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TENTATIVE BIOLOGICAL CRITERIA
FOR ASSESSING POTENTIAL
HAZARDS FROM NUCLEAR EXPLOSIONS

Prepared by
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Technical Progress Report
on
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Lovelace Foundation for Medical Education and Research
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PREFACE

Though the actual preparation of this manuscript was undertaken for the Defense Atomic Support Agency, most of the information contained herein has been the outcome of two investigative efforts; namely research on The Biological Effects of Blast from Bombs supported through the Office of the Surgeon, Defense Atomic Support Agency of the Department of Defense under Contract No. DA-49-146-XZ-055 and a program in Selected Aspects of Weapons Effects supported by the Civil Effects Branch of the Division of Biology and Medicine of the United States Atomic Energy Commission under Contract No. AT(29-1)-1242.

ABSTRACT

Available, but tentative and incomplete biological criteria of use in assessing human hazards from nuclear explosives were presented along with the source of data from which they were derived. The criteria were related to effects parameters employing free-field, some "geometric," and translational scaling to the end that areas at potential risk from nuclear detonations ranging in yield from one kt to 100 Mt could be estimated. The problem areas involved and many of the uncertainties due to lack of both physical and biological data as well as to the fact that the conditions of exposure represent a major factor in determining the environmental variations that challenge man and hence in controlling the incidence of casualties as well as survival were noted and briefly discussed. The utility of the range-yield-effects relationships set forth was emphasized as was the need for a continued collaborative effort between biologically and physically oriented personnel to improve understanding biological response on the one hand and basic effects phenomenology on the other.

TENTATIVE BIOLOGICAL CRITERIA FOR ASSESSING POTENTIAL HAZARDS FROM NUCLEAR EXPLOSIONS

Clayton S. White

I. INTRODUCTION

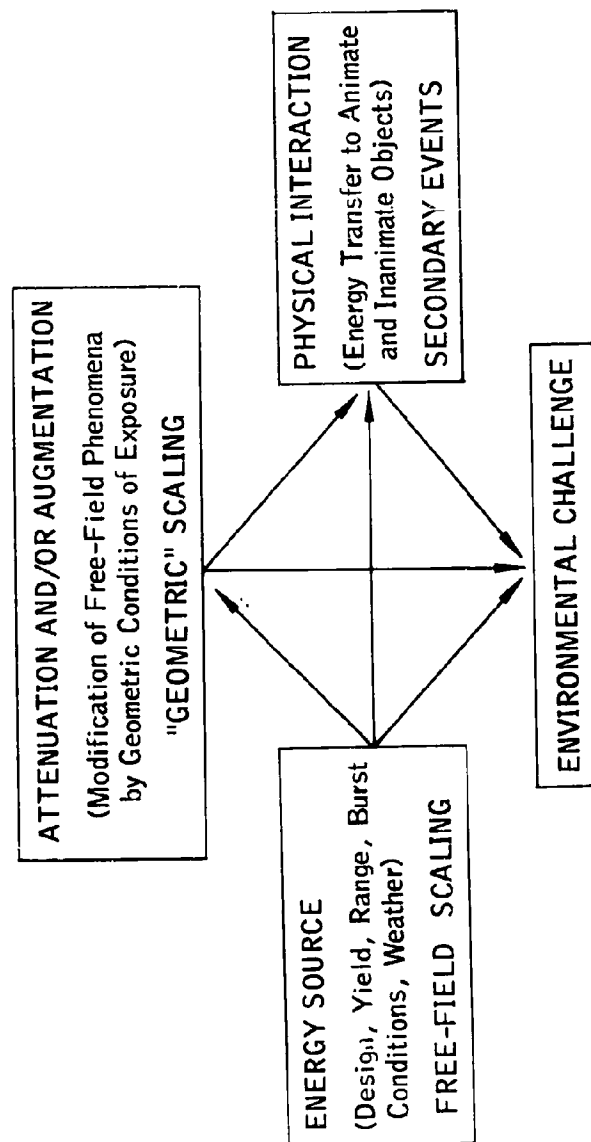
Prior discussions among individuals participating in the Sub-Group N and N-1 Panel of the Tripartite Technical Cooperation Program uncovered an interest in biological criteria that could be of value in assessing various levels of hazard from environmental variations associated with nuclear explosions. Since relevant studies have already called attention to the problem areas involved,¹⁻⁴ set forth tentative though crude criteria,¹⁻⁷ and pointed out one approach to applying these to nuclear detonations over a wide range in explosive yield,³⁻⁴ it was thought advisable to summarize the initial and exploratory work carried out to date in order that a common working base might be used as a foundation for planning any collaborative efforts judged desirable by tripartite personnel.

II. PROBLEM AREAS

There are several physical, biophysical and biomedical parameters which, if identified, quantitated and interrelated, offer a conceptual guide of potential value to those interested in weapons effects. These may be segregated into problem areas noted in Figures 1 and 2⁴ and Table 1.³

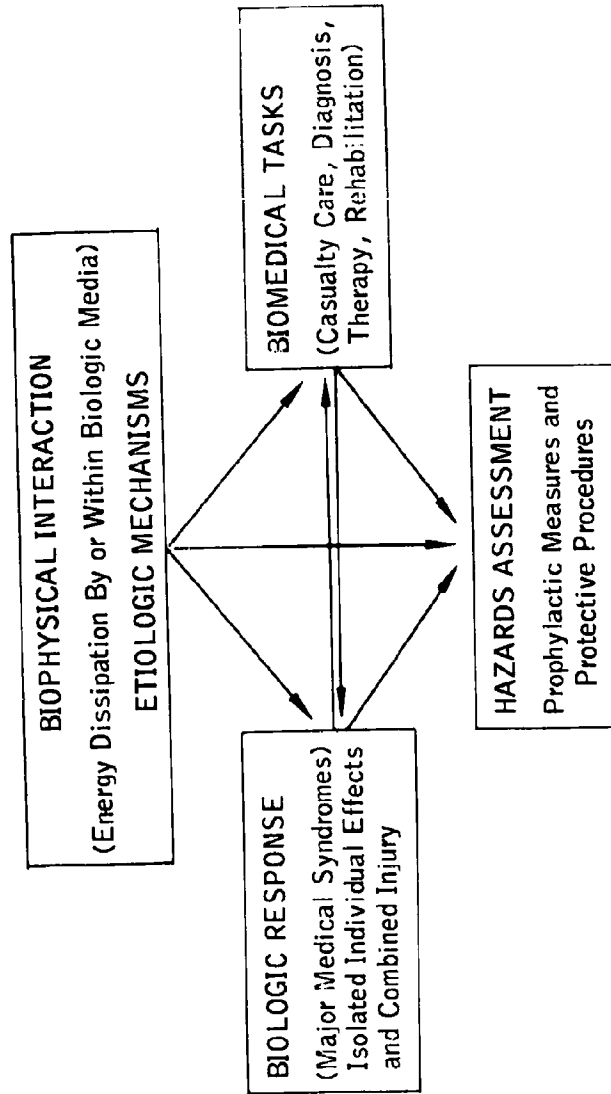
It is helpful on the one hand to appreciate that very great differences may exist between exposures in the open for which free-field scaling is applicable and exposures in situations where free-field scaling is inappropriate to give the environmental parameters that may challenge man; i.e., "geometric" and "secondary-event" scaling is required as diagrammatically indicated in Figure 1. On the other hand, almost all biological criteria refer to a specified level of environmental variation measured very close to the biological target of interest; viz., not outdoors if the target is indoors, not on the top floor of a multistory building if the location of interest is the basement. Thus, biologically oriented investigators employ the "skin dose" concept and work in the problem areas depicted in Figure 2.

There are, however, grave difficulties in integrating the biological and physical parameters to the end that hazards assessment may be realistically related to a nuclear source, but appreciable progress has been made in developing some of the quantitative data needed to tie together the problem areas summarized in Table 1. Appropriate examples will appear in subsequent sections of the text.



Physically Oriented Problem Areas Relevant to Biological
Effects of Nuclear Explosions

Figure 1



Biomedically Oriented Problem Areas Relevant to Biological
Effects of Nuclear Explosions

Figure 2

TABLE 1

PROBLEM AREAS RELEVANT TO BIOLOGIC
EFFECTS OF NUCLEAR WEAPONS

Source	Design Yield Burst conditions Range Weather	Free-field scaling
Attenuation and Augmentation	Modification of "free- field" phenomena by geometric conditions of exposure	"Geometric" scaling
Physical Interaction	Energy transfer to: Physical objects and biological material	Secondary events
Biophysical Interaction	Energy dissipation by or within biologic targets	Etiologic mechanisms
Biologic Response	Major medical syndromes Isolated individual effects and combined injury	Hazards assessment
Biomedical Tasks	Therapeutic and prophylactic measures	Casualty care Rehabilitation Protective procedures

III. TENTATIVE BIOLOGICAL CRITERIA

Available animal and human data supplemented where required by best approximations have allowed tentative biological criteria to be set forth. These will be summarized below.

A. Blast

1. Primary Effects (Pressure)

It is now known that mammalian tolerance to pressure variations which follow explosive events is dependent upon the rate, magnitude and character of the pressure rise and fall as well as the size of the species of interest.^{5, 6, 8, 9} Too, it is clear that biological response to typical and near-typical wave forms is different than is the case for disturbed wave forms.^{5, 6, 8, 9} The former will be discussed first.

a. Classical or Near-Classical Wave Forms

For a given mammalian species, the response to "fast"-rising overpressures is determined by both the magnitude and duration of the pulse. Reasonably reliable estimates applicable to human adults are available for explosive yields down to at least one kt. The data are summarized in Table 2.^{1, 3-6, 8-16}

Thus far, no systematic study of tolerance in the very young and very old has been carried out, but there are a few data for rats indicating that the young are more susceptible than adults.¹⁵ Also, recent exploratory investigations in mice show that tolerance to overpressure is also a function of the ambient pressure at which exposure occurs;¹⁷ i. e., biological scaling to obtain figures applicable for exposure at different altitudes no doubt will come to be a future refinement in blast biology.

b. Disturbed Wave Forms

(1) Stepwise Increases in Overpressure

In some exposure situations, stepwise increases in overpressure may occur.^{1, 8, 10} This can involve the application of the incident, followed by the reflected pulse.¹⁸⁻²⁰ An animal "appreciates" these biologically as a single rise in overpressure if the time interval is short; i. e., like 0.1 to 0.4 msec for small animals^{6, 19, 20} and 0.5 to 1.0 msec for the dog.⁶ For longer intervals of time, perhaps a few msec for animals as large as man, the organism "sees" the pressure as two separate pulses and tolerance rises by about a factor of two.

No more precise statement can be made at the present time, mainly because the area has been insufficiently investigated.

TABLE 2

TENTATIVE CRITERIA FOR PRIMARY BLAST EFFECTS*

Critical organ or event	Related max pressure, psi	
	Incident No reflection	Incident With reflection
Lung damage: [†]		
Threshold	15	6.4
Lethality: [†]		
Threshold	30-42	12-15
50 percent	42-57	15-19
Near 100 percent	58-80	19-25
Eardrum failure: [†]		
Threshold	5	2.3

*Applies to "fast"-rising overpressures of "long" duration occurring at location of exposure.

[†]Data from WT-1179,⁸ TID-5764,⁹ WT-1467,¹⁰ WT-1470,¹¹ DASA 1242,¹² 1335,⁶ 1246,¹³ 1271,¹ Zalewski¹⁴ and Richmond, DASA Project - Unpublished.¹⁵

(2) Other Wave Forms

For smooth-rising wave forms and those increasing rapidly, but in small incremental steps, the mammal exhibits an increase in tolerance by factors of from 3 to 5 depending mostly upon the magnitude of the early fast components of the pulse.²¹⁻²² Here also, no more definitive statement is possible because critical studies have not yet been carried out. However, it is known that mammals weighing about 35-40 lbs and having a P_{50} of 50 psi from "fast"-rising, "long"-duration overpressures will tolerate well over 200 psi if the time to P_{max} is reached in 20 or more msec.²¹

2. Secondary Blast Effects (Missiles)

Debris (missiles) energized by blast overpressures, winds, ground shock and gravity may or may not pose a hazard, depending mostly upon the kind, character, mass and velocity of the missile; the angle of impact; the area and organ of the body involved, and whether or not penetration or perforation occurs. Though the situation is admittedly complex, crude and incomplete but useful biological criteria are available to help assess possible hazards from secondary missiles.^{5, 11, 23-26} These are shown in Tables 3 and 4.³

3. Tertiary Blast Effects (Displacement)

Dynamic accelerative and decelerative events which may be associated with gross bodily displacement by blast pressures, winds, ground shock and gravity may pose serious problems depending mostly upon the magnitude of the accelerative or decelerative forces involved; the time, distance and angle over which they are applied; the character of the contact surface concerned, and the area of the body involved.

Because the accelerative experience from aerodynamic factors that are in themselves non-hazardous can result in highly challenging translational velocities if impact with a hard surface occurs, tentative biological criteria were developed in terms of impact velocity. These are set forth in Table 5.^{3, 25-28} Even though crude and incomplete, the criteria are helpful in assessing not only the various levels of decelerative injury that may follow translation, but in evaluating some of the possible hazards from accelerative loading that can occur in shelters responding to ground-shock phenomena.

To date, no useful biological criteria are available for deceleration by tumbling over hard or other types of surfaces. Some work, however, has been done on the physics of the tumbling process.²⁹

4. Miscellaneous Blast Effects

Numbered among miscellaneous blast effects are possible hazards from exposure to dust, blast-induced fires and non-line-of-site thermal burns from hot, dust-laden air and hot debris.^{1, 4, 8, 10, 30, 31}

TABLE 3

TENTATIVE CRITERIA FOR SECONDARY BLAST EFFECTS*

Critical organ or event	Related velocity for 10-gm glass fragment ft/sec ⁺
Skin laceration:	
Threshold	50
Serious wounds:*	
Threshold	100
50 percent	180
Near 100 percent	300

*Data from AECU-3350²³ and WT-1470.¹¹

⁺Figures represent impact velocities with unclothed biological target.

TABLE 4

TENTATIVE CRITERIA FOR SECONDARY BLAST EFFECTS

Critical organ or event	Related impact velocity for 10-lb object ft/sec
Cerebral concussion:*	
Mostly "safe"	10
Threshold	15
Skull fracture:*	
Mostly "safe"	10
Threshold	15
Near 100 percent	23

*Data from Lissner and Evans;²⁴ Zuckerman and Black;²⁵
Gurdjian, Webster and Lissner.²⁶

TABLE 5

TENTATIVE CRITERIA FOR TERTIARY BLAST EFFECTS

Critical organ or event	Related impact velocity ft/sec*
Total body: [†]	
Mostly "safe"	10
Lethality threshold	20
Lethality 50 percent	26
Lethality near 100 percent	30
Skull fracture: [†]	
Mostly "safe"	10
Threshold	13
50 percent	18
Near 100 percent	23

Note: Fractures of the feet, ankles and lower limbs occur at impact velocities above 12 ft/sec where cadavers with knees locked are dropped feet first onto a hard, flat surface.

*Applies to uncontrolled impact with a hard, flat surface.

[†]Data from DASA 1245;²⁷ Swearingen, McFadden, Garner and Blethrow;²⁸ Zuckerman and Black;²⁵ and Gurdjian, Webster and Lissner.²⁶

Unfortunately, no meaningful biological criteria are at hand for assessing the hazard from hot dust-laden air and debris.⁴ Similarly, the interplay of thermal, blast and environmental phenomena responsible for the non-line-of-site thermal burns observed at the Nevada Test Site is not well understood. Even so, it is quite possible that these and related phenomena may very well represent one of the major causes of casualties among individuals exposed in conventional buildings and other open structures, particularly for nuclear explosions of high yield.

B. Thermal Radiation

Biological response to direct thermal radiation or to flame generally depends upon the magnitude of the thermal energy involved, the rate and time of its application, the amount and color of skin pigment, the part of the covered and uncovered portion of the body exposed, the character of the clothing, if any, and the per cent of the total surface area involved.

Useful tentative biological criteria were developed, as shown in Table 6⁷ using data from Glasstone³² and Oughterson and Warren.³³ The upper portion of the table notes the cal/cm² required at different yields to produce first and second degree burns of bare white skin. The lower portion of Table 6 shows, in the 20 kt column, data scaled for the survival curve for clothed individuals exposed in the open at Hiroshima. Attention is directed to the curve of Figure 3 which notes free-field values for thermal energy estimated by the scaling laws³² for the ranges associated with 50 per cent and "low" and "high" levels of survival for persons exposed in Hiroshima. Thus, the lower three numbers of 5, 9 and 20 cal/cm² under the 20 kt column for various levels of lethality in Table 6 represent arbitrary, tentative, but conservative criteria based on human experience in Japan. The numbers to the right of these in Table 6 are scaled "equivalent" values for the higher yield. The values for the threshold of injury and those associated with few if any injuries also represent arbitrarily chosen figures which, however, bear a common-sense relation to the data given by Glasstone³² for first and second degree burns.

Since the individuals exposed in the open in Japan were clothed, it is well to point out that two of the problem areas mentioned earlier are involved. First, there is the matter of "geometric" scaling, for if the clothing does not ignite, it acts as an attenuating factor to protect the skin. Second, if it does catch fire, then this secondary event produces a hazard in its own right above and beyond that from direct thermal radiation. Finally, it is helpful to recognize that (a) most if not all of the survivors exposed in the open at Hiroshima had much less than 50 per cent of the body surface burned, (b) many individuals survived exposures well above 20 cal/cm², (c) the cal/cm² needed to ignite many fabrics fall within or above the range of numbers associated with various levels of lethality in Table 6, (d) even the lightest clothing gives protection by a factor of 2 and in a few cases, by factors of about 4 and (e) the "behavior" of clothing worn by exposed individuals is not easy to assess.

Even though the situation is admittedly complex and bothersome unknowns are involved and more than a few will regard the thermal criteria with skepticism, perhaps many more will accept them as a beginning - arbitrary, flimsy and crude as they are - knowing that "something" is better than nothing and that the uncertainties involved are no greater in magnitude than a host of

TABLE 6
TENTATIVE BIOLOGICAL CRITERIA FOR THERMAL RADIATION*

Critical event	Thermal radiation in cal/cm ² for indicated explosive yield				
	20 kt	100 kt	1 Mt	10 Mt	20 Mt
First degree burn	2.5		3		4
Second degree burn	4.5	5	6.5	9	10
Lightly clothed (summer)					
Few if any injuries	2.5		3		4
Significant injury threshold	4	4.5	6	8.5	9.5
Lethality					
Threshold	5	6.0	8	10.0	11
Near 50 per cent	9	11.0	14	18.0	20
Near 100 per cent	20	24	31	40	43
Burns due to hot debris and hot, dust-laden air.				No biological criteria available, but probably a serious problem for large-yield explosions.	

*ENW, 1962;³² Oughterson and Warren, 1956;³³ Project Harbor.⁷

Note: Immediate survival in some Japanese buildings was near 90 per cent even though the outdoor, free-field thermal flux ranged from 50-100 cal/cm².

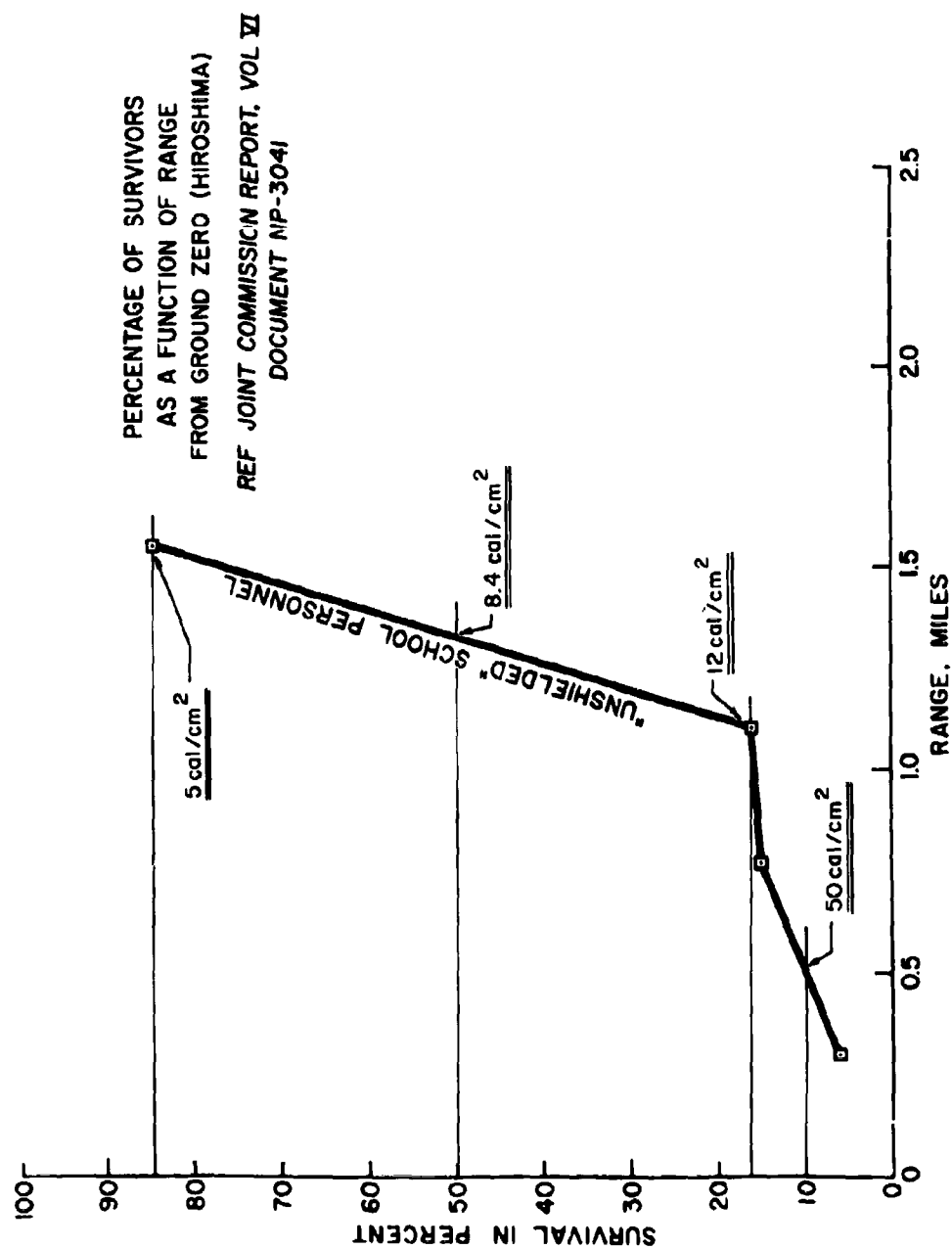


Figure 3

others applicable to the physical and biological facets of weapons effects.

Temporary and permanent loss of vision from light fluxes and focusing of thermal energy on the retina can range from bothersome transitory to serious hazards; the latter are limited mostly to looking directly at the fireball.

Though some applicable biological data are at hand, they are not noted here. Of course, it is important that the population learn not to look at bright luminous objects in the sky.

C. Nuclear Radiation

Biological response to ionizing radiation varies with the type and energy of the radiations, the total dose, the rate at which the dose is accumulated, the species and the portion of the body involved. Only penetrating radiations will be considered here, making no distinction between either neutrons or gamma rays - the RBE is taken as one - or the energies of each.

Table 7 shows tentative biological criteria for immediate nuclear radiations relating whole body dose to various levels of human response.^{7, 34, 35} Criteria in two other areas are not discussed here; namely, (1) the situation for protracted exposure to radiations which is complex, controversial and involves the matter of equivalent residual dose (ERD) discussed in a recent report of the National Committee of Radiation Protection and Measurements³⁴ and (2) the estimates for performance decrement covered by Alpen at the Washington meeting of the Tripartite Technical Cooperation Program, Panel N-1, Sub-Group N.³⁶

D. Combined Injury

Unfortunately, only a few studies have been carried out in which the synergistic or combined biological effects of more than one environmental variation have been studied. This, without question, is an area that deserves attention in the future.⁴

IV. RELATING BIOLOGICAL CRITERIA TO NUCLEAR EXPLOSIONS

A. The Range-Yield-Effect Relationships (General)

One means of relating the tentative biological criteria to nuclear explosions over a wide range of yield is to employ free-field scaling,^{3, 4, 28, 32} some "geometric" scaling (viz., for maximal pressure reflections) and "secondary-event" or translational scaling^{37, 38} to estimate the ranges inside which the potential exists for producing the specified biological effect or response.

1. Blast

Range-yield-effect relationships can be developed from such an exercise. Examples, using the blast criteria, are shown in Figures 4, 5 and 6 for surface bursts at sea level having yields ranging from 1 kt to

TABLE 7
TENTATIVE BIOLOGICAL CRITERIA
FOR PENETRATING NUCLEAR RADIATIONS*

Critical event	Dose in rads for whole body exposure**
No discernable immediate effects	50
Sickness dose:	
Threshold	100
Acceptable "emergency" dose	200 [†]
Lethality:	
Threshold	200 [†]
Near 50 per cent	450
Near 100 per cent	1000

*National Committee on Radiation Protection and Measurements
Report No. 29, August 1962.³⁴

**The figures apply to doses accumulated from immediate exposures
of a few seconds to brief ones of up to four days.

[†]If the exposure is protracted, longer than four days, this
figure may be taken as 250 r.

Note: The equivalent residual dose (ERD) is uncertain in man and
if recovery occurs at all, it is clear that the process is prolonged
and for planning purposes, it is best to ignore the recovery process
for doses in excess of 250 r.

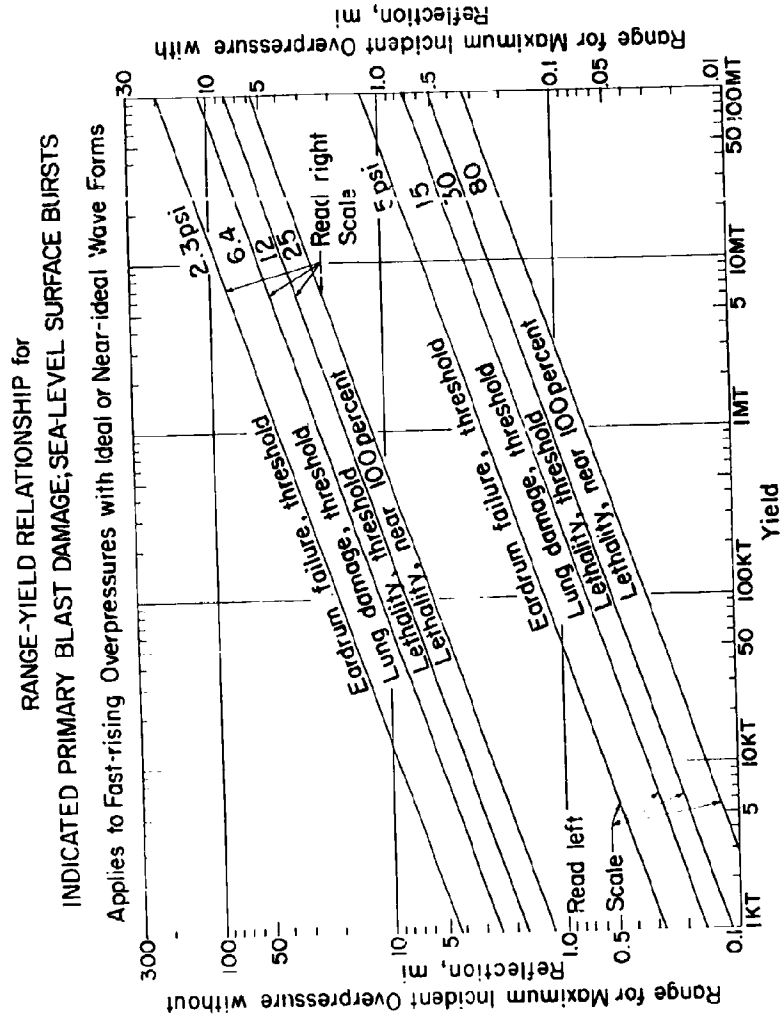


Figure 4

RANGE-YIELD RELATIONSHIP for INDICATED SECONDARY BLAST DAMAGE from 10-gm WINDOW-GLASS FRAGMENTS* for SEA-LEVEL SURFACE BURSTS

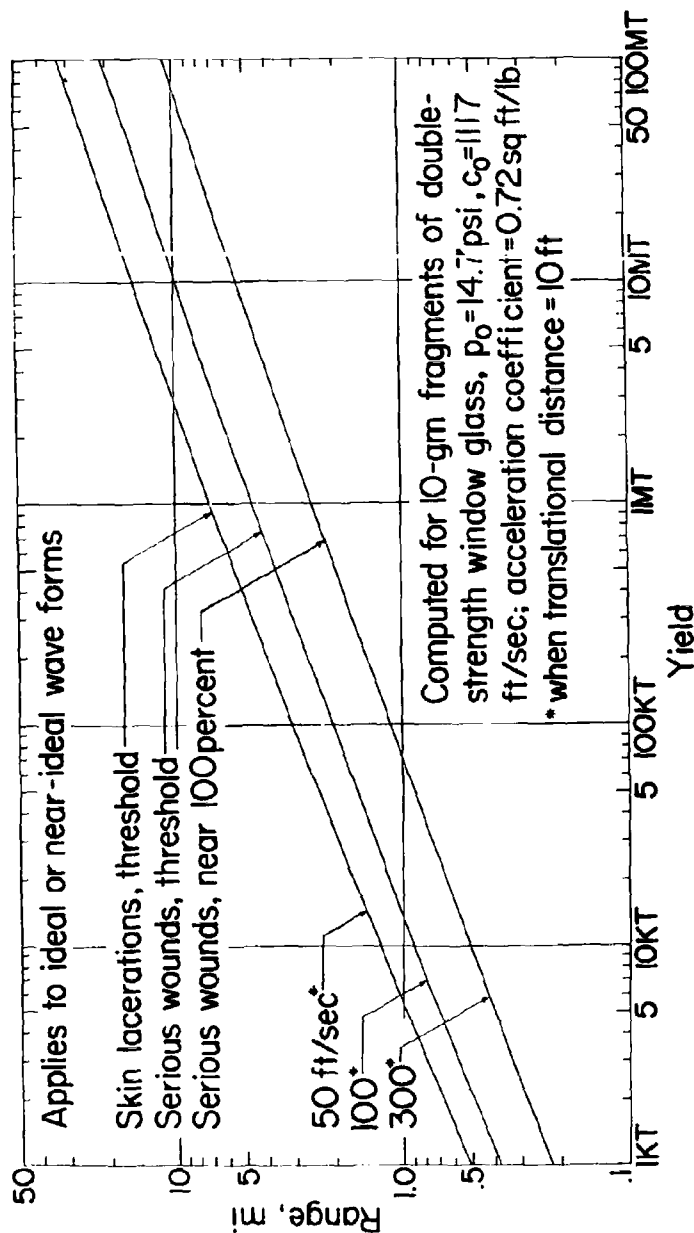


Figure 5

RANGE-YIELD RELATIONSHIP for INDICATED TERTIARY BLAST DAMAGE to 165-lb AVERAGE MAN* for SEA-LEVEL SURFACE BURSTS

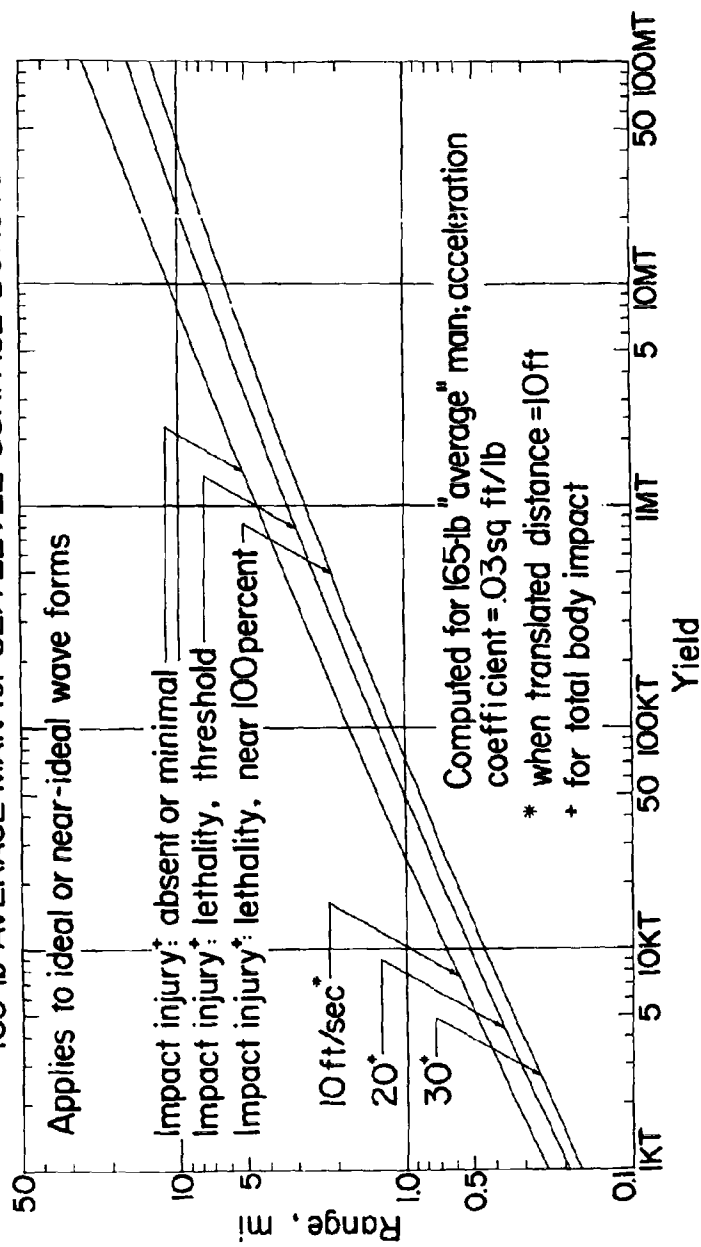


Figure 6

100 Mt.³ Figure 7, also for sea-level surface bursts, but for yields from one up to only 20 Mt, is included to illustrate how the major effects comparatively change as functions of range and yield.

2. Thermal Radiation

In relating the criteria for thermal injury to the scaled thermal effects data, information in The Effects of Nuclear Weapons³² for 10-mi visibility was chosen to prepare Figure 8.⁷ Values appearing for yields above 10 (for burns) and 20 Mt (for thermal energy) were arbitrary extrapolations.

Disturbing uncertainties that need attention in the future concern (a) the cal/cm² required to produce skin burns and ignition of various types of clothing as these vary with the shape of the thermal pulse, (b) the most realistic estimates of the configuration of the thermal-time pulse, particularly for large yield explosions and of the variations due to burst height (air density change) and (c) the basic characteristics of the atmosphere which innately involve large variations in transmissivity due to changes in weather and alterations associated with air pollution due to industry and other sources commonly associated with urban areas. Among other things these matters mean that biological criteria for surface bursts should be applied with great caution to situations involving air bursts.

3. Initial Nuclear Radiation

Free-field values for initial nuclear radiations were scaled from The Effects of Nuclear Weapons³² for surface bursts at sea level using an air density ratio of $\rho/\rho_0 = 1$ for neutrons and $\rho/\rho_0 = 0.9$ for gamma rays up to and including yields of 20 Mt. Above this yield, values were obtained by the same procedure except that the slope of the curve giving the increase in the scaling factor of W'/W with yield was "fixed" at 20 Mt and extrapolated as a straight line to compute figures for the higher yields. In addition, to calculate air-dose (free-field) figures for the surface burst, the air-burst values for gamma radiation were reduced by $1/3$.³²

Figure 9 was prepared by combining the biological criteria for initial radiations noted in Table 7 with the calculations discussed above to set forth the range-yield-effect relationships for estimating the maximal ranges of the different potential hazards from ionizing radiations.

Of major concern, especially in the case of high explosive yields, is the fact that initial nuclear radiations, by definition, include prompt neutron and gamma rays, and all other early and delayed radiations that occur during the first minute after detonation.³² Three points concerning the latter deserve speculation. First, the radiation induced in the air³⁹ and soil should not be ignored. Second, since much of the delayed component of the immediate nuclear radiation is due to gamma rays from fission products in the fireball and the rising cloud, the relevant numerical values for dose are sensitive both to the fission-fusion ratio and to cloud height; thus, figures may vary widely on the one hand and on the other may or may not fall to insignificant values within one minute. Third, it is necessary to understand the

COMPARATIVE-EFFECTS DATA SHOWING RANGES INSIDE WHICH INDICATED BIOLOGICAL RESPONSES MAY OCCUR for SEA-LEVEL SURFACE BURSTS

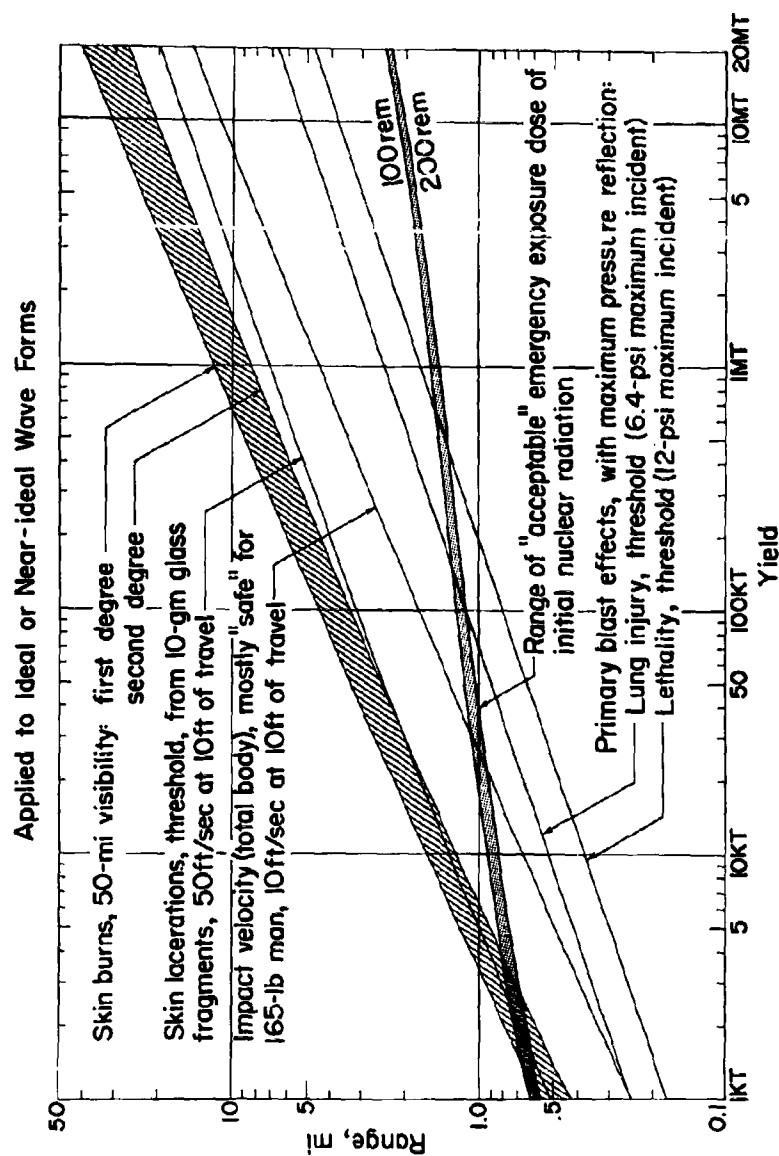


Figure 7

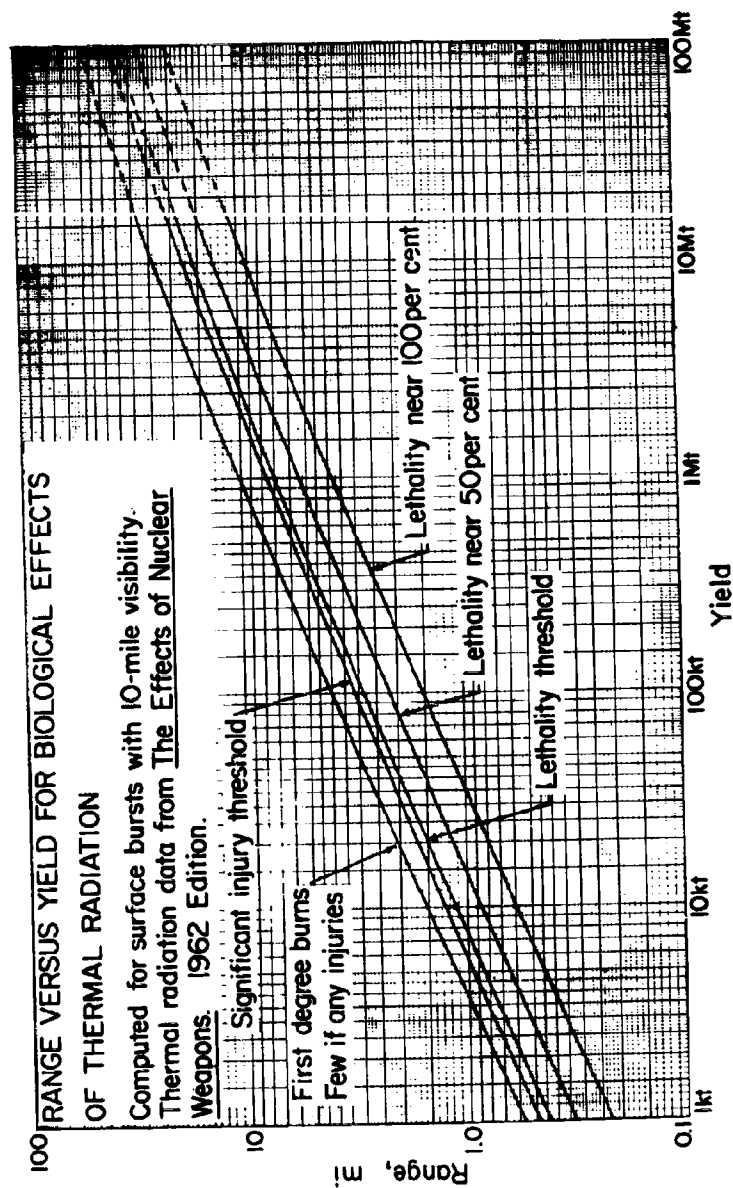


Figure 8

RANGE VERSUS YIELD FOR BIOLOGICAL EFFECTS OF INITIAL NUCLEAR RADIATION

Computed for surface bursts, $\rho/\rho_0 = 1.0$ for neutrons, $\rho/\rho_0 = 0.9$ for gamma rays. Nuclear radiation data from The Effects of Nuclear Weapons, 1962 Edition.

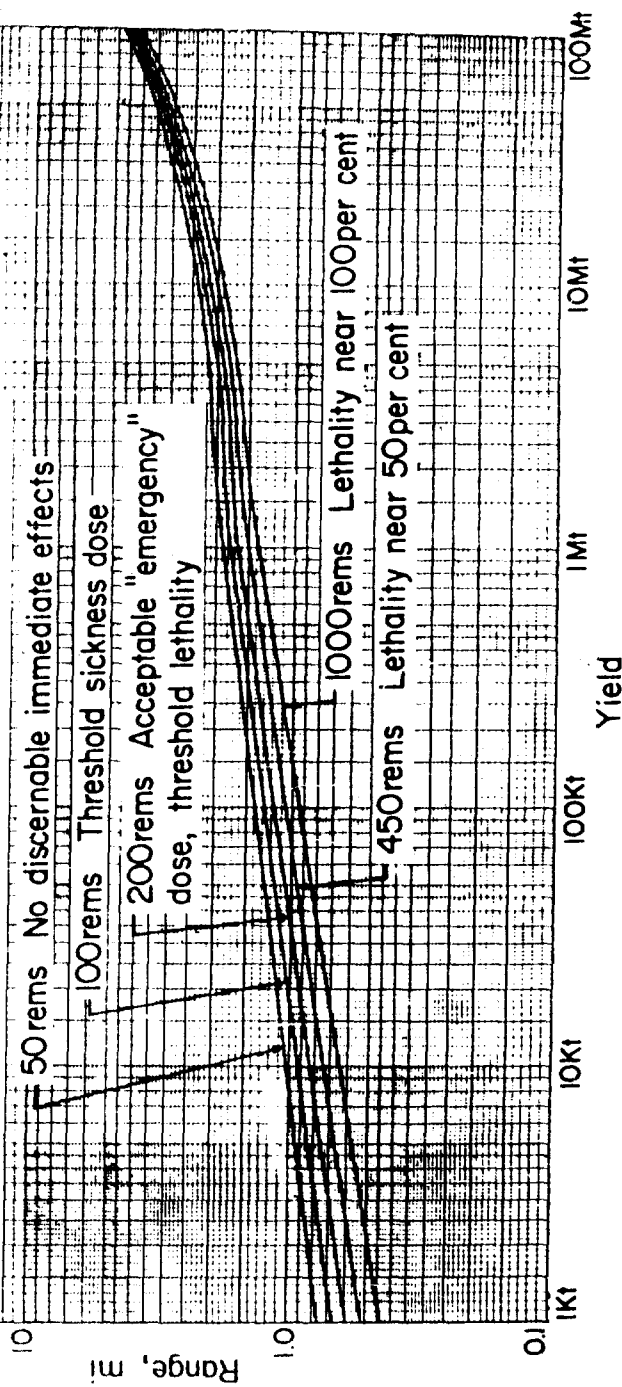


Figure 9

interplay of the factors just mentioned with the rate of travel, the magnitude and the time history of the pressure variations associated with the blast wave.

B. The Range-Yield-Effect Relationships (Specific)

1. Hiroshima and Nagasaki

Figures 10-13, taken from a recent study,⁴ exemplify the applications of the biological criteria for various blast effects, to the Hiroshima and Nagasaki explosions. Free-field, ³² "geometric" and "secondary-event" scaling ³⁷⁻³⁸ were employed assuming that 20 kt was a representative yield for each city ³² and that the burst heights were 606 and 480 meters for Hiroshima and Nagasaki, respectively. ³⁹

Range-effects charts for Hiroshima and Nagasaki containing scaled information for all the major physical parameters are shown in Figures 14 and 15.⁴ Though such diagrams are somewhat involved, they are most useful, for with knowledge of biological criteria referable to blast, thermal and initial nuclear radiations, one may note all the potential hazards which challenge man either at ground zero or any other range of interest. Even so, it is necessary to point out that a reasonable amount of caution needs be used in interpreting such data in terms of any "real" situation.

For example, consider Figure 16, germane to the Hiroshima explosion, showing survival curves for individuals exposed in the open, in school houses, in concrete buildings (20-day figures) and for the overall average for the city.^{4, 33, 40} The data, among several things discussed in other studies,^{1, 4} show that the conditions (geometry) of exposure are major factors determining survival; they therefore deserve critical consideration by those who would assess the biological effects of nuclear war.

2. High Yield Explosions

Using the scaling procedures described above, range-effects charts were prepared for yields of 1, 10, 20 and 100 Mt for two burst conditions; namely (a) surface bursts at sea level and (b) air bursts with the burst height chosen to maximize the ground range of each overpressure shown down to 1 psi. Figures 17-24 show the comparative data.

Using the biological criteria and the information in Figure 21 for the 20 Mt surface burst, Table 8 was assembled to show the range order, starting at ground zero, for each of the several levels of the different biological effects. The table allows one to appreciate the comparative relationships between the major effects and gives the ranges inside which the potential exists for producing each of the hazards specified.

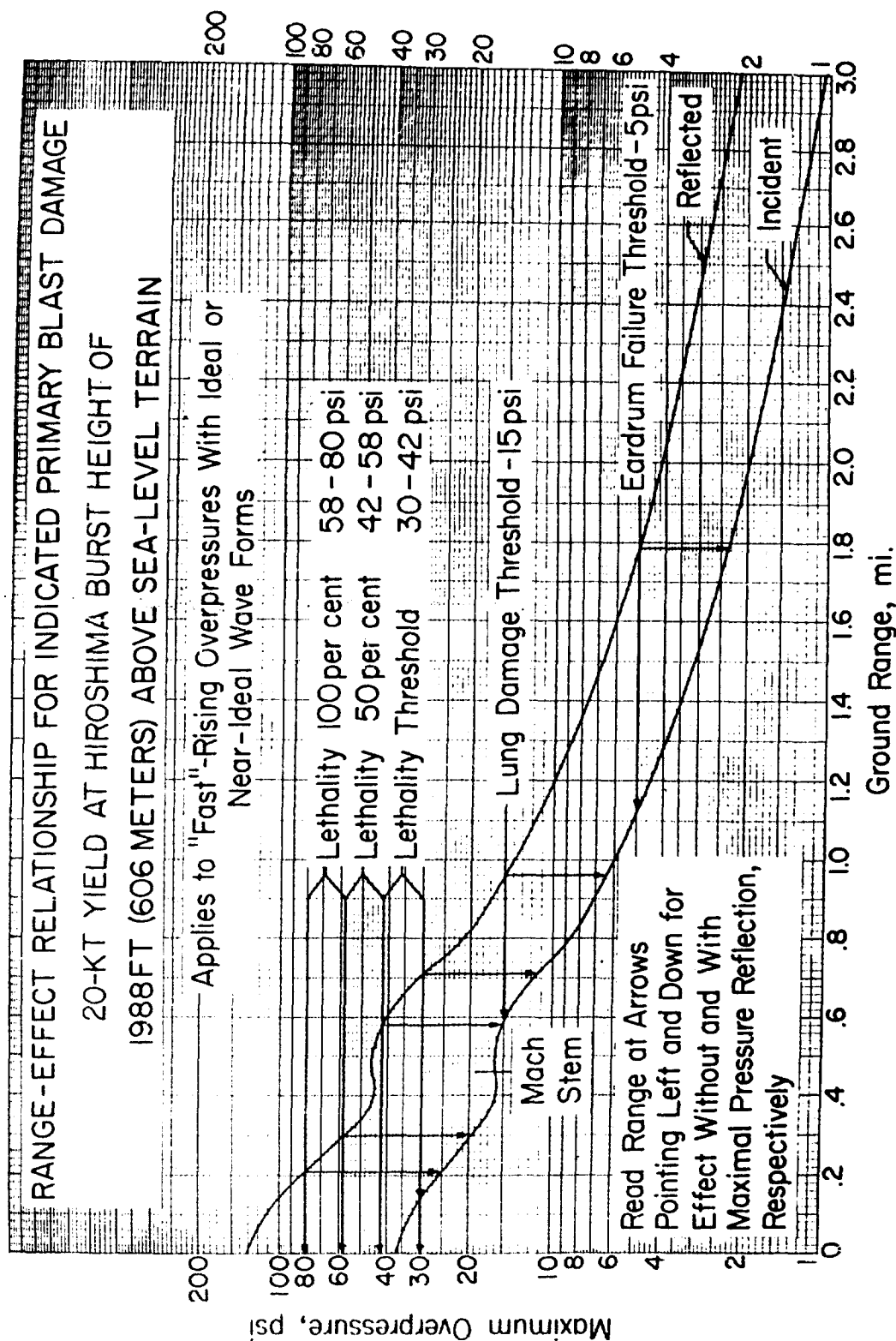


Figure 10

THE VELOCITY-RANGE RELATIONSHIP FOR TRANSLATIONAL EFFECTS 20-KT YIELD AT HIROSHIMA BURST HEIGHT OF 1988 FT (606 METERS)

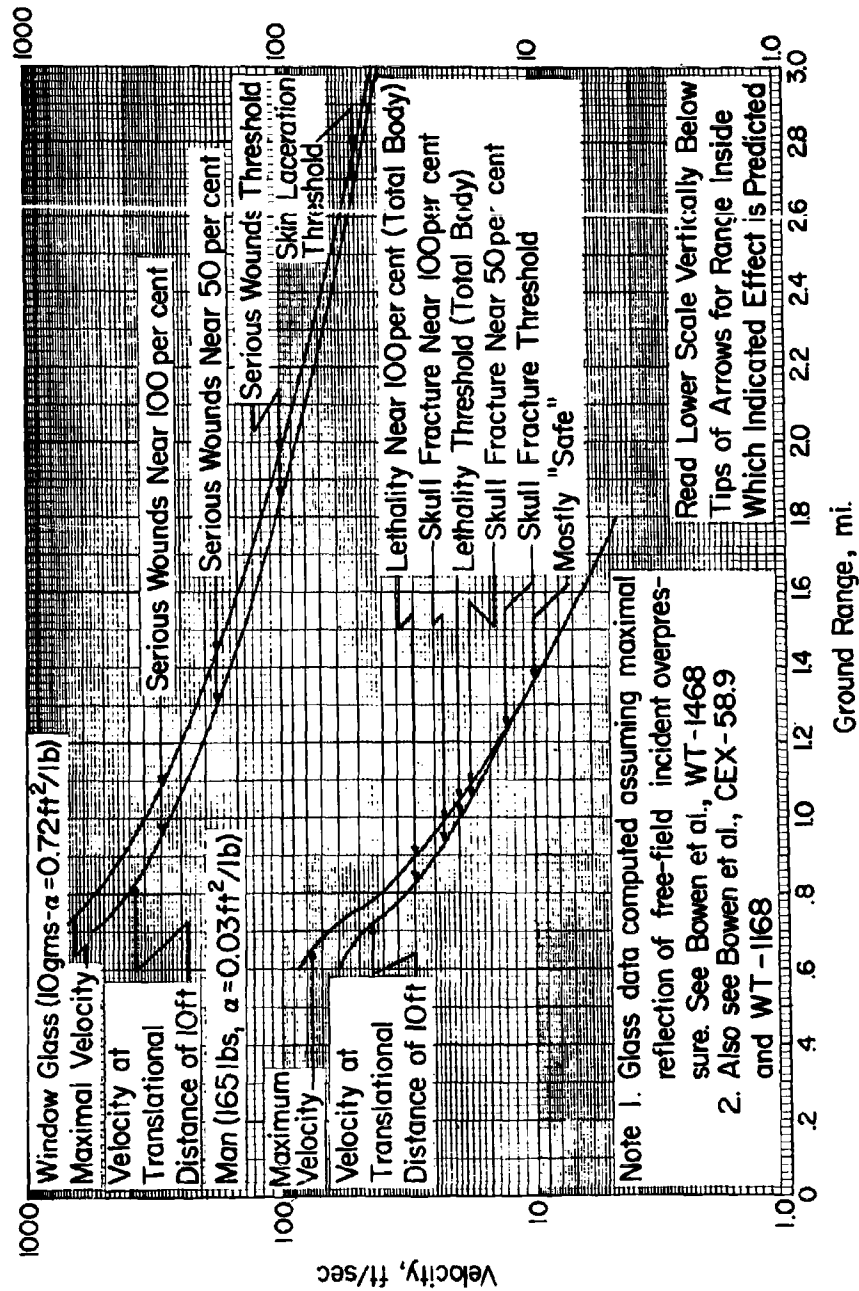


Figure 11

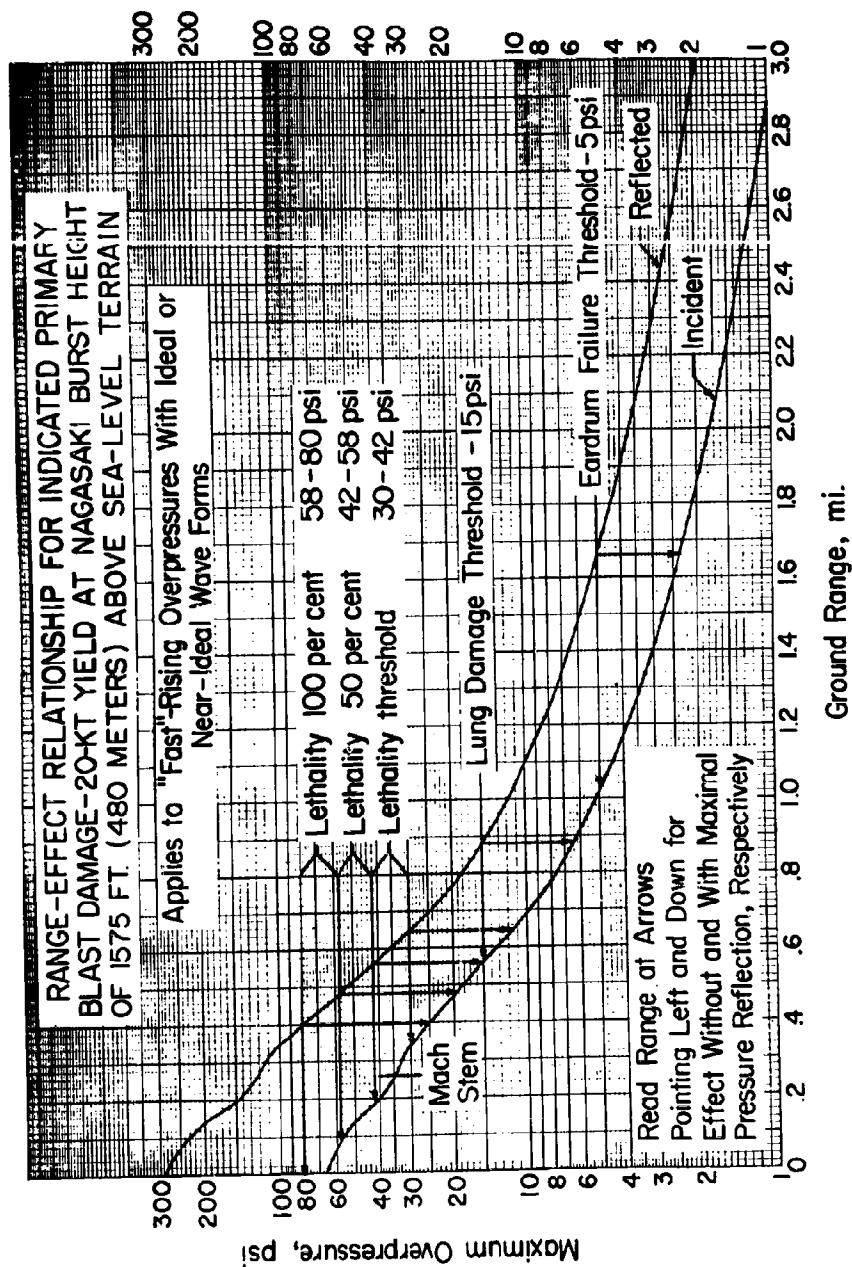


Figure 12

THE VELOCITY-RANGE RELATIONSHIP FOR TRANSLATIONAL EFFECTS 20-KT YIELD AT NAGASAKI BURST HEIGHT OF 1575FT (480 METERS)

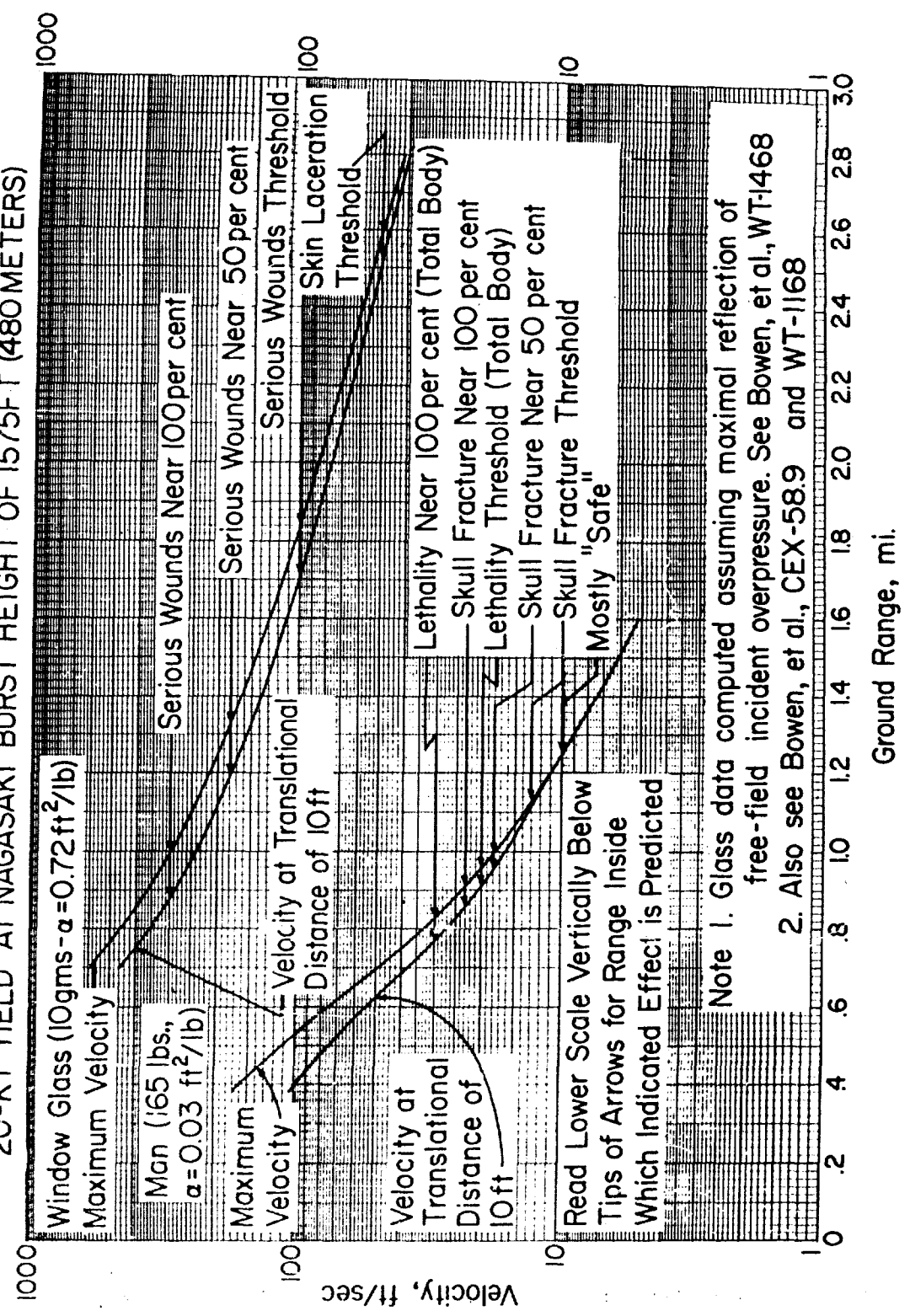


Figure 13

COMPARATIVE RANGE-EFFECTS RELATIONSHIPS FOR HIROSHIMA -
20-KT BURST AT 1988ft (606m) ABOVE SEA-LEVEL TERRAIN

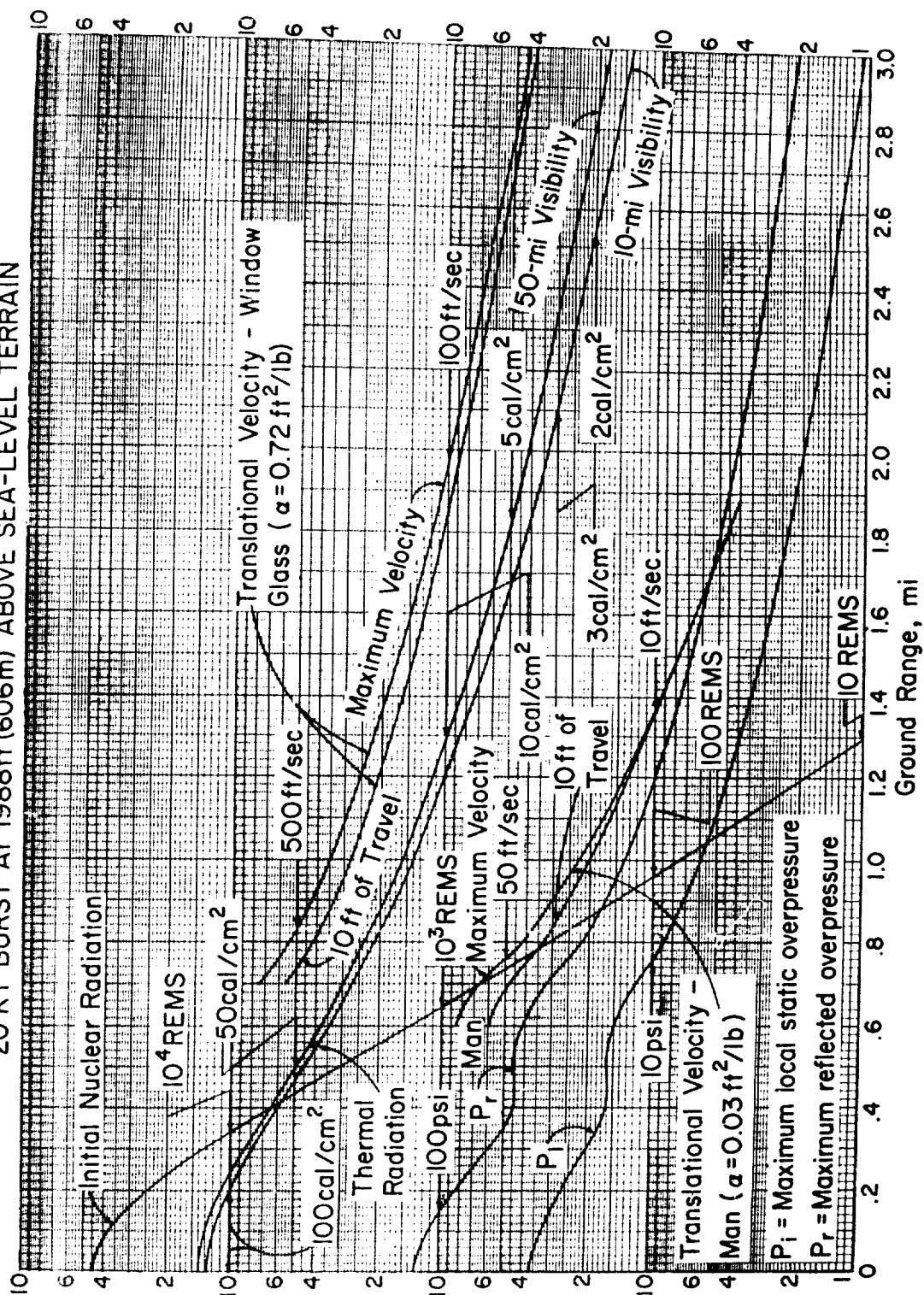


Figure 14

20k1 BURST AT 15/50N (480m) ABOVE SEA-LEVEL TERRAIN

Graph showing the relationship between Ground Range (mi) and various physical quantities for a 20k1 BURST AT 15/50N (480m) ABOVE SEA-LEVEL TERRAIN.

The X-axis represents Ground Range (mi) from 0 to 3.0.

The Y-axis represents various physical quantities on a logarithmic scale from 1 to 100,000.

Curves plotted include:

- Initial Nuclear Radiation
- Thermal Radiation
- Translational Velocity - Window Glass, $a = 0.72 \text{ ft}^2/\text{lb}$
- Maximum Velocity
- 100cal/cm²
- 100psi
- 1000psi
- 100REMS
- 1000REMS
- 10000REMS
- 10ft/sec
- 100ft/sec
- 1000ft/sec
- 40ft/sec
- 50-mile visibility
- 10-mile visibility
- Translational Velocity - Man, $a = 0.03 \text{ ft}^2/\text{lb}$
- P_1 = Maximum local static overpressure
- P_r = Maximum reflected overpressure

Figure 15

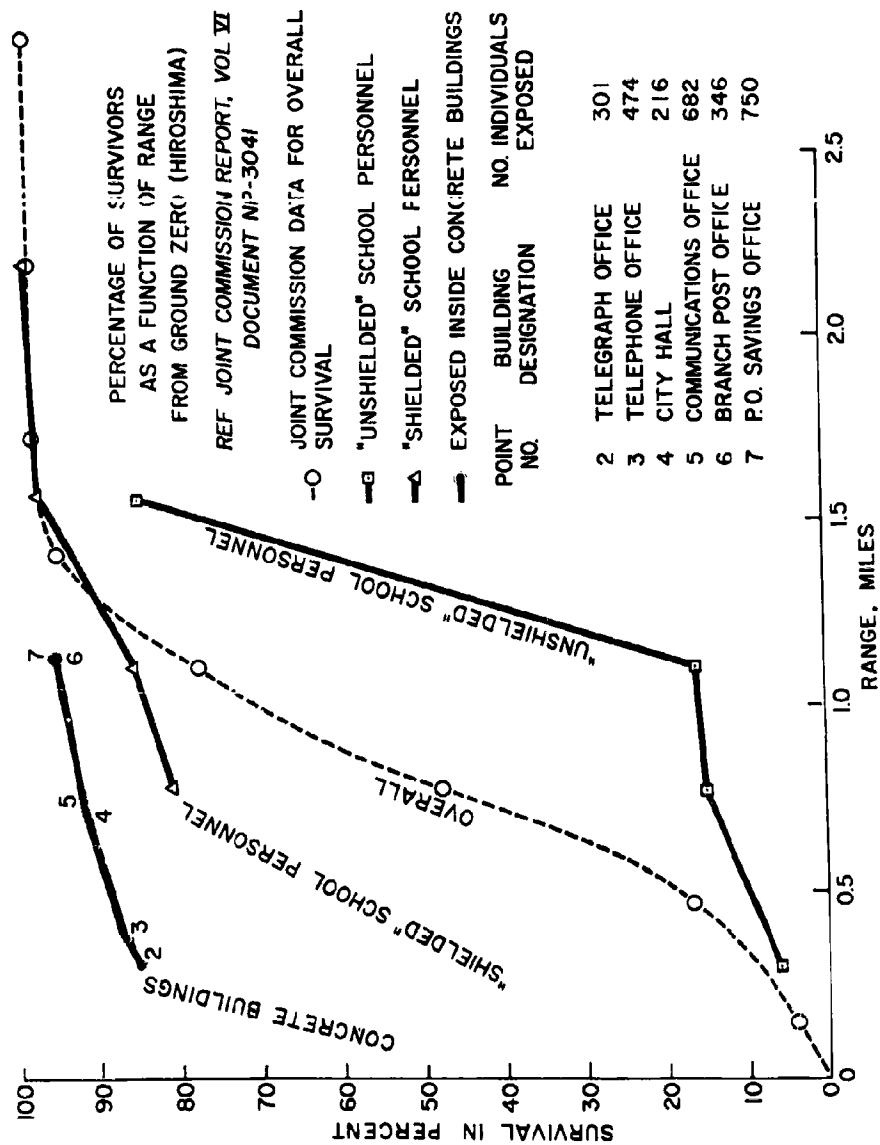


Figure 16

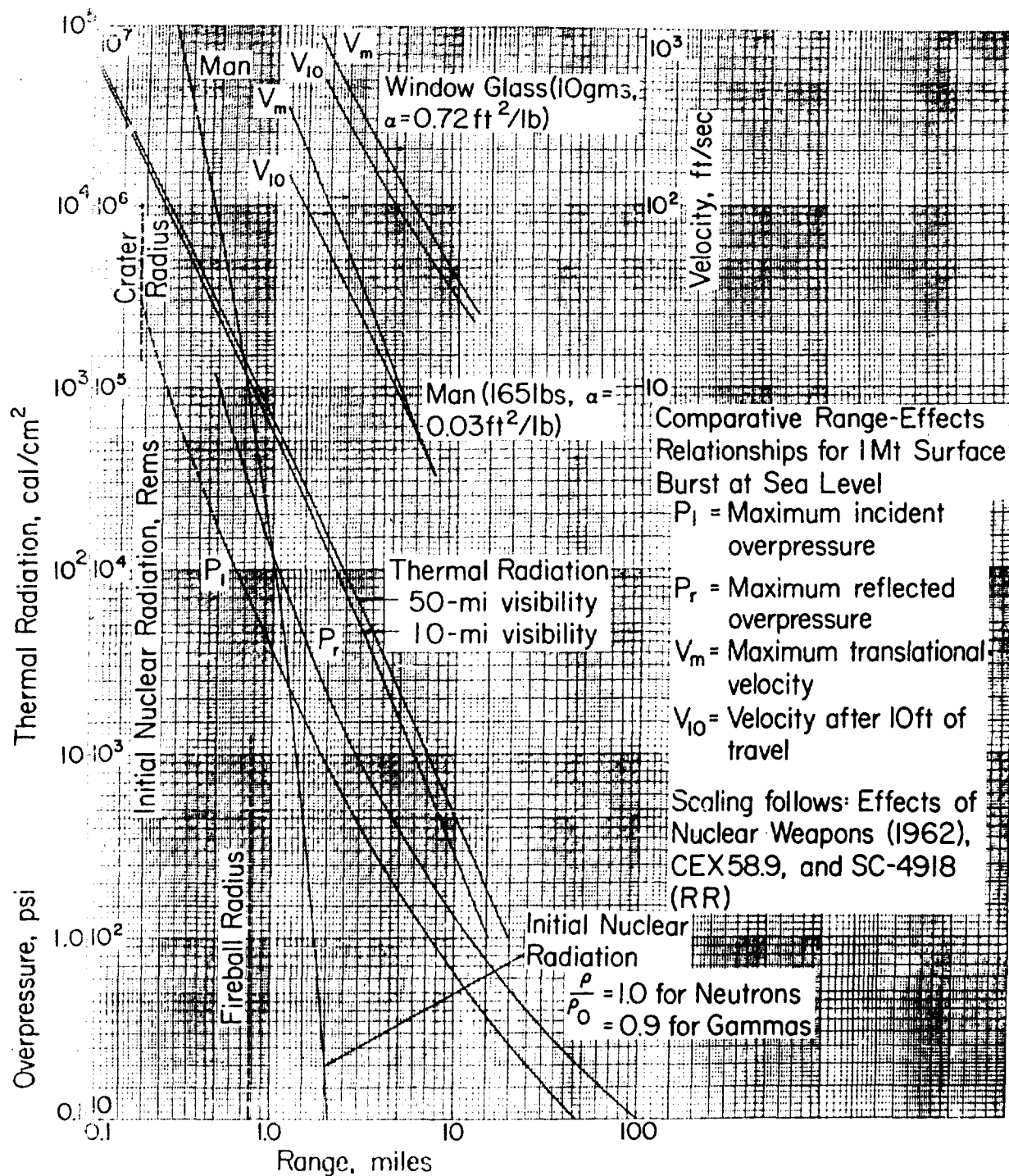


Figure 17

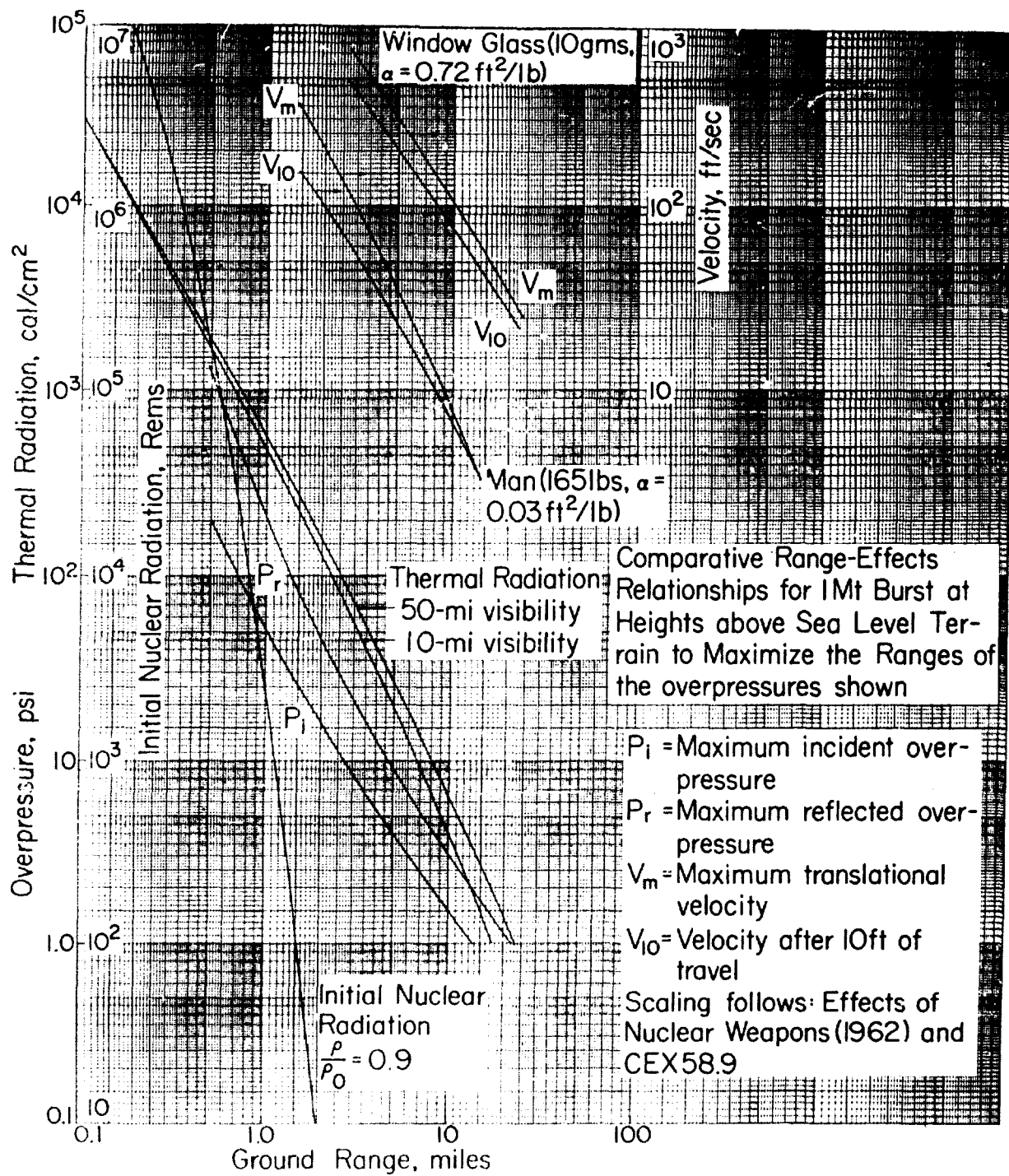


Figure 18

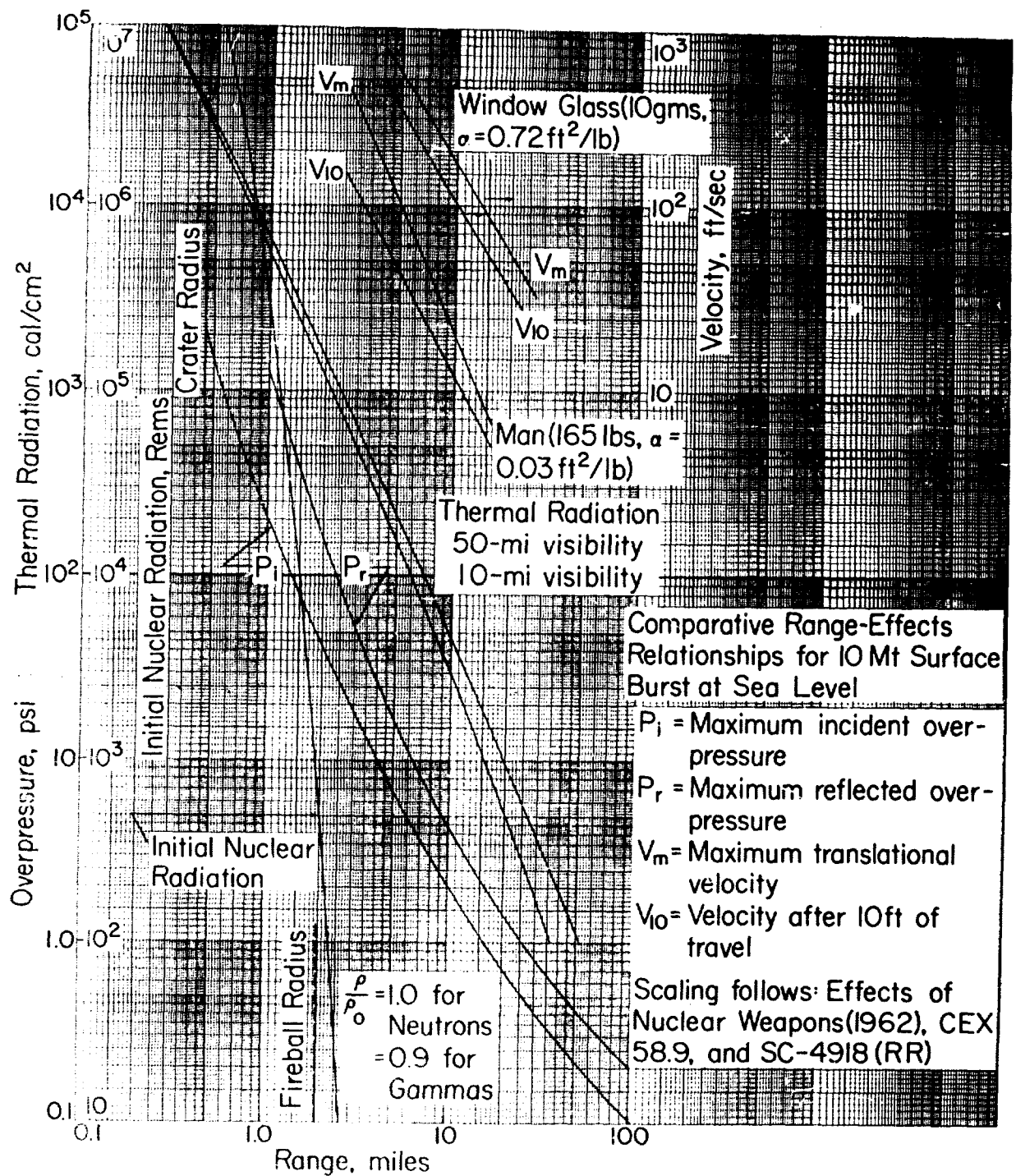


Figure 19

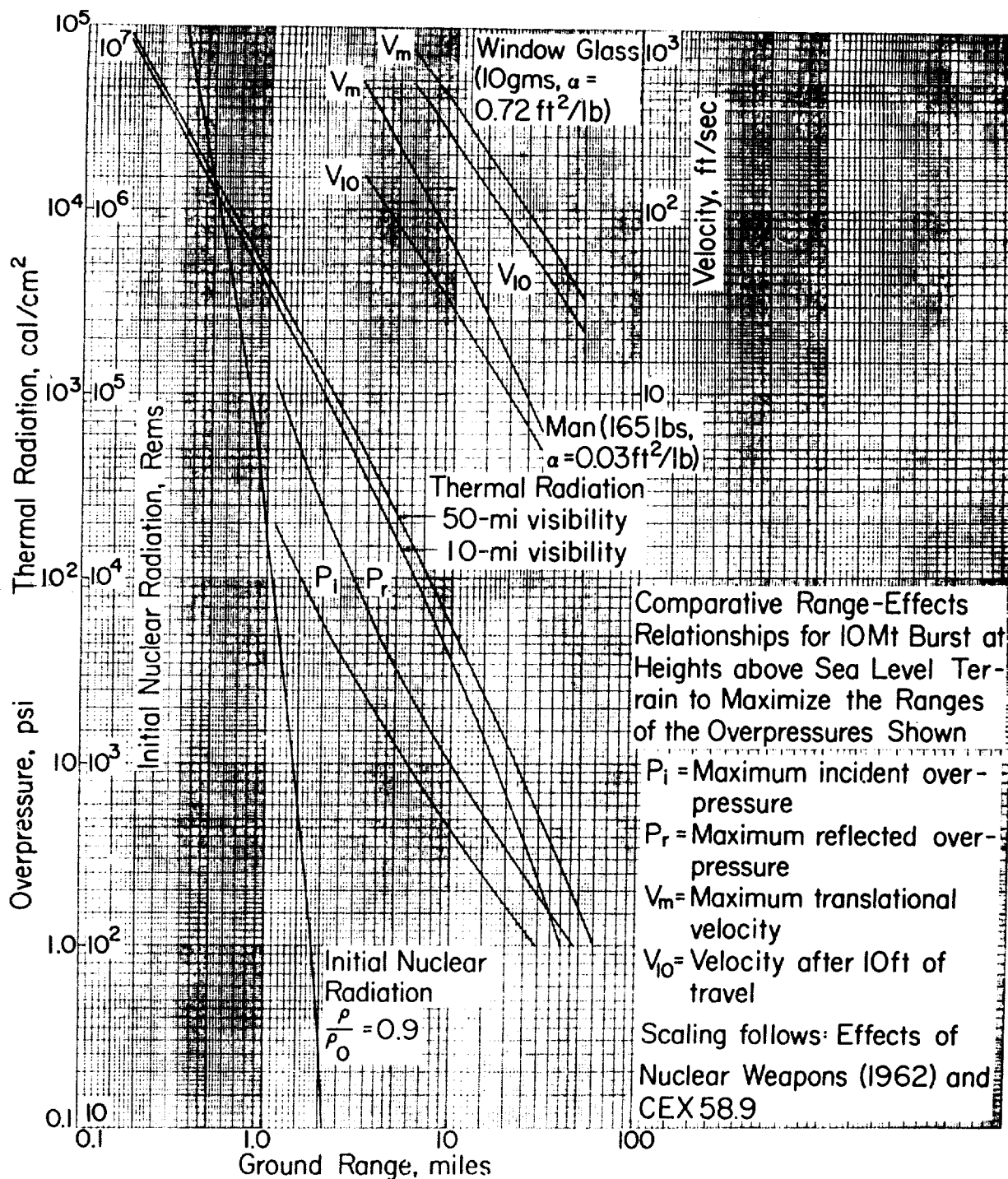


Figure 20

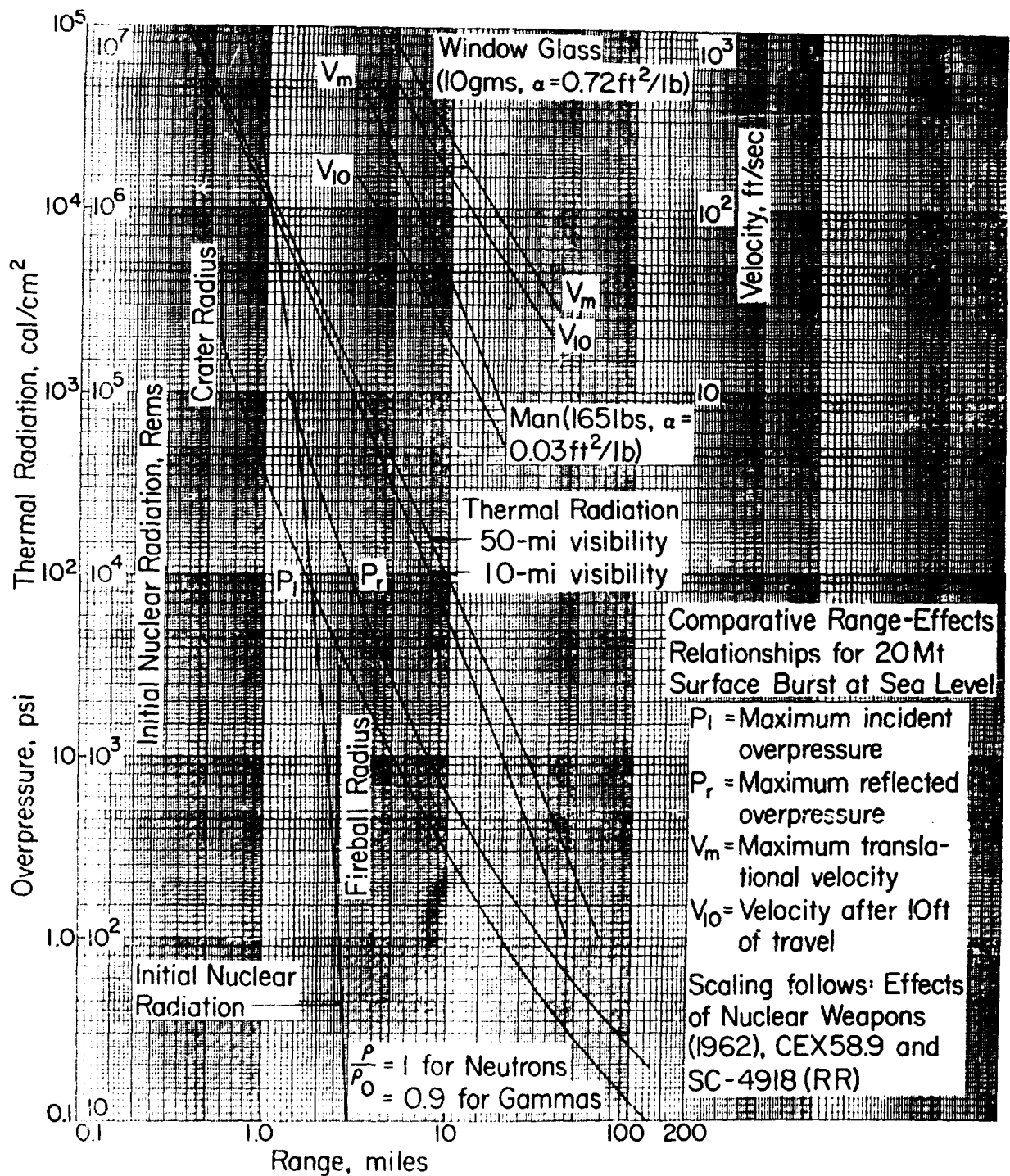


Figure 21

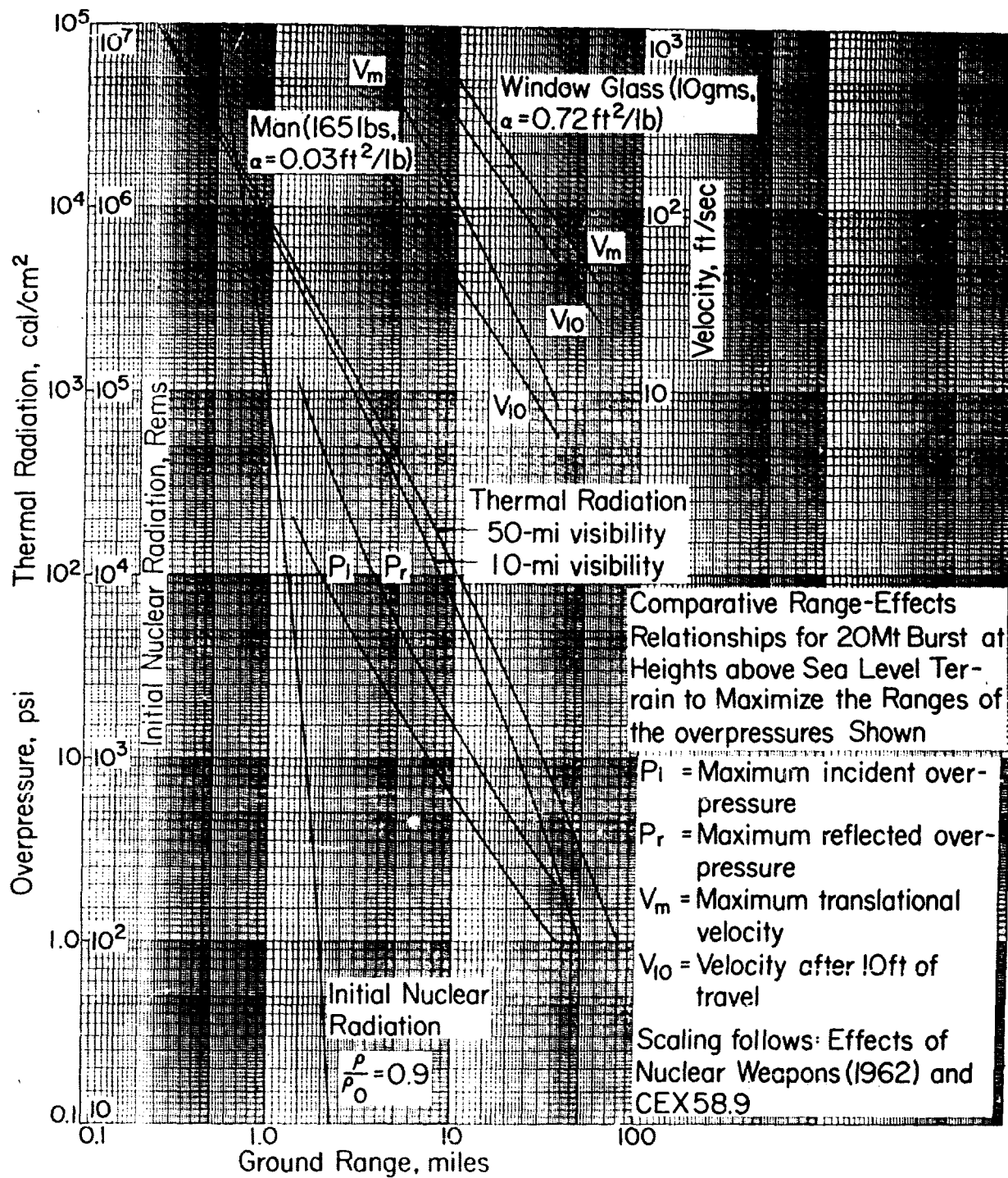


Figure 22

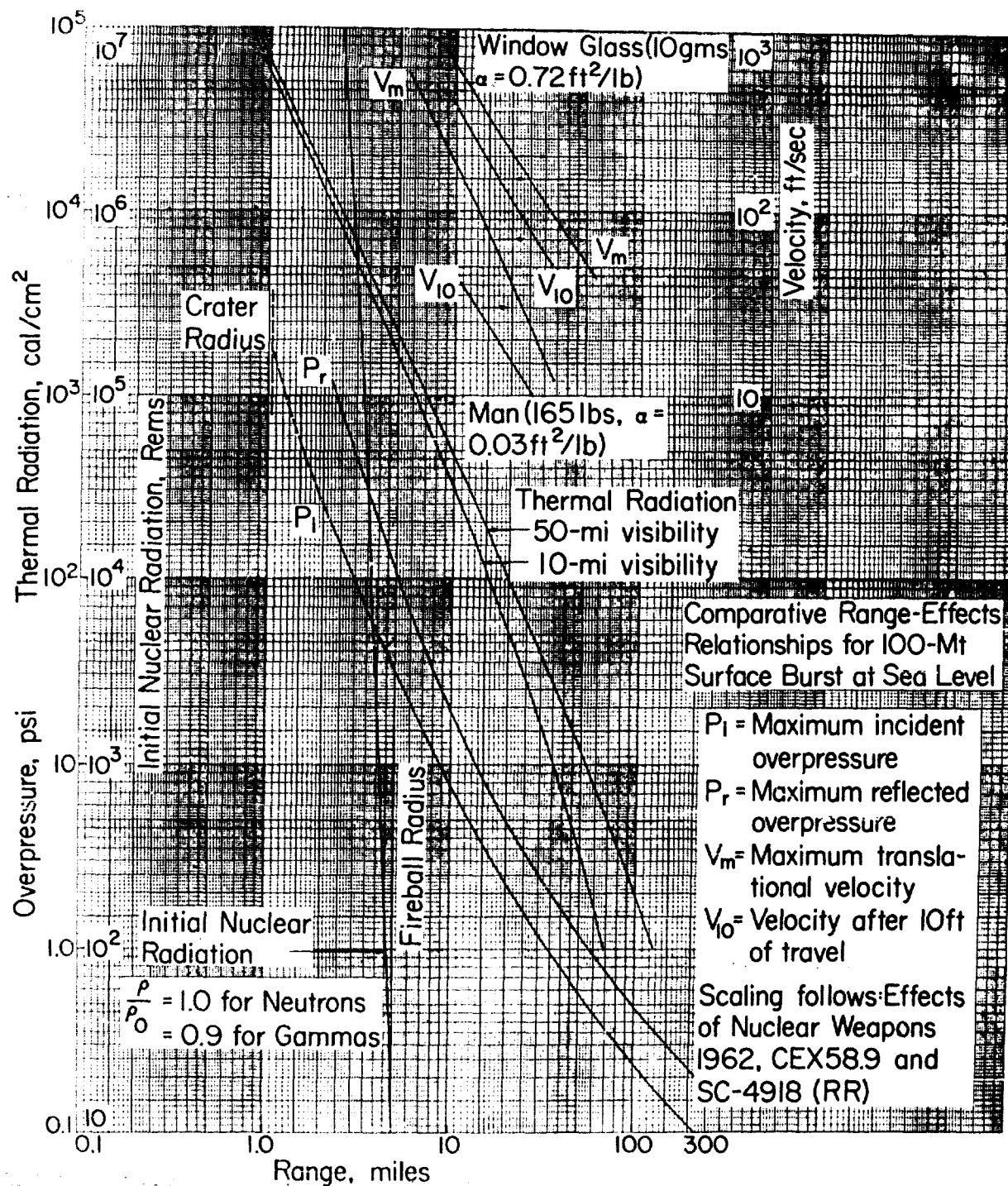


Figure 23

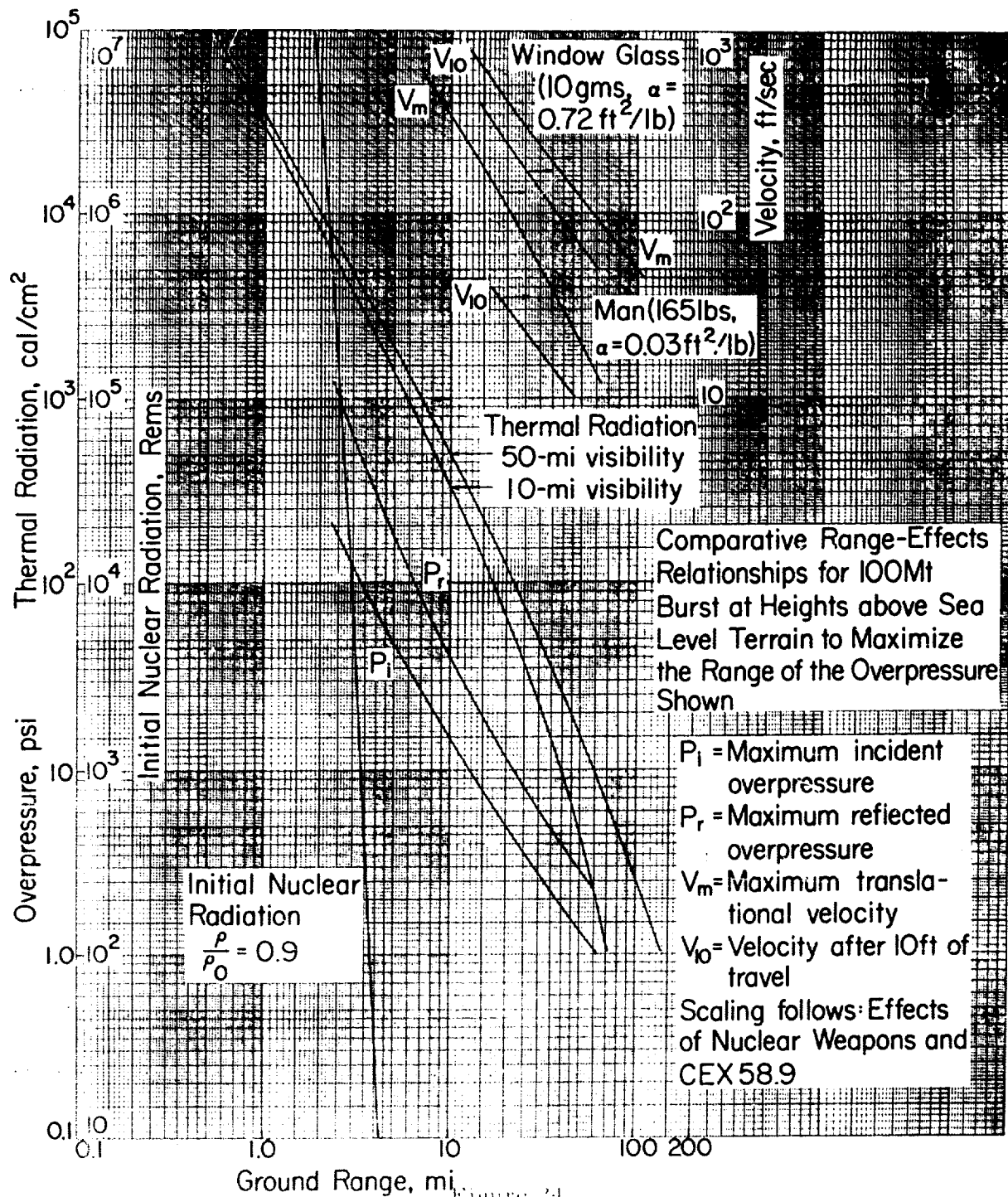


Figure 24

TABLE 8
COMPARATIVE BIOLOGICAL EFFECTS AS A FUNCTION OF RANGE
FOR 20-MT SURFACE BURST AT SEA LEVEL

Biological event or effect	Range mi	Maximum incident overpressure psi	Initial nuclear radiation* rems	Thermal radiation	
				50-mile visibility cal/cm ²	10-mile visibility cal/cm ²
Crater: inside radius, dry soil	.33	> 200	> 10 ⁷	> 10 ⁵	> 10 ⁵
Crater: outside radius dry soil	.65	> 200	> 10 ⁷	32,000	29,000
Nuclear radiation: lethality					
Near 100 per cent	2.2	59	1000	2400	2000
Near 50 per cent	2.4	49	450	2000	1600
Threshold	2.5	44	200	1800	1500
Nuclear radiation: acceptable "emergency" dose	2.5	44	200	1800	1500
Initial nuclear radiation: injury, threshold	2.6	41	100	1700	1400
Fireball radius, maximum	2.6	41	100	1700	1400
Nuclear radiation:					
No discernable effect	2.7	38	50	1600	1300
Primary blast: lethality, threshold — without pressure reflection	3.0	30	11.0	1200	1000
Lung damage, threshold — without pressure reflection	4.2	15	< 1	600	470
Primary blast: lethality, threshold — maximum pressure reflection	4.7	12	< 1	480	360
Lung damage, threshold — maximum pressure reflection	6.6	6.4	< 1	230	160
Eardrum failure, threshold — without pressure reflection	7.5	5.0	< 1	170	120

*Computed for an air-density ratio, $\rho/\rho_0 = 1.0$ for neutrons; $\rho/\rho_0 = 0.9$ for gamma rays.

TABLE 8 (Continued)

Biological event or effect	Range mi	Maximum incident overpressure psi	Initial nuclear radiation* rems	Thermal radiation	
				50-mile visibility cal/cm ²	10-mile visibility cal/cm ²
Impact injury: lethality, threshold†	9.6	3.3	< 1	100	68
Eardrum failure, thresh- old - maximum pres- sure reflection	12	2.3	< 1	62	39
Impact injury: skull frac- ture, threshold†	12	2.3	< 1	62	39
Serious wounds from 10-gm glass fragments, threshold†	12	2.3	< 1	62	39
Thermal radiation: lethality					
Near 100 per cent	12	2.3	< 1	---	42
Impact injury, threshold†	14	1.8	< 1	44	26
Thermal radiation: lethality					
Near 50 per cent	16	1.4	< 1	---	20
Threshold	20	1.0	< 1	---	11
Thermal radiation					
Skin lacerations from 10-gm glass fragments, threshold†	20	1.0	< 1	20	10
Skin burns - second degree, 10-mi visibility	20	1.0	< 1		10
Thermal radiation, threshold					
Significant injury	22	0.88	< 1	---	9.5
Skin burns - second degree, 50-mi visibility	27	0.66	< 1	10	
Skin burns - first degree, 10-mi visibility	28	0.62	< 1		4
Skin burns - first degree, 50-mi visibility	39	0.40	< 1	4	
Window glass fails	130	0.1	< 1	< 1	< 1

*Computed for an air-density ratio, $\rho/\rho_0 = 1.0$ for neutrons; $\rho/\rho_0 = 0.9$ for gamma rays.

†After 10 ft of travel.

Figure 25, illustrating the computed velocity-displacement-overpressure relationship for a 20-Mt burst at sea level,³ is included to emphasize the great magnitude of the translational velocities and distances of travel required to reach maximal velocities that can result from exposure to large yield explosions. Few appreciate that velocities up to near 500 ft/sec may be involved and displacement distances (if there is no obstruction) of 100 to 1000 ft may occur at overpressures ranging from 1.5 to 25 psi.

Also, to emphasize the importance of the translational problem as well as the significance of burst height, Table 9 was prepared for a 20-Mt yield to show the differences in the ranges predicted for tertiary blast effects when the explosion occurs at sea level and at a height chosen to maximize the range of the hazard specified.

V. DISCUSSION

Of course, any attempt to integrate appropriate biological and physical parameters to help assess the biomedical effects of nuclear weapons will have an overall reliability that depends critically upon the validity of the biological criteria, the scaling procedures, and the numerical data employed. Because experience with large-yield explosions is meager indeed, all the predictions concerning multimegaton detonations needs be regarded with considerable skepticism. This is particularly the case for effects associated with thermal and initial nuclear radiation. Understanding of blast phenomenology appears to be more advanced except perhaps where cratering and ground shock is involved.

Even though there no doubt will be future advances in "the state of the art" and all biological and physical factors will become better defined and more thoroughly investigated, the analytical approach described in previous sections of this report seems significant for several reasons. Among them are the following. First, there is the fact that a conceptual fabric is now at hand to guide thinking and planning empirical and theoretical work.

Second, it is possible, on a relative basis at least, to specify the ranges and areas placed at risk by the several major environmental variations produced by nuclear explosions of stated yield.

Third, given a yield and specific targets - cities or otherwise - it is also feasible to state the number of individuals placed at risk if appropriate population density figures are properly employed.

Fourth, using the areas and number of people at risk, a reasonably sound base is at hand for attempting to assess various approaches to total defense (military and civil) including various levels of protective procedures and construction.

Fifth, the approach taken in applying or relating biological criteria to nuclear effects parameters using the scaling exercises employed makes it clear that it is very difficult, if not impossible, to make reliable estimates of casualties that might occur from nuclear detonations over unprepared populated areas.

VELOCITY vs. DISPLACEMENT for 165-lb MAN-20-MT SEA-LEVEL SURFACE BURST
 COMPUTED for ACCELERATION COEFFICIENT = .03 sq ft/lb; $P_0 = 14.7$ psi; $c_0 = 1117$ ft/sec

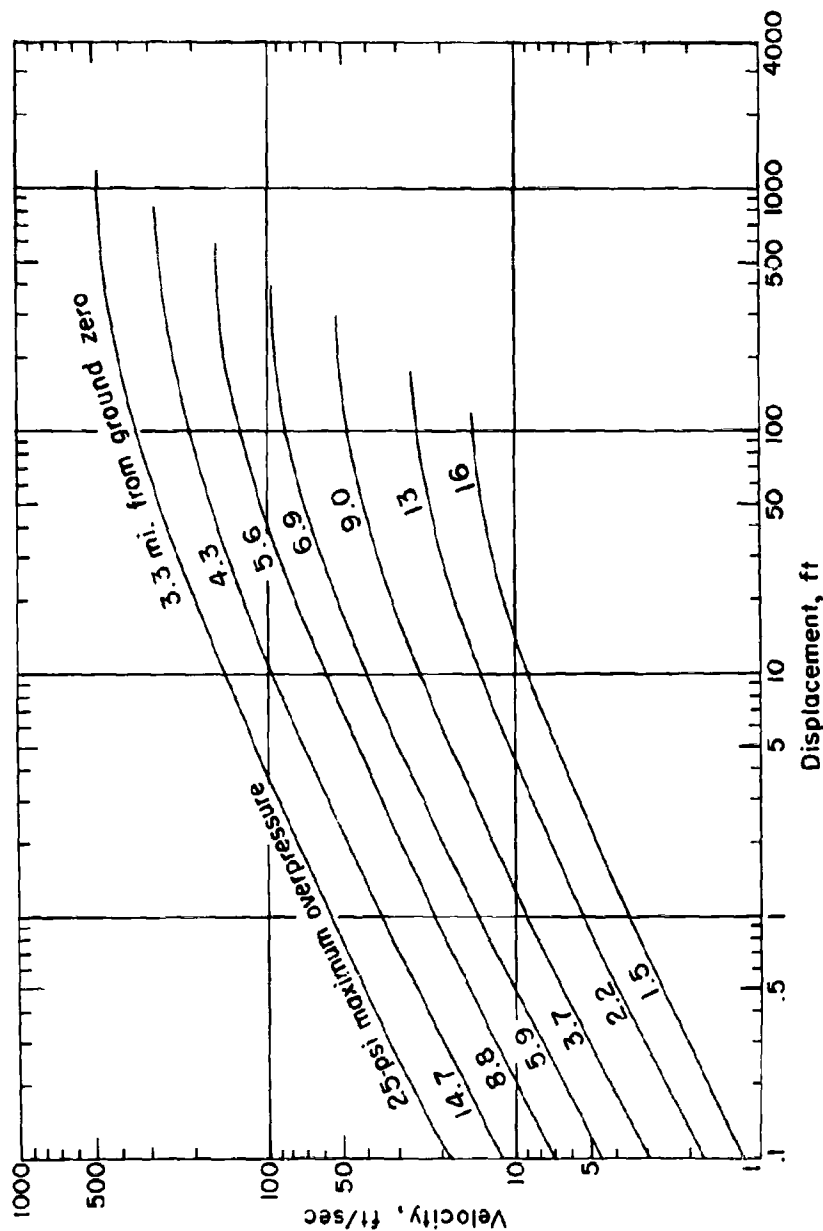


Figure 25

TABLE 9

RANGES INSIDE WHICH THE TERTIARY BLAST HAZARDS NOTED
ARE PREDICTED FREE FIELD FOR A 20-MT BURST AT SEA LEVEL
AND AT BURST HEIGHTS MAXIMIZING THE RANGE OF THE EFFECT SHOWN*

	Maximizing burst heights	Surface burst sea level
Impact injury mostly "safe"	25 mi	14 mi
Skull fracture threshold	21 mi	12 mi
Skull fracture near 50 per cent	17 mi	10 mi
Impact lethality threshold (whole body)	16 mi	9.6 mi
Skull fracture near 100 per cent	15 mi	9.0 mi
Impact lethality near 50 per cent (whole body)	14 mi	8.4 mi
Impact lethality near 100 per cent (whole body)	12 mi	7.8 mi

*Data taken from DASA 1341³ and from Figures 21 and 22 combined
with the translational criteria for tertiary blast hazards.

Finally, those interested in specific conditions of exposure - houses, shelters, vehicles, field fortifications, gun emplacements, etc. - can now assess the adequacy as well as the shortcomings of the biological criteria that have been defined. If they are judged deficient, definitive measurements of the environmental parameters of interest can be taken to guide the future work of biomedical personnel in assessing human hazards from all explosive sources be they conventional or nuclear or simply the failure of high pressure vessels and the detonation of explosive fuels, cryogenic or otherwise.

VI. SUMMARY

1. The physically and biologically oriented problem areas of concern to those who would assess and refine understanding the biomedical effects of nuclear weapons were defined.
2. Tentative, though incomplete, biological criteria useful in assessing hazards from blast phenomena and from thermal and initial nuclear radiations were set forth.
3. Range-yield-effects relationships were developed by combining the tentative biological criteria with physical-effects parameters obtained using free-field, some "geometric," and translational scaling over a wide range of explosive yields; viz, from 1 kt to 100 Mt. The criteria were also applied specifically to the Hiroshima and Nagasaki explosions.
4. Comparative range-effects diagrams, using appropriate scaling procedures and extrapolations where necessary, were prepared for the following yields and burst conditions: (a) 20 kt detonated at Hiroshima and Nagasaki burst heights and (b) 1, 10, 20 and 100 Mt burst at a sea-level surface and at burst heights above sea-level terrain chosen to maximize the ranges of local static overpressures from 1 to 200 psi.
5. The significance of employing biological criteria along with comparative range-effects data to estimate the ranges inside which and the areas over which the potential exists for producing specified biological hazards from nuclear explosions was emphasized.
6. Also, attention was directed to the apparent soundness of properly combining population density figures with computed hazard areas to estimate the number of persons who might be placed at risk from nuclear explosions of specific yield and under specified burst conditions.
7. In contrast, data were cited to show that the conditions of exposure undoubtedly represent major factors in determining survival, and it was noted that any current attempt to estimate the number of casualties that might occur to an unprepared population from nuclear explosions, particularly those of large yield, was fraught with considerable if not insurmountable uncertainties.
8. The deficiencies of biological and physical data along with information needed to improve and advance knowledge of biological effects of nuclear explosions were briefly noted in appropriate portions of the material presented.

9. Critical assessment of the tentative biological criteria set forth and adequate definition of the environmental variations as they might apply to a variety of exposure conditions by interested civilian and military personnel were suggested as a desirable means of accelerating the periodic and progressive liaison between biological and physical scientists considered essential to maximize progress in environmental medicine as it applies to all sources of explosive phenomena, nuclear or otherwise.

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