COMPARATIVE EFFECTS DATA
OF
BIOLOGICAL INTEREST

by

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FIRST DRAFT

Corrected and Expanded

10 April 1959

Prepared for the
Division of Biology and Medicine
of the Atomic Energy Commission
under Contract AT(29-1)-1242

Lovelace Foundation for Medical Education and Research
Albuquerque, N. M.

Table 1

CALCULATED WIND VELOCITY RELATIONS WITH PRESSURE PARAMETERS (SEA LEVEL)

Max pressure in psi			Wind Velocity	Max pressure in psi			Wind Velocity
Incident	Reflected	Dynamic	mph	Incident	Reflected	Dynamic	mph
1	2	0.02	40	20	60	8	470
2	4	0.1	70	30	90	16	670
5	11	0.6	160	50	200	40	940
10	25	2	290	100	500	125	1500

A hurricane wind of 120 mph exerts a dynamic pressure of about 0.25 psi.

Table 2

RELATION BETWEEN OVERPRESSURE AND PHYSICAL DAMAGE

Type of structural material	Over-pressure psi	Physical effects	Type of structural material	Over-pressure psi	Physical effects
Window glass	0.5	Shatters	Reinforced-concrete frame buildings	4-6	Moderate damage
Houses, wooden	1-2	50% damage		6-8	Severe damage
	4-5	Destroyed	Wall bearing massive buildings	6-8	Moderate damage
brick	5	Destroyed		8-10	Severe damage
Apartments, brick	4-5	Moderate damage	Motor vehicles	2-3	Light damage
	5-7	Severe damage		10-15	Severe damage

Selected from The Effects of Nuclear Weapons

Table 3

RELATION BETWEEN OVERPRESSURE AND MISSILE PARAMETERS

Max pressure psi	Type of missile	Velocity ft/sec geometric mean	Velocity ft/sec range	Mass, gms geometric mean	Mass, gms range	Max missile density No/sq ft
1.9	Window glass	108	50-178	1.45	0.03-10	0.4
3.8	Window glass	168	60-310	0.58	0.01-10	159
5.0	Window glass	170	50-400	0.13	0.002-140	388
8.5	Natural stones	275	167-413	0.23	0.038-22.2	35

Table 4

BLAST DISPLACEMENT OF 160 LB ANTHROPOMETRIC DUMMIES

Max pressure psi	Max Q psi	Initial dummy position	Max horizontal velocity ft/sec	Time to max velocity sec	Displacement in ft
5.3	1.8	Standing	21.4	0.5	21.9 downwind
		Prone	zero	-	None
6.9	15.4	Standing	not known	not known	256 downwind 44 to right
		Prone	not known	not known	124 downwind 20 to right

Thermal

Ignition Energies - Thermal energies required to ignite houses and a few common materials are noted in Table 5. The reader will note that more energy is required to ignite material for larger than for smaller weapons. One reason for this is the fact that energy is delivered to the target faster for the smaller than it is for the larger explosive yields.

Ignition Points for American Cities - Exterior ignition points per acre in and near American Cities are given in Table 6.

Fire Storm - The reader is referred to The Effects of Nuclear Weapons for information regarding fire storm.

Table 5

THERMAL ENERGIES REQUIRED FOR IGNITING HOUSES AND MATERIAL*

Material	Ignition energy cal/cm^2 20 KT	10 MT
Wooden houses - weathered	12	
- freshly painted white	25	
Newspaper	3	6
Wool flannel, black	8	16
Cotton shirting, tan	7	13
Cotton auto seat covers, green, brown, white	9	16
Rayon taffeta, wine	2	3
Fine kindling fuels	5	7
Fine grass	5	10

*Selected from The Effects of Nuclear Weapons

Table 6

EXTERIOR IGNITION POINTS IN AND NEAR SURVEYED AMERICAN CITIES

Classification of area	Approx. no. ignition points per acre	Classification of area	Approx. no. ignition points per acre
Wholesale distribution	27	Small manufacturing	7
Slum residential	20	Downtown retail	4
Neighborhood retail	11	Good residential	3
Poor residential	9	Large manufacturing	3

Biological Parameters

Blast

Pressure (Primary) Effects - Ignoring the eardrum, it is now known that the tolerance of mammals to variations in environmental pressure depends a great deal on the maximal overpressure, the rate of pressure development (time to Pmax), the character of the rising portion of the pressure curve and the duration of the overpressure. Some of these factors are intimately related with the geometry of exposure; e.g., whether or not an animal is close to a wall or other reflecting surface.

Damaging and fatal conditions for man are not known with certainty. However, estimates can be set forth based on animal experiments and a few instances of human exposure.

"Fast"-rising overpressures of long duration - Nuclear detonations produce blast overpressures much longer in duration than those obtained with high explosives; e.g., like 0.5 to several seconds for the former and 1 to 20 msec for the latter. Under conditions of exposure in which pressures are applied almost instantaneously, such as might be the case for a target located against a solid surface where an incident and reflected overpressure could envelop the animal practically simultaneously, biologic tolerance is relatively low. Table 7 shows data for several species of animals exposed against the steel plate closing the end of a shock tube. Overpressures rose sharply in a few tens of microseconds (millionths of a second) and endured for several seconds. A tentative estimate of man's

Table 7

SHOCK TUBE MORTALITY DATA FOR "FAST"-RISING LONG DURATION OVERPRESSURES WHEN INCIDENT AND REFLECTED PRESSURES ARE APPLIED ALMOST SIMULTANEOUSLY

Animal Species	Overpressure in psi for indicated mortality 1%		50%		99%		Threshold press. for lung injury psi	
	Incident	Reflected	Incident	Reflected	Incident	Reflected	Incident	Reflected
Mouse	7	20	11	30	15	44	6	15
Rabbit	9	25	12	33	15	44	6	15
Guinea pig	10	28	13	37	17	48	6	15
Rat	10	28	14	39	18	53	6	15
Man*		25-35		40-50		55-65		15

*Tentative estimate. Data AEC Project, Lovelace Foundation, Albuquerque, N. M.

Table 8

EXPOSURE TO "SLOW"-RISING OVERPRESSURES OF LONG DURATION

Max overpressure psi	Time to max pressure msec	Duration of overpressure sec	Damage observed ruptured eardrums	hemorrhagic sinuses	lung contusion
167	155	5	yes	yes	none
118	85	20	yes	yes	none
156	86	20	yes	yes	minimal
170	60	10	yes	yes	none
86	28	10	yes	yes	none
130	30	10	yes	yes	minimal

Data AEC Project, Lovelace Foundation, Albuquerque, N. M.

tolerance, if exposed under similar conditions, is also included in the table.

"Slowly" rising overpressures of long duration - In marked contrast is the much greater tolerance of mammals to slowly rising overpressures of long duration. Table 8 shows sample data obtained in a shock tube wherein no fatalities were noted. Fatal conditions for such exposures are not known either for experimental animals or for man, but it is very likely that slowly developing overpressures up to over 200 psi, such as might occur in large enclosed areas being pressurized through small openings, would not prove very hazardous to man if displacement by blast winds were avoided.

consists of two fast-rising steps is intermediate between that noted in the previous two sections. As noted in Table 7, Pmax reflected associated with 50 per cent mortality (P_{50}) for guinea pigs was 37 psi for single, fast-rising long duration overpressures. Simply exposing the animal 1 foot away from, instead of against, the plate closing the end of the shock tube raises the P_{50} reflected pressure to 58 psi. Under such circumstances the steep incident pressure of about 20 psi enveloped and passed by the animal, struck the end-plate, and the fast-rising reflected overpressure of 58 psi reached the animal about 1.6 msec later. Tolerance of man under such circumstances is not known for long duration overpressures, but estimates for conditions involving short duration incident and reflected pressures wherein human fatality occurred have been published. Such data will now be noted.

"Fast"-rising overpressures of short duration - Desaga* described exposure of 13 men in an open-topped, antiaircraft gun emplacement to blast produced by high explosive bombs. Two individuals situated in a corner close to the walls were fatally injured. The incident and max reflected overpressures of probably 10 - 20 msec durations were estimated at 58 and 235 psi, respectively.

For exposures to single, short-duration, sharp-rising pressure pulses produced by high explosives not involving reflections from nearby surfaces, tolerance varies with the duration of the incident overpressure as shown by Table 9 giving the just fatal conditions for dogs.

Eardrums - Though eardrum rupture under emergency conditions is not in itself a serious injury, it is well to set forth the available data. Tolerance of the tympanic membranes of animals exposed to blast overpressures at the Nevada Test Site correlated fairly well with the max overpressure. The data are summarized in Table 10 which also shows results noted by Zalewski** in experiments on human cadavers.

Secondary (Missiles) -

Penetrating - The impact-velocity relationships for glass fragments to pass through the body wall of dogs and reach the abdominal cavity are shown in Table 11, while Table 12 notes the threshold for penetrating wounds

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*Desaga, H., German Aviation Medicine World War II, Vol. II, pages 1274-1293, U. S. Government Printing Office 1950.

**Zalewski, T., Zeits Ohrenheilk, 52:109-128, 1906.

Table 9

FAST-RISING "SHORT" DURATION OVERPRESSURES REQUIRED FOR NEAR 100 PER CENT MORTALITY IN DOGS

Max static overpressure psi	Overpressure duration msec
216	1.6
219	1.6
125	4.1
85	8.6
79	10.3
76	11.8

Table 10

PRESSURE TOLERANCE OF THE EARDRUMS OF DOG AND MAN

Species	Max pressures in psi for the noted conditions		
	Minimal	Average	Maximal
Dog*	5	31	90
Man**	5	20-33	43

*Data from 1953, 1955, 1957 Nevada Field Tests.
**Data from Zalewski. Human eardrum tolerance varies with age, hence the variation from 33 psi for ages 1-10 yr to 20 psi for ages above 40 yr.

Table 11

THE VELOCITY-MASS-PROBABILITY RELATIONSHIPS REQUIRED FOR SMALL WINDOW GLASS FRAGMENTS TO TRAVERSE THE ABDOMINAL WALL AND REACH THE PERITONEAL CAVITY OF DOGS

Mass of glass fragments	Impact velocities in ft/sec for indicated probabilities of penetration in per cent		
gms	1%	50%	99%
0.05	320	570	1,000
0.1	235	410	730
0.5	160	275	485
1.0	140	245	430
10.0	115	180	355

Data from AECU-3350

Table 12

EFFECTS OF MISSILES ON HUMAN CADAVERS

Type missile	Mass gms	Velocity ft/sec	Effect on man
Spherical bullets	8.7	190	Slight skin laceration
	8.7	230	Penetrating wound
	7.4	360	Abrasion and crack of tibia
	7.4	513	Travels through thigh
Bullets	6-10	420-266	Threshold for bone injury
	6-15	751-476	Fractures large bones

Data from Journée

FOR

Following submission of th
Division of Biology and Medicine
copies were critically reviewed b
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in the presentation to justify repro
first draft which essentially comp
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expanded version of the work can
appropriately present the inter-re
nuclear explosions comprising a h

Most of the quantitative da
informative and useful text The E
authors wish to acknowledge thei
was so competently edited and pr
Department of Defense.

:EWORD

e initial draft of this brochure to the of the Atomic Energy Commission, by over 25 selected individuals, all ons effects. Though most recognized rk, pointed out errors, and offered cism, enough interest was expressed oduction of a corrected version of the rises the material that follows. Major under way. Consequently, the pres- nterim measure to serve only until an be made available which will more lations between the several effects of azard to man.

ta utilized were drawn from the very Effects of Nuclear Weapons and the r indebtedness to this source which epared by Samuel Glasstone for the

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and skeletal fracture determined with bullets by Journée* using human material.

Nonpenetrating - Some appreciation of the biological effects of nonpenetrating missiles may be obtained by consulting Table 13. The table gives data regarding chest damage in dogs from the impact of missiles against the thoracic wall and the range of impact velocities over which human skull fracture** can be anticipated if the head were struck with an object weighing about 10 lbs (near the average weight of the human head).

Displacement (Tertiary) - It is likely that most injuries associated with displacement by blast winds will occur during decelerative impact with some hard object. Table 14 gives data from relevant animal experiments with an extrapolation to man along with a comparison with automobile accident statistics+. Table 15 sets forth impact velocities for experimental fracture of the human skull, feet and spine. Though the impact velocities are low for severe injury to humans when deceleration is abrupt and occurs over a very short distance, survival of man from falls involving 80 - 90 mph velocities has occurred when the deceleration was less rapid and involved distances of several inches.++

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*Journee, Rev. D'Art., 1907.

**Gurdjian, E. S., Webster, J. E., and Lissner, H. L., Am. Jour. Surg., 78:736-742, 1949.

+De Haven, Hugh, Mech. Engineering, 66:264-268, 1944.

++De Haven, Hugh, War Medicine, 2:586-596, 1942.

Table 13

EFFECTS OF MISSILE IMPACT ON THE CHEST AND HEAD

Biological effects observed	Threshold velocities in ft/sec for missiles of indicated weights	
	0.8 lbs	0.4 lbs
*Lung hemorrhages		
side of impact only (unilateral)	45	80
impact side and opposite side (bilateral)	110	125
*Rib fracture	60	120
*Internal lacerations from fractured ribs	90	120
*Fatality within 1 hr	155	170
**Experimental fracture human skull	15-23 ft/sec range of velocities for 10 lb object (7-15 lbs wt range of human adult head)	

*Data AEC Project, Lovelace Foundation, Albuquerque, N. M.
**Computed from data of Gurdjian.
*Experimental results using dogs.

Table 14

AVERAGE VELOCITIES OF IMPACT AGAINST A HARD SURFACE ASSOCIATED WITH 50 PER CENT MORTALITY OF THE INDICATED SPECIES OF ANIMALS WITH EXTRAPOLATION TO MAN*

Species of Animal	Average animal mass gms	Average impact velocity for 50 per cent mortality		Equivalent height of fall (approx.) ft
		ft/sec	mph	
Mouse	19	38	26	22
Rat	180	44	30	30
Guinea pig	650	31	21	15
Rabbit	2, 600	31	21	15
Man (computed)	72, 574 (160 lbs)	27	18	11

National Safety Council release on urban automobile accidents shows 40 and 70 per cent of fatalities were associated respectively with speeds of or less than 20 and 30 mph. — Quoted from De Haven.

*Data AEC Project, Lovelace Foundation, Albuquerque, N. M.

Table 15

APPROXIMATE IMPACT VELOCITIES AND EQUIVALENT HEIGHTS OF DROP FOR FRACTURE OF HUMAN SPINE, SKULL, FEET AND ANKLES

Effects on man	Impact velocity		Equivalent ht of drop	Comment
	ft/sec	mph	in.	
Experimental skull fracture*	13.5 - 22.9	9.5 - 15.0	37 - 91	Range of 1 to 99 per cent fracture of cadaver heads dropped on flat metal surface.
Fracture - feet and ankles**	12 - 13	8 - 9	25 - 30	Impact table data using cadavers with knees locked.
Fracture - lumbar spine***	8	6	12	Estimated for impact on hard surface in sitting position.

*Data from Gurdjian.
**Data from Draeger et al. Report NMRI Project X5-17, dated 30 Mar 1945.
***Computed from data of Ruff, German Aviation Medicine World War II, Vol. I, pages 584-597, U.S. Government Printing Office, 1950.

Thermal

Skin Burns - In setting forth the thermal energies required to burn the exposed human skin it is necessary to do this in relation to explosive yield. A given amount of energy if applied quickly produces a more severe burn than if applied slowly. A consequence of this is the fact that the energy required to produce a burn of the same severity is greater for the larger than the smaller yield explosions since the latter apply energy more slowly. Table 16 summarizes the approximate relation between thermal energy and skin burns for bare white skin. Table 17, assembled from the data of Evans, et al.* and Brooks, et al.**, shows that much lower thermal energies are required to burn the skin of negro volunteers compared with white volunteers.

Flash Blindness - Byrnes[+] has stated temporary loss of vision can be expected as far away as 35 mi from a night detonation of a 20 KT nuclear detonation.

Retinal Burns - Retinal burns according to Byrnes[+] may occur as far away as 35 mi from a 20 KT nuclear detonation in clear weather. There is more of a hazard at night because the pupil is dilated.

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*Evans, E. I., Brooks, J. W., Schmidt, F. H., Williams, R.C. and Ham, Jr., W. T., Surgery, 37:280-297, 1955.

**Brooks, J. W., Schmidt, F.H., Williams, R.C., and Ham, Jr., W. T., Surgical Forum, VIII, 125-128, 1958.

[+]Byrnes, V.A., JAMA, 168;778-779, 1958.

Table 16

THERMAL ENERGIES FOR BURNS OF BARE WHITE SKIN

Degree of burn	Thermal energy in cal/cm^2 for the indicated explosive yields		
	1 KT	100 KT	10 MT
First degree	2	2.5	3.5
Second degree	4	5.5	8
Third degree	~~3.5~~ 6.0	8	11

Data from The Effects of Nuclear Weapons

Table 17

COMPARISON OF THERMAL ENERGIES APPLIED OVER 540 MSEC REQUIRED FOR BURNS OF THE SKIN OF WHITE AND NEGRO VOLUNTEERS

Degree of burn	Thermal energy in cal/cm^2	
	White subjects	Negro subjects
None	2.0	not stated
First degree	3.2	not stated
Second degree	3.9	1.8-2.9
Third degree	4.8	3.3-3.7

Data from Evans, et al. and Brooks, et al.

Ham, et al.* have estimated that threshold lesions to the human retina could occur at 9 to 14 mi from a 1 to 100 KT night detonation when visibility was 25 mi and if the eye were completely dark adapted and the blink reflex excluded all light after 150 msec.

Appreciation of the hazard to man from retinal burns due to fireball light is apparently far from complete, particularly for bursts above or in the high terrestrial atmosphere.

Ionizing Radiation

Acute Exposure** - The probable early effects in humans of acute exposure to ionizing radiation over the whole body are listed in Table 18.

Chronic Exposure - If exposure to radiation is not acute but prolonged, some of the tissues of the body undergo repair and the degree of the biological effect depends, among other things, upon the balance maintained between the continuing repair and radiation damage. For doses accumulated over a 1 or 2 day period, the repair process is not very effective, but on and after the third day, particularly at low dose rates, very appreciable differences occur. Tables 19 and 20 summarize applicable estimates made by the U. S. Public Health Service.

Accumulative Genetic Effects - Long term genetic effects attributable to exposure to ionizing radiation above the natural background (4.3 to 5.5 r over 30 yrs

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*Ham, Jr., W. T., Wiesinger, H., Schmidt, F.H., Williams, R.C., Ruffin, R.S., Schaffer, M.C., and Guerry, III, D., Am. Jour. Ophthal., 46:700-723, 1958.

**Radiological Health Handbook, U. S. Department of Health, Education and Welfare, Public Health Service, U. S. Department of Commerce, Office of Technical Services, 1957.

Table 18

PROBABLE EFFECTS IN HUMANS OF ACUTE EXPOSURE TO IONIZING RADIATION OVER THE WHOLE BODY

Acute dose r	Probable Effect
0 - 25	No obvious injury.
25 - 50	No serious injury. Possible blood changes.
50 - 100	Blood cell changes, some injury. No disability.
100 - 200	Injury, possible disability.
200 - 400	Injury and disability certain, death possible.
400	Fatal to 50 per cent.
600 or more	Fatal.

Data from Radiological Health Handbook, U. S. Department of Health, Education and Welfare, citing The Effects of Nuclear Weapons as the source of the information.

Table 19

ESTIMATE OF EFFECTIVE DOSE AND LETHALITY OF VARIOUS DOSE RATES TO MAN*

Day	Accumulated Dose (r)	Effective Accumulated Dose (r)	Estimated Mean Survival Time (Days)	Estimated percent Deaths in 30 days
		200 r/day		
1	200	200	--	30
3	600	542	20	60
5	1000	819	15	85
10	2000	1326	10	100
		100 r/day		
1	100	100	--	8
3	300	271	--	35
5	500	409	15	50
10	1000	663	15	75
		50 r/day		
1	50	50	--	0
3	150	135	--	15
5	250	204	30	25
10	500	330	30	40
15	750	395	30	50

*Based on 250 kvp x-rays. Corrections should be made for higher energy radiations. e.g. 1000 kvp x-or gamma radiation would have a relative biological effectiveness of approximately 70% of 250 kvp x-rays.

From Radiological Health Handbook.

Table 20

ESTIMATED DOSES FOR VARYING DEGREES OF INJURY TO MAN*

Accumulated Daily Dose (r) or Dose Rate	Period of Time	Effect
500 r/day	2 days	Mortality close to 100%
100 r/day	Until Death	Mean survival time approximately fifteen days. 100% mortality in 30 days.
60 r/day	10 days	Morbidity and mortality high with crippling disabilities.
30 r/day	10 days	Disability, moderate.
10 r/day	365 days	Some deaths.
3 r/day	Few months	No drop in efficiency.
0. 5 r/day	Many months	No large scale drop in life span.

*Based on 250 kvp x-rays. Corrections should be made for higher energy radiations. e.g. 1000 kvp x-or gamma radiation would have a relative biological effectiveness of approximately 70% of 250 kvp x-rays.

From Radiological Health Handbook.

INTRODUCTION

In the material which follows selected weapons effects data have been assembled for quick reference as an aid to those interested in the physical and biological effects of nuclear weapons. The quantitative data have been preceded by two sections chosen to facilitate orientation of the reader. The first contains brief definitions of the terminology employed throughout the brochure and the second deals grossly with the physical and biological consequences of the several environmental variations created by nuclear explosions. Such information will foster appreciation of the comparative ranges for the major effects as these vary with explosive yield and as these contribute to the total hazard to man.

It is well here to point out that the values for any given effect can vary considerably depending on many factors not the least of which are weapon design and yield, location of burst, weather, terrain, and range from the detonation. Even though the numbers chosen are the outcome of theoretical and full-scale studies in which many uncertainties were appreciated, they nevertheless represent best approximations which are probably accurate within plus or minus 10 - 30 per cent and hence are reasonably valid for the purposes of orientation and protective planning.

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Emergency Exposure - It is of interest to
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*National Academy of Sciences—National R
Effects of Atomic Radiation — Summary Repo

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The Adequacy of Government Research Progr

efinable. However, responsible individuals
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nd
als to 50 r to the reproductive organs
additional up to the age of 40 yrs.

note here that a responsible body of scientists
the maximal permissible radiation exposure
following statement was made: "However, it
nce that total doses 150 - 200 r, delivered
would result in no apparent acute effects
a small percent of those exposed."**

esearch Council Report entitled The Biological
rt, 1956.

es—National Research Council Report entitled
rams in Non-Military Defense, dated 1958.

Hospitalization - Such an opinion is consistent with experience gained in human radiation accidents and treatment summarized by Gerstner*. This author also noted the percent of the exposed population that might require hospitalization. The data along with a very general assessment of the clinical course is noted in Table 21.

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*Gerstner, H. B., JAMA, 168:381-388, 1958.
Gerstner, H. B., Report 58-6, U. S. Air Force School of Aviation Medicine, 1957.

Table 21

ESTIMATED CLINICAL COURSE AND HOSPITALIZATION REQUIREMENTS FOR HUMANS EXPOSED TO VARIOUS ACUTE DOSES OF PENETRATING RADIATION

Dose in r	Percent individuals following indicated clinical symptoms						Percent needing hospital-ization	Maximal time of hospitali-zation weeks
	trivial	light	moderate	serious	grave	fatal		
0 - 200	98	2					none	0
200 - 300	1	33	64	2			2	6
300 - 400			6	68	26		94	7
400 - 500				3	58	39	100	9
500 - 600					6	94	100	11
above 600						100	100	11

Compiled from Gerstner

QUANTITATIVE WEAPONS EFFECTS DATA

The material which follows, along with the explanatory remarks opposite each table or illustration sets forth selected weapons effects data as a function of explosive yield for surface and typical air bursts. Some assessment of the comparative hazard to man from blast, thermal and ionizing radiations can be obtained by referring to previous sections of the brochure.

Perhaps the reader will share with the authors the conclusion that prophylactic protection from weapon-produced variations in the environment is desirable and that provision of such protection would markedly enhance the chances of survival for a high percentage of the population should nuclear war ever occur.

Table 22

In Table 22 are tabulated the approximate ranges from ground zero and the circular areas over which the indicated selected weapons effects may occur as a function of explosive yield. It was assumed that slant ranges for initial ionizing radiation and thermal data are a reasonable approximation of the ground range and that atmospheric conditions were clear.

Table 22

COMPARATIVE WEAPONS EFFECTS DATA

Explosive Yield	1 KT	20 KT	100 KT	1 MT	10 MT	20 MT
Range (mi) from Ground Zero for Various Parameters						
700 rem (Initial)	0.42	0.70	0.96	1.44	2.04	2.27
100 rem "	0.62	0.99	1.29	1.81	2.55	2.88
30 rem "	0.74	1.18	1.51	2.07	2.91	3.30
5 PSI (Typical Air Burst)	0.39	1.06	1.81	3.90	8.40	10.6
5 PSI (Sfc Burst)	0.28	0.77	1.32	2.85	6.14	7.74
1 PSI (Typical Air Burst)	1.00	2.71	4.64	10.0	21.5	27.1
1 PSI (Sfc Burst)	0.86	2.35	4.02	8.65	18.6	23.5
Second Degree Burns	0.48	1.72	3.40	9.00	23.8	31.9
First Degree Burns	0.69	2.47	4.97	13.3	36.0	49.2
Area (sq mi) Corresponding to Above Ranges						
700 rem (Initial)	0.55	1.54	2.90	6.51	13.1	16.2
100 rem "	1.21	3.08	5.23	10.3	20.4	26.1
30 rem "	1.72	4.37	7.16	13.5	26.6	34.2
5 PSI (Typical Air Burst)	0.48	3.53	10.3	47.8	222	353
5 PSI (Sfc Burst)	0.25	1.86	5.47	25.5	119	189
1 PSI (Typical Air Burst)	3.14	23.1	67.6	314	1450	2310
1 PSI (Sfc Burst)	2.32	17.4	50.8	235	1090	1730
Second Degree Burns	0.73	9.29	36.3	254	1780	3200
First Degree Burns	1.50	19.2	77.6	556	4070	7600

Data from The Effects of Nuclear Weapons

Table 23

Table 23 gives the approximate ground ranges in miles for selected values of initial ionizing radiation, overpressure and thermal radiation computed for typical air bursts of indicated yields assembled in such a way as to aid appreciation of the interrelation between the individual effects. For example, a ground range of about 3 miles is shown for 100 rem initial radiation from a 20 MT detonation at which distance an overpressure of near 19 psi can be expected along with a thermal load of over 1000 cal/cm^2. Ten miles from ground zero 1 psi is predicted for a 1 MT explosion at which location there would occur less than 10 rem and about 6 cal/cm^2 of initial ionizing and thermal radiation, respectively. Referring to the bottom of the table, one can see that 6 cal/cm^2 of thermal energy is sufficient to produce second degree burns to the exposed bare skin.

Since the data in Table 23 are for typical air bursts, no significant short term fallout hazard would occur. As in the previous table, slant ranges for ionizing and thermal radiations were considered to be a reasonable approximation of the ground range.

The symbols > and >> mean "greater than" and "much greater than", while < and << mean "less than" and "much less than", respectively.

Table 23

COMPARATIVE EFFECTS DATA OF BIOLOGICAL INTEREST

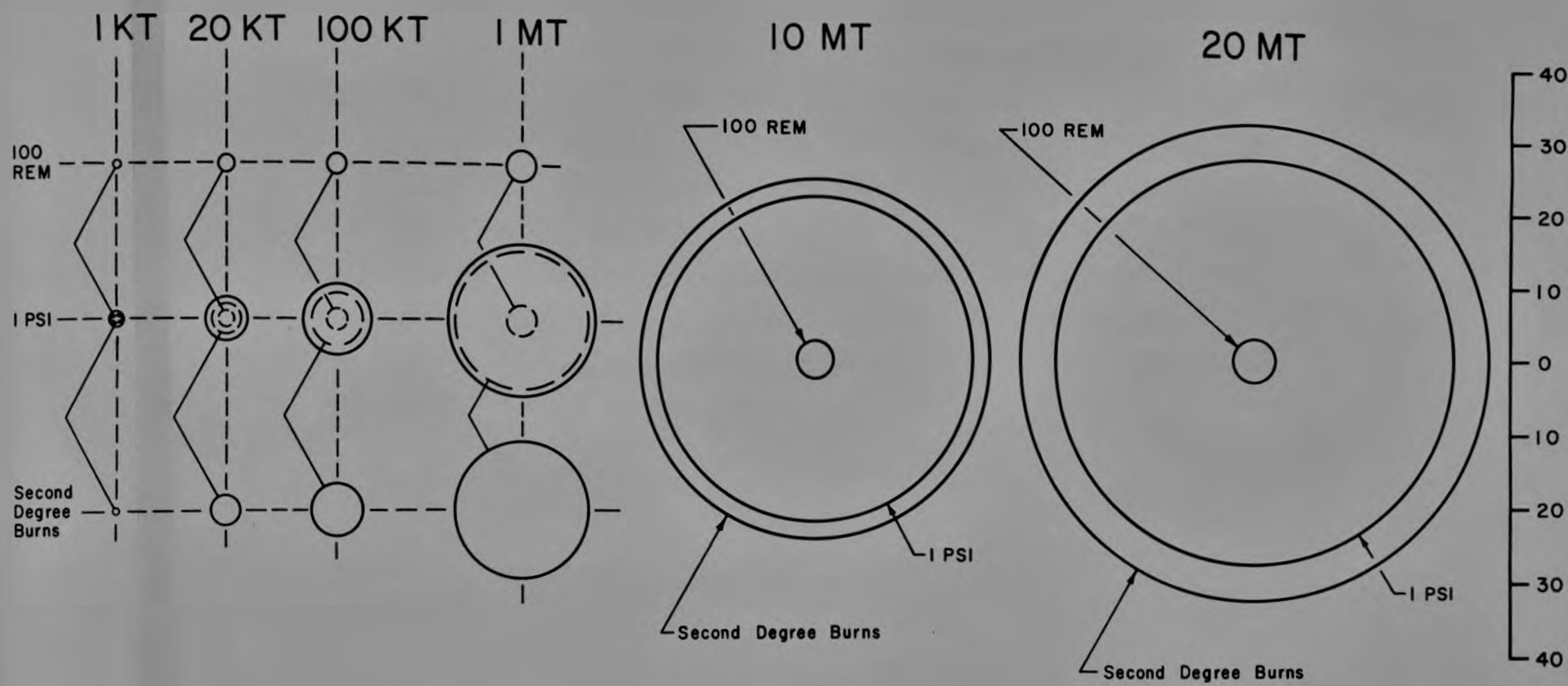
Explosive Yield	1 KT	20 KT	100 KT	1 MT	10 MT	20 MT
30 REM Range, mi	0.74	1.18	1.51	2.07	2.91	3.30
Pressure, psi	1.70	4.16	6.60	11.1	15.6	17.0
Thermal, cal/cm^2	1.70	12.4	36.0	182	880	>1000
100 REM Range, mi	0.62	0.99	1.29	1.81	2.55	2.88
Pressure, psi	2.30	5.55	8.30	12.4	17.4	18.8
Thermal, cal/cm^2	2.50	18.0	52.0	240	>1000	>1000
1 PSI Range, mi	1.00	2.71	4.64	10.0	21.5	27.1
Radiation, REM	<10	<10	<10	<10	≪10	≪10
Thermal, cal/cm^2	0.88	2.02	3.30	5.90	11.4	13.8
5 PSI Range, mi	0.39	1.06	1.81	3.90	8.40	10.6
Radiation, REM	900	64	<10	<10	<10	<10
Thermal, cal/cm^2	7.00	15.8	24.5	46.0	89.0	105
Second Degree Burn						
Range, mi	0.48	1.72	3.40	9.00	23.8	31.9
Pressure, psi	3.6	2.2	1.7	1.2	<1	<1
Radiation, REM	380	<10	<10	<10	≪10	≪10
First Degree Burn Dose, cal/cm^2	2.0	2.5	2.7	3.2	3.7	3.8
Second Degree Burn Dose, cal/cm^2	4.1	4.9	5.4	6.2	7.2	7.5
Third Degree Burn Dose, cal/cm^2	6.0	7.3	8.1	9.4	10.8	11.4

Data from *The Effects of Nuclear Weapons*

Figure 1

The scaled ranges and areas applicable to 100 rem initial radiation, 1 psi and second degree burns for typical air bursts are shown in Figure 1 as these parameters vary with explosive yield. The relative gain in range and areas covered by blast and thermal effects compared with initial ionizing radiation as weapon weight increases deserves emphasis. For yields of 1 MT or less the areas of second degree burns are smaller than those for 1 psi overpressure; whereas, for the higher yields the reverse is true. Slant ranges for ionizing and thermal radiation were assumed to be reasonable approximations of the ground range.

Figure 1



Environmental Variations due to Blast, Thermal, and Initial Ionizing Radiations for Indicated Explosive Yields

(Data from Effects of Nuclear Weapons for typical air bursts)

TERMINOLOGY A

Bursts

Surface - Bursts on or above the s contact between the fireb

Typical Air - Air bursts avoiding c surface of the earth at su mal blast damage to an a

Explosive Yield

Kiloton (KT) - A unit of explosive y is equivalent in energy to 1000 tons of TNT.

Megaton (MT) - A unit of explosive kilotons or 1,000,000 ton

Fission Yield

Fission yield refers to that portion utable to nuclear fission. Megatons of fission yield tons of total yield.

Blast Pressures

Overpressure - The transient pres produced by an explosion source of the detonation.

ND DEFINITION

urface at heights which involve
all and the surface of the earth.

contact between the fireball and
ıch heights as to produce maxi-
.verage city.

ield for a nuclear explosion which
that released by the detonation of

yield equivalent in energy to 1000
s of TNT.

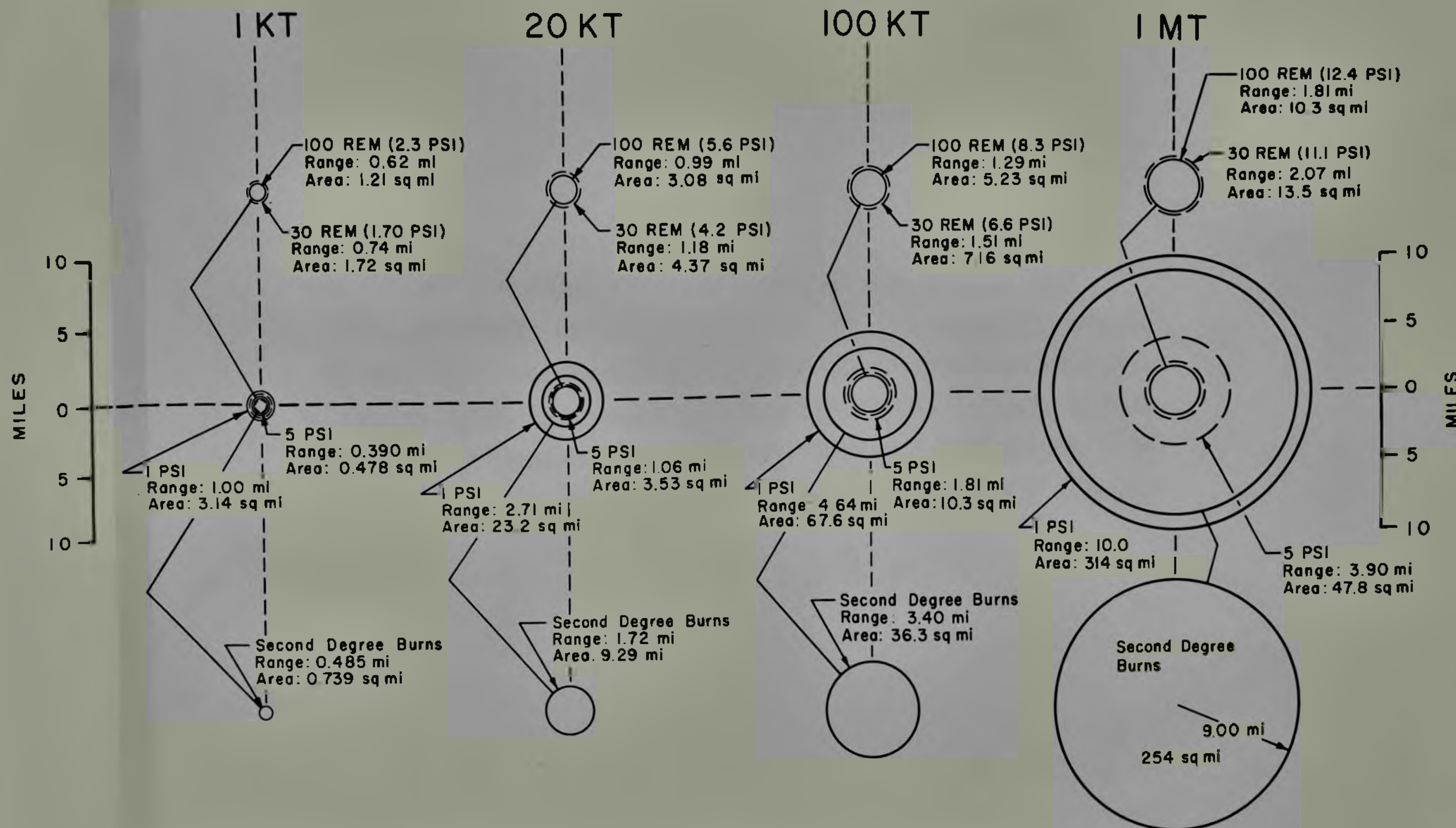
of the total explosive yield attrib-
The units are kilotons or megatons.
are to be distinguished from mega-

sure variation above the ambient
which travels radially from the

Figure 2

The scaling relations for 30 and 100 rem initial radiation, 1 and 5 psi, and second degree burns are shown to the same scale in Figure 2 for typical air bursts ranging from 1 KT to 1 MT. The reader will note that the 100 rem radius extends well beyond the 5 psi line for a 1 KT yield. These two radii are almost equal for the 20 KT, but the 5 psi line extends much beyond the 100 rem range for yields of 100 and 1000 KT. Slant range for ionizing and thermal radiation was considered a fair approximation of the ground range.

Figure 2



Environmental Variations due to Blast, Thermal, and Initial Ionizing Radiation for 1, 20, 100, and 1000 KT Explosive Yields

(Data from Effects of Nuclear Weapons)

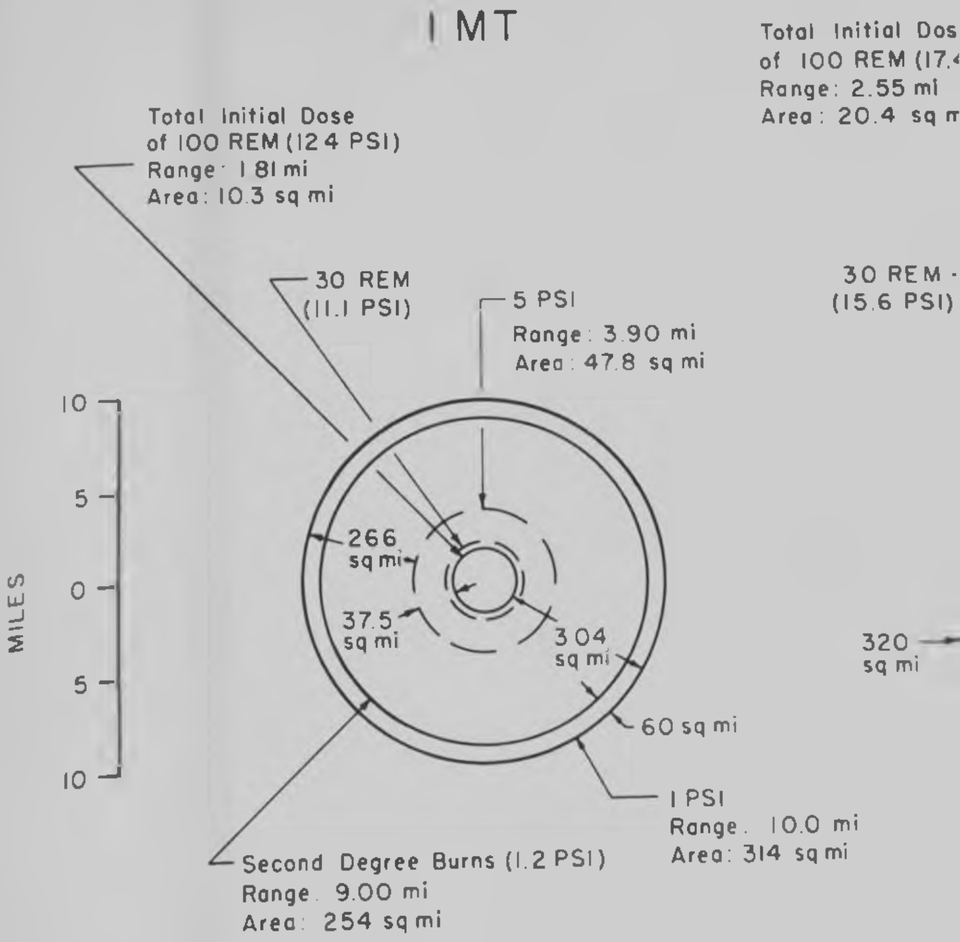
Pressure data are for typical air bursts.

Slant Ranges shown for Ionizing and Thermal Radiation

Figure 3

A comparison of the radii and ranges for 1 and 5 psi blast overpressure, 30 and 100 rem initial radiation, and second degree burns is shown to the same scale for typical air bursts of 1 and 10 MT yield in Figure 3. Slant ranges for ionizing and thermal radiation was assumed to be a reasonable approximation of the ground range.

Figure



Environmental Variations du

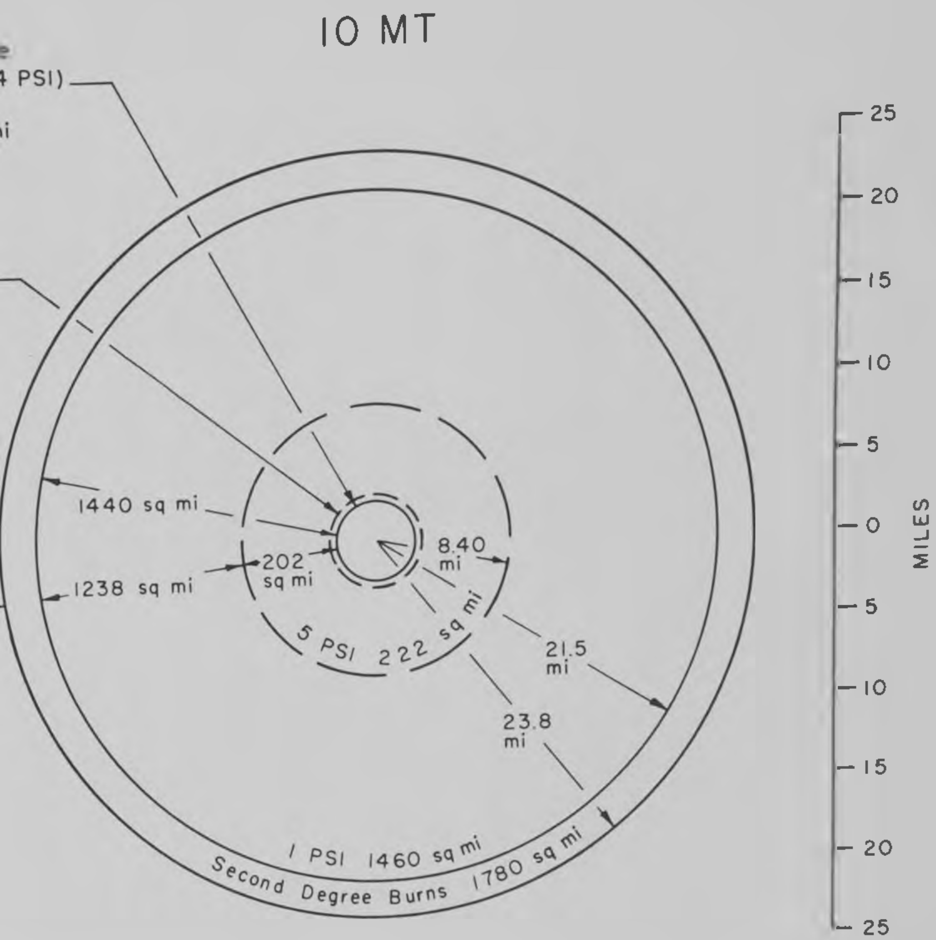
Ionizing Radiation for 1

(Data from Effects of Nuclear

Pressure data are for typical

Slant Ranges shown for Ioniz

3



ue to Blast, Thermal, and Initial
MT and 10 MT Explosive Yields
Weapons)

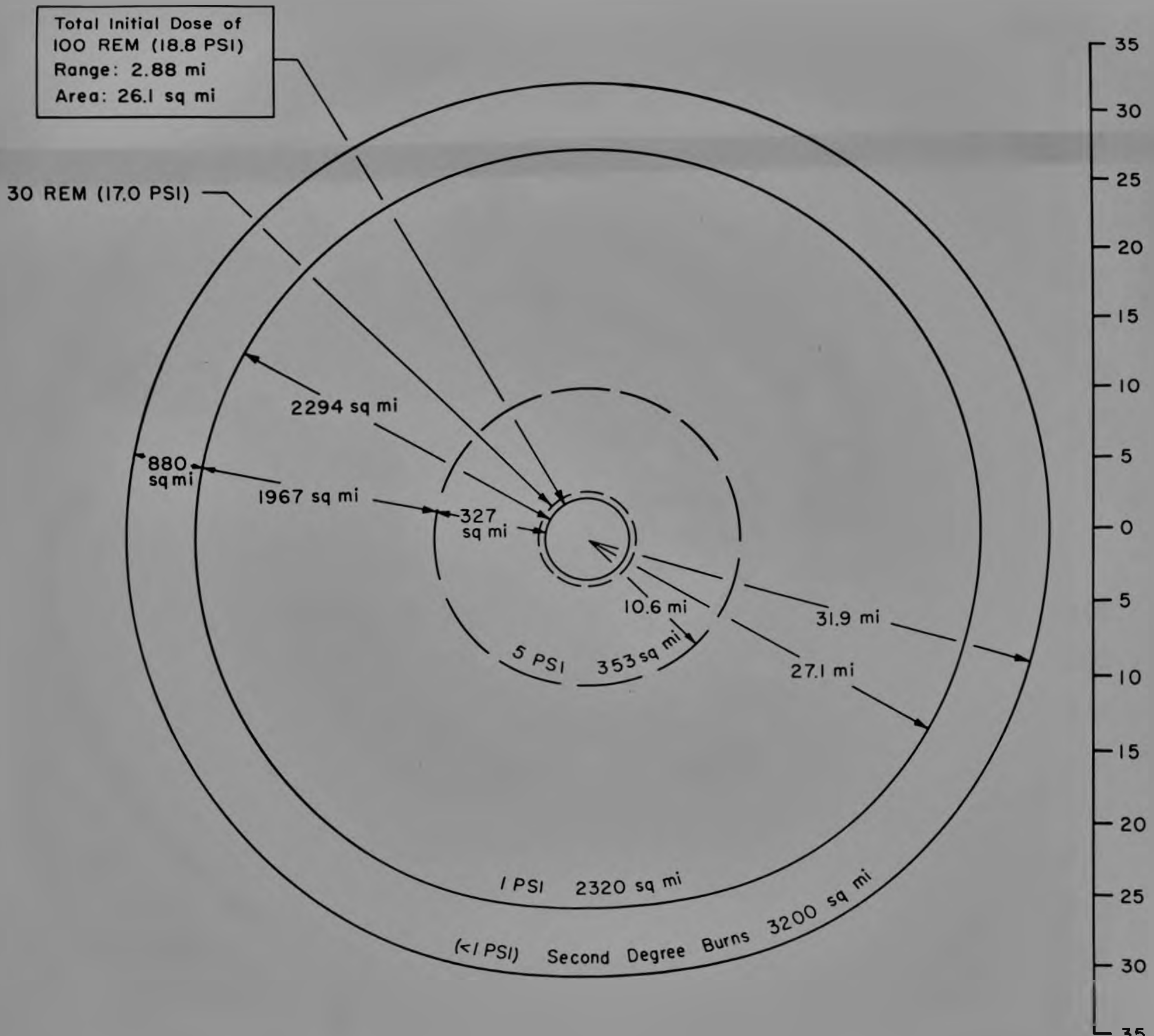
air bursts.
ing and Thermal Radiation

Figure 4

A comparison of the indicated effect parameters is shown in Figure 4 for the 20 MT typical air burst drawn to the same scale as in Figure 3. It was assumed that the slant ranges for thermal and ionizing radiation were reasonable approximations of the ground ranges.

It is instructive to contemplate Figure 4 from the point of view of human hazard. Exposure to 100 rem of initial radiation would cause no immediate incapacitation. However, casualties from thermal and blast would be very high at the 100 rem location, about 3 miles from ground zero where the overpressure and thermal flux would be close to 19 psi and over 1000 cal/cm^2, respectively. Indeed, casualties from blast, flash burns and fire would be heavy out to the 5 psi location where houses would be completely destroyed by blast. Still further out, injuries would lessen and be minimal due to blast at the 1 psi line where wooden frame houses suffer 50 per cent damage. Serious flash and fire hazards for unprotected persons would exist out to and even beyond the second degree burn line. One reason for this is the fact that thermal fluxes required to ignite fine kindling fuels are very close to those which produce second degree burns of the bare skin. There would be no immediate fallout problem for the case under discussion involves an air burst.

Figure 4



Environmental Variations due to Blast, Thermal, and Initial Ionizing Radiation for 20 MT Explosive Yield

(Data from Effects of Nuclear Weapons)

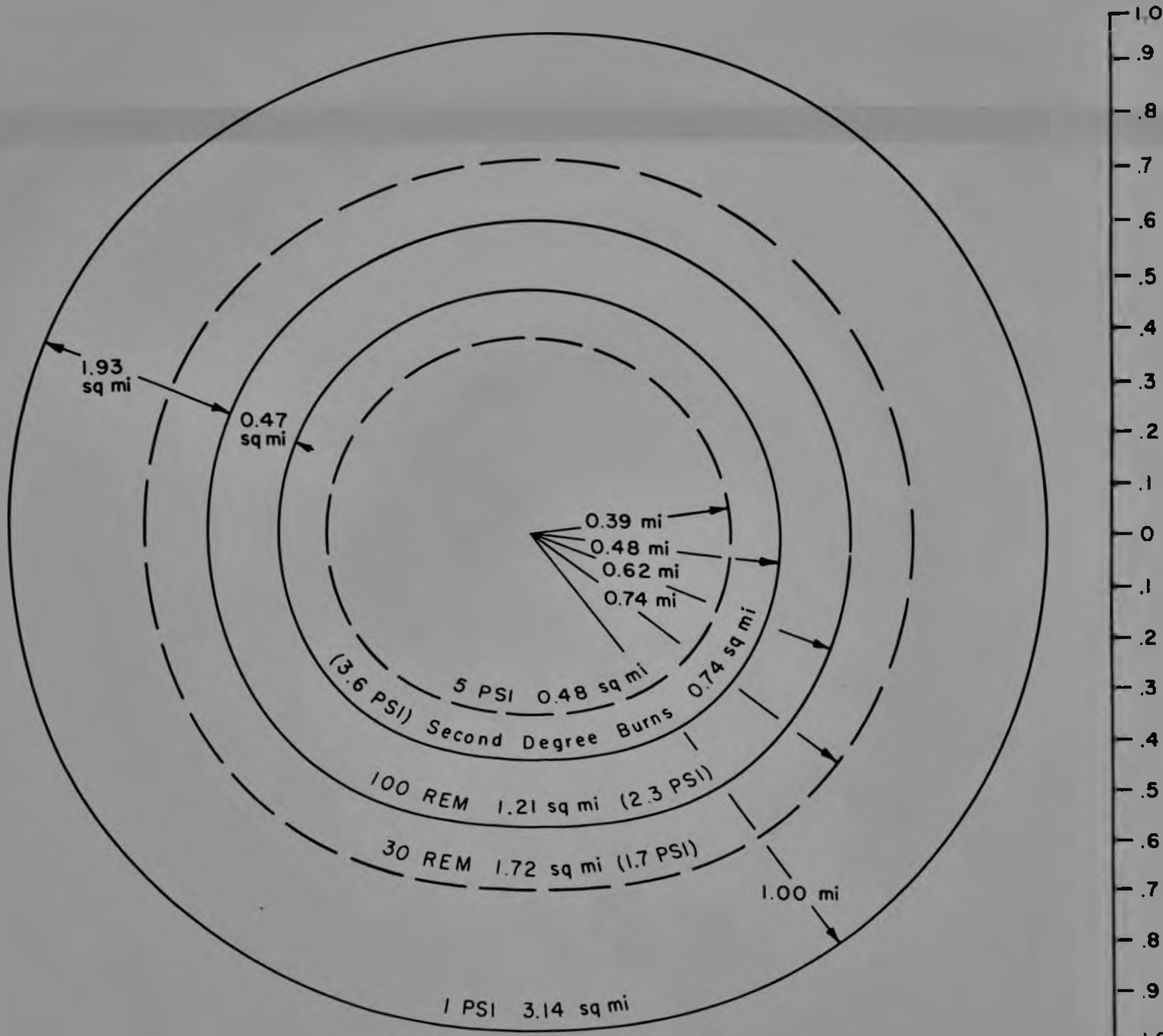
Pressure data are for typical air bursts.

Slant Ranges shown for Ionizing and Thermal Radiation

Figures 5, 6, 7

Figures 5, 6 and 7 show expanded plots of selected effects data for typical air bursts at yields of 1, 20 and 100 KT. It was assumed that slant ranges for ionizing and thermal radiation are reasonable approximations of the ground ranges.

Figure 5



Environmental Variations due to Blast, Thermal, and Initial Ionizing Radiation for 1 KT Explosive Yield

(Data from Effects of Nuclear Weapons)

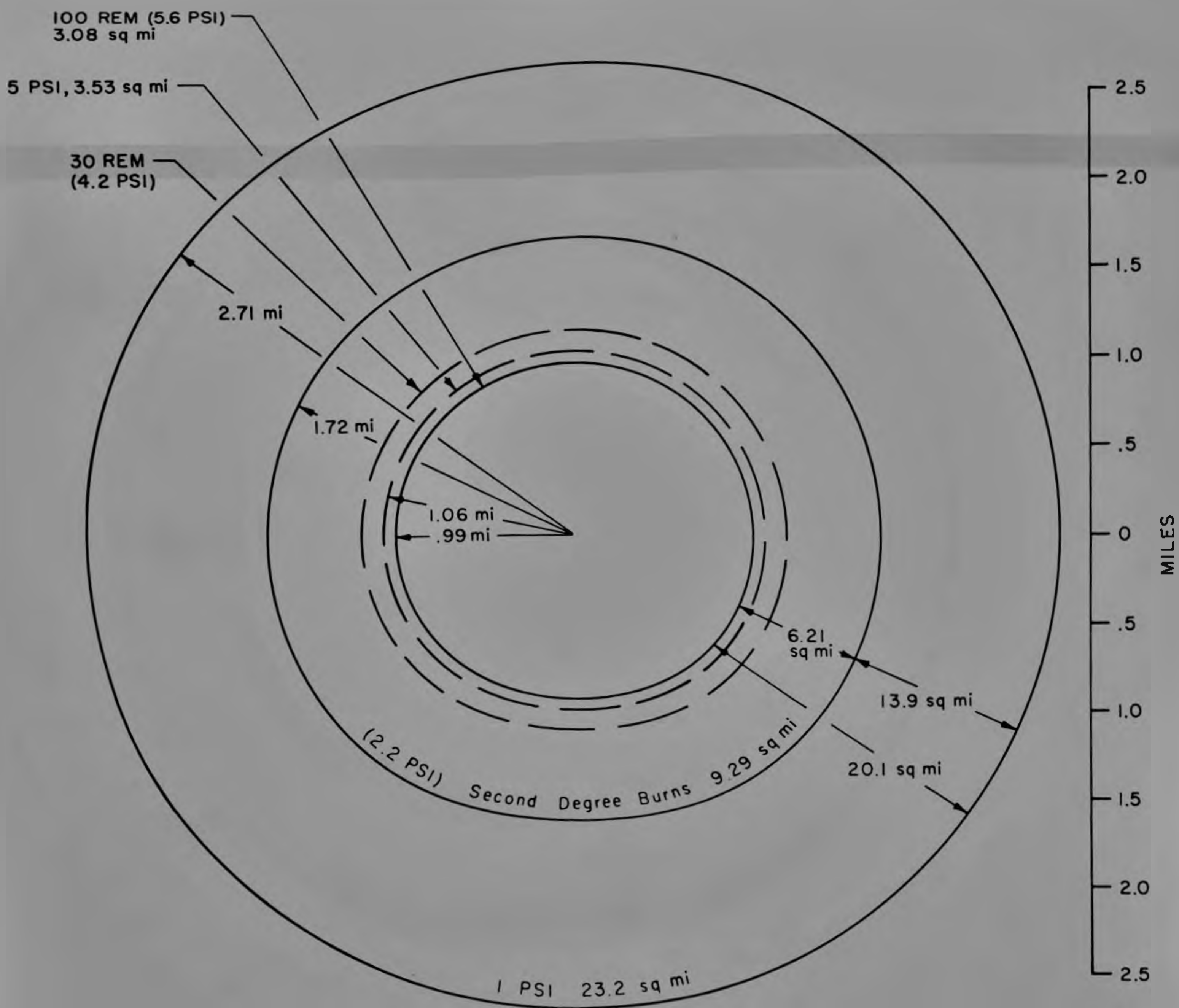
Pressure data are for typical air bursts.

Slant Ranges shown for Ionizing and Thermal Radiation

Figures 5, 6, 7

Figures 5, 6 and 7 show expanded plots of selected effects data for typical air bursts at yields of 1, 20 and 100 KT. It was assumed that slant ranges for ionizing and thermal radiation are reasonable approximations of the ground ranges.

Figure 6



Environmental Variations due to Blast, Thermal, and Initial Ionizing Radiation for 20 KT Explosive Yield

(Data from Effects of Nuclear Weapons)

Pressure data are for typical air bursts.

Slant Ranges shown for Ionizing and Thermal Radiation

Local Static or Incident Pressure - The overpressure measured side-on to the advancing front of an explosive-produced overpressure.

Reflected Pressure - The "instantaneous" pressure which occurs when a pressure front strikes a surface.

Dynamic Pressure (Q) - The difference between the pressures measured head-on and side-on to an advancing pressure pulse associated with an explosion. Thus, Q or dynamic pressure is a measure of the force exerted by the blast winds.

Pounds per square inch (psi) - A unit used to express the force exerted by blast-produced pressures.

Maximal Overpressure (Pmax) - The maximal overpressure existing at any location due to an explosion. This may refer to incident or reflected pressures.

Primary, Secondary and Tertiary Blast Effects - Primary, secondary and tertiary blast effects are biologically those due respectively to (a) pressure variations per se, (b) the impact of penetrating or nonpenetrating missiles energized by the blast, and (c) the physical displacement of a target by blast winds which may be damaging during the accelerative or decelerative phase of the experience.

Thermal Radiation

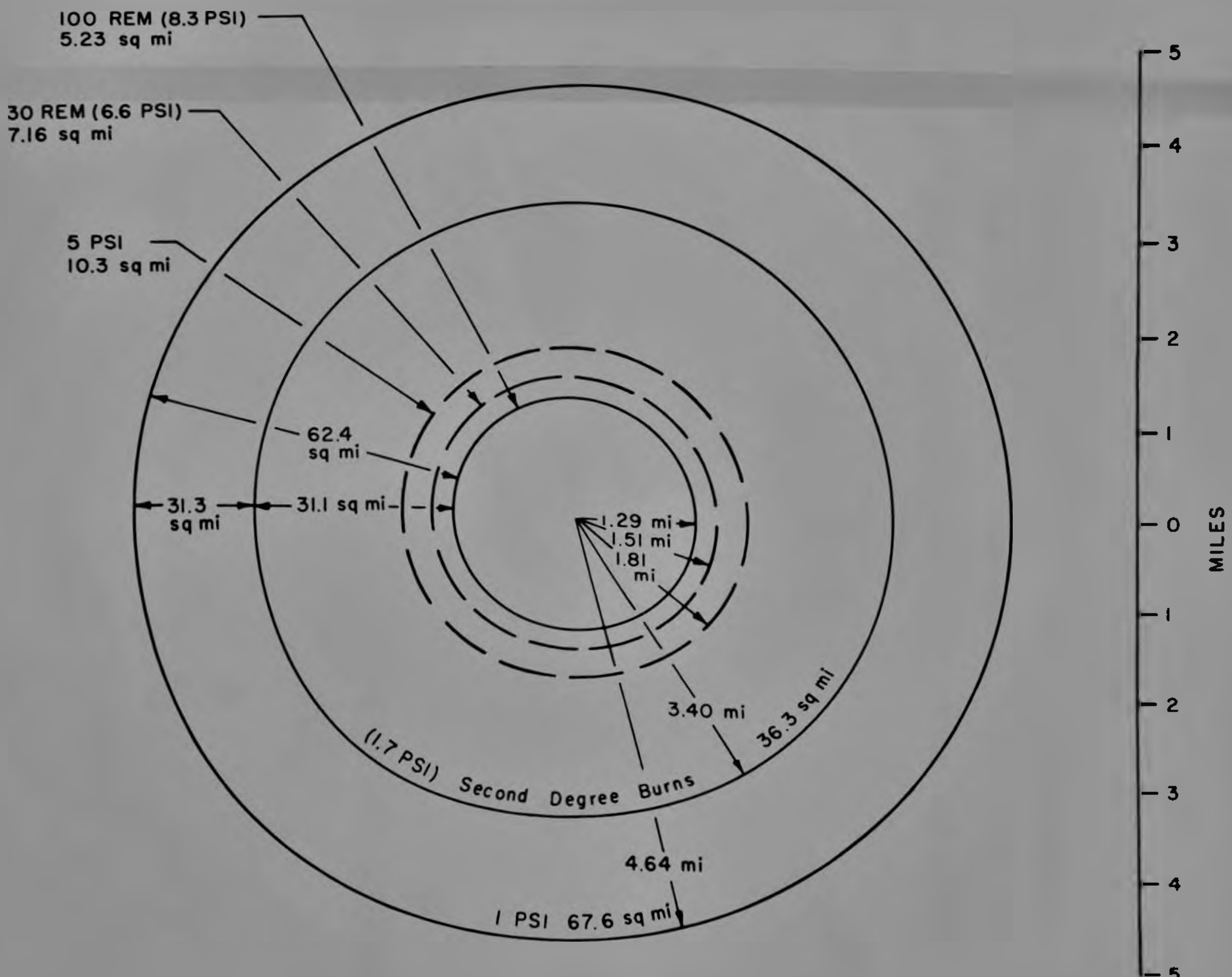
Thermal radiation refers to that portion of the energy of an explosion released as heat producing rays whether as visible light or invisible radiation in the ultraviolet and infrared portions of the energy spectrum.

Calories per square centimeter (cal/cm^2) - A unit conventionally used to denote

Figures 5, 6, 7

Figures 5, 6 and 7 show expanded plots of selected effects data for typical air bursts at yields of 1, 20 and 100 KT. It was assumed that slant ranges for ionizing and thermal radiation are reasonable approximations of the ground ranges.

Figure 7



Environmental Variations due to Blast, Thermal, and Initial Ionizing Radiation for 100 KT Explosive Yield

(Data from Effects of Nuclear Weapons)

Pressure data are for typical air bursts

Slant Ranges shown for Ionizing and Thermal Radiation

Figure 8

Figure 8 summarizes graphically the yield-distance relationships for effects produced by typical air bursts and allows comparison of the ground ranges for 30 and 100 rem initial radiation, 1 and 5 psi and first and second degree burns. It was assumed that clear weather conditions prevailed and that slant range for ionizing and thermal radiation represented a reasonable approximation of the ground range.

Figure 8

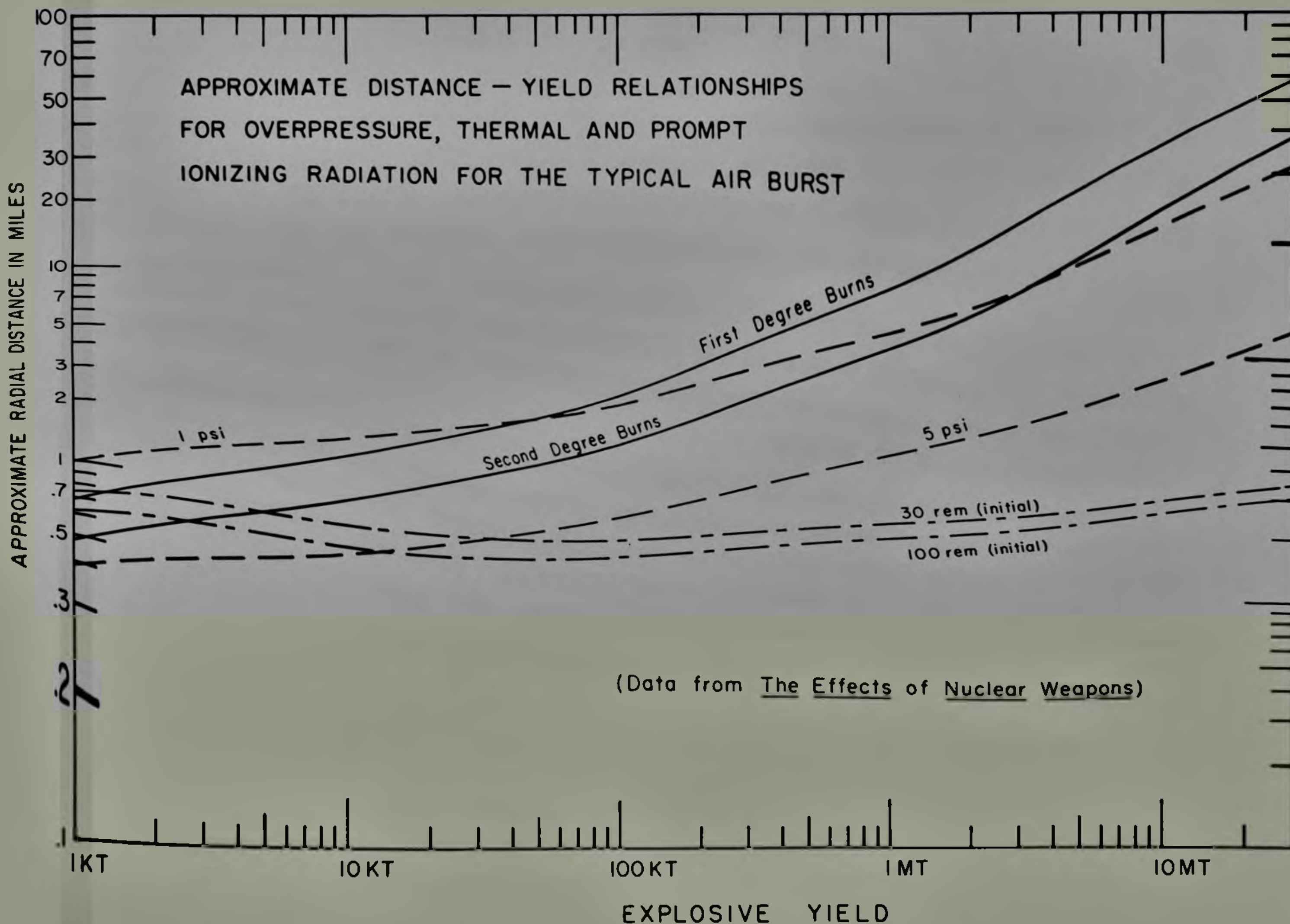

APPROXIMATE DISTANCE — YIELD RELATIONSHIPS
FOR OVERPRESSURE, THERMAL AND PROMPT
IONIZING RADIATION FOR THE TYPICAL AIR BURST
APPROXIMATE RADIAL DISTANCE IN MILES
100
70
50
30
20
10
7
5
3
2
1
.7
.5
.3
.2
.1
First Degree Burns
Second Degree Burns
1 psi
5 psi
30 rem (initial)
100 rem (initial)
(Data from The Effects of Nuclear Weapons)
1KT
10KT
100KT
1MT
10MT
EXPLOSIVE YIELD

Table 24

Table 24 presents approximate comparative effects data for a surface burst of 20 MT total yield. The presence of fallout radiation is the principle difference between this type of explosion and one detonated in the air. Ranges for the 1 and 5 psi lines are somewhat shorter for the surface burst compared with the air burst.

Assumptions made in computing the fallout pattern were (1) an effective wind of 15 mph, and (2) 50 per cent of the total yield was derived from fission. The latter assumption was necessary since the fusion process does not contribute significantly to the radioactivity of the fallout.

The somewhat hypothetical "1 hour reference dose rates" in roentgens per hour were used as a means of illustrating the relation between the fallout hazard within the immediate target area and the blast,radiation and thermal effects. The 1 hour reference dose rate is defined as the dose rate 1 hour after the detonation assuming that the fallout were complete at that time. The somewhat artificial significance of these dose rates in terms of accumulated dose is discussed in connection with Table 25.

The symbol > means greater than, while < means less than.

Table 24

COMPARATIVE EFFECTS DATA FOR A 20 MT SURFACE BURST

	Range (mi)	Area (mi^2)
>First Degree Burns	49.2	7600
>Second Degree Burns	31.9	3200
>Third Degree Burns	29.0	2640
>1 PSI	23.5	1730
>5 PSI	7.74	189
>30 REM (Initial)	3.30	34.2
>100 REM (Initial)	2.88	26.1
>30 R/hr Fallout (1 hr Reference Dose Rate)		2180*
>100 R/hr " " " " "		1400*
>300 R/hr " " " " "		1090*
>1000 R/hr " " " " "		851 *
>3000 R/hr " " " " "		515 *
>1 PSI, <30 R/hr		357
>1 PSI, <100 R/hr		1010
>Second Degree Burns, <1 PSI		1460
>Second Degree Burns, <30 R/hr		1680
>Second Degree Burns, <100 R/hr		2370

*Measured only to First Degree Burn Line.
Effective wind assumed to be 15 mph.

Data from The Effects of Nuclear Weapons

Figure 9

Figure 9 graphically presents the effects data set forth in Table 24 referable to a surface detonation of a nuclear weapon having an assumed fission yield of 10 MT but a total yield of 20 MT.

The somewhat hypothetical fallout contours in terms of the 1 hour reference dose rates are depicted only to the first degree burn limit approximately 49 miles from ground zero although the fallout might actually extend several hundred miles from the target area as dictated by the winds aloft. In the illustration a 15 mph effective wind was assumed.

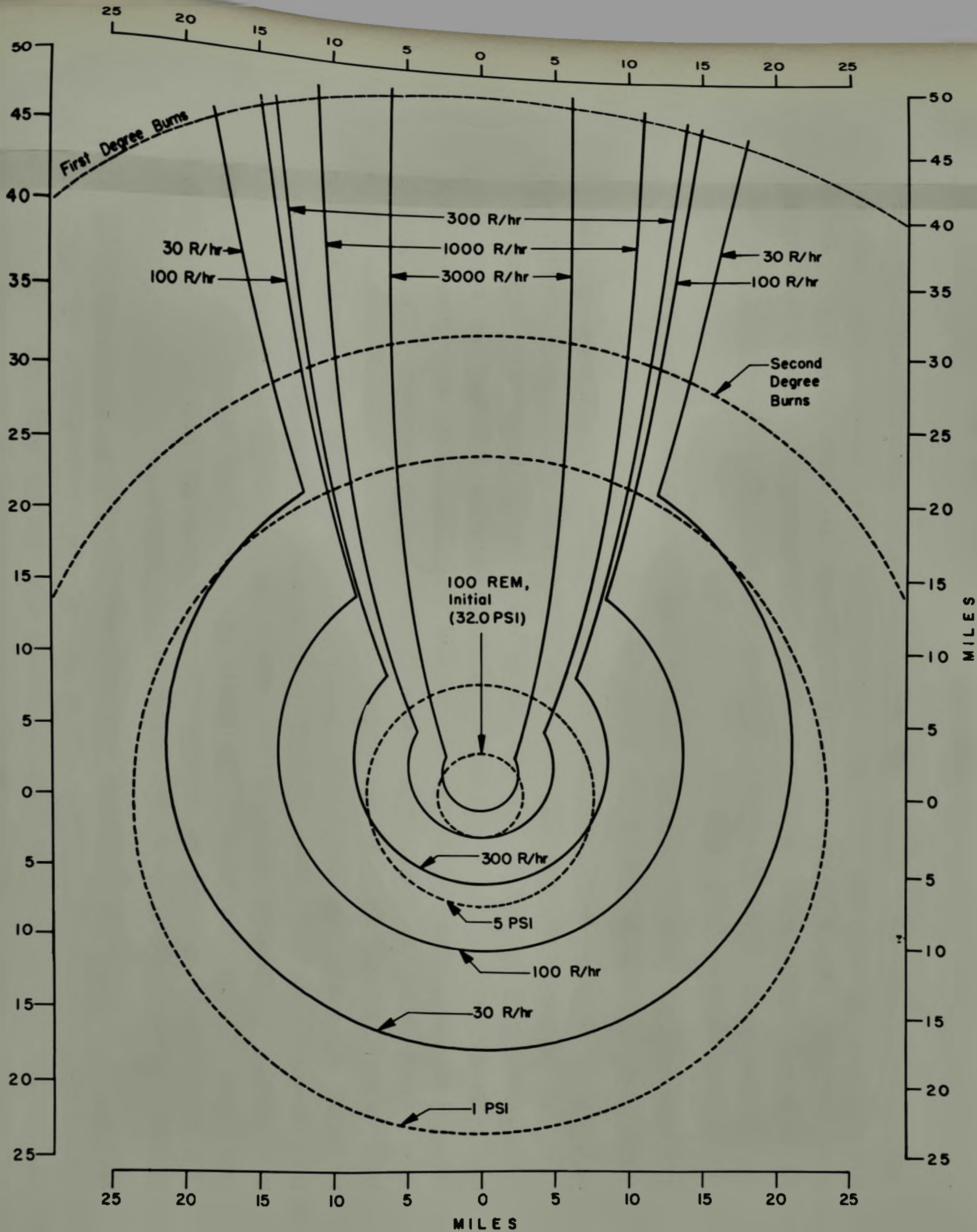


Figure 9

COMPARATIVE EFFECTS FOR A 20 MT SURFACE BURST

Residual radiation data — one hour reference dose rates — computed for a fission yield of 10 MT and an effective wind of 15 mph

Ta

Table 25 shows the exposure dose rat
tions as functions of the time after detonati
unprotected locations. Accumulation of rac
after the detonation. It is well to note that
able, the exposure doses within the shelter
doses tabulated in the body of the table.

Two examples will be given of ways
accumulated dose from penetrating fallout

Example 1. Assume that an individu
1000 r/hr 1 hr reference iso-dose rate lin
would have accumulated approximately 160
(see table). Such a value assumes that the
within 15 min after the burst. At the end c
1000 r/hr. At the end of the second hour,
would have dropped to near 435 r/hr and th
the other hand, the fallout was not complet
lated dose would be near 650 r shown in pa
between the accumulated doses shown for
exposures would be fatal, but were a fallo
(3 ft of earth) available and used, the accu
r instead of 1600, 2250 and 650 r for the e

Example 2. Assume an individual
the burst he measured an exposure dose r
dose rate in Table 25 the individual knows
dose rate contour, but more important he
he would accumulate 460 r were he to lea

ble 25

e and accumulated dose from penetrating radia-
on and selected 1 hour reference dose rates in
diation dose was calculated starting at 15 min
were a shelter equivalent to 3 ft of earth avail-
would be approximately 1/1000 of the exposure

Table 25 might be useful to crudely approximate
radiations.

ial were exposed to fallout radiations near the
ie shown in Figure 9. This person, if unprotected,
0 r at the end of the first hour after detonation
fallout was complete at this location in question
of 1 hr after the explosion the dose rate would be
Table 25 shows that the exposure dose rate
ie total accumulated dose would be 2250 r. If, on
e until 1 hr after detonation, then the total accumu-
rentheses in Table 25 which gives the difference
1 hr (1600 r) and 2 hrs (2250 r). Of course, such
ut shelter giving radiation attenuation of 1 in 1000
mulated doses would have been 1.6, 2.25 and 0.65
xamples considered above.

survived the burst by taking shelter and 6 hrs after
ate of 128 r/hr outside the shelter. By locating this
his shelter was near the 1000 r/hr 1 hr reference
notes the figure (460) in the table which tells him
ve the shelter for the next 6 hrs.

Table 25

ACCUMULATED RADIATION DOSE AND DOSE RATE AS A FUNCTION OF 1 HR REFERENCE DOSE RATE AND TIME AFTER DETONATION

1 hr Ref. Dose Rate:	30 R/hr		100 R/hr		300 R/hr		1000 R/hr		3000 R/hr	
Time after detonation	Dose* r	Dose rate r/hr	Dose* r	Dose rate r/hr	Dose* r	Dose rate r/hr	Dose* r	Dose rate r/hr	Dose* r	Dose rate r/hr
1 hr	47.9	30.0	160	100	479	300	1600	1000	4790	3000
(1 hr)$^{+}$	(19.5)$^{+}$		(65)		(195)		(650)		(1950)	
2 hrs	67.4	13.1	225	43.5	674	131	2250	435	6740	1310
(2 hrs)	(16.8)		(56)		(168)		(560)		(1680)	
4 hrs	84.2	5.68	281	19.0	842	56.8	2810	190	8420	568
(2 hrs)	(8.9)		(29)		(89)		(290)		(890)	
6 hrs	93.1	3.49	310	12.8	931	34.9	3100	128	9310	349
(6 hrs)	(13.9)		(46)		(139)		(460)		(1390)	
12 hrs	107	1.52	356	5.07	1070	15.2	3560	50.7	10700	152
(12 hrs)	(11.0)		(39)		(110)		(390)		(1100)	
24 hrs	118	.662	395	2.21	1180	6.62	3950	22.1	11800	66.2
(12 hrs)	(7.0)		(20)		(70)		(200)		(700)	
36 hrs	125	.407	415	1.36	1250	4.07	4150	13.6	12500	40.7
(12 hrs)	(4.0)		(14)		(40)		(140)		(400)	
48 hrs	129	.269	429	.96	1290	2.69	4290	9.6	12900	26.9
	(69)		(231)		(690)		(2310)		(6900)	
Infinity Dose	198		660		1980		6600		19800	

*Doses computed starting at 15 min after detonation.
$^{+}$Numbers in parentheses represent differences between adjacent values.

Data from <u>The Effects of Nuclear Weapons</u>

the magnitude of thermal en

Ignition Energy - That thermal "dose"
specified material.

Skin Burns -

First degree burns - flash or flam
and roughly similar to a moc

Second degree burns - burns which
the skin. In case a significa
usually require expert medic

Third degree burns - burns of suc
thickness of the skin with he
small areas, particularly in
of the body, require prolong

Flash Blindness - A temporary loss of

Retinal Burns - Destruction of portion
nerves concerned with sight
light source on the retina.

Ionizing Radiation

Initial Radiations - The initial nuclear
rays — are those emitted fro
in 1 min after a nuclear det

Residual Radiations - The residual nu
beta particles — are those e

ergy reaching any given target.

expressed in cal/cm^2 required to ignite

e burns producing only redness of the skin
derate sunburn.

n produce superficial or deep blisters of
nt area of the body is involved, these burns
cal care.

h severity as to completely destroy the full
aling by scar formation. Even relatively
volving the face, hands, or flexion surfaces
ed medical attention including skin grafting.

vision due to exposure to intense light.

s of the inner wall of the eye containing the
due to the focusing of an image of an intense

radiations — mostly neutrons and gamma
m the ball of fire and the cloud column with-
onation.

clear radiations — mostly gamma rays and
mitted after 1 min following a nuclear explo-

sion and consist of emanations from fission products or from induced activity in air, soil or other material.

Fallout Radiation - That portion of the residual radiations which falls to the surface of the earth from the radioactive cloud or cloud stem.

Roentgen (r)* - The unit of exposure dose of X- or gamma radiation.

Roentgen per hour (r/hr)* - The unit of exposure dose rate expressed in exposure dose per unit time.

Relative Biological Effectiveness (RBE)*, ** - An expression used to compare the biological effectiveness of different kinds of ionizing radiation.

Roentgen Equivalent Man (rem)*, ** - The unit of RBE dose and is equal to the radiation dose in rads (a unit of absorbed dose) multiplied by an appropriate RBE**.

(Note: While there are very real distinctions between exposure dose (r), absorbed dose (rads) and biologically effective dose (rem), the r and rad units are numerically speaking not too different. Neither does the rem value for X- or gamma radiations numerically vary much from those expressed in r or rad units since the RBE by definition is approximately 1. Once the absorbed dose (in rads) for neutrons is converted

---

*Taken from U. S. Bureau of Standards Handbook 62, dated 1956, to which the reader is referred for more precise definitions and explanations. Also see Radiological Health Handbook, U. S. Department of Health, Education and Welfare, 1957.

**For the data given later covering initial radiations, the rem values were computed using an RBE for bomb neutrons of 1.7 as was done in The Effects of Nuclear Weapons.

to rem, using an appropriate RBE, the numerical value represents a gamma equivalent of the neutron dose. Consequently, for practical purposes, the reader may regard the rem values noted in future sections of the brochure as roughly equivalent numerically to the exposure dose in roentgens. Although, strictly speaking, this is technically incorrect, the errors involved in such an approximation are generally much smaller than the other sources of uncertainty and seem acceptable on this basis.)

ORIENTATION

Physical Parameters

Blast

Pressure (Incident, Reflected, Dynamic) and Wind Velocity - Since both overpressure and wind are responsible for damage by blast, it is helpful to note the approximate relationships set forth in Table 1. It is important to appreciate the relationship between the incident and reflected pressure and to know that field experience has shown considerable variation in the dynamic pressures related with a given psi. For example, at an incident overpressure of 6 - 7 psi a dynamic pressure of about 15 psi was measured in the 1957 Nevada Test Series.*

Pressure and Structures - Table 2 details a few of the approximate relationships between overpressure produced by nuclear blast and damage to structures.

Pressure and Missiles** - The velocities and masses of glass and stone missiles energized by blast winds in full-scale nuclear tests at the Nevada Test Site are set forth in Table 3.

Pressure and Displacement of Man* - The measured maximum velocity and displacements of 160-pound anthropometric dummies exposed to nuclear blast at the Nevada Test Site to simulate man are shown in Table 4.

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*WT-1469

**WT-1166, WT-1468, AECU-3350