield of 1 kiloton (kt), and to a standard atmosphere (1013 millibars) and a standard temperature ($15^{o}C$).

All tabular data have been prepared with a common or standard set of values for the radius (in feet) of the shock out from the point-of- burst or from Ground Zero (GZ), the point on the surface of the ground directly under the point-of-burst. Corresponding values of time-of-arrival (T of A, or T) in seconds or milliseconds (msecs), overpressure in psi, and height of triple point in feet have been retained in these units to simplify comparison with other nuclear airblast data.

Section 2 presents general data from which are prepared the scaling factors for yield, pressure, distance and time.

Section 3 presents the original and the scaled data for the four events or rounds of Operation Buffalo and Section 4 presents similar data for Operation Antler.

The data for each round, in scaled and unscaled form, are assembled and graphed. The figures are inserted at the end of the section since data from more than one round may appear on each figure.

Scaled data from one parameter, e.g. overpressure, have been plotted for comparison purposes on one curve for all seven events of Buffalo and Antler in Section 5. Section 6 provides data for the locus of the triple point, and Section 7 summarizes data on the precursor for the two airburst events.

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2. GENERAL DATA[1]

The overpressure of an outgoing shock will occur at a distance from an explosion that is proportional to the cube root of the energy yield. If D_o is the distance (or slant range) from a reference explosion of W_o kilotons, at which a certain overpressure or dynamic pressure is observed, then for any explosion of W kilotons energy these same pressures will occur at a distance D given by

$$\frac{D}{D_o} = \left(\frac{W}{W_o}\right)^{1/3}$$

If the reference explosion is 1 kiloton (kt) then $W_o = 1$

$$D = D_o \times W^{1/3}$$

where D_o refers to the distance from a 1 kt explosion,

A scaled height-of-burst (HOB) is defined as

$$\text{Scaled HOB} = \frac{\text{Actual HOB}}{W^{1/3}}$$

For explosions of different energies having the same scaled HOB, the cube root scaling law may be applied to distances from ground zero (GZ), as well as distances from the explosion. If d_o is the distance from GZ that a particular overpressure or dynamic pressure is observed for a 1 kt explosion, then for an explosion of W kt energy the same pressure will be observed at a distance d given by

$$d = d_o\ (W)^{1/3}$$

The distances are now from GZ, rather than from the explosion (slant range).

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[1] The notes on scaling factors are taken from Reference 5.

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Cube root scaling can also be applied to arrival time of the shock front, positive phase duration and impulse, where these quantities are themselves scaled according to the cube root law.

The relationships are:

$$\frac{t}{t_o} = \frac{d}{d_o} = \left(\frac{W}{W_o}\right)^{1/3} \quad \text{and} \quad \frac{I}{I_o} = \frac{d}{d_o} = \left(\frac{W}{W_o}\right)^{1/3}$$

where t_o represents arrival time or positive phase duration.

I_o is the impulse and

d_o is the distance from GZ

for a reference explosion of energy W_o; and t, d and I refer to any explosion of energy W.

The relations above apply to a homogeneous standardized atmosphere, i.e.

standard pressure is 14.7 psi or 1013 millibars, and

standard temperature is 15°C or 288°K

If the ambient atmospheric conditions are different for a specified explosion as compared to those in the reference explosion, correction factors must be applied. If the ambient pressure P and the absolute temperature T are not the same as P_o and T_o in the reference 1 kt explosion, then the overpressure is given by

$$p = p_o \frac{P}{P_o}$$

where the p's refer to the respective overpressures at a given distance. The corrected values of distance for a specified pressure are given by

$$d = d_o W^{1/3} \left(\frac{P_o}{P}\right)^{1/3}$$

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and for arrival time or positive phase duration at the appropriate scaled distance by

$$t = t_o W^{1/3} \left(\frac{P_o}{P}\right)^{1/3} \left(\frac{T_o}{T}\right)^{1/2} .$$

For $T = T_o$ and $P = P_o$, those equations reduce to the ones given previously.

The following tables provide data to calculate the scaling factors for the four rounds of Operation Buffalo and the three rounds of Operation Antler. For example, in Table 2.1 the right hand column gives the scaled HOB (to 1 kt) for each explosion. Round 1 of Buffalo is at a height of 31 metres (102 feet) with a measured yield of 12.9 kt. The corresponding scaled HOB is

$$\frac{102 \text{ feet}}{(12.9)^{1/3}} = 43.4 \text{ feet}$$

The scaled values for HOB are shown in Column 7 of Table 2.3. The scaling factors for yield, which are the inverse of the cube root of the measured yield, are given in Column 6.

The corrected values of distance for a specified atmospheric pressure P (and 1 kt) are given by

$$d_o = d \left(\frac{P}{P_o}\right)^{1/3} = d \left(\frac{998}{1013}\right)^{1/3} = 0.995\ d \text{ for Buffalo 1.}$$

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Similarly, the scaling factor for time-of-arrival or positive duration (for Buffalo 1) is

$$\frac{t_o}{t} = \left(\frac{P}{P_o}\right)^{1/3} \left(\frac{T}{T_o}\right)^{1/2} = \left(\frac{998}{1013}\right)^{1/3} \left(\frac{295}{288}\right)^{1/2} = 0.995 \times 1.012$$

$$= 1.007$$

The pressure for a 1 kt explosion is $p_o = p\left(\frac{P_o}{P}\right)$

$$= \left(\frac{1013}{998}\right)p = 1.015p \quad \text{(Buffalo 1)}$$

where p is the overpressure measured at an ambient atmospheric pressure of 998 millibars.

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TABLE 2.1 - Yield and Height-of-Burst (HOB[1])

Operation and Round	Type	Height (m)	Measured Yield (kt)	Scaled HOB (feet)
Buffalo 1	Tower	31	12.9	43.4
2	Surface	0.2	1.4	0
3	Airburst (free fall)	150	2.88	346
4	Tower	31	10.8	46
Antler 1	Tower	31	0.93	104
2	Tower	31	5.67	57
3	Airburst (balloon system)	300	26.6	339[2]

1 Document SFS/A/26 dated 14.3.84 AWRE.

"This TABLE contains UK Government (Ministry of Defence) Official Information".

2 Photo-optical measurements give a height-of-burst of 1013 feet, and this figure is used to obtain the scaled HOB of 339 feet.

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TABLE 2.2 - Ambient Air Conditions

Operation and Round	Ambient Air			Scaling Factor to 1 kt $(\frac{1}{W^{1/3}})$
	Pressure (millibars)	Temperature (°C)	Relative Humidity (%)	
Buffalo 1	998	22	18	0.426
2	992	22.6	35	0.894
3	998	24.1	35	0.703
4	994	13.1	84	0.452
Antler 1	1001	17.5	-	1.024
2	1004	13	68	0.561
3	988	35	-	0.335

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TABLE 2.3 - Scaling Factors to 1 kiloton - Buffalo and Antler

Round	Height-of-Burst (feet)	Yield (kt)	Atmospheric		Scaling Factor Yield	Scaled HOB (feet)	Scaling Factor		
			Pressure (millibars)	Temp. (°C)			Distance	Pressure	Time
B 1	102	12.9	998	22	0.426	43.4	0.995	1.015	1.007
2	0.66	1.4	992	22.6	0.894	0	0.993	1.021	1.006
3	492	2.88	998	24.1	0.703	346	0.995	1.015	1.011
4	102	10.8	994	13.1	0.452	46	0.994	1.019	0.991
A 1	102	0.93	1001	17.5	1.024	104	0.996	1.011	1.000
2	102	5.67	1004	13	0.561	57	0.997	1.009	0.994
3	1013	26.6	988	35	0.335	339	0.992	1.025	1.025

Standard Pressure P_o = 1013 millibars

Standard Temperature T_o = 15°C = 288°K

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3. OPERATION BUFFALO - Time-of-Arrival and Overpressure

Original data (unscaled for yield or for ambient atmospheric conditions)[1] are presented as a function of shock radius at a standardized set of distances. The data are scaled to 1 kt yield and to a standard atmosphere, and tabulated at the same standard distances.

Round Two was a surface shot and the ground debris reduced the light intensity so the shock was observed only to some 1200 feet. A Wilson condensation, as well as low cloud reflection, obliterated the free air shock in Round Four (1200 feet) although the shock at ground level was observed to a distance of 3000 feet.

Section 3.5 assembles the scaled values of Time-of-Arrival and of Overpressure for the four rounds.

[1] The overpressure, under the heading of "Original Data" in the tables, has been calculated on a basis of a standard atmosphere (14.7 psi).

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TABLE 3.1.1 - Shock Radius versus Time-of-Arrival and Overpressure of the Free Air Shock - Scaled to 1 kt - Operation Buffalo Round One

Shock Radius (feet)	Original Data		Scaled to 1 kt	
	Time-of-Arrival (msecs)	Overpressure* (psi)	Time-of-Arrival (msecs)	Overpressure (psi)
0				
100				
200			20	350
300			46	129
400		(552)	82	63.1
500	(53)	310	127	37.4
600	73	195	180	25.1
700	100	133	240	18.5
800	126	95	302	14.3
900	167	70	370	11.5
1000	210	54	424	9.4
1100	255	43	520	7.9
1200	305	36	592	6.7
1300	357	30.4	670	5.9
1400	413	25.5	750	5.1
1500	470	22.3	830	4.6
1600	529	19.5	910	4.0
1700	591	17.0	992	3.6
1800	654	15.4	1075	-
1900	719	14.0	1154	-
2000	786	12.7		
2200	924	10.7		
2400	1070	9.1		
2600	1213	7.9		
2800	1362	6.9		
3000	1511	6.1		
3200	1666	5.5		
3400	1826	4.8		
3600	1989	4.4		
3800	2148	3.9		
4000	2315	3.6		
4200	2475			
4400	2638			

* The overpressures in column 3 are based on a standard atmosphere (14.7 psi).

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TABLE 3.1.2 - Shock Radius versus Time-of-Arrival and Overpressure of the Shock at Ground Level - Scaled to 1 kt - Operation Buffalo - Round One

Shock Radius (feet)	Original Data		Scaled to 1 kt	
	Time-of-Arrival (msecs)	Overpressure* (psi)	Time-of-Arrival (msecs)	Overpressure (psi)
0				
100				
200				
300			31	
400			72	
500			116	53.2
600			162	36.5
700	72		216	23.9
800	110	75	276	17.7
900	149	70	342	13.8
1000	189	65.6	412	11.1
1100	230	60	480	9.1
1200	272	53	554	7.9
1300	321	44.2	623	7.3
1400	369	36.8	696	-
1500	421	31.3		
1600	472	26		
1700	527	22.3		
1800	587	19.5		
1900	649	17.3		
2000	711	15.8		
2200	842	12.8		
2400	978	11.0		
2600	1116	9.2		
2800	1263	8.0		
3000	1414	7.5		
3200				
3400				
3600				
3800				
4000				
4200				
4400				

* The overpressures in column 3 are based on a standard atmosphere (14.7 psi).

07110027

TABLE 3.2.1 - Shock Radius versus Time-of-Arrival and Overpressure of the Free Air Shock - Scaled to 1 kt - Operation Buffalo - Round Two

Shock Radius (feet)	Original Data		Scaled to 1 kt	
	Time-of-Arrival (msecs)	Overpressure* (psi)	Time-of-Arrival (msecs)	Overpressure (psi)
0				
100		(144) 541		
200	23.5	295	24	232
300	49	135	53	105
400	82.5	75	91	58.8
500	123	47	138	36.2
600	172	31.5	194	25.1
700	228	23.3	254	18.4
800	290	18.0	320	14.1
900	354	14.3	390	10.9
1000	420	11.5	460	8.6
1100	489	9.0	536	6.9
1200	(565)	7.4	-	-
1300				
1400				
1500				
1600				
1700				
1800				
1900				
2000				
2200				
2400				
2600				
2800				
3000				
3200				
3400				
3600				
3800				
4000				
4200				
4400				

* The overpressures in column 3 are based on a standard atmosphere (14.7 psi).

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TABLE 3.2.2 - Shock Radius versus Time-of-Arrival and Overpressure of the Shock at Ground Level - Scaled to 1 kt - Operation Buffalo - Round Two

Shock Radius (feet)	Original Data		Scaled to 1 kt	
	Time-of-Arrival (msecs)	Overpressure* (psi)	Time-of-Arrival (msecs)	Overpressure (psi)
0				
100				
200	(270) 44	(260) 230	(30)	(313)
300	52	160	57	117
400	83	80	92	57.8
500	127	44.5	138	33.4
600	177	29	200	21.5
700	236	20.3	260	15.0
800	298	14.8	335	11.0
900	367	10.8	406	-
1000	438	-	-	-
1100				
1200				
1300				
1400				
1500				
1600				
1700				
1800				
1900				
2000				
2200				
2400				
2600				
2800				
3000				
3200				
3400				
3600				
3800				
4000				
4200				
4400				

* The overpressures in column 3 are based on a standard atmosphere (14.7 psi).

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TABLE 3.3.1 - Shock Radius versus Time-of-Arrival and Overpressure of the Free Air Shock - Scaled to 1 kt - Operation Buffalo - Round Three

Shock Radius (feet)	Original Data		Scaled to 1 kt	
	Time-of-Arrival (msecs)	Overpressure* (psi)	Time-of-Arrival (msecs)	Overpressure (psi)
0				
100				
200		(743)	(20)	254
300	29	220	50	94.6
400	59	108	88	60.1
500	94	67	140	31.5
600	138	44	198	25.6
700	191	32	264	16.5
800	246	25	330	12.8
900	306	20.4	404	10.1
1000	370	16.5	478	8.3
1100	436	13.8	556	6.9
1200	504	11.8	637	5.6
1300	575	10.0	716	4.7
1400	651	8.8	800	4.0
1500	728	7.7	880	-
1600	805	6.7	964	-
1700	882	6.0		
1800	958	5.0		
1900	1042	4.5		
2000	1121	4.0		
2200	1287	-		
2400				
2600				
2800				
3000				
3200				
3400				
3600				
3800				
4000				
4200				
4400				

* The overpressures in column 3 are based on a standard atmosphere (14.7 psi).

07110030

TABLE 3.3.2 - Shock Radius versus Time-of-Arrival and Overpressure of the Shock at Ground Level - Scaled to 1 kt - Operation Buffalo - Round Three

Shock Radius (feet)	Original Data		Scaled to 1 kt	
	Time-of-Arrival (msecs)	Overpressure* (psi)	Time-of-Arrival (msecs)	Overpressure (psi)
0	-		-	
100	98		74	
200	113		92	
300	132		122	
400	161		160	
500	195		206	
600	236		(250)	
700	284		288	31.2
800	332		352	24.4
900	(375)		410	19.5
1000	405	31.2	473	15.8
1100	462	26.4	538	13.0
1200	522	22.3	607	10.8
1300	586	19.2	680	9.2
1400	647	16.7	753	7.9
1500	712	14.5	830	6.7
1600	775	12.8	910	5.8
1700	841	11.0	990	5.1
1800	907	9.8	1070	4.7
1900	980	8.7	-	-
2000	1052	7.9		
2200	1205	6.4		
2400	1358	5.3		
2600	1515	4.7		
2800	-	-		
3000				
3200				
3400				
3600				
3800				
4000				
4200				
4400				

* The overpressures in column 3 are based on a standard atmosphere (14.7 psi).

07110031

TABLE 3.4.1 - Shock Radius versus Time-of-Arrival and Overpressure of the Free Air Shock - Scaled to 1 kt - Operation Buffalo - Round Four

Shock Radius (feet)	Original Data		Scaled to 1 kt	
	Time-of-Arrival (msecs)	Overpressure* (psi)	Time-of-Arrival (msecs)	Overpressure (psi)
0				
100				
200			16	368
300	14		49	127
400	30	496	76	66.7
500	51	270	122	42.7
600	74	167	176	(29.4)
700	103	115		
800	137	81		
900	177	65		
1000	219	52		
1100	266	44		
1200	318	-		
1300				
1400				
1500				
1600				
1700				
1800				
1900				
2000				
2200				
2400				
2600				
2800				
3000				
3200				
3400				
3600				
3800				
4000				
4200				
4400				

* The overpressures in column 3 are based on a standard atmosphere (14.7 psi)

07110032

TABLE 3.4.2 - Shock Radius versus Time-of-Arrival and Overpressure of the Shock at Ground Level - Scaled to 1 kt - Operation Buffalo - Round Four

Shock Radius (feet)	Original Data		Scaled to 1 kt	
	Time-of-Arrival (msecs)	Overpressure * (psi)	Time-of-Arrival (msecs)	Overpressure (psi)
0				
100				
200			12	540
300	(11)		33	181
400	(24)	713	64	91.3
500	(39)	385	105	55.9
600	60	235	156	36.3
700	86	160	208	24.9
800	119	116	270	18.3
900	157	91	334	13.9
1000	195	70	404	11.6
1100	233	58	475	9.8
1200	283	47	547	8.6
1300	331	38.5	620	-
1400	383	32	684	-
1500	434	27.5		
1600	490	23		
1700	551	20.1		
1800	613	17.7		
1900	675	15.8		
2000	746	14.4		
2200	883	11.8		
2400	1030	10.3		
2600	1174	9.1		
2800	1319	-		
3000	1466			
3200				
3400				
3600				
3800				
4000				
4200				
4400				

* The overpressures in column 3 are based on a standard atmosphere (14.7 psi).

07110033

TABLE 3.5.1. - Shock Radius versus Time-of-Arrival - Operation Buffalo - Free Air Shock Scaled to 1 kt

Shock Radius (feet)	Time-of-Arrival (msecs) Scaled to 1 kt			
	Round 1	Round 2	Round 3	Round 4
200	20	24	(20)	16
300	46	53	50	49
400	82	91	88	76
500	127	138	140	122
600	180	194	198	176
700	240	254	264	
800	302	320	330	
900	370	390	404	
1000	424	460	478	
1100	520	536	556	
1200	592		637	
1300	670		716	
1400	750		800	
1500	830		880	
1600	910		964	
1700	992			
1800	1075			
1900	1154			

07110034

TABLE 3.5.2 - Shock Radius versus Time-of-Arrival - Operation Buffalo - Shock at Ground Level - Scaled to 1 kt

Shock Radius (feet)	Time-of-Arrival (msecs) Scaled to 1 kt			
	Round 1	Round 2	Round 3	Round 4
100			74	
200		(30)	92	12
300	31	57	122	33
400	72	92	160	64
500	116	138	206	105
600	162	200	(250)	156
700	216	260	288	208
800	276	335	352	270
900	342	406	410	334
1000	412	-	473	404
1100	480	-	538	475
1200	554		607	547
1300	623		680	620
1400	696		753	684
1500	-		830	-
1600			910	-
1700			990	
1800			1070	
1900				

07110035

TABLE 3.5.3 - Shock Radius versus Overpressure - Operation Buffalo - Free Air Shock Scaled to 1 kt

Shock Radius (feet)	Overpressure (psi) Scaled to 1 kt			
	Round 1	Round 2	Round 3	Round 4
200	350	232	254	368
300	129	105	94.6	127
400	63.1	58.8	60.1	66.7
500	37.4	36.2	31.5	42.7
600	25.1	25.1	25.6	(29.4)
700	18.5	18.4	16.5	
800	14.3	14.1	12.8	
900	11.5	10.9	10.1	
1000	9.4	8.6	8.3	
1100	7.9	6.9	6.9	
1200	6.7		5.6	
1300	5.9		4.7	
1400	5.1		4.0	
1500	4.6		-	
1600	4.0		-	
1700	3.6			
1800				
1900				

07110036

TABLE 3.5.4 - Shock Radius versus Overpressure - Operation Buffalo
Shock at Ground Level Scaled to 1 kt

Shock Radius (feet)	Overpressure (psi) Scaled to 1 kt			
	Round 1	Round 2	Round 3	Round 4
200		(313)		540
300		117		181
400		57.8		91.3
500	53.2	33.4		55.9
600	36.5	21.5		36.3
700	23.9	15.0	31.2	24.9
800	17.7	11.0	24.4	18.3
900	13.8	-	19.5	13.9
1000	11.1	-	15.8	11.6
1100	9.1	-	13.0	9.8
1200	7.9	-	10.8	8.6
1300	7.3	-	9.2	-
1400	-	-	7.9	-
1500	-	-	6.7	-
1600	-	-	5.8	-
1700	-	-	5.1	-
1800	-	-	4.7	-
1900				

07110037

4. OPERATION ANTLER - Time-of-Arrival and Overpressure

Original data (unscaled for yield or for ambient atmospheric conditions)[1] are presented as a function of shock radius at a standardized set of distances. The data are scaled to 1 kt yield and to a standard atmosphere, and tabulated at the same standard distances.

Rounds One and Two were tower bursts, and Round Three was an airburst.

Section 4.4 assembles the scaled values of Time-of-Arrival and of Overpressure for the three rounds.

[1] The overpressure, under the heading of "Original Data" in the table, has been calculated on a basis of a standard atmosphere (14.7 psi).

07110038

TABLE 4.1.1 - Shock Radius versus Time-of-Arrival and Overpressure of the Free Air Shock - Scaled to 1 kt - Operation Antler - Round One

Shock Radius (feet)	Original Data		Scaled to 1 kt	
	Time-of-Arrival (msecs)	Overpressure* (psi)	Time-of-Arrival (msecs)	Overpressure (psi)
0				
100				
200	26	263	20.5	(272)
300	50	105	50	109
400	90	54	88	56.3
500	144	32	142	33.3
600	198	21.5	198	22.1
700	260	15.5	257	15.9
800	324	11.8	320	12.1
900	394	9.5	392	9.8
1000	470	7.8	466	8.1
1100	546	6.75	542	6.9
1200	622	5.85	618	6.0
1300	702	5.15	696	5.3
1400	780	4.7	775	4.9
1500	860	4.25	854	4.3
1600	940	3.85	937	4.0
1700	1020	3.54	1016	3.6
1800	1102	3.28	1100	3.4
1900	1180	3.05	1180	3.1
2000	1266	2.85	1263	2.9
2200	1430	2.5	1430	2.6
2400	1600	2.28	1597	2.3
2600	1778	2.07	1772	2.1
2800	1946	1.89	1948	2.0
3000	2120	(1.75)	2120	1.85
3200	2292	-	2296	(1.72)
3400				
3600				
3800				
4000				
4200				
4400				

* The overpressures in column 3 are based on a standard atmosphere (14.7 psi).

07110039

TABLE 4.1.2 - Shock Radius versus Time-of-Arrival and Overpressure of the Shock at Ground Level - Scaled to 1 kt
Operation Antler - Round One

Shock Radius (feet)	Original Data		Scaled to 1 kt	
	Time-of-Arrival (msecs)	Overpressure* (psi)	Time-of-Arrival (msecs)	Overpressure (psi)
0				
100				
200				
300	49	166	50	172
400	81	88	81	90
500	122	48	120	51.4
600	172	29	170	30.6
700	232	19.6	228	20.4
800	293	14.4	290	14.8
900	361	11.1	358	11.7
1000	432	8.9	428	9.3
1100	504	7.3	500	7.8
1200	581	6.3	576	6.47
1300	658	5.4	654	6.0
1400	738	4.85	730	4.9
1500	815	4.4	809	4.4
1600	(904)		894	
1700				
1800				
1900				
2000				
2200				
2400				
2600				
2800				
3000				
3200				
3400				
3600				
3800				
4000				
4200				
4400				

* The overpressures in column 3 are based on a standard atmosphere (14.7 psi).

071100

TABLE 4.2.1 - Shock Radius versus Time-of-Arrival and Overpressure of the Free Air Shock - Scaled to 1 kt - Operation Antler - Round 2

Shock Radius (feet)	Original Data		Scaled to 1 kt	
	Time-of-Arrival (msecs)	Overpressure* (psi)	Time-of-Arrival (msecs)	Overpressure (psi)
0				
100				
200			(19)	339
300	21	522	45	134
400	38	267	80	65.9
500	68	156	126	38.7
600	102	102	178	26.6
700	140	69	237	19.4
800	181	51	304	15.1
900	232	39	373	12.1
1000	285	32	443	9.9
1100	343	25.5	514	8.3
1200	400	21.5	589	7.2
1300	458	18.3	670	6.5
1400	524	15.9	746	5.6
1500	593	14	825	5.1
1600	661	12.3	904	(4.5)
1700	728	11.0	984	-
1800	800	9.8	1066	-
1900	867	8.9		
2000	952	8.2		
2200	1106	7.0		
2400	1261	6.1		
2600	1421	5.4		
2800	1580	5.0		
3000	1743	4.6		
3200	1906	(4.2)		
3400				
3600				
3800				
4000				
4200				
4400				

* The overpressures in column 3 are based on a standard atmosphere (14.7 psi).

07110041

TABLE 4.2.2 - Shock Radius versus Time-of-Arrival and Overpressure of the Shock at Ground Level - Scaled to 1 kt - Operation Antler - Round Two

Shock Radius (feet)	Original Data		Scaled to 1 kt	
	Time-of-Arrival (msecs)	Overpressure* (psi)	Time-of-Arrival (msecs)	Overpressure (psi)
0				
100				
200	9	-	15	436
300	18	450(350)	37	157
400	33	335	70	81.3
500	57	180	108	49.6
600	82	120	156	32.7
700	118	86	212	22.9
800	156	64	274	16.8
900	200	49	340	12.9
1000	248	39	410	10.5
1100	297	31	480	8.7
1200	353	25	556	7.5
1300	412	21	629	6.5
1400	474	17.5	706	5.8
1500	539	15	782	5.2
1600	600	13.2		(4.7)
1700	670	11.7		
1800	742	10.3		
1900	816	9.4		
2000	892	8.6		
2200	1039	7.2		
2400	1190	6.2		
2600	1344	5.5		
2800	1498	4.9		
3000	(1658)	-		
3200				
3400				
3600				
3800				
4000				
4200				
4400				

* The overpressures in column 3 are based on a standard atmosphere (14.7 psi).

07110042

TABLE 4.3.1 - Shock Radius versus Time-of-Arrival and Overpressure of the Free Air Shock - Scaled to 1 kt -Operation Antler - Round Three

Shock Radius (feet)	Original Data		Scaled to 1 kt	
	Time-of-Arrival (msecs)	Overpressure* (psi)	Time-of-Arrival (msecs)	Overpressure (psi)
0				
100				
200			20	244
300			48	102
400	20.5	1254	88	52
500	37	362	138	31
600	57	244	195	20.8
700	82	179	259	15.2
800	110	134	327	11.8
900	141	102	397	9.6
1000	176	80	471	8.0
1100	215	63	-	-
1200	257	52		
1300	302	43		
1400	351	36		
1500	402	31		
1600	456	26.7		
1700	511	23.5		
1800	539	20.8		
1900	629	18.6		
2000	691	16.8		
2200	818	13.9		
2400	951	11.8		
2600	1087	10.2		
2800	1228	9.0		
3000	1371	8.0		
3200				
3400				
3600				
3800				
4000				
4200				
4400				

* The overpressures in column 3 are based on a standard atmosphere (14.7 psi)

07 110043

TABLE 4.3.2 - Shock Radius versus Time-of-Arrival and Overpressure of the Shock at Ground Level - Scaled to 1 kt - Operation Antler - Round Three

Shock Radius (feet)	Original Data		Scaled to 1 kt	
	Time-of-Arrival (msecs)	Overpressure* (psi)	Time-of-Arrival (msecs)	Overpressure (psi)
0				
100				
200			85	
300			113	(115)
400	208		149	71.5
500	226		191	51.0
600	248		239	39.2
700	272		290	31.6
800	299		344	26.2
900	329		402	22.3
1000	362	96.2	462	19.2
1100	397	82.1	525	16.9
1200	434	71.5		
1300	473	63.1		
1400	514	56.4		
1500	557	51 0		
1600	602	46.3		
1700	648	42.5		
1800	695	39.2		
1900	743	36.3		
2000	793	33.8		
2200	896	29.6		
2400	1003	26.2		
2600	1114	23.5		
2800	1228	21.2		
3000	1346	19.2		
3200	1466	17.6		
3400				
3600				
3800				
4000				
4200				
4400				

* The overpressures in column 3 are based on a standard atmosphere (14.7 psi)

07110044

TABLE 4.4.1 - Shock Radius versus Time-of-Arrival - Operation Antler - Free Air Shock Scaled to 1 kt

Shock Radius (feet)	Time-of-Arrival (msecs) Scaled to 1 kt		
	Round 1	Round 2	Round 3
100			
200	20.5	(19)	19.7
300	50	45	48.4
400	88	80	88.3
500	142	126	138
600	198	178	195
700	257	237	259
800	320	304	327
900	392	373	397
1000	466	443	471
1100	542	514	
1200	618	589	
1300	696	670	
1400	775	746	
1500	854	825	
1600	937	904	
1700	1016	984	
1800	1100	1066	
1900	1180		
2000	1263		
2200	1430		
2400	1597		
2600	1772		
2800	1948		
3000	2120		
3200	2296		

07110045

TABLE 4.4.2 - Shock Radius versus Time-of-Arrival - Operation Antler - Shock at Ground Level Scaled to 1 kt

Shock Radius (feet)	Time-of-Arrival (msecs) Scaled to 1 kt		
	Round 1	Round 2	Round 3
100			
200		15	85
300	50	37	113
400	81	70	149
500	120	108	191
600	170	156	239
700	228	212	290
800	290	274	344
900	358	340	402
1000	428	410	462
1100	500	480	525
1200	576	556	
1300	654	629	
1400	730	706	
1500	809	782	
1600	894		
1700			
1800			
1900			
2000			
2200			
2400			
2600			
2800			
3000			
3200			

07110046

TABLE 4.4.3 - Shock radius versus Overpressure - Operation Antler - Free Air Shock Scaled to 1 kt

Shock Radius (feet)	Time-of-Arrival (msecs) Scaled to 1 kt		
	Round 1	Round 2	Round 3
100			
200	(272)	339	244
300	109	134	102
400	56.3	65.9	51.6
500	33.3	38.7	30.8
600	22.1	26.6	20.8
700	15.9	19.4	15.2
800	12.1	15.1	11.8
900	9.8	12.1	9.6
1000	8.1	9.9	8.0
1100	6.9	8.3	
1200	6.0	7.2	
1300	5.3	6.5	
1400	4.9	5.6	
1500	4.3	5.0	
1600	4.0	(4.5)	
1700	3.6		
1800	3.4		
1900	3.1		
2000	2.9		
2200	2.6		
2400	2.3		
2600	2.1		
2800	2.0		
3000	1.85		
3200	(1.72)		

07110047

TABLE 4.4.4 - Shock Radius versus Overpressure - Operation Antler - Shock at Ground Level Scaled to 1 kt

Shock Radius (feet)	Overpressure (psi) Scaled to 1 kt		
	Round 1	Round 2	Round 3
100			
200		436	
300	172	157	(115)
400	90	81.3	71.5
500	51.4	49.6	51.0
600	30.6	32.7	39.2
700	20.4	22.9	31.6
800	14.8	16.8	26.2
900	11.7	12.9	22.3
1000	9.3	10.5	19.2
1100	7.8	8.7	16.9
1200	6.5	7.5	
1300	6.0	6.5	
1400	4.9	5.8	
1500	4.4	5.2	
1600		(4.7)	
1700			
1800			
1900			
2000			
2200			
2400			
2600			
2800			
3000			
3200			

07110048

5. TIME-of-ARRIVAL AND OVERPRESSURE (all rounds)

Scaled values of the Time-of-Arrival and of the Overpressure have been assembled for the seven rounds of Operations Antler and Buffalo. A mean value and a standard deviation have been calculated at each value of shock radius for the shock in free air. Values for the shock near the ground vary, depending on the height of burst. Consequently the surface shot (B2) and the four tower shots (A1, A2, B1, B4) have been grouped separately from the two airbursts (B3 and A3).

07110049

TABLE 5.1 - Shock Radius versus Time-of-Arrival
Free Air Shock Scaled to 1 kt

Shock Radius (feet)	Time-of-Arrival (msecs) A1	A2	A3	B1	B2	B3	B4	Mean Value (msecs)
100								
200	(20.5)	(19)	19.7	20	24	(20)	16	19.9 ± 2.4
300	50	45	48	46	53	50	49	48.4 ± 2.9
400	88	80	88	82	91	88	76	84.7 ± 5.4
500	142	126	138	127	138	140	122	133 ± 7.9
600	198	178	195	180	194	198	176	188.3 ± 9.8
700	257	237	259	240	254	264		251.5 ±10.6
800	320	304	327	302	320	330		316 ±11.4
900	392	373	397	370	390	404		387 ± 13
1000	466	443	471	424	460	478		456 ± 19
1100	542	514		520	536	556		534 ± 17
1200	618	589		592		637		609 ± 23
1300	696	670		670		716		688 ± 22
1400	775	746		750		800		768 ± 25
1500	854	825		830		880		847 ± 25
1600	937	904		910		964		929 ± 28
1700	1016	984		992				997 ± 17
1800	1100	1066		1075				1080 ± 18
1900	1180			1154				1167 ± 18
2000	1263							1263
2200	1430							1430
2400	1597							1597
2600	1772							1772
2800	1948							1948
3000	2120							2120
3200	2296							2296

07110050

TABLE 5.2 - Shock Radius versus Time-of-Arrival - Shock at Ground Level Scaled to 1 kt

Shock Radius (feet)	Time-of-Arrival (msecs)							Mean Value (msecs)	
	A1	A2	A3	B1	B2	B3	B4	Airburst A3+B3	Surface and Tower A1+A2+B1+B2+B4
100						74		74	
200		15	85		(30)	92	12	88	19 ± 10
300	50	37	113	31	57	122	33	118	42 ± 12
400	81	70	149	72	92	160	64	155	76 ± 11
500	120	108	191	116	138	206	105	198	117 ± 13
600	170	156	239	162	200	(250)	156	246	169 ± 18
700	228	212	290	216	260	288	208	289	225 ± 21
800	290	274	344	276	335	352	270	348	289 ± 27
900	358	340	402	342	406	410	334	406	356 ± 29
1000	428	410	462	412		473	404	467	414 ± 10
1100	500	480	525	480		538	475	531	484 ± 11
1200	576	556		554		607	547	607	558 ± 12
1300	654	629		623		680	620	680	632 ± 15
1400	730	706		696		753	684	753	704 ± 20
1500	809	782				830		830	796 ± 19
1600	894					910		910	894
1700						990		990	
1800						1070		1070	
1900									
2000									
2200									
2400									
2600									
2800									
3000									

071005

TABLE 5.3 - Shock Radius versus Overpressure - Free Air Shock Scaled to 1 kt and a Standard Atmosphere

Shock Radius (feet)	Shock Overpressure (psi)							Mean Value (psi)
	A1	A2	A3	B1	B2	B3	B4	
100								
200	(272)	339	244	350	232	254	368	294 ± 56
300	109	134	102	129	105	94.6	127	114.4 ± 15
400	56.3	65.9	51.6	63.1	58.8	60.1	66.7	60.4 ± 5
500	33.3	38.7	30.8	37.4	36.2	31.5	42.7	35.8 ± 4.2
600	22.1	26.6	20.8	25.1	25.1	25.6	(29.4)	25.1 ± 2.7
700	15.9	19.4	15.2	18.5	18.4	16.5		17.4 ± 1.6
800	12.1	15.1	11.8	14.3	14.1	12.8		13.5 ± 1.2
900	9.8	12.1	9.6	11.5	10.9	10.1		10.8 ± 0.9
1000	8.1	9.9	8.0	9.4	8.6	8.3		8.9 ± 0.7
1100	6.9	8.3		7.9	6.9	6.9		7.38 ± 0.67
1200	6.0	7.2		6.7		5.6		6.38 ± 0.7
1300	5.3	6.5		5.9		4.7		5.60 ± 0.8
1400	4.9	5.6		5.1		4.0		4.90 ± 0.7
1500	4.3	5.1		4.6				4.67 ± 0.4
1600	4.0	(4.5)		4.0				4.17 ± 0.3
1700	3.6			3.6				3.6
1800	3.4							3.4
1900	3.1							3.1
2000	2.9							2.9
2200	2.6							2.6
2400	2.3							2.3
2600	2.1							2.1
2800	2.0							2.0
3000	1.85							1.85
3200	(1.72)							(1.72)

TABLE 5.4 - Shock Radius versus Overpressure
Shock at Ground Level Scaled to 1 kt
and a Standard Atmosphere

Shock Radius (feet)	Shock Overpressure (psi)							Mean Value (psi)		
	A1	A2	A3	B1	B2	B3	B4	Surface	Tower	Airburst
								B2	A1+A2+B1+B4	A3+B3
100										
200		436			(313)		540	(313)	488 ± 74	
300	172	157	115		117		181	117	170 ± 12	115
400	90	81.3	71.5		57.8		91.3	57.8	87.5 ± 10	71.5
500	51.4	49.6	51.0	53.2	33.4		55.9	33.4	52.5 ± 2.7	51.0
600	30.6	32.7	39.2	36.5	21.5		36.3	21.5	34.0 ± 2.9	39.2
700	20.4	22.9	31.6	23.9	15.0	31.2	24.9	15.0	23.0 ± 1.9	31.4
800	14.8	16.8	26.2	17.7	11.0	24.4	18.3	11.0	16.9 ± 1.5	25.3
900	11.7	12.9	22.3	13.8	-	19.5	13.9	-	13.1 ± 1.0	20.9
1000	9.3	10.5	19.2	11.1		15.8	11.6		10.6 ± 1.0	17.5
1100	7.8	8.7	16.9	9.1		13.0	9.8		8.9 ± 0.8	15.0
1200	6.5	7.5	-	7.9		10.8	8.6		7.6 ± 0.9	10.8
1300	6.0	6.5		7.3		9.2	-		6.6 ± 0.7	9.2
1400	4.9	5.8		-		7.9			5.3 ± 0.6	7.9
1500	4.4	5.2				6.7			4.8	6.7
1600	-	(4.7)				5.8			(4.7)	5.8
1700		-				5.1				5.1
1800						4.7				4.7
1900						-				-
2000										

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6. TRIPLE POINT LOCI OF TOWER BURSTS AND AIRBURSTS

If an expanding spherical shock intersects or impacts perpendicularly on a surface, it is reflected. As the shock expands and the circle of intersection on the surface enlarges, the angle of incidence becomes smaller and, when the angle between the incident and reflected shock is reduced to 40^{o} to 50^{o} depending on the shock pressure, the incident and reflected shocks fuse into a single more powerful shock frequently referred to as the Mach Stem or Mach shock. The juncture of the incident, reflected and Mach shocks is known as the Triple Point.

For airbursts, the angle separating the incident and reflected shocks is reduced slowly as the shock expands, and the triple point describes a path similar to a flat saucer. If the burst is close to the ground, the triple point rises rapidly and traces a path similar in shape to a parabola.

Triple Point data are assembled in Tables 6.1 and 6.2 for three rounds of Operation Buffalo and for two rounds of Operation Antler respectively. The triple point coordinates are given in Table 6.3, scaled to 1 kt, and they are separated according to the Height-of-Burst. The bowl-shaped locus of the triple point is apparent wherethe values of HOB are nearly equal (tower shots), and the vertical and horizontal scales of distance are the same. The locus traces a much shallower path for the two airbursts (where the horizontal distance is scaled to half the vertical).

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Event Antler 1 was a tower shot, but no data are available for the triple point. Antler 2 has a scaled HOB of 57 feet, compared to 43.4 and 46 feet for Buffalo 1 and 4 respectively, which may account for some flattening of the triple point locus as plotted in Figure 6.1.

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TABLE 6.1 - Coordinates of Triple Points (Buffalo)
(not scaled)

Shock Radius (feet)	Height of Triple Point Above Ground (ft)		
	Round 1	Round 3	Round 4
	Scaled Height-of-Burst (ft)		
	43.4	346	46
200	25		40
300	70		80
400	122		135
500	183		210
600	268		295
700	385		395
800	527		525
900	695		720
1000	880	140	
1100	1080	175	
1200		215	
1300		253	
1400		287	
1500		325	
1600		362	
1700		415	
1800		465	
1900		510	
2000		565	
2100		620	
2200		680	
2300		745	
2400		805	

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TABLE 6.2 - Coordinates of Triple Points (Antler)
(not scaled)

Shock Radius (feet)	Height of Triple Point Above Ground (feet)	
	Round 2	Round 3
	Scaled Height-of-Burst (feet)	
	57	339
100	7.3	
200	29.3	
300	69.5	
400	131	
500	210	
600	316	
700	429	
800	573	
900	756	
1000	-	
1100		-
1200		90
1300		97
1400		107
1500		119
1600		134
1700		150
1800		170
1900		191
2000		215
2100		241
2200		270
2300		300
2400		333

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TABLE 6.3 - Coordinates of Triple Points
(Scaled to 1 kt)

Shock Radius (feet)	Height of Triple Point (ft)		
	Tower Burst		Airburst
	B1 + B4	A2	B3 + A3
100	20	14	
200	72	56	
300	155	136	
400	325	250	30
(450)	(430)	-	-
500	-	415	44
600			70
700			95
800			125
900			160
1000			200
1100			245
1200			290
1300			340
1400			400
1500			450
1600			510
1700			565

Scaled HOB
B1 43.4 feet - Tower Burst
B4 46 feet - Tower Burst
A2 57 feet - Tower Burst
B3 346 feet - Airburst
A3 339 feet - Airburst

07110058

7. PRECURSOR

A precursor, or advance pressure wave, has been observed on a number of airburst nuclear events progressing out close to the ground, and ahead of the Mach front. The precursor does not exhibit the vertical pressure front of the classical shock, and the wave form can be observed as a sort of curved wedge moving outward and upward. Such a pressure front was observed for the two airbursts (A3 and B3), shortly after the incident shock impacted on the ground and was reflected. Close to the surface of the ground, it accelerated ahead of the Mach Stem and continued to increase its lead to a maximum to the point where the main shock overpressure had dropped to a level of 30 to 35 psi. Thereafter it was not visible on the photographic records, although it was recorded by the UK blast gauges. Below 30 to 35 psi it began to lose its lead over the Mach stem, and the Mach stem shock front could be seen reforming. At a pressure level about 10 to 15 psi the precursor had apparently dissipated and the gauge records exhibited the classical Friedlander shape. No precursor waveforms were recorded photographically for the tower bursts although the FMT pressure gauge traces indicated their presence. No precursor and no Mach stem (or triple point) were observed photographically for the surface burst (B2).

A plot (unscaled) of the Time-of-Arrival of the precursor of B3 is shown in Figure 3.5.3, and for A3 in Figure 4.4.2.

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The same scaling factors for yield and for ambient atmospheric conditions have been applied to the precursor data that were used for ground and free air shock data, and the data are tabulated in Table 7.1, and plotted in Figure 7.1. Time-of-Arrival data have been recorded by the UK FMT gauges and the scaled values are included for comparison.

Data of the time-of-arrival of the precursor at five UK FMT gauge sites on Operation Buffalo were obtained from original FMT records (1956), and slightly revised values were obtained for three sites in a private communication (1984). Both sets of data were included in the scaled averages.

Time-of-arrival data for the UK gauge sites for Operation Antler were obtained from Reference 3 (Operation Antler). All scaled values were fitted to an arbitrary equation by least squares methods, from which were calculated the numbers in the right hand column of Table 7.1.

All values of the precursor radius are measured from Ground Zero, the point on the ground directly under the centre-of-burst.

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TABLE 7.1- Radius versus Time of Precursor
FMT Gauge and Photo-optical Measurements
Scaled to 1 kt

Precursor Radius (feet)	Time-of-Arrival of Precursor (msecs)				Average Time-of-Arrival (msecs)
	Buffalo 3		Antler 3		
	FMT	PO	FMT	PO	
200		90		82	86
300	(112)	109		102	108
400	123	132		126	127
500	147	159	162	156	156
600	178	191	203	197	192
700	221		250	252	241
800	279		307		293
900	348		380		361
1000			460		(440)

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8. REFERENCES

1. "A Photo-optical Method for the Measurement of Free Air Shock Overpressure". by R.B. Harvey Suffield Technical Paper No. 122. 1 April 1957. Unclassified.

2. "A Photo-optical Method for the Measurement of Free Air Shock Overpressures", by R.B. Harvey, J.E. Mayhood and E.A. Jackman. AWRE Report No. T67/57. Nov. 1957. Unclassified.

3*. "Vol I Part 1. The Measurement of Free Air Shock Overpressures. - Buffalo". by R.B. Harvey, Aug. 1984. Unclassified.

"Vol I Part 2. Ibid - Antler", Sep. 1984.

4*. "Vol I Part 3. A Comparison of Free Air Pressure Measurements for Buffalo and Antler". by R.B. Harvey, Nov. 1984. Unclassified.

5. "The Effects of Nuclear Weapons" edited by Samuel Glasstone. US Department of Defense, 1957.

* These references are sub-headings of a series of reports. prepared at DRES, under the general heading:

Photo-optical Studies of Nuclear Airblast
Operations Buffalo (1956) and Antler (1957)

The security classification of AWRE Report T67/57 Nov 1957 is regraded to UNCLASSIFIED by authority of Reference SCC 505 dated 15 Jan 1985 AWRE, Foulness

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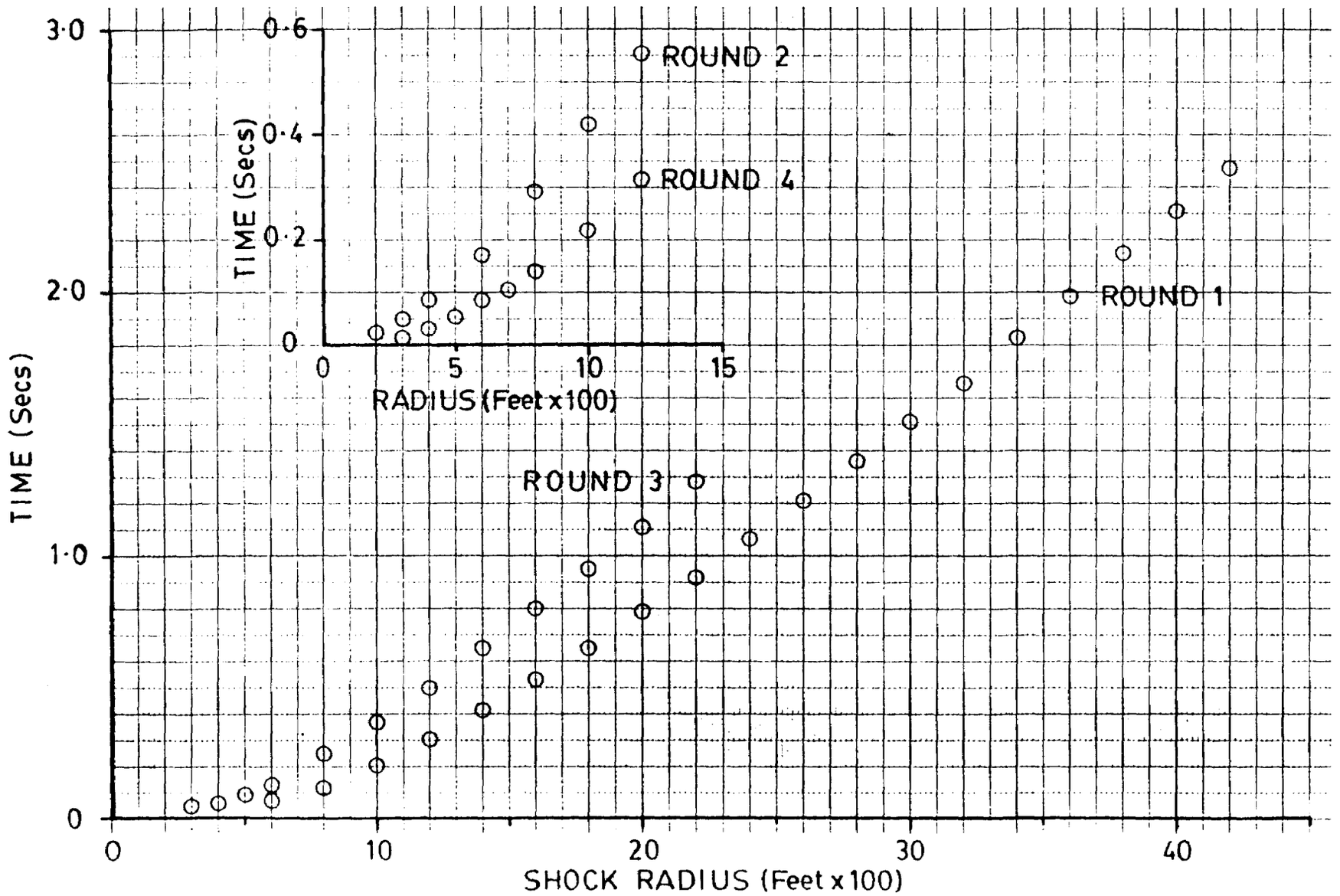

FIGURE 3.5.1. SHOCK RADIUS vs TIME-OF-ARRIVAL (IN FREE AIR) - BUFFALO 1-4

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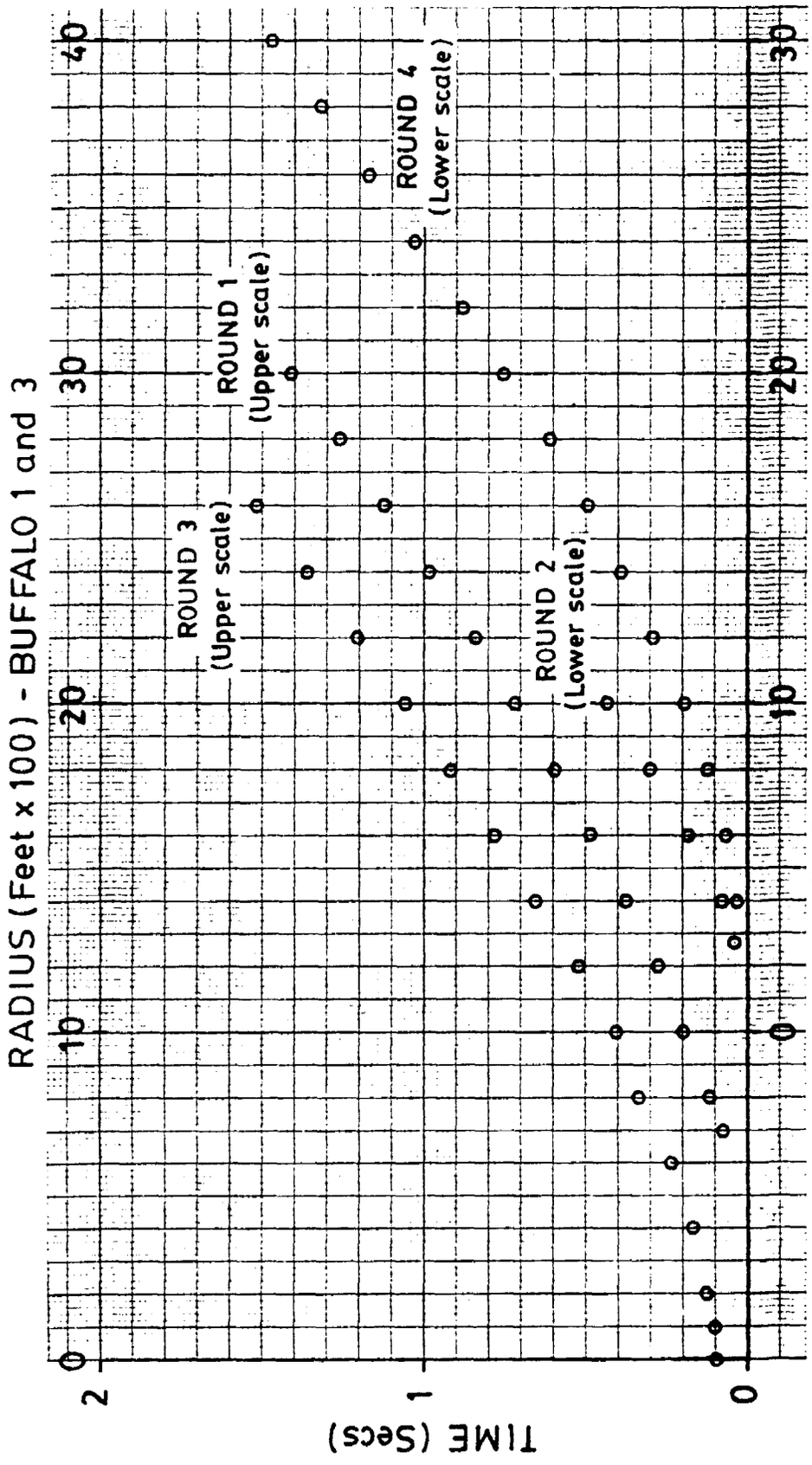

FIGURE 3.5.2 SHOCK RADIUS vs TIME NEAR GROUND LEVEL - BUFFALO

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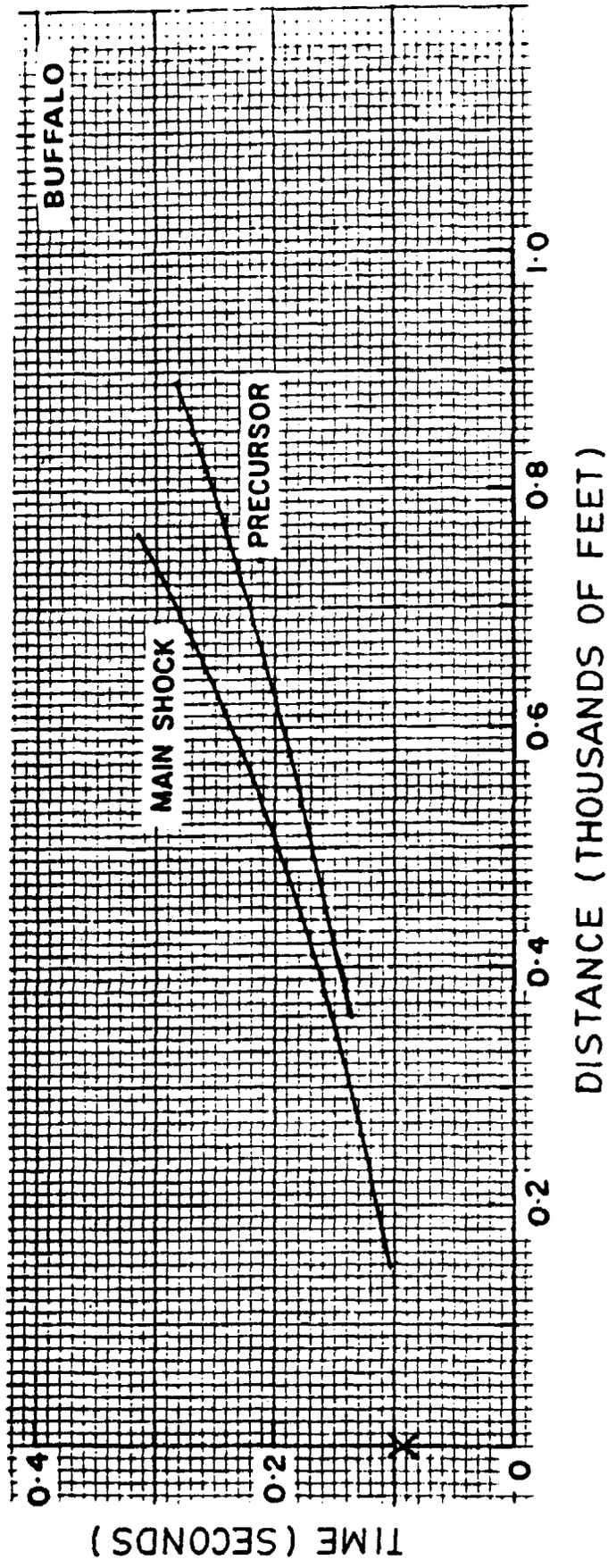

FIGURE 3.5.3 TIME vs DISTANCE CURVES OF MAIN SHOCK WAVE AND PRECURSOR NEAR GROUND LEVEL - BUFFALO 3

07110065

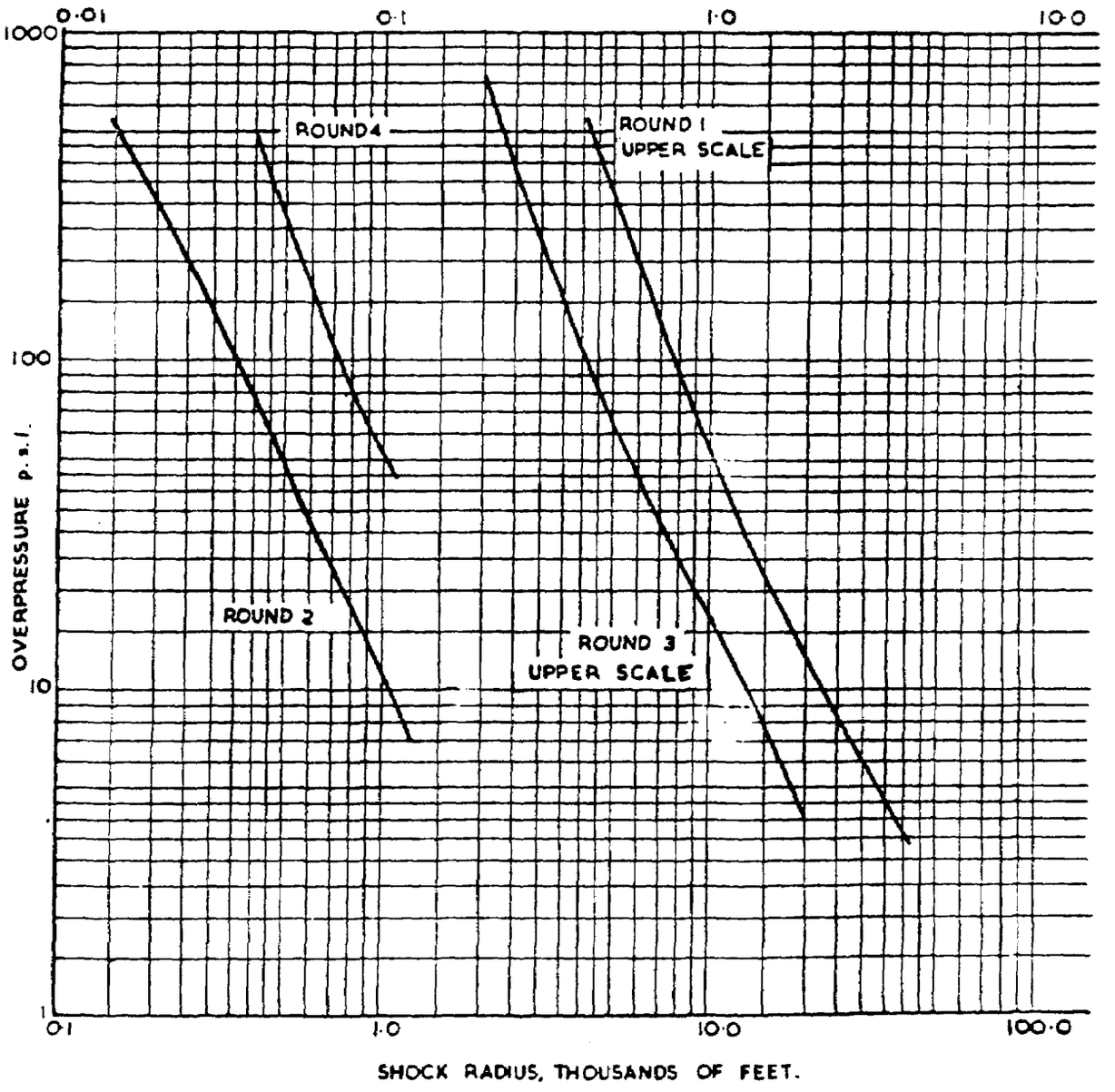

FIG. 3.5.4 OVERPRESSURE VERSUS DISTANCE IN FREE AIR REGION.

07110066

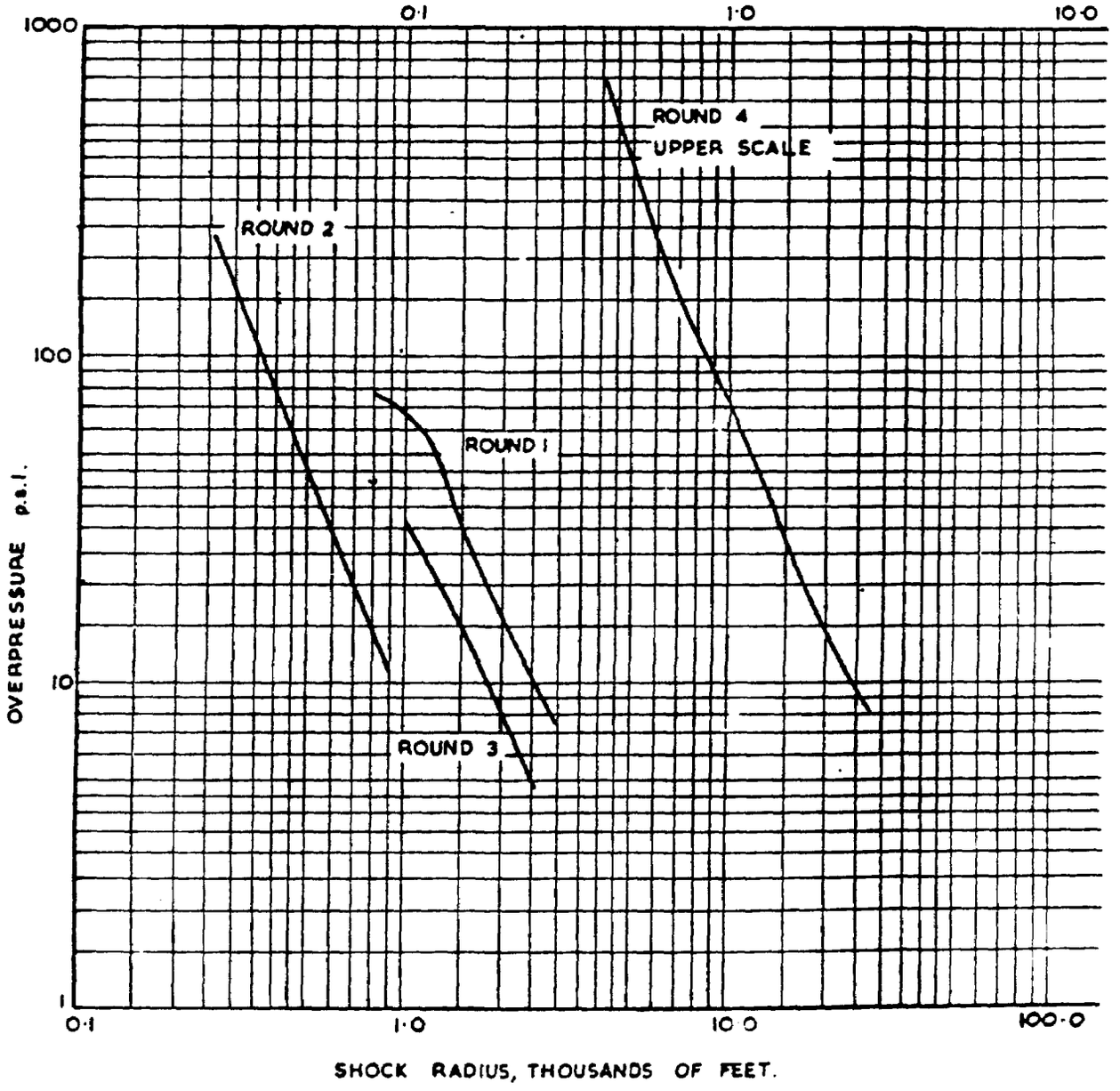

FIG. 3.5.5 OVERPRESSURE VERSUS DISTANCE NEAR GROUND LEVEL.

07110067

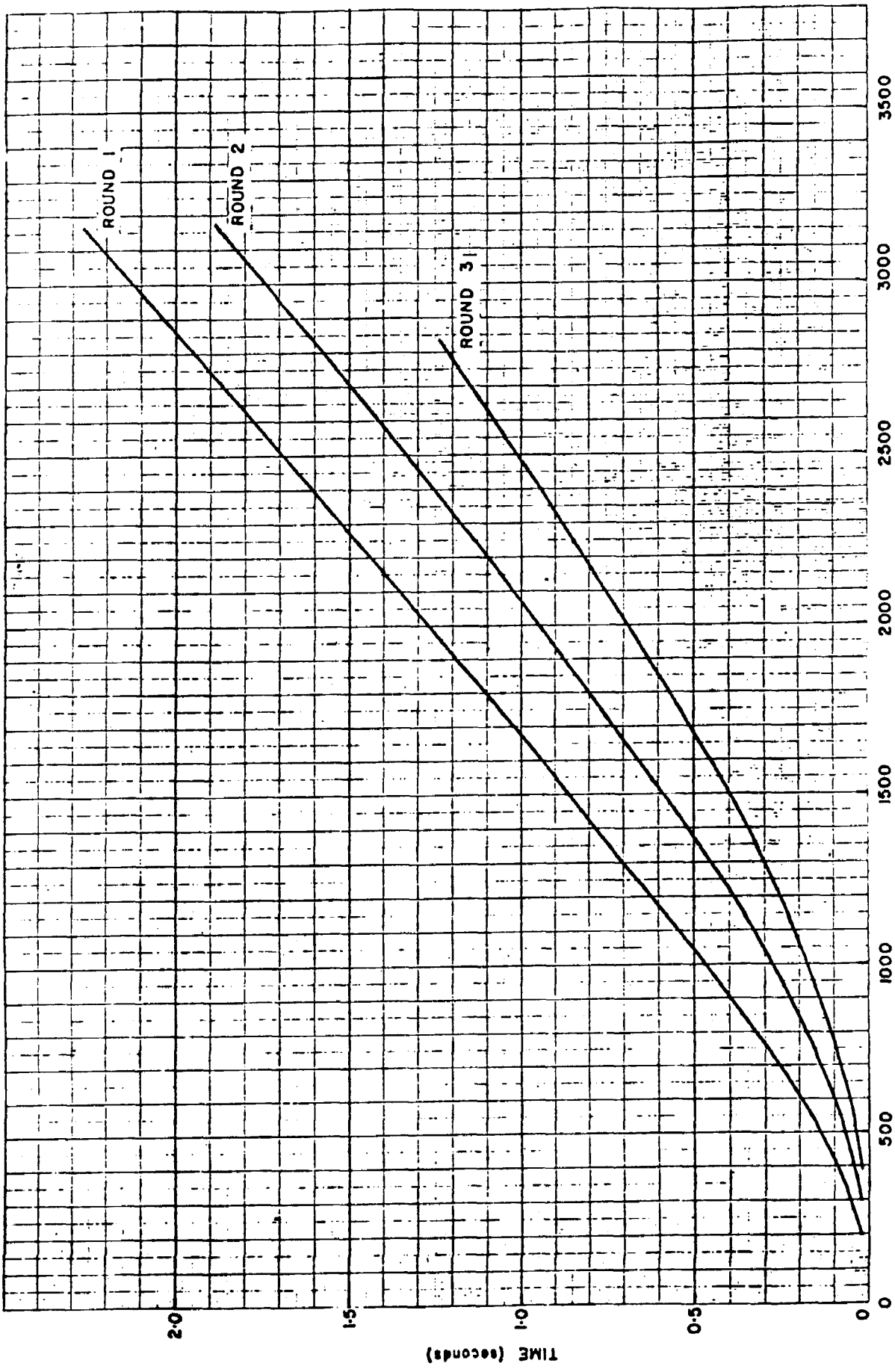

FIG. 4.4.1 SHOCK RADII versus TIME IN FREE AIR REGION

07110068

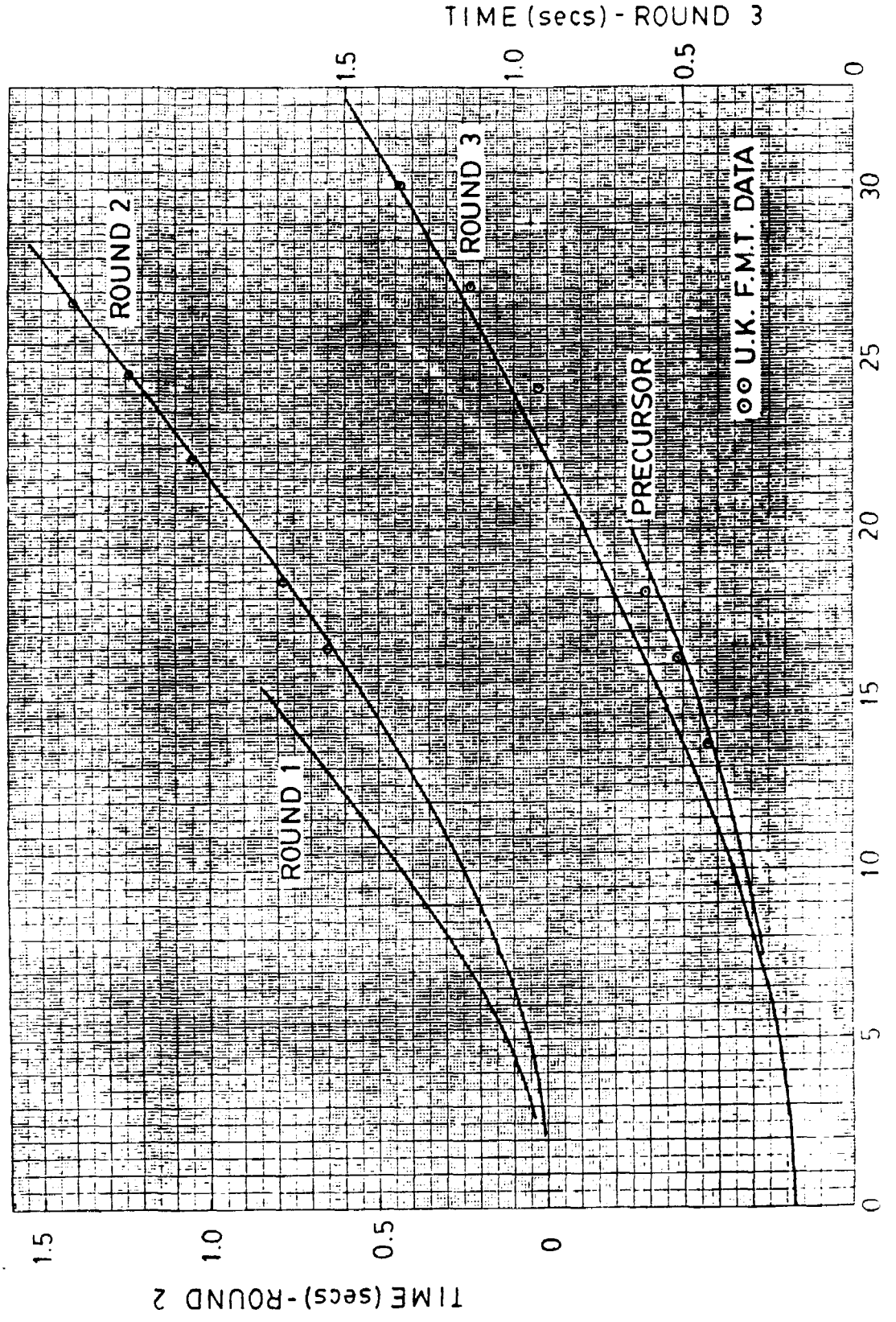

FIGURE 4.4.2 SHOCK RADII vs TIME (NEAR THE GROUND)

07110069

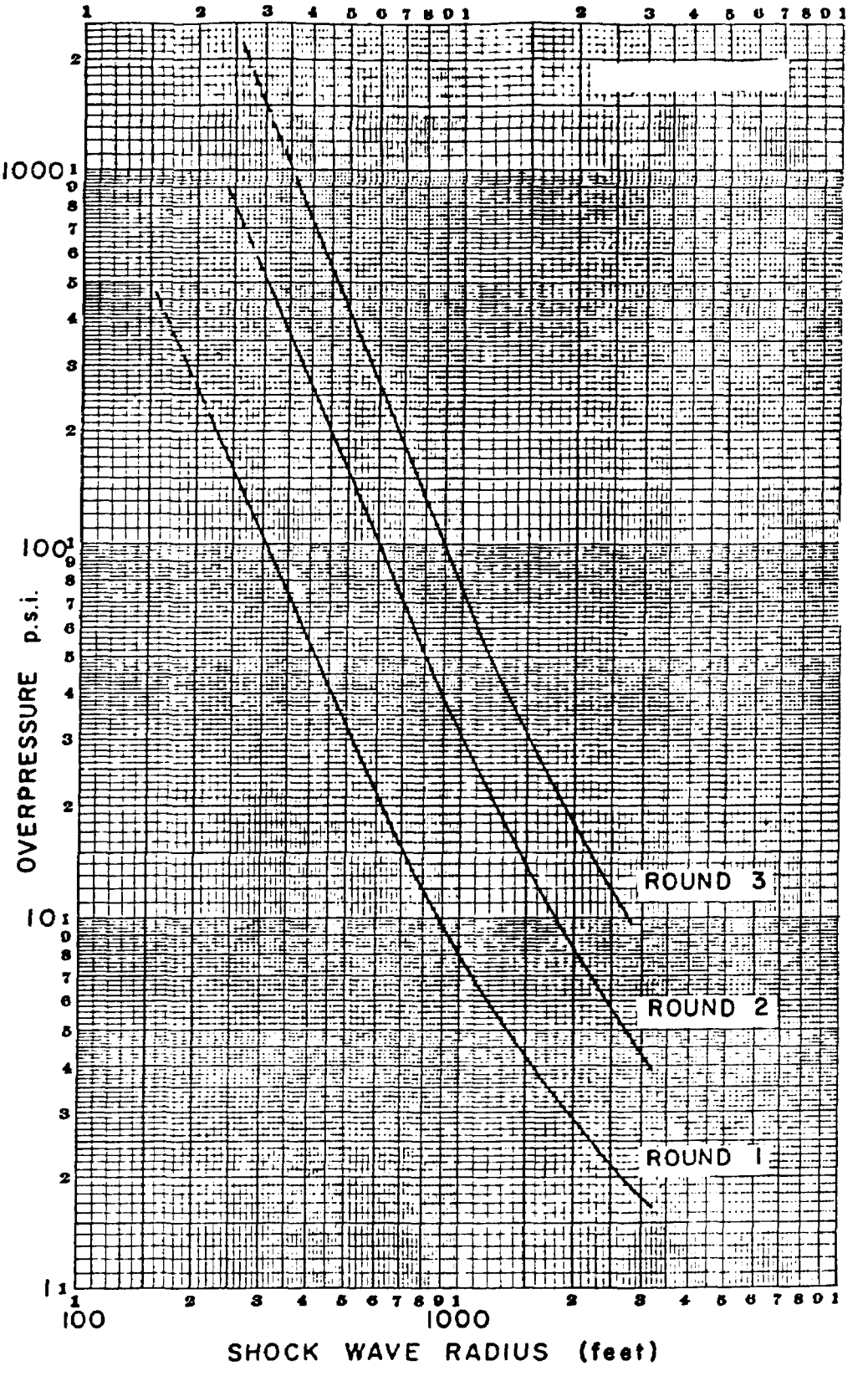

FIG.4.4.3 SHOCK RADIUS versus OVERPRESSURE
FREE AIR REGION

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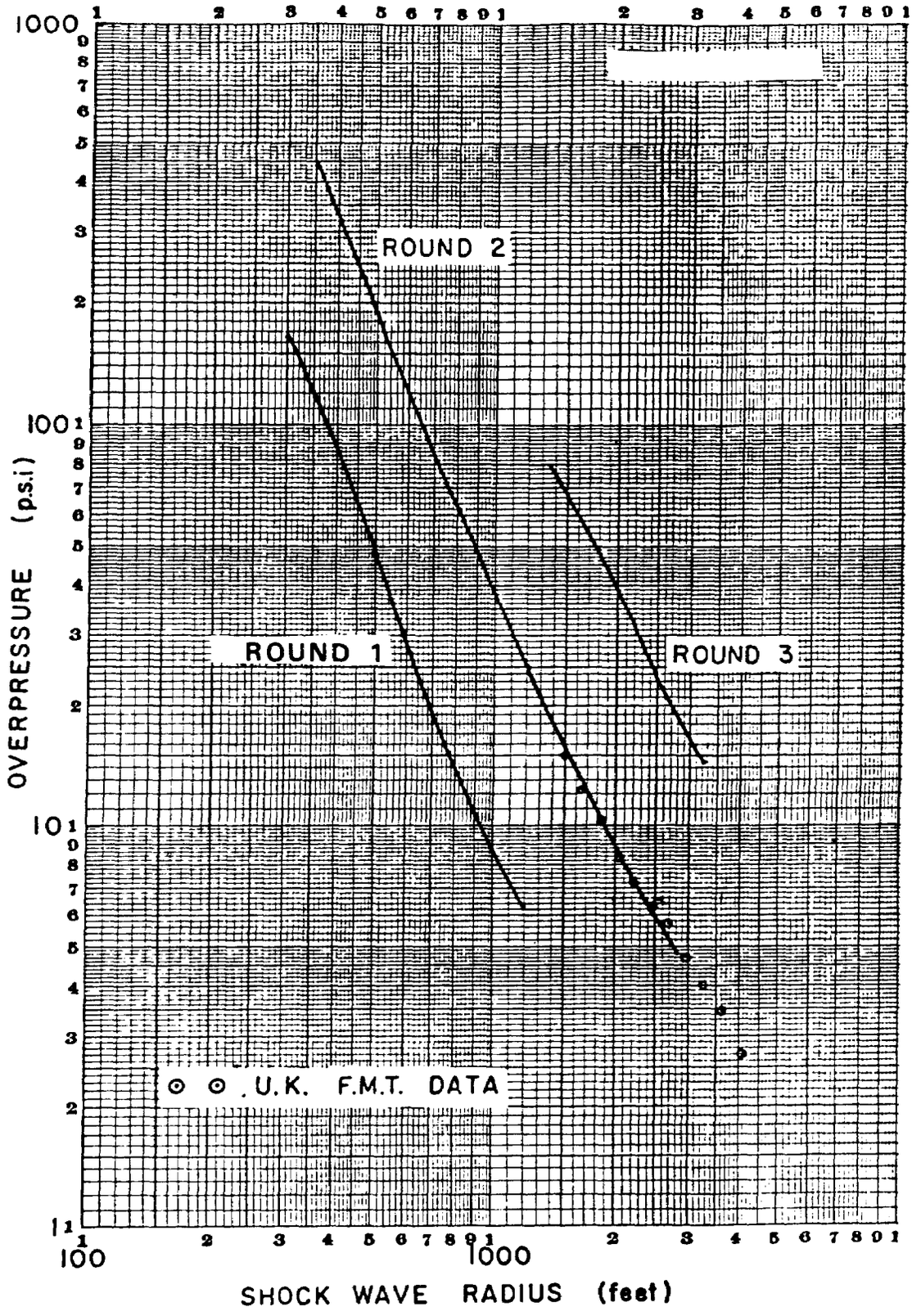

FIG. 4.4.4 SHOCK RADIUS versus OVERPRESSURE NEAR THE GROUND

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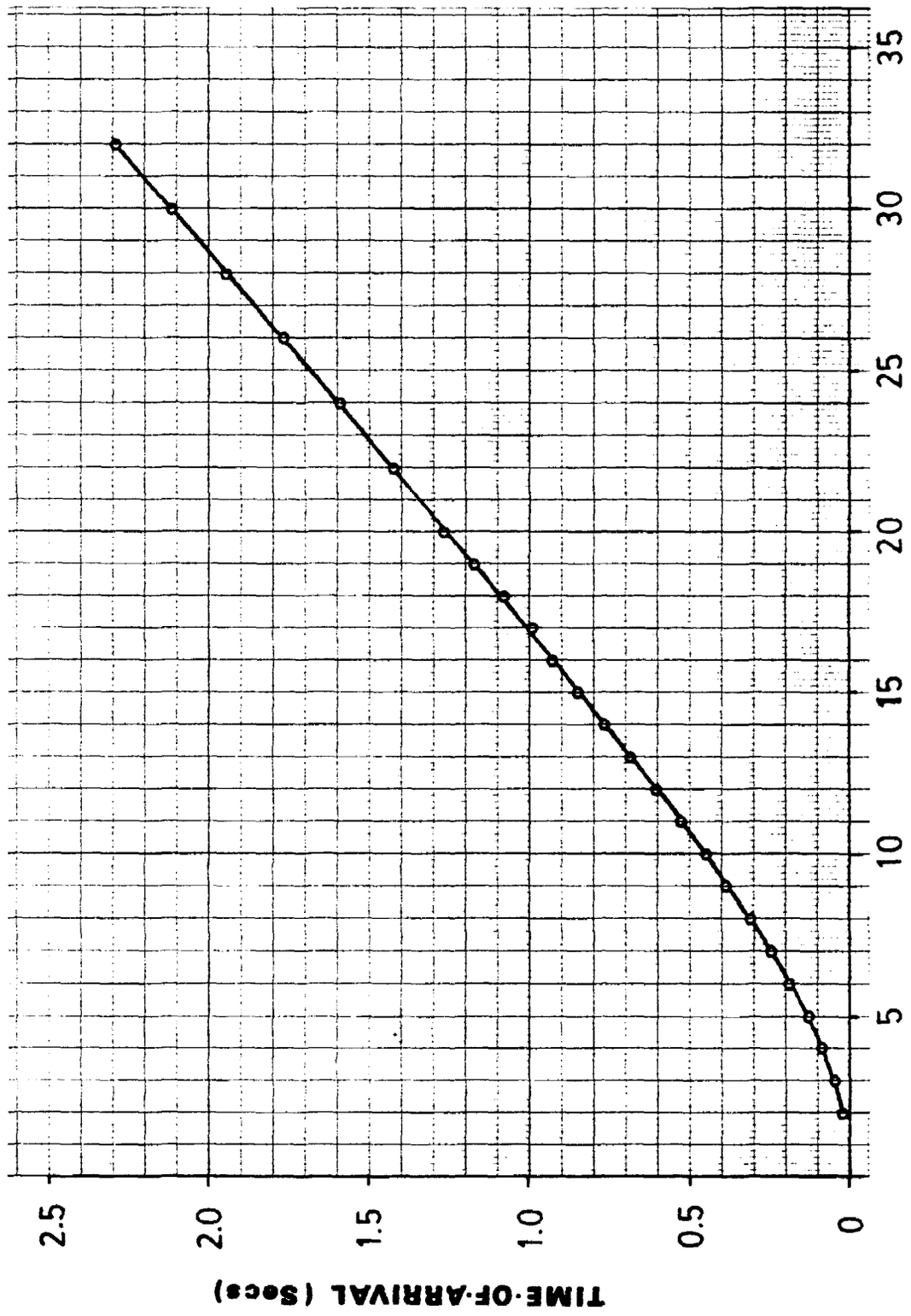

FIGURE 5.1. SHOCK RADIUS vs TIME IN FREE AIR REGION (Scaled to 1 KT)
(Average of seven rounds of Operations ANTLER and BUFFALO)

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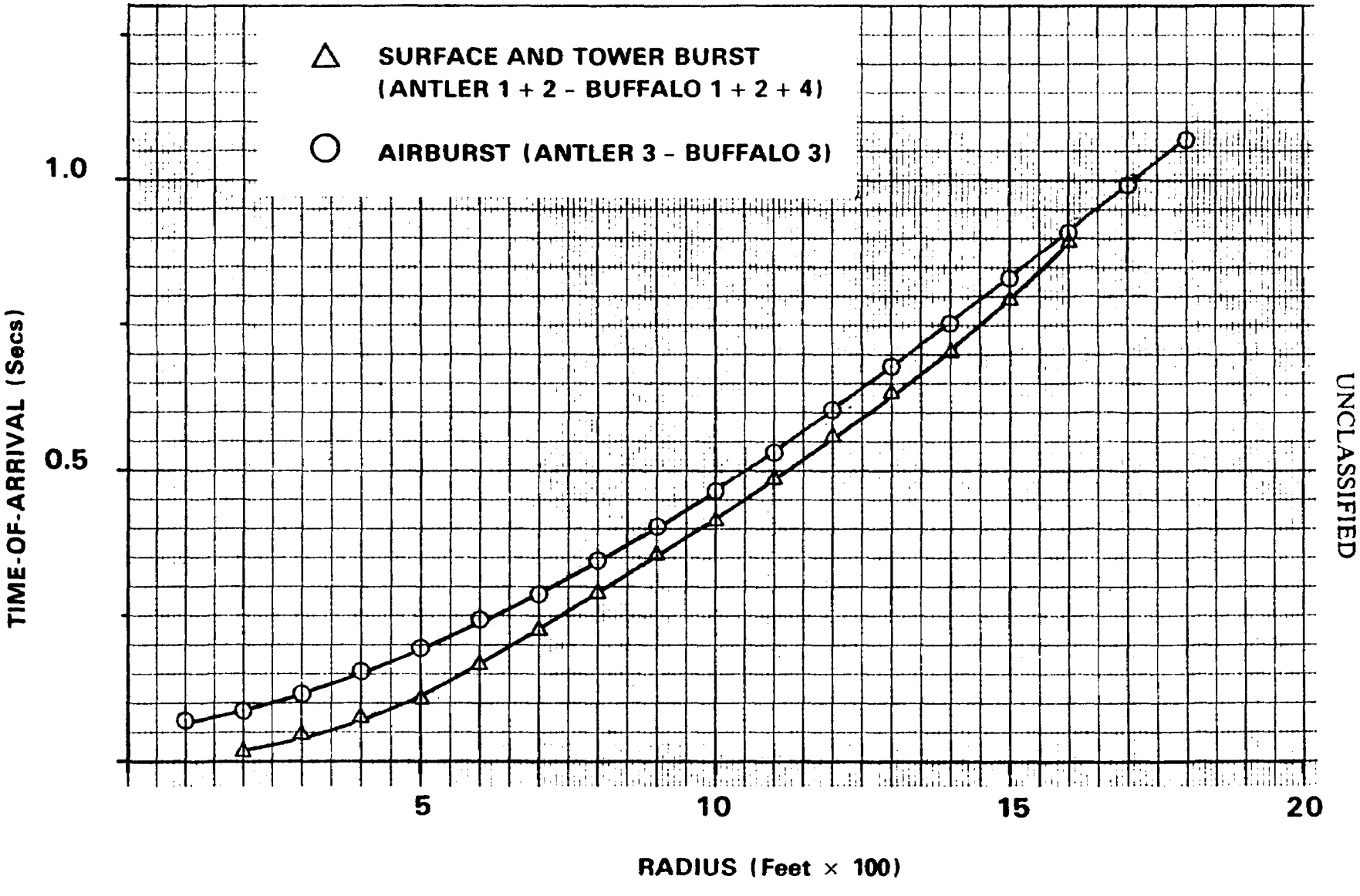

FIGURE 5.2. RADIUS vs TIME FOR GROUND LEVEL SHOCK (Scaled to 1 KT)
(Average of seven rounds of Operations ANTLER and BUFFALO)

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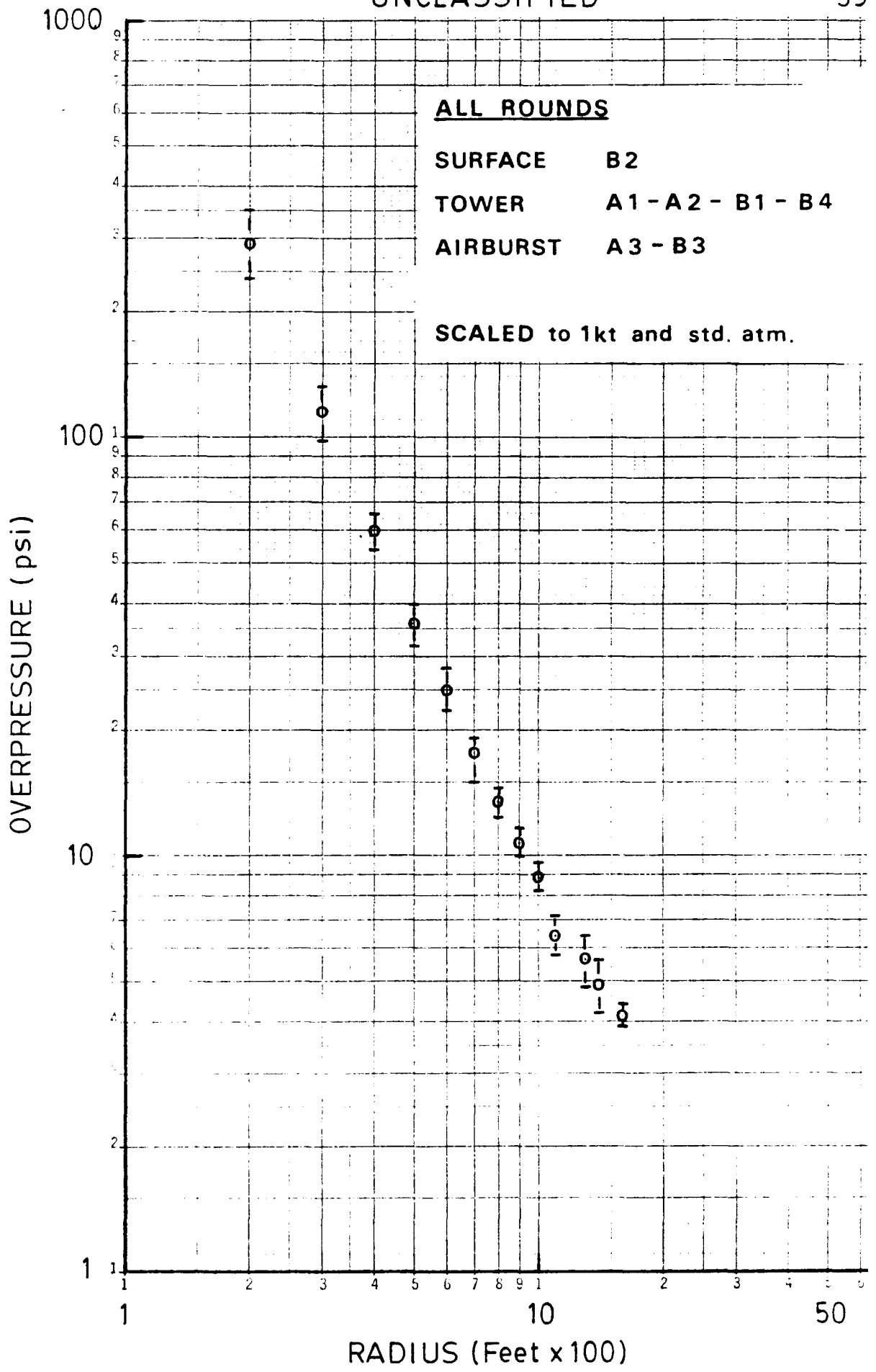

FIGURE 5.3 OVERPRESSURE vs RADIUS (In free air)

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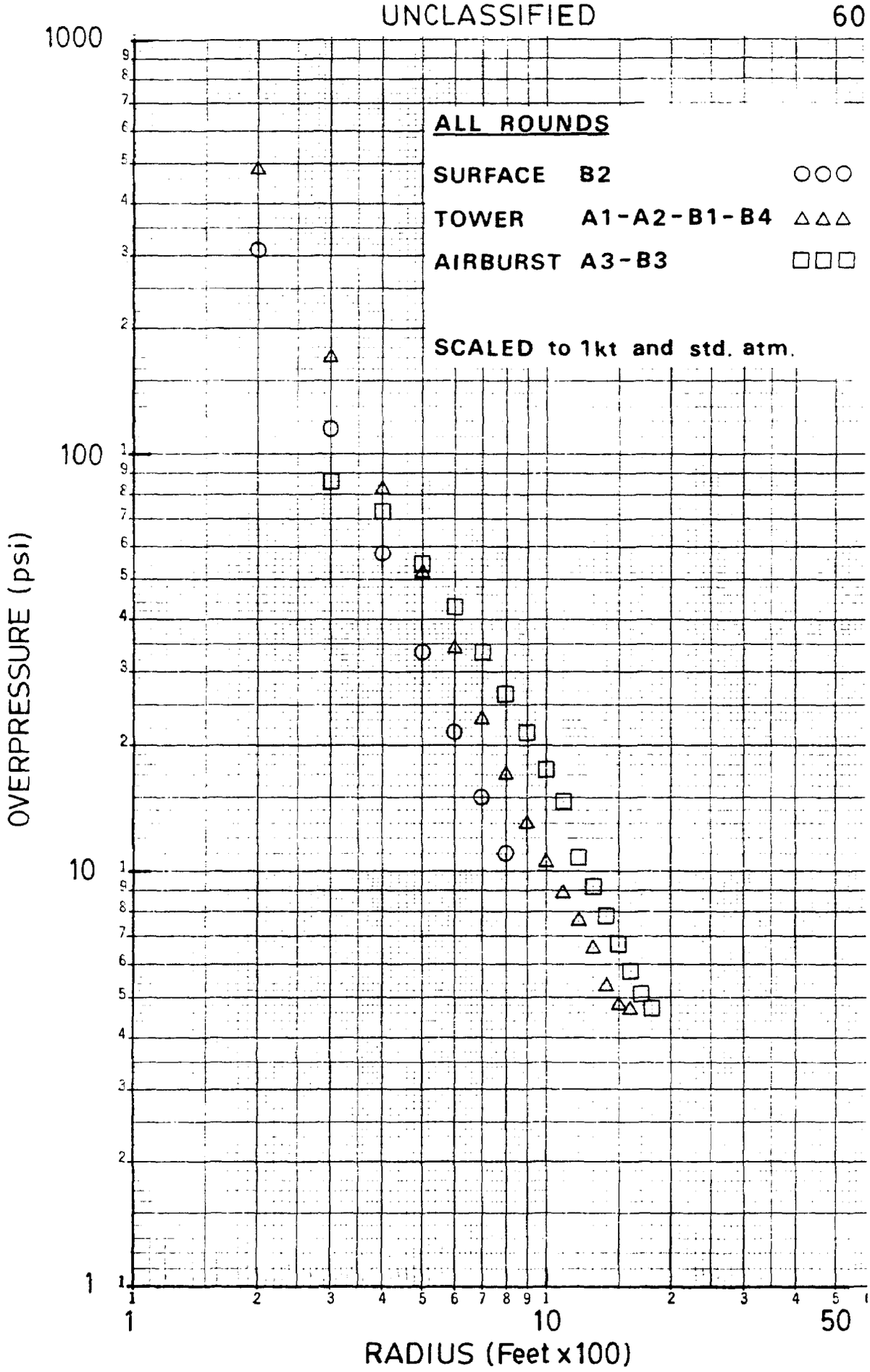

FIGURE 5.4 OVERPRESSURE vs RADIUS (At ground level)

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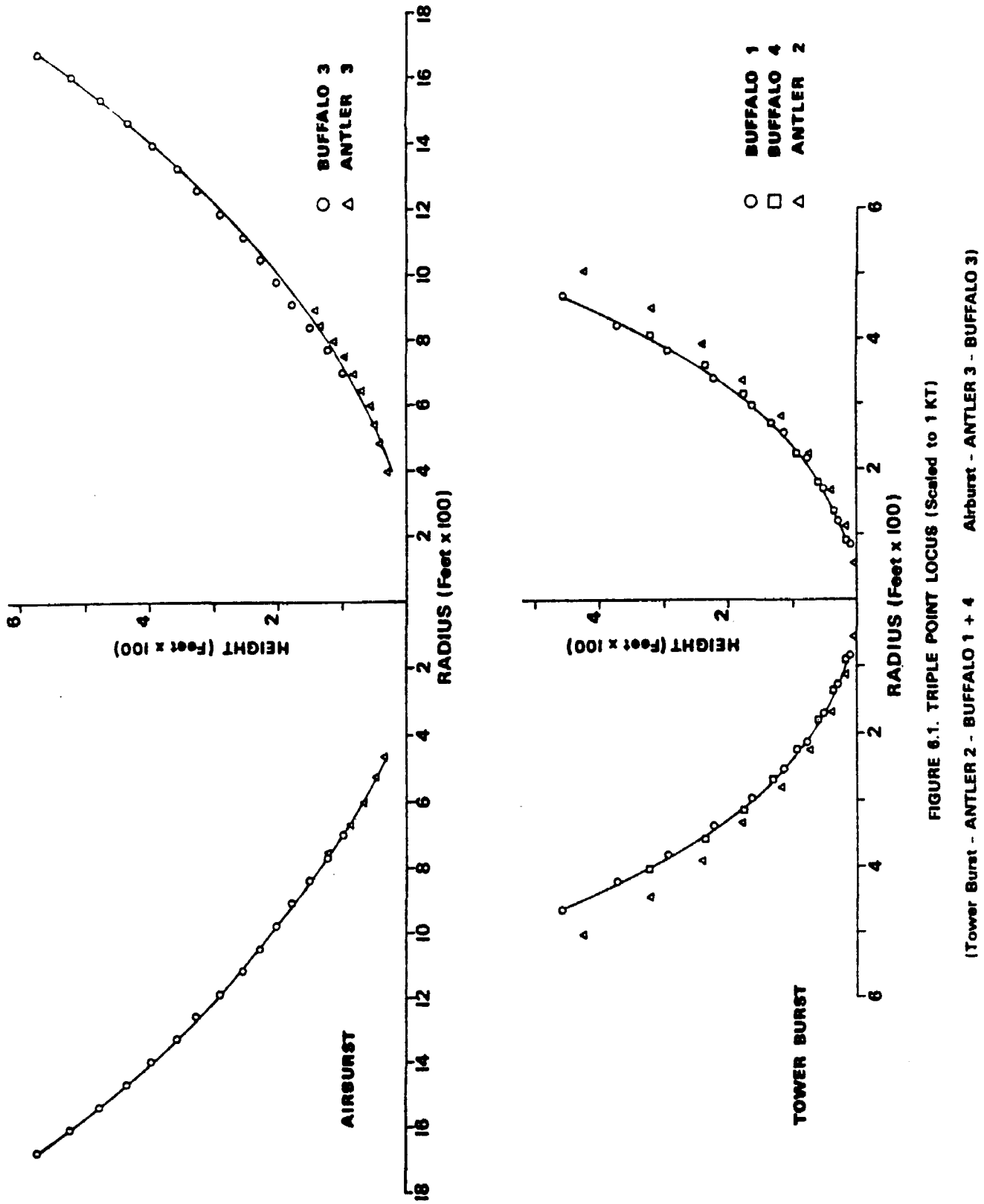

FIGURE 6.1. TRIPLE POINT LOCUS (Scaled to 1 KT)

(Tower Burst - ANTLER 2 - BUFFALO 1 + 4 Airburst - ANTLER 3 - BUFFALO 3)

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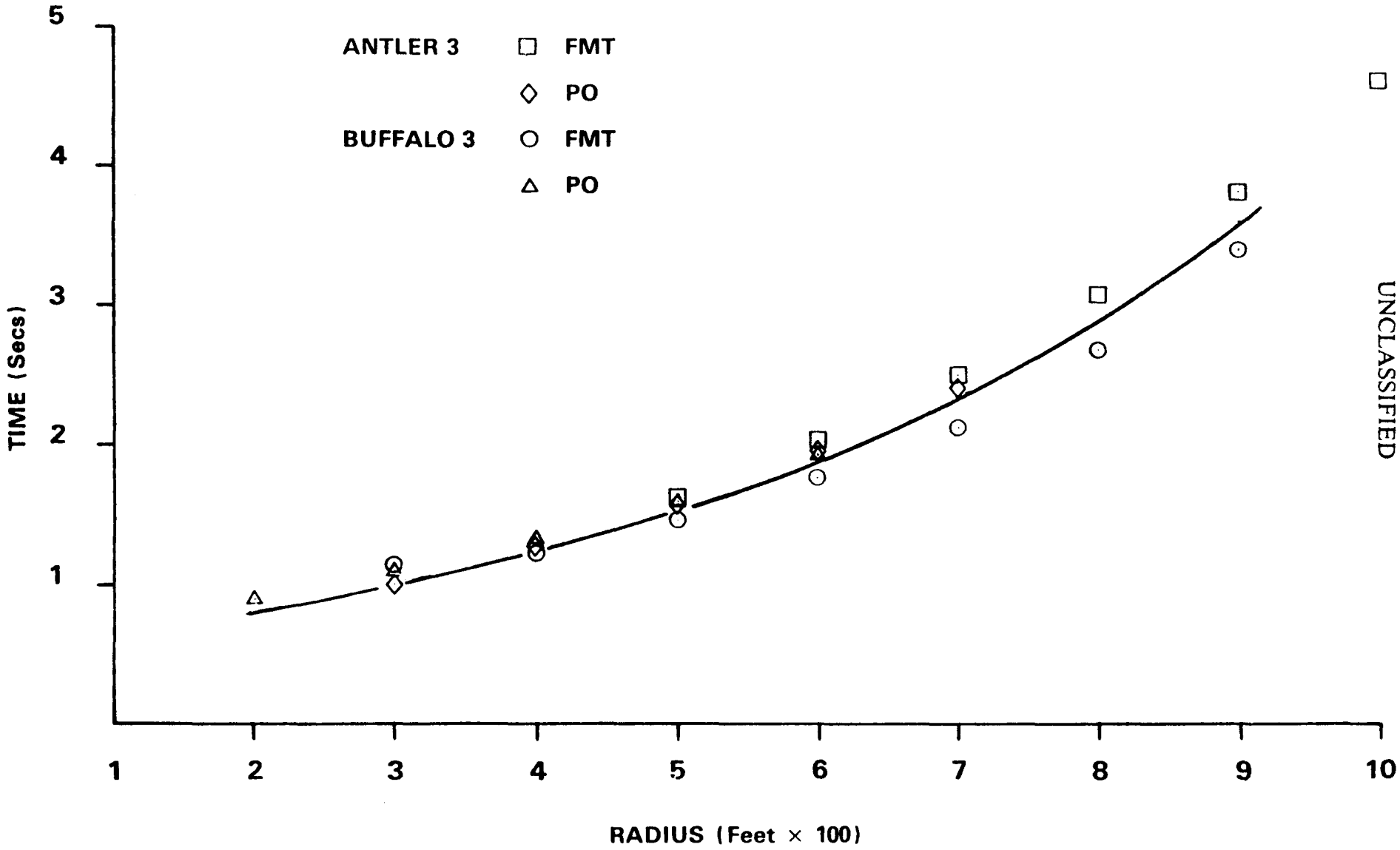

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FIGURE 7.1. RADIUS vs TIME FOR PRECURSOR (Scaled to 1 KT)

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