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CIVIL EFFECTS STUDY

THE NATURE OF THE PROBLEMS
INVOLVED IN ESTIMATING
THE IMMEDIATE CASUALTIES
FROM NUCLEAR EXPLOSIONS

Clayton S. White

Issuance Date: July 1971

CIVIL EFFECTS TEST OPERATIONS
U.S. ATOMIC ENERGY COMMISSION

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THE NATURE OF THE PROBLEMS INVOLVED IN ESTIMATING THE IMMEDIATE CASUALTIES FROM NUCLEAR EXPLOSIONS

By

Clayton S. White

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Approved for publication by: L. J. DEAL

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Lovelace Foundation for Medical Education and Research
Albuquerque, New Mexico

March 1971

This report is published in the interest of providing information which may prove of value to the reader in his study of effects data derived principally from nuclear weapons tests and from experiments designed to duplicate various characteristics of nuclear weapons.

This document is based on information available at the time of preparation which may have subsequently been expanded and re-evaluated. Also, in the preparation of this report for publication, some classified material may have been removed. Users are cautioned to avoid interpretations and conclusions based on unknown or incomplete data.

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PREFACE

This report, an updated version of a paper assembled from available published nuclear effects data, was initially prepared as a contribution to the Albuquerque Conference on Disaster Medical Care at the invitation of the sponsoring agencies; namely, the American Medical Association Committee on Disaster Medical Care/Council on National Security in cooperation with the New Mexico Medical Society. As a courtesy and with the support of the Civil Effects Branch of the Division of Biology and Medicine of the U. S. Atomic Energy Commission, the entire text, briefly and selectively summarized before attendees on the first day of the conference held at the Sheraton-Western Skies Motor Hotel, Albuquerque, New Mexico, November 15-16, 1968, was reproduced as Lovelace Foundation Document LF-1242-1 and made available on request to those technically interested in nuclear effects. Since no further copies are available, the manuscript was revised as a progress report on AEC Contract AT(29-2)-1013, so that the data therein could be presented on July 1, 1970, before participants and faculty at the 1970 OCD Summer Institute sponsored by the Office of Civil Defense and the American Society for Engineering Education held at the U. S. Air Force Academy, June 29-July 24, 1970, near Colorado Springs, Colorado.

ABSTRACT

It was pointed out that considerable progress has been made in assembling range-yield-effects data for nuclear detonations applicable to a variety of burst conditions and that tentative though incomplete biomedical criteria have been formulated for assessing the hazards of exposure to blast as well as ionizing and thermal radiations. Even so, it was noted that great care must be taken if meaningful concepts are to come from a combined use of the physical and biomedical data.

In emphasis of this fact, the physically and biologically oriented problem areas were presented and discussed. Also, survival data for the Hiroshima explosion were used to show that the conditions of exposure more than any other factors determined immediate survival and more than anything else was responsible for keeping the casualty figures as low as they were.

A major deterrent in applying the experience in Japan to a more generalized situation is the lack of information about the differences between "free-field" parameters and the environmental variations that will actually occur at the locations of people immediately following the burst. The relevant problems are complex and difficult and there has been neither widespread appreciation of the need to "move out of the streets and into exposure locations" nor with one exception much progress in translating "free-field dose" to "exposure dose" at locations of interest. The exception is the Ichiban I Program being carried out cooperatively by personnel from Oak Ridge National Laboratory and the Atomic Bomb Casualty Commission.

A second difficulty in generalizing across the range-yield spectrum of effects is the fact that, all other things being the same, the ratios of the major effects parameters to one another change with yield; viz., the range-yield-effects curves for thermal and ionizing radiation and for blast are not parallel with one another.

Even so, tentative biomedical criteria can be combined with range-effects data for different yields and burst conditions to define the ranges inside which and the areas over which specified potential hazards exist. Also, given a completely flat terrain, the absence of structures and all people exposed in the open, casualty estimates for such "free-field" exposure conditions might perhaps be credible. In the presence of terrain variations and the many types of buildings in cities and urban complexes, there can be no satisfactory predictions until positional, geometric and orientational factors along with others defining the conditions of exposure have been recognized and assessed. The state of the art currently does not include this sophistication and any but the grossest estimation of nuclear casualties is hardly possible today.

ACKNOWLEDGMENTS

The writer wishes to acknowledge specifically the following: the timely and understanding action of Mr. L. Joe Deal, Chief, Civil Effects Branch, Division of Biology and Medicine, U. S. Atomic Energy Commission, who arranged for the reproduction of the earlier version of this paper under AEC Contract AT(29-1)-1242 and who encouraged and arranged support for its revision under AEC Contract AT(29-2)-1013; the persuasive talent of Dr. A. H. Schwichtenberg, member of the American Medical Association Committee on Disaster Medical Care, who stimulated another attempt to further communications between the laboratory and the potential users of nuclear-related data as they bear upon environmental medicine and on health and safety in civilian, industrial and military populations; the perceptive decision of Professor Lowell B. Jackson, Director, The 1970 Nuclear Defense Design Summer Institute, to include immediate nuclear effects information in the program, a course that can only further the complete understanding of modern explosives and promulgate data applicable to a variety of natural disasters; the expert and knowledgeable cooperation of the late Mr. I. Gerald Bowen, formerly Head, Physics Department, Lovelace Foundation, whose competent help made possible inclusion of range-yield-effects information for various explosive yields including those consistent with best available estimates for the yield of the Japanese explosions; the help of Dr. Robert K. Jones, Dr. Donald R. Richmond and Dr. E. Royce Fletcher in revising tabular data to include the most recent experimental results available; aid with illustrative material provided by Mr. Robert A. Smith, Mrs. Adele K. Sphar, Mr. Martin J. Schortje, Mr. Joe E. Foster and Mr. Dale Calvert; and the effective efforts of Mrs. Ruth P. Lloyd, Mrs. Martha E. Mitchell and Mrs. K. Maureen Gilmore, all of whom with Miss Mildred E. Blake and Mr. Fred C. Rupprecht contributed editorially and who, assisted by Mrs. Carol M. Riemen, processed the preliminary and final manuscripts.

More generally, gratitude is expressed to the Division of Biology and Medicine of the Atomic Energy Commission and the Defense Atomic Support Agency of the Department of Defense for providing support making possible a continuous investigative program in nuclear effects at the Lovelace Foundation for almost 20 years; and to many members of the Lovelace staff for the use of their data, generously made available for this and many other publications.

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THE NATURE OF THE PROBLEMS INVOLVED IN ESTIMATING THE IMMEDIATE CASUALTIES FROM NUCLEAR EXPLOSIONS

1 INTRODUCTION

This presentation will encompass a basic exercise in environmental medicine that illustrates a portion of the "current state of the art" and some of the constraints bearing upon the estimation of casualties from a nuclear detonation of significant yield. Physical concepts on the one hand and biological ones on the other plus the not straightforward tasks of bringing them together will be presented to help illustrate the nature of the problems faced by those who would assess the consequences of transient but large-scale variations in the environment of man.

Before proceeding, it is appropriate to say several other things. First, one should emphasize that many uncertainties are appreciated by those who think about high-order detonations. Among them are design, yield, range, burst height, ambient pressure, weather, terrain, and locale such as bursts over or near a sea coast, over heavily or sparsely populated areas or "high" along the trajectory of one of today's ocean- and continent-spanning missiles.

*Research contracts since 1951 with the Division of Biology and Medicine of the Atomic Energy Commission and since 1959 with the Defense Atomic Support Agency of the Department of Defense are acknowledged with appreciation; such support has made possible at the Lovelace Foundation continuous research programs in blast and shock biology and nuclear effects that are still under way. Also acknowledged are the contributions of various members of the Lovelace staff who over the years have authored more than 100 publications in this area; viz., T. L. Chiffelle in Pathology; D. R. Richmond in Comparative Environmental Biology; R. K. Jones in Hematology and Pathology; R. V. Taborelli in Engineering; the late I. G. Bowen and E. R. Fletcher in Physics.

Second, of necessity, limits must be placed upon the scope of what can be set forth briefly. Material included will bear mostly upon highly selected immediate effects which follow a nuclear detonation in a time period of less than one, but sometimes up to a few minutes. Even though many of the principles involved will apply, there is no intention of talking about the intermediate effects — apparent in a matter of many days or weeks — or about late effects seen in several months or a span of many years. Neither will there be data about fallout included, even though in the case of a surface or a near-surface burst, residual radiation, including fission products, can occur very early and can be considered a late immediate effect or an "early" intermediate effect under some circumstances particularly for high-yield surface detonations.

Third, though illustrative material from both field and laboratory experience will mostly involve blast effects — direct due to pressure variations; indirect due to translational events such as penetrating or nonpenetrating debris or to whole-body displacement and impact; and miscellaneous matters such as dust, non-line-of-site burns due to hot, dust-laden air or blast-induced fires — there is considerable commonality in assessing environmental hazards. As a consequence, much pertinent to blast effects will in principle apply also to problems involving both thermal and ionizing radiations.

Fourth, in what follows, an attempt will be made

(a) To present selected information from field data obtained at the Nevada Test Site and published material from the laboratory and relevant full-scale experience in Japan.

(b) To speak about the tentative biomedical criteria and their use in preparing range-effects and range-yield-effects diagrams.

(c) To summarize the concepts set forth and to draw a few simple conclusions about what must be done in the future if rationality is to guide those who would bring even a modicum of precision into the information system employed for estimating casualties from modern nuclear and thermonuclear explosives.

2 "FREE-FIELD" VERSUS "NON-FREE-FIELD" EFFECTS

2.1 General

By "free-field" effects is meant those environmental variations which occur over flat terrain free of buildings and significant flora fol-

lowing a large-yield nuclear explosion. Many manuals, including The Effects of Nuclear Weapons¹ and scaling procedures such as employed by Fletcher et al.² to design the nuclear bomb effects computer procurable from the U. S. Government Printing Office, are available for those who would learn how blast effects and those attributable to ionizing and thermal radiation vary in magnitude for a variety of conditions. In the presence of above- and below-ground structures, enough variation in terrain and heavily forested land, major environmental variations quite different from "free-field" effects at the same range may well occur at many locations of interest. Unfortunately, systematized quantitative data about such "non-free-field" circumstances are sparse indeed and this fact represents a serious deficiency in the literature bearing upon industrial health and safety.

These simple, but important matters will be illustrated from post-war experiments at the Nevada Test Site and war experience in Japan, following which a few additional points will be emphasized.

2.2 Nevada Test Site

1. 1953

Figure 1 shows cross sections of two circular 7-ft diameter, 50-ft long, tubular underground structures entered by walk-down ramps through openings without doors subjected to a 16-kt nuclear detonation in 1953.³ An outside or "free-field" overpressure of 13.5 psi was recorded on one occasion at a range similar to that for the structure. At different locations inside one shelter, overpressures were higher; they varied from 12.5 to 25 psi. All exposed animals were recovered, but exhibited different degrees of lung hemorrhage, being progressively more severe at locations farther and farther from the door. A few were mildly singed though the estimated outside thermal levels were approximately 100 cal/cm^2 .

Also the winds at some locations both inside and outside the structure were calculated at times to be near or above sonic velocities. Consequently, measures had to be taken to prevent translation of the exposed animals. This was accomplished by carefully using restraint lines and heavy, custom-fit harnesses to which each animal was trained pre-shot.

2. 1955

Figure 2 depicts diagrammatically a partitioned, underground structure tested open in 1955 at a ground range of 1050 ft from

Fig. 1—Plan view of 601 and 602 shelters and contents as used in Experiment I. Maximum recorded overpressures and their durations are also shown.³

a tower detonation of 29 kt.⁴ The maximal outside overpressure recorded was 91 psi. The pressures inside averaged 67 or 22 psi depending upon the size of the opening through which the blast wave entered. On the "fast"-fill side of the shelter, the pulse came down the stairs, made two 90-degree turns and spilled into the structure. Eight gauges recorded pressures ranging from 64 to 73 psi. On the "slow"-fill side, the blast wave entered by way of a 3-ft square vertical chimney. Inside pressures, from four gauges, ranged from 21 to 23 psi.

Of 20 "large" animals carefully restrained to prevent whole-body translation, all were recovered alive except one of 10 in the "fast"-fill side exposed opposite the entry door. The subject, torn from his harness, subsequently suffered "instant" fatality by violent impact

Fig. 2—Plan view of partitioned group (blast biology) shelter.⁴

against the opposite wall. This animal exhibited second degree burns from the hot, dust-laden gases entering the shelter. However, others were singed only on the side towards the entry way, but no serious burns were apparent. There was one pneumothorax and various degrees of lung hemorrhage (mostly minor), subendocardial petechiae, two hemorrhagic spleens, mesenteric petechiae, one leg fracture in two non-fatally displaced animals, and an 83-per cent rupture of the tympanic membranes.

3. 1957

Among many 1957 field experiments of note, two will be mentioned here. The first was in an underground structure 900 ft from ground zero known as UK 3.7 exposed on the 37-kt Priscilla Shot detonated 700 ft above the terrain to a "free-field" overpressure of 65 psi. Figure 3⁵

shows a cross section of the shelter, about 20 ft long, in which 1/2-in. steel balls were suspended in aluminum foil envelopes from the ceiling. The "steelies" have an acceleration coefficient near that for "average" man. They were hurled against the downstream wall by the blast winds, even though the latter passed through a "baffled" entry way. Their velocity at impact, determined by a "missile-absorber" technique, averaged 129 ft/sec or about 90 mph. Also caught in and recovered from the styrofoam absorber were small stones. These came either from outside or were scoured from the concrete walls of the entry way. They ranged in weight mostly from 10 to 100 mg. Their mean velocity was 376 ft/sec, but in many instances was between 550 and 800 ft/sec, well within the range for penetration of the skin, the eyeball and the body wall of thin subjects.

The second group of experiments in 1957 involved several heavy, closed, buried structures exposed to from 7.5 to 200 psi.⁶⁻⁸ In one series, carried out at the request of the Office of Civil Defense, mice were located in several shelters among those shown diagrammatically in Figure 4.⁹ Shelter ranges varied between 4320 and 840 ft from a tower explosion of 43 kt. "Free-field" overpressures were recorded from 7.2 to 175 psi. Inside overpressures were monitored at 0.2 to 14.4 psi, their being a "slow" leak through the ventilation system on one occasion. There were no early deaths attributable to blast or other nuclear effects; although in one shelter, animals succumbed to carbon monoxide gas from a motor-driven generator.

2.3 Japan

Figure 5, a per cent survival versus range plot of Hiroshima, was prepared several years ago for a presentation in Albuquerque. The data were taken from the text of Oughterson and Warren.¹⁰ They show three different exposure conditions along with the average for the entire city. Though subsequent studies have shown the need to revise the data, and particularly question the validity of the point marked 1 on Figure 5, such changes have not altered the loud and clear message shown by the data; namely, that exposure conditions can be a major factor in survival and that in Japan there was a substantial change in the 50-per cent survival range depending upon the location of individuals; i.e., compare the curve for "free-field" exposures in the open with that for personnel inside heavy structures. The latter were only special in that they were of seismic design.

Fig. 4—Layout of Smoky shelters.^{6,9}

Overpressures, thermal and ionizing radiation levels associated with the S_{50} ranges for the four curves, can now be estimated as shown in Table 1.

The information given in Figure 5 and Table 1 of course raises a significant question; namely, what effect or combination of effects were responsible for the casualties for each exposure condition? The reader, along with the author, can contemplate the figures and ponder their meaning and look later on at some more recent data to be presented subsequently.

Fig. 5—Percentage of survivors as a function of range from Ground Zero (Hiroshima). (Ref. Joint Commission Report, Vol. VI, Document NP-3041.)

TABLE 1

ESTIMATES FOR S_{50} SURVIVAL RANGES FOR HIROSHIMA.
 12.5 KT AT 1870 FT (570 METERS) ABOVE SEA-LEVEL TERRAIN
 (PRESSURE AND THERMAL DATA FROM ENW;¹ IONIZING
 RADIATION AFTER AUXIER ET AL.¹¹)

EXPOSURE CONDITION	RANGE MI	MAX. PRES. PSI	IONIZ. RAD. RAD	THER. RAD CAL/CM ²
"OPEN"	1.3	3	<10	5
AVERAGE	0.8	7	90	13
WOODEN BUILDINGS	0.45	13	2,000	32
CONCRETE BUILDINGS	0.12	24	20,000	80

It is also important that the literature shows there were close to 45,000 "early" fatalities among 255,000 civilians at risk in Hiroshima.¹⁰ This means 210,000 persons, more or less, walked or were helped out of the city. Of these, the uninjured numbered near 110,000, the surviving casualties between 70 and 75 thousand and the non-survivors about 20 to 25 thousand. This of course indicates that people plus buildings, particularly heavy ones, are a tough target, that there is a difference between physical and biological destruction (the two concepts should not be confused) and that one should be alert for the possibility of many more early survivors in case of a nuclear conflict than have been estimated over the past several years.

2.4 Implications

From what has been presented thus far, a number of things can be said.

First, it is amply clear from experience at the Nevada Test Site and in Japan that positional and orientational factors are of importance under both "free-field" and "non-free-field" situations from the physical as well as biological points of view.

Second, the conditions of exposure, including structural design, shape of openings and other geometric factors can critically alter the "free-field" parameters: indeed depending on details, the "inside" environment may be much worse, the same, or less challenging than that "outside."

Third, it follows that the location of people at burst time along with relevant positional, orientational and geometric factors emerge as highly significant matters in determining the number, kind and distribution of potential casualties.

Fourth, further refinement in analysis will require knowledge of the environmental variation — the "dose" if you will — at the location of the target whether "free-field" or "non-free-field;" whether on the street, in the attic, on the ground floor or in the basement; whether inside "light," "heavy" or a variety of other structural designs. This mostly is a problem for engineers and physically oriented personnel both empirically and theoretically oriented.

Fifth, there is a need for adequate and indeed quite precise dose-response data for single effects and for combinations of environmental stresses. Work in this area aimed at formulating more

meaningful biomedical criteria for hazards assessment is not moving ahead as rapidly as it should. This mostly is a problem for biophysically and biomedically oriented personnel including those wise in comparative physiology and the use of intraspecies mammalian studies to help make meaningful extrapolations applicable to man.

3 TENTATIVE BIOMEDICAL CRITERIA AND THEIR APPLICATION

3.1 General

The complex, tedious, difficult and expensive task of providing information from which to formulate satisfactory biomedical criteria cannot be discussed here. Neither can the data be presented from which currently available criteria have been derived. Suffice it to say that a beginning has been made¹²⁻¹⁴ and tentative criteria are at hand.¹⁴⁻¹⁹ What follows is a brief discussion of their proper application and the critical problems that emerge.

3.2 Application of Tentative Biomedical Criteria

Attempts have been made to utilize the available biomedical criteria and selected examples will now be presented.

1. "Free-Field"

a. For a Specified Yield

Figure 6¹⁹ shows, for "free-field" conditions, a range-effect diagram scaled for a 20-kt burst at 1988 ft (606 meters).

Fig. 6—Range-effect relationship for indicated primary blast damage from 20-kt yield at Hiroshima burst height of 1988 ft (606 meters) above sea-level terrain.

Superimposed on the incident and reflected pressure curves are tentative blast criteria* for "fast"-rising, "long"-duration overpressures. These include the estimated thresholds for eardrum failure and lung damage as well as the magnitudes of the overpressures for various levels of survival.¹⁹ It is clear that, by using the figures given, it is possible to specify the ranges inside which various specified effects can be anticipated. Also, if one chooses, the area may be predicted over which there is a potential for a defined type of damage.

Such an exercise might be useful and valid within a reasonable expectation for individuals exposed in the open. However, let it be quite clear that such is not the case for "non-free-field" conditions; i. e., the application of the biomedical criteria using scaled "free-field" data can "say" absolutely nothing meaningful about the shape of the casualty curves for different types of biomedical damage inside the range of interest for the several specified effects. Certainly full-scale experience and that at the Nevada Test Site cited previously make this quite obvious.

b. For a Broad-Yield Spectrum

Criteria for various blast effects and for defined damage from ionizing and thermal radiation can be assembled in range-yield-effects diagrams that are useful. Note Figure 7 for example.^{16, 19} The estimated ranges for specified effects are shown for sea-level surface bursts across a yield spectrum from one kt to 20 Mt on a "free-field" basis. There are several important points apparent from the figure. Three will be mentioned.

First, the ranges for first and second degree burns increase the most with yield. Those for 100 and 200 rem of ionizing radiation increase the least. Various specified blast effects hold an intermediate position. The steepest curve on the chart is for whole-body translation and this hazard for large yields could easily compete with window glass as the most far-reaching effect particularly on a cloudy day or over hazy cities, which conditions would sharply depress the transmission of thermal radiation.

Second, the nonparallel nature of the range-yield-effects curves makes it necessary to consider the changing

*These have been revised. See White et al.;¹⁸ Richmond et al.;²⁰ Jones et al.;²¹ Bowen et al.;²² and Tables 3, 4, and 5 appearing subsequently.

Fig. 7—Comparative-effects data showing ranges inside which indicated biological responses may occur for sea-level surface bursts.

ratio of the major effects to one another when estimating hazards at various yields. Among other things this means — all other things being equal — that (a) the pattern of environmental stressors changes with yield; (b) the distribution of casualties could be different at low, intermediate, and high yields and (c) the "mix" among different kinds of damage among those suffering multiple injuries will also vary much with yield.

Third, the Hiroshima and Nagasaki experience applies only to the 10- to 25-kt portion of the yield spectrum. Straight-forward use of the casualty data would be easier if the curves in Figure 7 were all parallel, but since this is not the case, extrapolation can hardly be made to the lower and particularly to the higher yields. Any meaningful use of the full-scale data poses difficult problems indeed.

2. "Non-Free-Field"

Be this as it may, there is no end to man's ingenuity, and personnel of the Dikewood Corporation working under support from the Atomic Energy Commission and the Office of Civil Defense have pushed ahead with analytical studies. With considerable per-

Fig. 8—Percentage of Hiroshima survivors as functions of range and exposure conditions.

ceptiveness and much effort, they have progressed in reassessing the Japanese data available today. Some of their data will now be cited.

a. Survival-Range Data for Various Structures

Davis, Baker and Summers have prepared estimated range-lethality curves for various conditions for both Hiroshima and Nagasaki.²³ Figure 8, plotted to depict survival percentages, shows the results for Hiroshima.* Besides an estimated curve for "free-field" exposures (OU) and for outside shielded structures (OS), 10 other conditions were identified. These included basement, ground and upper floors of seismic, reinforced concrete buildings; non-seismic, reinforced concrete structures; light steel-frame buildings; wood-frame commercial and civilian dwellings and vehicles.

The 50-per cent survival ranges (S_{50}), shown in the figure, ranged from 0.10 to 0.75 mi for the sample studied by the Dikewood workers. Their average for all curves combined was 0.6 mi.

*Prepared by the late I. G. Bowen, Head, Department of Physics, Lovelace Foundation for Medical Education and Research, Albuquerque, New Mexico.

b. The S₅₀ "Free-Field" Effects Data

Table 2, * prepared from the indicated sources, is of great interest for this presentation. This is so for a number of reasons; among them are:

First, the S₅₀ point on each curve can be taken to represent an equivalent biological challenge, i. e., survival was 50 per cent.

Second, the "free-field" air-dose values for the major effects at each S₅₀ range vary widely; viz., from 25 psi - 80 cal/cm² - 22,000 rad for a range of 0.1 mi to 8 psi - 15 cal/cm² - 150 rad for a range of 0.75 mi.

Third, however the "free-field" parameters were in reality altered by the conditions of exposure, it is unlikely that the inside "dose" was the same for each effect - rather the equivalent biological response was no doubt due to various combinations of the major effects.

Fourth, thus again the need for knowing more about environmental conditions at the locations of exposure and for having biomedical criteria equal to the challenge posed by realistic combinations of the effects occurring where people are or will be is strongly emphasized.

3.3 The Effects-Range Cascade

Several years ago, the author with the help of the late I. G. Bowen prepared Figure 9, showing by a series of horizontal bar graphs the increasing ranges for each specified effect as estimated from scaled data for a 20-Mt sea-level surface burst combined with the tentative biomedical criteria available at that time.¹⁶ Moving from right to left and top to bottom, what might be termed the "effects-range cascade" illustrates very well on a "free-field" basis many of the potential immediate challenges that can be anticipated and range over which each might occur.

It is an interesting exercise to contemplate "climbing" the cascade from the bottom to top and from right to left. In doing so,

*Prepared by the late I. G. Bowen, Head, Department of Physics, Lovelace Foundation for Medical Education and Research, Albuquerque, New Mexico.

TABLE 2
FIFTY-PER CENT SURVIVAL CONDITIONS FOR HIROSHIMA

LOCATION	HORIZONTAL RANGE ²³ DIKEWOOD		MAX OVER- PRESSURE ENW ¹ psi	THERMAL RADIATION ENW ¹ cal/cm ²	INITIAL IONIZING RADIATION ENW ¹ ORNL ¹¹	
	mi	ft			rem	rad
SRC, SEISMIC REINFORCED CONCRETE (ALL)	.20	1,056	19.8	67	23,500	13,300
SRC, BASEMENT	.10	528	25.6	80	37,300	22,000
SRC, LOWER FLOORS	.08	422	26.4	83	39,800	23,100
SRC, MIDDLE FLOORS	.20	1,056	19.8	67	23,500	13,300
SRC, UPPER FLOORS	.23	1,214	18.0	63	19,600	10,800
NON-SEISMIC REINFORCED CONCRETE	.32	1,690	14.0	49	10,500	5,700
LIGHT STEEL FRAME	.46	2,429	13.3	32	3,720	1,830
OUTSIDE SHIELDED	.48	2,534	13.2	30	3,180	1,550
VEHICLES	.48	2,534	13.2	30	3,180	1,550
WOOD FRAME COMMERCIAL	.49	2,587	13.1	29	2,930	1,430
WOOD FRAME DWELLING	.55	2,904	12.0	25	1,860	850
OUTSIDE UNSHIELDED	.75	3,960	7.9	15	430	151

Fig. 9—Comparative biological effects as a function of range for 20-Mt surface burst at sea level. (After Effects of Nuclear Weapons,¹ CEX-58.8,¹⁴ DASA-1341,¹⁵ and DASA-1462.¹⁶ See DASA-1856¹⁷ for latest revision of biomedical criteria.)

think first about simple and progressively more complicated ways to avoid or prevent injury. Second, as the range decreases, think anew about the changing character of the "free-field" effects and assess their hazard potential. For example, the far-reaching thermal fluxes can easily be avoided simply by being indoors and far enough from windows. Injury from glass and displacement can be minimized or prevented by staying away from glazed areas, doors and other openings. The failure of light structures at 3 to 5 psi poses problems unless one moves to basements, prepares and occupies "hardened" areas within the building, or chooses to vacate the lighter and occupy the heavier structures.

Now that the point is made, there is no need to belabor the matter further except to say that in Japan some of the seismic structures proved to be surprisingly "hard." Such an impressive instance was Building 402 listed by Davis et al. as a part of the Nagasaki University Hospital. The estimated overpressure at the location of the building, 2145 ft from the hypocenter, was 30 psi.²³ The per cent structural damage was listed as "none" in the Dikewood report.

There were several such heavy, concrete buildings in Japan. Many stood up at overpressures ranging from 15 to 30 psi. If one notes the intermediate bar of the "cascade" in Figure 9 labeled "30 psi," notes the values of the other "free-field" parameters at the shorter ranges and at the same time keeps in mind the test and full-scale experience already mentioned in this presentation, the tasks facing those who would estimate casualties for a "housed" population can be more realistically appreciated. To be sure, hardly anyone who reads this far and knows the old adage that "an ounce of prevention is worth a pound of cure" can hardly escape asking why more advantage has not been taken of the knowledge at hand. Protection well within the radius of the fireball and right up to the crater lip for surface bursts is possible today. Technical feasibility is not the problem and the reader can well ask what constraints, other than economic, need countering to the end that widespread protective construction will become a reality.

4 THE PROBLEM AREAS

4.1 General

It will be helpful now to bring together the points made thus

far. Such a synthesis will be useful in at least two ways; namely, first it will aid those who would improve the conceptualization of the information system required for a rational approach to casualty estimation, and second it will guide those who would move ahead in research to provide the missing data base with which the system can be improved. The relevant problem areas of interest to physically and biologically oriented personnel have been outlined elsewhere,¹⁷ but will be summarized below.

4.2 The Problem Areas

1. Biomedically Oriented

The biomedically oriented problem areas are delineated in Figure 10. The reader will recognize that the several portions of the diagram simply outline a logical approach to hazards assessment when the latter is to depend upon dose-response relationships. The

Fig. 10—Biomedically oriented problem areas.¹⁷

difficulties come when one wishes to work quantitatively and formalize the necessary criteria encompassing those levels of specified environmental variations that are tolerable; bothersome; associated with the threshold of injury; give a decrement in performance; produce frank minor and serious casualties; and are associated with low, intermediate and high levels of lethality.

It is necessary on the one hand to search for one or more of the stressing physical parameters that is or are significant biologically. This, of course, is basic to the definition of "dose" and needs be practically chosen to ease integration with the major effects parameters. On the other hand, it is equally important to identify and quantitate the biological response or responses that is or are significant along with the critical organ or portions of the body, damage to which contributes to the biological outcome of the stress. Most who work in these areas appreciate the need for elucidating etiologic mechanisms as an aid to interpreting symptomatology, sharpen diagnosis and therapy and to guide thinking about prophylactic and protective measures.

In relation to nuclear effects, biomedical researchers face two other important matters. One concerns the necessity for employing animals to investigate hazardous situations and the emerging problems of intraspecies extrapolations from which estimates for man can be derived. The other concerns the choice of levels of the major effects parameters to be studied, singly and in combinations, as well as the fixing of priorities among empirical and theoretical studies to optimize progress in the years ahead. In this regard, consideration of physical concepts, liaison and physically oriented personnel and an appreciation of their problem areas are all essential. Attention will now be so directed.

2. Physically Oriented

The need for guidance regarding all the environmental variations that can occur at inhabited locations following nuclear explosions can hardly be overemphasized. To help summarize the complexities involved, Figure 11 is presented.¹⁷ The many tasks include efforts to develop a quantitative understanding of the major "free-field" parameters and their relation to the explosive source; to learn how and by what amount the conditions of exposure and geometric factors augment or alleviate the "free-field" effects; to

grasp the aerodynamic principles of the translational process wherein objects including man are "energized" by blast shock and winds^{5,24} as well as by ground shock and gravity; and to recognize the importance of positional and orientational factors for exposures in the open as well as in shielded or partly shielded situations.

Fig. 11—Physically oriented problem areas.¹⁷

There are many difficulties and complexities involved, but an increased effort to move ahead will pay high dividends. Nuclear casualty estimates will become more precise. The identification of "safe" and "hazardous" areas in existing buildings will become more feasible and meaningful. The philosophy of providing "slanted" or "hardened" design for "closed" or "open" protective structures can be more fully explored. Analysis of the experience in Japan can be

broadened and the results can contribute more to environmental medicine and the understanding of nuclear effects on man.

4.3 Synthesis

In summary there continues to be a need to advance the understanding of nuclear effects both upon animals and man and upon the environment in which they may be exposed. All concerned must continue working to complete the quantitative fabric needed to interrelate adequately all the problem areas noted in Figures 10 and 11 above. For certain this will require the collaborative efforts of perceptive individuals trained in the physical, biophysical, biological and biomedical sciences. Much of the information needed is simply not at hand. However, much more is now known than in the past including a formalization of the conceptual base for the information system needed to widen man's grasp of nuclear effects. This will and can be improved. Such efforts, along with research to provide the data base for making the system more quantitative, provide a challenge to the best minds in the land.

5 THE ICHIBAN PROGRAM, REVISED COMPARATIVE EFFECTS CHARTS FOR HIROSHIMA AND NAGASAKI AND THEIR RELATION TO BIOMEDICAL CRITERIA

5.1 The Ichiban Program

One of the most stimulating and productive efforts in environmental medicine as it touches nuclear effects was initiated by the Health Physics Division of the Oak Ridge National Laboratory in 1956. Known as the Ichiban Program, the studies have been conducted in collaboration with the Atomic Bomb Casualty Commission.^{11,25-31} They have been supported by the U. S. Atomic Energy Commission through the U. S. National Academy of Sciences, National Research Council and carried out in cooperation with the Ministry of Health and Welfare of the Japanese Government. The effort, aimed at determining the radiation exposures of survivors at Hiroshima and Nagasaki, is mentioned here because it goes to the heart of the important difference between "free-field" or air dose — dependent mostly on yield, design, burst height, range and weather — and exposure dose, which, except for unshielded situations in the open, is much determined by the exposure conditions including geometric, positional and orientational factors noted in Figure 11 and discussed in the preceding material.

The program has been highly successful and illustrates very well the kind of effort needed to advance the understanding of nuclear effects from the point of view of ionizing radiation. There have been significant advances (a) in improving scaling procedures for setting forth the "free-field" distribution of radiation in air above the air-ground interface and (b) in providing simplified means for assessing the shielding factors for many types of structures including those in which people survived in Japan.

5.2 Revised Comparative Effects Charts for Hiroshima and Nagasaki

Additional details of this remarkable program cannot be given here, but it is appropriate to point out that for some time broadening the Ichiban studies to include all weapons effects has been under way.^{19, 32, 33} Progress of necessity has been slow. However, since Auxier et al.^{11, 30} published reassessed yield and burst height figures for Hiroshima and Nagasaki,* there was an opportunity to move ahead. As a consequence, the late Bowen³⁴ prepared comparative effects diagrams consistent with the Ichiban values. Because these are germane to the subject matter of this paper and update charts published previously,¹⁹ they are included here as Figures 12 and 13.

The curves show "free-field" range-effects data for the major effects and certain other arbitrarily chosen conditions defined in the charts. The left scale (the Y axis) represents, as appropriate: pressures in psi; ionizing radiation in rads or rem; thermal radiation in cal/cm²; and translational velocities for a 10-gm fragment of window glass and an average, "tumbling," 168-lb man in ft/sec.†

Though the charts are somewhat complex, they help one appreciate the changing character of the "free-field" environmental variations and some of the possible translational processes as they vary with range for the two explosions. To appreciate both the

*Hiroshima--12.5 kt at a burst height of 570 m (1870 ft).
Nagasaki--22 kt at a burst height of 500 m (1640 ft).

†The acceleration coefficient, α , noted in the figures, is defined as the area of the object presented to the wind multiplied by the drag coefficient divided by the mass; the units are sq ft/lb--see CEX-58.9.²⁴

Fig. 12—Comparative range—yield effects relationships for Hiroshima 12.5-kt burst at 1870 ft (570 meters) above sea-level terrain.

significance of the changing ratio of the major effects with range, one needs to contemplate at least two other questions; namely, (1) at what levels do the major environmental variations depicted in Figures 12 and 13 become damaging and hazardous? and (2) how and by what amount are the effects parameters shown altered under "non-free-field" conditions? The answer to the second question raises major difficulties and tasks similar to those the Ichiban scientists have worked on for over a decade and which will occupy many competent people for years ahead. The first question could be answered if appropriate criteria were at hand. Since tentative though quite incomplete criteria have been formulated, they will be presented below.

5.3 Tentative Biomedical Criteria

The tentative hazards assessment criteria available are shown in Table 3 for "fast"-rising overpressures of "long"-duration, in Table 4 for blast-energized missiles, in Table 5 for whole-body displacement, in Table 6 for thermal radiation, and in Table 7 for

Fig. 13—Comparative range—yield effects relationships for Nagasaki 22-kt burst at 1640 ft (500 meters) above sea-level terrain.

penetrating nuclear radiations. With a little thought one can employ the criteria, somewhat as illustrated in Figure 6 for primary blast effects, to each of the appropriate curves in Figures 12 and 13. As noted previously this will bear directly only upon "free-field" exposures. However, for "non-free-field" conditions, use of the criteria is sharply limited, but the ranges inside which the potential exists for a given type of damage can be rationally specified. Certainly it is clear that whether or not injury occurs will depend critically upon the detailed conditions of exposure. It should be equally obvious that an important question has been posed; namely, how does one use biomedical criteria under "non-free-field" conditions? The answer, of course, is first to learn how, given the "free-field" parameters, to specify the environmental variations that will occur at inhabited locations wherever they may be, and second, if the criteria available are not appropriate to the kinds and combinations of known variations, then one designs and carries out investigations to remedy the deficiency. These should be high priority items among those who would advance the understanding of nuclear effects.

TABLE 3

TENTATIVE BIOMEDICAL CRITERIA FOR DIRECT (PRIMARY)
BLAST EFFECTS IN YOUNG ADULTS APPLICABLE TO "FAST"-RISING,
"LONG"-DURATION OVERPRESSURES IN AIR
AMBIENT PRESSURE: 14.7 PSI
(REVISED FROM REFERENCE 17)*

	Overpressure in Psi for Different Orientations		
	P_e	P_{ir}	P_{if}
Eardrum Rupture			
Threshold	5.0	2.3	
50 Per Cent	15-20	6.3-8.0	
Lung Damage			
Threshold	10-12	4.4-5.4	9-10
Lethality			
Threshold	33-50	12-17	23-31
50 Per Cent	50-76	17-24	31-43
Near 100 Per Cent	76-115	24-33	43-60

P_e : Maximum effective overpressure, which may be

- (a) the maximum reflected overpressure if the subject is against a reflecting surface,
- (b) the incident maximum overpressure plus the associated maximum dynamic pressure for freestream exposure if the long axis of the subject is perpendicular to the direction of travel of the blast wave,
- (c) the incident maximal overpressure for freestream exposure if the long axis of the subject is parallel to the direction of travel of the blast wave.

P_{ir} : The incident maximum overpressure, which would reflect at normal incidence to the indicated maximum effective overpressure, P_e .

P_{if} : The incident maximum overpressure, which when added to the associated maximum dynamic pressure, results in a total overpressure equal to the indicated maximum effective overpressure, P_e .

*Data from Zalewski;³⁵ Hirsch;³⁶ Richmond et al.;²⁰ Bowen et al.;³⁷ and White et al.^{18,38}

TABLE 4

TENTATIVE CRITERIA FOR INDIRECT BLAST EFFECTS
INVOLVING SECONDARY MISSILES

(Reproduced from Reference 18)

Kind of Missile	Critical Organ or Event	Related Impact Velocity ft/sec
Nonpenetrating 10-lb object	Cerebral Concussion:*	
	Mostly "safe"	10
	Threshold	15
	Skull Fracture:*	
	Mostly "safe"	10
	Threshold	15
	Near 100 per cent	23
Penetrating 10-gm glass fragments	Skin Laceration:†	
	Threshold	50
	Serious Wounds:†	
	Threshold	100
	50 per cent	180
	Near 100 per cent	300

*Data from Lissner and Evans;³⁹ Zuckerman and Black;⁴⁰ Gurdjian, Webster and Lissner.⁴¹

†Data from Bowen et al.;⁴² Goldizen et al.;⁴³ and White et al.;^{14, 18} figures represent impact velocities with unclothed skin. A serious wound arbitrarily defined as a laceration of the skin with missile penetration into the tissues to depth of 10 mm or more.

It is appropriate to note that the inadequacies of the criteria set forth in Tables 3 to 7 are fully appreciated; they are deficient, crude, and represent only fragmentary samples of the entire hazards fabric needed to assess the biomedical implications of immediate nuclear effects. The criteria must be and will be extended and improved. They are offered in the hope that the inadequacies plainly apparent will stimulate a wide segment of the scientific community to make positive contributions. In the meantime the criteria at hand are useful if employed properly and care should be taken to see that

TABLE 5
TENTATIVE CRITERIA FOR INDIRECT (TERTIARY)
BLAST EFFECTS INVOLVING IMPACT

(Revised from Reference 18)

Condition Critical Organ or Event	Related Impact Velocity ft/sec
<u>Standing Stiff-legged Impact*</u>	
Mostly "safe"	
No significant effect	<8 (?)
Severe discomfort	8 - 10
Injury	
Threshold	10 - 12
Fracture threshold (heels, feet and legs)	13 - 16
<u>Seated Impact*</u>	
Mostly "safe"	
No effect	<8 (?)
Severe discomfort	8 - 14
Injury	
Threshold	15 - 26
<u>Skull Fracture⁺</u>	
Mostly "safe"	10
Threshold	13
50 per cent	18
Near 100 per cent	23
<u>Total Body Impact[†]</u>	
Mostly "safe"	10
Lethality threshold	21
Lethality 50 per cent	54
Lethality near 100 per cent	138

*Data from Draeger, Barr, Dunbar, Sager and Shelesnyak;⁴⁴ Black, Christopherson and Zuckerman;⁴⁵ Swearingen, McFadden, Garner and Blethrow;⁴⁶ Hirsch;⁴⁷ and Eiband.⁴⁸

⁺Data from Gurdjian, Webster and Lissner;⁴¹ Zuckerman and Black.⁴⁰

[†]Data from Lewis, Lee and Graham;⁴⁹ Richmond et al.;⁵⁰ and Jones et al.²¹

TABLE 6

TENTATIVE BIOMEDICAL 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;¹ Oughterson and Warren, 1956;¹⁰ Project Harbor;³² DASA-1462.¹⁶

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

they are not misapplied by either health and safety people in industry or analysts interested in nuclear effects. In this regard the reader is referred to the references given. These will also help emphasize that, though many revisions in the numerical data lie ahead, it is important to know that only a multitude of sound contributions can broaden and improve the validity of what is now at hand.

6 DISCUSSION

What has been presented here has been limited to the nature of the problems encountered in attempting to estimate casualties

TABLE 7
TENTATIVE BIOMEDICAL 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 1962.⁵¹

**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.

from immediate nuclear effects. Beyond those already mentioned, there are several other reasons for this. Four will now be noted. First, as important as intermediate and late effects admittedly are, the writer has had only a little experience with fallout and other delayed consequences of nuclear explosions. Therefore others more qualified must speak to these matters.

Second, survival needs be considered a stepwise process that initially requires living for milliseconds, seconds and minutes before survival for hours, days, and weeks can be realistically considered. Priorities in assessing casualties should be assigned in this order.

Third, the early effects have been neglected all too long. The concentration of population in the cities and urban complexes of this country, along with the ability of available, very high-yield nuclear devices — or multiple smaller ones for that matter — to place large areas at risk, is a potent reason for wanting to focus attention on matters of significance to what might be the majority and not the minority of our population.

Fourth, the highly hazardous character of the immediate effects needs emphasizing as one means among many of urging that more and increasing attention be directed to prophylaxis in general and to prevention of casualties specifically; certainly, this is a much more desirable course than learning better how to estimate them and then care for those whose injury occurred because "society" cared more about rockets, missiles and the backside of the moon than performing realistically on the surface of the earth.

The difficulties and complexities of the many problems faced by all interested in improving the understanding of nuclear effects and their many implications should there be a nuclear war often seem overwhelming and even frightening. New data come slowly and progress takes so long. In the meantime it is heartening, however, to know that already the tentative criteria that have been developed through biological studies of the consequences of exposure to high-yield explosives have been useful in many segments of our society. The range-safety manuals at missile-launch sites carry the available data. Those who manufacture and use explosives and other "detonable" products, such as high pressure cylinders and boilers, employ the documented data as safety criteria to guide design of work spaces and to formulate operating procedures that emphasize safety and minimize the chances of serious trauma. The work on combined effects under way promises to shed light upon injuries occurring at high speeds on the highway and among service men in Viet Nam. In reality the time response of the major body systems to severe and multiple stress is far from understood. Indeed they will not be unless a major effort can be mounted in this portion of the research frontier.

These facts give reason enough to move ahead with the physical, biophysical and biomedical studies of nuclear-related environmental variations. They will be useful even if we do not have a nuclear war, and with the sagacity and wisdom to apply what is learned,

the products of research might not keep the peace, might not save the cities, but they might save our lives so we, along with the nation, could survive.

7 SUMMARY

A. The need for distinguishing between "free-field" environmental variations which follow a high-yield explosion and those that occur at "non-free-field" locations was emphasized by citing post-war experiments at the Nevada Test Site and war experience from Japan indicating that among the many variables influencing survival, the conditions of exposure emerged as critical determinants.

B. Thus in addition to such factors as design, yield, range, burst height, weather and barometric pressure all of which influence scaling the "free-field" parameters, orientational and positional as well as geometric factors bearing upon the conditions of exposure along with the physical interaction responsible for translational events involving both debris and man, must all be considered in estimating casualties. This is so because it is necessary to know that environmental variations occur at all inhabited locations wherever they may be.

C. In addition to such physically oriented information, there is a need for dose-response data for single effects and combinations of environmental stresses, which information is basic to formulating finalized versions of the tentative biomedical criteria for hazards assessment. Until the physical as well as the biomedical information is adequate, the numbers, kinds, seriousness and distribution of injuries from nuclear explosives can hardly be specified.

D. Tentative biomedical criteria currently available were presented and their utility as well as their deficiencies were discussed. *51 reference (unsh)*

E. "Free-field" range-effects diagrams for selected yields were presented to illustrate a valid use of the criteria to assess unshielded situations in the open and to specify the ranges inside which the potential for a specified injury might exist under "non-free-field" conditions; however,

it was noted that such a procedure alone can say nothing valid about the shape of the casualty curves at the closer ranges.

- F. Range-yield-effects curves across a yield spectrum from 1 kt to 20 Mt were presented. The nonparallel character of the several curves was pointed out. This fact, and the associated changing ratios of the major "free-field" effects with yield and ranges, were noted as prohibitive constraints in scaling the Japanese casualty experience to lower and particularly to higher yields.
- G. Survival-range curves under a variety of exposure conditions for Hiroshima and Nagasaki were cited from the recent literature as were newly available burst heights and yields for the Hiroshima and Nagasaki explosions of 12.5 and 22 kt, respectively. Such data were used to help scale the "free-field" parameters associated with the 50-per cent survival ranges for several exposure conditions. The wide variation in the values obtained for the major effects were pointed out to emphasize the need for more information about "non-free-field" versus "free-field" exposure conditions and for more data from which to formulate improved biomedical criteria for realistic combinations of effects occurring at the occupied locations of interest.
- H. The remarkable success of the Ichiban Program — initiated in 1956 and aimed at determining, from adequate "free-field" information, quantitatively the radiations in air, and from appropriate shielding data, the radiation exposure of survivors in Japan — was cited as an example of a remarkable contribution to environmental medicine. Work under way to extend the analysis to the other major effects was mentioned and an accelerated effort was urged.
- I. The physically — and biomedically — oriented problem areas were delineated to help conceptualize the information system needed by those who would, through a quantitative data fabric, improve the understanding of nuclear effects. The essentiality of a collaborative effort among physically, biophysically and biomedically oriented talent to obtain

the data base for improving and extending the system was emphasized.

- J. Progress in the past has been such that it was now considered "time" to take effects data "out of the streets" and "into" the attics, basements, and intermediate floors of homes and commercial structures; and into tunnels, trains, vehicles, and all other exposure sites and conditions of interest to the end that casualty estimates may not only be made rational and realistic, but that the need for practicing prevention through protective construction will be judged a wise and necessary way of bringing balance between medical needs and capabilities in case of a major disaster.

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