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ORO-R-17
Appendix B

Defense of the US against Attack by Aircraft and Missiles (u)

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Appendix B

Effectiveness of Some Civil Defense Actions in Protecting Urban Populations (u)

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The Johns Hopkins University
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10 April 1957

SUBJECT: Distribution of Study by the Operations Research Office, ORO-R-17, Appendix B.

TO: **Planning Staff**
Room 3335, GSA Bldg.
Washington, D. C.
ATTN: MR. RALPH E. SPEAR, ASST. ADMINISTRATOR

10 CYS

1. A copy of a study by the Operations Research Office, The Johns Hopkins University, "Effectiveness of Some Civil Defense Actions in Protecting Urban Populations" (U) is inclosed.

2. As an element of a broad study on defense of the United States, the Operations Research Office investigated passive defense measures. The inclosed document presents certain results of this analysis.

3. The parent study has not yet been completed. However, in view of current interest among many agencies of the government in the subject matter of the inclosed paper, it is being distributed now for information.

4. Since the Department of the Army is not charged with responsibility for activities referred to in the recommendations contained on page 4 of the paper, the Army has adopted no position at this time on these recommendations.

FOR THE CHIEF OF RESEARCH AND DEVELOPMENT:

Roland P. Carlson

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Colonel, GS
Chief, Operations Research Division

1 Incl
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Appendix B

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HOME DEFENSE DIVISION
PASSIVE DEFENSE GROUP
Report ORO-R-17, Appendix B
Published December 1956

Effectiveness of Some Civil Defense Actions in Protecting Urban Populations (u)

Appendix B of Defense of the US against Attack by Aircraft and Missiles (u)

by

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In addition the author wishes to thank Miss Jane Ingersoll, Mr. Bertram Lindman, Miss Peggy Simmons, and members of the review board: Mr. Marshall Andrews, Lt Col R. B. Crayton, Dr. John H. Gardner, Brig Gen John G. Hill, RAdm Marion N. Little, Lt Col O. Q. Matteson, Dr. Thornton L. Page, Dr. Marcel Vigneras, and Col William Withers.

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SUMMARY

PROBLEM

Assuming some prior warning, to evaluate the feasibility, effectiveness, and costs of several courses of preattack civil defense action: mass evacuation, seeking ordinarily existing shelter, seeking shelter in towns, villages, and farms, and seeking underground public or private shelter.

FACTS

Weapons systems cost-effectiveness studies indicate high probability now and for the next several years of target penetration by attacking aircraft. At no time do such studies envisage an airtight defensive system. No system now exists capable of attacking and destroying intercontinental ballistic missiles (ICBM).

In spite of the fact that passive measures can do much to attenuate the effects of the damage that current and proposed active defense systems must permit, the US has followed a wavering and ineffective passive defense policy that has never won the support of Congress or the public. This study examines passive measures that might be essential ingredients of a balanced passive-active air defense system.

DISCUSSION

Six urban centers — Washington (studied in detail), Boston, Dayton, Milwaukee, St. Louis, and San Francisco — were chosen as targets, and the feasibility, effectiveness, and costs of various courses of preattack civil defense action for these cities were investigated.

Feasibility

An examination of the capacities of the radial road nets leading out of the target cities indicated that for only one, Dayton, was mass radial evacuation feasible within the most probable warning time that the cities would receive. This was true even though the model did not allow for losses in starting time, panic, failure to follow the plan, vehicle breakdowns, etc. A survey of the national highway program and possible new radial routes to speed evacuation indicated that these roads could not be made available within the time period when mass evacuation may be effective (prior to the ICBM). The feasibility of evacuating urban targets to smaller towns and villages was examined, using Washington and Baltimore as targets, and Frederick and Hagerstown, Md., and Fredericksburg, Va., as the host towns. This tactic required many times the most probable warning times expected and had the effect of creating three new highly concentrated population targets. Legislative apathy and public lack of knowledge of weapons effects seem to be the principal barriers to shelter programs — technical know-how exists and adequate shelter designs have been built and tested at atomic weapon test sites.

SUMMARY

Effectiveness

Attacks with one to four 10-Mt ground-burst weapons aimed at the population centers of the target cities with circular probable errors (CEP) ranging from 4000 to 12,000 m were made, and the proportions of the target population killed were computed when the civil defense tactic was: seeking the best shelter now available, evacuating radially outward for a period of time equal to 1956 and 1959 expected warning times, and seeking underground private or public shelter.

Results indicated that mass evacuation is not as effective in reducing casualties as underground shelter when multiweapon attacks, large inaccuracies in delivery, or fallout from nearby targets are taken into account. Mass radial evacuation, if the population is unshielded, precludes the use of atomic warheads in antiaircraft guided missiles.

The use of best existing shelter, attenuating radiation by 0.9, is the least desirable course of action, resulting in higher proportions of target population killed than either mass radial evacuation or underground shelter. Deaths in this case are due principally to blast and thermal effects and to the fact that lethal radiation doses are received by shelter occupants before rescue workers — impeded by debris and high radiation — can reach them.

Public and private shelters appear to provide the best protection from all effects and to give military forces the greatest flexibility to meet the attack with any warhead at any altitude. The effectiveness of shelter close to the population need not be dependent on the successful functioning of the distant-early-warning network (as is the case with evacuation tactics).

If the US and USSR have equal capabilities in air offense and defense, a decided advantage will go to the nation with the best passive defense system. In this regard it appears that the nation that can place its population in shelter possesses a basic advantage — an aggressor may be greatly deterred if he cannot be sure of striking a truly crippling blow. A shelter program would be particularly effective in this connection if it were accompanied by a gradual reduction in urban vulnerability.

Costs

Compared to an estimated $50 million in direct costs for an evacuation program for 170 major cities, the range for shelter systems may be from $6 billion to $30 billion, but shelter construction costs need be sustained only once and maintenance costs are negligible. Also, shelter systems can contribute to the area's economy and welfare by serving dual purposes, e.g., for subways and below-grade parking areas, without losing appreciable value as shelter.

CONCLUSIONS

Feasibility

1. The feasibility of mass evacuation has not been proven by actual test in any large city. There are serious difficulties facing realistic practice on the necessary scale. Current survival plan projects in a number of large cities may find ways of overcoming the difficulties.

2. Mass evacuation of large cities to smaller villages and towns is not feasible within expected warning times.

3. Radial roads to permit mass evacuation of major cities could not be built in time for this tactic to have any value.

4. The feasibility of an underground shelter construction program has not been proven to the point of stimulating Congress to provide public funds. The technical know-how for large shelter construction exists, although one of the most promising and inexpensive designs has not been tested.

Effectiveness

5. In the Washington area, against attack with one to four 10-Mt ground-burst weapons all aimed at the population center with a 4000-m CEP, results were as follows:

a. Use of underground shelter, evacuation with 1959 warning time, and evacuation with 1956 warning time are all more effective civil defense measures than use of existing shelter.

b. Use of underground shelter and evacuation with 1959 warning time are more effective than evacuation with 1956 warning time.

c. Use of underground shelter is more effective against several weapons than evacuation with 1959 warning time, and is as effective as such evacuation against a single weapon.

6. In the Boston area, against attack with 10-Mt ground-burst weapons aimed at the population center, use of underground shelter is more effective than any other civil defense measure for all weights of attack from one to four weapons and for all CEP from 4000 to 12,000 m, even when effects of fallout are completely ignored; the superiority of underground shelter is further increased when fallout is considered.

7. In the Milwaukee and St. Louis areas, against attack with 10-Mt ground-burst weapons, when effects of fallout are ignored, evacuation with 1959 warning time is the most effective measure for a CEP of 4000 m, and underground shelter is the most effective measure for a CEP of 12,000 m. When fallout is considered, the superiority of evacuation with 1959 warning time for a CEP of 4000 m is reduced and perhaps eliminated, depending on the local and regional fallout pattern, and the superiority of underground shelter for a CEP of 12,000 m is further increased.

8. In the Dayton area, against attack with 10-Mt ground-burst weapons, when effects of fallout are ignored, evacuation with 1959 warning time is the most effective measure for all CEP from 4000 to 12,000 m. When fallout is considered, the superiority of evacuation is reduced and perhaps eliminated, depending on the local and regional fallout pattern.

9. Any increase in radiation effects resulting from attacks on other nearby targets will increase the effectiveness of underground shelter relative to the other possible civil defense tactics. This relative superiority will be most drastic when the total fallout intensity reaches a level where the 0.9 protection factor of best shelter now available permits occupants to receive a lethal dose.

10. Shelter that will attenuate radiation effects by 0.9 (ordinary basement shelter) is not adequate in urban targets:

a. At 2 to 4 miles from ground zero, individuals in basement shelters would receive an LD_{50} dose in 3 hr; at 4 to 5 miles, in 6 hr. At these distances fallen trees and other debris in a high radiation field would make rescue operations impossible within the hours of life left to occupants of basement shelters.

b. At distances that might be relatively debris-free (7 to 8 miles), LD_{50} doses would be received by occupants of basement shelters after 24 hr. Evacuation by shielded vehicles would be imperative to preserve life.

11. Since immediate postattack rescue and evacuation efforts may be impossible because of high radiation levels, public and private shelters need to be designed and stocked to permit survival within the shelter for periods as long as 10 days.

12. With widespread attack on many targets, mass evacuation tactics could result in 100 percent lethality among the evacuated population. This could be true even if the evacuated city were not itself successfully attacked.

Costs

13. The cost of an evacuation program for 170 major cities should not exceed $50 million in direct costs for plans, maps, and traffic signs and for recruiting, training, and equipping traffic control personnel. Indirect costs due to loss of wages, output, and profits are not considered in this estimate and could be very high, especially if the enemy should adopt "spoofing" tactics.

14. The cost of combination public-private shelter programs is largely dependent on the degree of protection desired. Two programs considered in this appendix are estimated at $6 billion and $33 billion each, for 170 major cities.

RECOMMENDATION

1. The Army should support the following activities:

a. A start should be made on a reduction-of-vulnerability plan and an underground shelter plan for each metropolitan target area, looking toward reduction of target values in the core area and a spacing of underground shelters to match future population distribution at the expected date of ultrashort warning for ICBM.

b. Construction of underground shelters should be started as soon as firm long-range shelter needs in any geographical subdivision of the metropolitan target area can be determined. The current "survival studies" being undertaken by various cities with federal funds should be utilized to determine local shelter needs rather than to designate evacuation routes.

c. The entire civil defense concept of postattack operations should be reexamined in light of probable high radiation levels that may render traditional rescue, medical, fire fighting, and other services at or near the site of the attack impossible.

d. Intensive R&D effort should be expended on testing existing shelter designs and on the design of multipurpose and improvised shelter.

EFFECTIVENESS OF SOME CIVIL DEFENSE ACTIONS IN PROTECTING URBAN POPULATIONS

INTRODUCTION

This study attempts to evaluate the effectiveness of alternative civil defense measures that can be taken between the first warning of attack and the attack itself in reducing deaths in urban targets from immediate effects. It does not attempt to investigate the problems of social control, feeding, housing, and medical care in the months following attack that might result in additional casualties. Long-range programs designed to reduce urban vulnerability, such as blast-resistant-building design and dispersion, are treated separately in Annex B of this appendix.

The importance of the present study may be summarized as follows:

(a) Passive and active defenses interact to reduce or enhance one another's effectiveness. For example, a civil defense policy of mass radial preattack evacuation of urban targets might reduce active defense effectiveness by precluding the use of nuclear warheads in surface-to-air missiles against bombers attacking at low altitudes. Conversely, a civil defense policy of deep shelter for occupants of urban targets would provide the ground commander with great flexibility to meet the attack with a weapon of any likely yield at any altitude.

(b) In some cases passive measures can be wholly or partly substituted for active measures. Critical facilities might be duplicated at a second location, equipment or the end product stockpiled, or the installation placed underground, and thereby serve as an alternative to point defenses for the facility.

(c) Passive measures change the nature of the target to be defended. Dispersal programs for industry, for example, alter the value of the target relative to its initial value and to the value of other targets in the system, and hence alter the number of batteries required to defend it. As a second example, populations in deep shelter can tolerate high radiation levels, and thus present different targets to be defended than an exposed population — populations in shelter may reduce the need for killing at great distances the bomb that if not killed would result in radiation conditions that could be lethal to an unsheltered population.

(d) Active defenses are probabilistic in their effectiveness (App G), and the problem of enemy electronic countermeasure capabilities is a grave one (App D). Passive defenses can offer a chance for survival should the active defenses not be completed at the time of the attack or not perform as envisioned.

(e) The kind of civil defense plans that exist, and their effectiveness, crucially affect the Army's preattack and postattack role. Lack of passive defense plans, or passive plans that lead to chaos or personnel losses of unmanageable proportions, may require the use of so many Army resources that it will be impossible for the Army to carry out its primary mission.

(f) Recent events have highlighted the role the military forces may have to play in civil defense. The declaration of martial law by the President in Operation Alert, 1955, has been subject to a wide variety of interpretations. At one extreme this move was interpreted to mean that civil defense had failed in its mission: "It [the declaration] suggested finitely that the Civil Defense organization would be overcome with paralysis within 36 hours. The simulated situation deteriorated so rapidly that the President, who apparently recognized the approaching paralysis, was forced to declare a state of nation-wide Martial Law."[1] At the other extreme, Dr. Charles Fairman, Professor of Law at Harvard University, testifying before a Congressional committee, described the declaration as "unstudied," "hashed up" for the occasion, and "falls apart upon examination." He went on to state: "Operation Alert bungled into crude compulsion where insight, administrative skill, and inspiring leadership were needed."[2] However the move is interpreted, the declaration of martial law emphasized the fact that the Army would be called on to play a larger role in the postattack period than had hitherto been made explicit.*

Adequate passive defenses, like adequate active defenses, strengthen our general posture for war. If the US and the Soviet Union have equal capabilities in air defense and offense, a decided advantage will go to the nation with the best-developed passive defense system. In this regard the nation that can place its population in shelters possesses a basic advantage. An aggressor may be greatly deterred if he cannot be sure of striking a truly crippling blow.

Public funds must be apportioned between the various active and passive programs constituting the air defense system; this study summarizes ORO findings on the feasibility, effectiveness, and costs of some ingredients of an effective passive defense system.

CHOICE OF TARGETS

It was felt advisable to make a detailed study of a single urban target (Washington) and generalize from this study to the degree indicated by more cursory studies of five other urban centers: Boston, Dayton, Milwaukee, St. Louis, and San Francisco.

The Washington metropolitan area was chosen as a primary test subject because, as the national capital, it was considered to have high priority as a target; its geographical features presented difficult, but not insurmountable, problems for solution; its proximity to ORO made it an economical subject for study; and a high degree of interest and cooperation from civil officials and other citizens promised to promote ease of study.

The other five cities were chosen to represent a variety of conditions that might influence civil defense actions. Boston was chosen because of its relatively large size and because water and adjacent targets imposed limitations on preattack movement. Dayton represents a smaller city where there is comparative freedom to move in any direction, and as an inland city it has a greater probability of receiving longer warning periods of impending attack. Milwaukee and St. Louis were chosen as larger inland cities, the former being limited in possible movement by Lake Michigan. Since both cities have been objects of FCDA studies, it was thought that further comparisons might be possible. San Francisco was chosen because, unlike the other targets studied, it is situated on the West Coast.

*Project LINEUP[1] is an exhaustive study of the roles the military forces might play in the civil defense effort. Recognizing that the existing civil defense structure may well collapse, it recommends a strong national civil defense command structure (as opposed to the present advisory functions of Federal Civil Defense). Supporting this hierarchy would be mobile support units composed of men not suited for active military training because of physical disabilities, family responsibilities, religious scruples, etc. These units would reduce the drain on Army resources (which would not be adequate to meet the effects of the widespread attack postulated in LINEUP in any event) and release large numbers of Army personnel to perform their primary mission.

Table 1 summarizes some aspects of the target cities. It is apparent that choice of these targets affords a rather general representation. Three are coastal cities and three are inland. The cities vary in size from 350,000 to 2,200,000. Two cities have relative freedom to move in any direction. Two are limited to 180-deg movement, and two (for different reasons) are limited to less than 180-deg possible movement. The principal activities of the cities also are varied.

TABLE 1

CHARACTERISTICS OF TARGET CITIES

City	Location	Population, thous	Movement limitations	Predominant activity
Boston	East Coast	2200	270 deg	Port, diversified industry
Dayton	Inland	350	None	Manufacturing
Milwaukee	Inland	800	180 deg	Port, food processing
St. Louis	Inland	1400	180 deg	Manufacturing
San Francisco	West Coast	2000	Peninsular	Port, petroleum, food processing
Washington	East Coast	1700	None	Government

URBAN COMPLEX AS A TARGET

General Population

Of the six targets studied, all but one, the San Francisco Bay area, have a single center of population, a point at which the explosion of a single weapon could produce more casualties than an explosion at any other point. In the case of Washington at least, there is no shift in the location of this point from day to night,* although there is a marked increase in density of population around this point during the working day (see Fig. 1). Figure 2 shows by concentric 4-mile bands [designed to correspond to Federal Civil Defense Administration (FCDA) zones of A, B, C, and D damage for a 10-Mt weapon with a ground zero (GZ) at the Ellipse, near the White House [3]] the distribution of day and night populations superimposed on the target area under consideration. This figure also shows the number of traffic lanes leaving each zone.

The nighttime (resident) population distributions of the other target areas (Boston, Dayton, Milwaukee, St. Louis, and San Francisco) are shown in Figs. 3 to 7. The numbers in the squares represent thousands of residents within units 2000 by 2000 m each. For each target the centroid of population is indicated. Since the San Francisco Bay area has two population clusters (Oakland and San Francisco), which are separated by water, two population centroids are indicated for this target.

Special Populations

Because of the importance of physicians in the postattack situation, the distribution of greater Washington area physicians during the day and night was plotted. It was found that although the density of physicians at the center of the city markedly increased during the day, this increase was proportional to the general increase in population density, and as in the population as a whole, there was no shift in the point of highest density from day to night.

*Daytime population figures were not available to permit similar comparisons within the other targets.

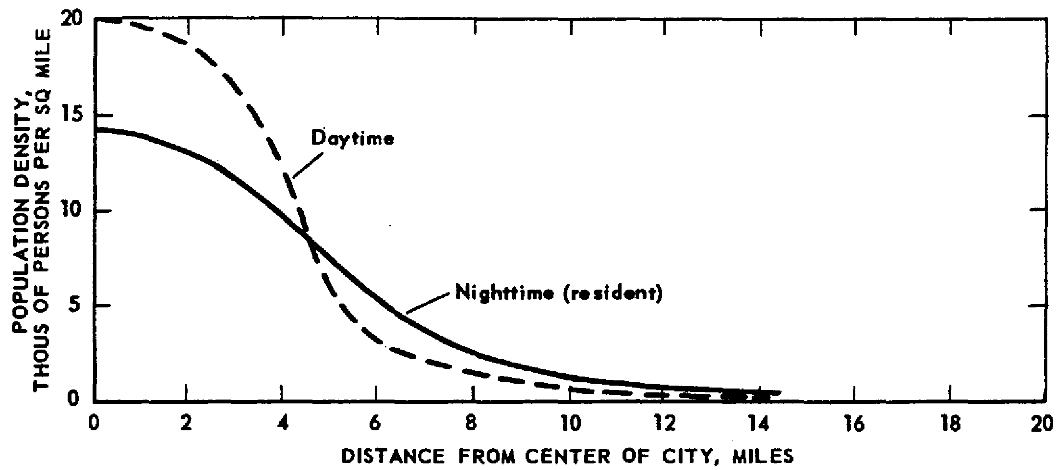

Fig. 1 — Washington Day and Night Population Density as Function of Distance from Center of City

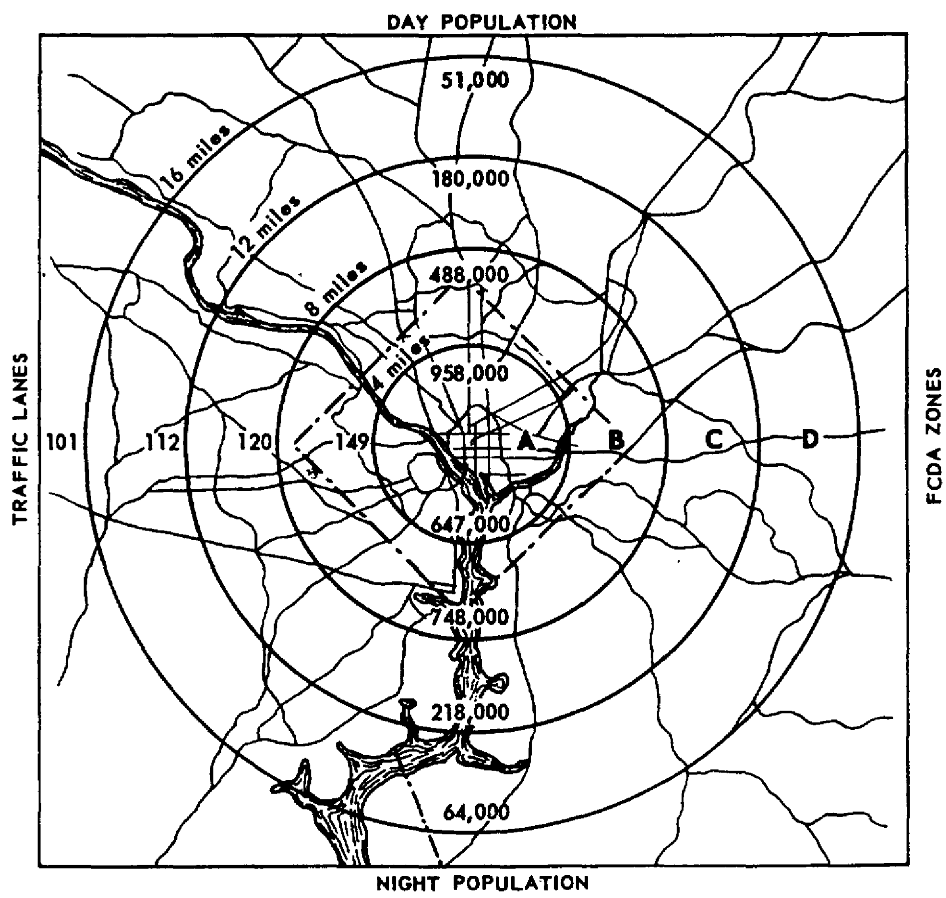

Fig. 2 — Population and Traffic-Lane Distribution of Washington Target

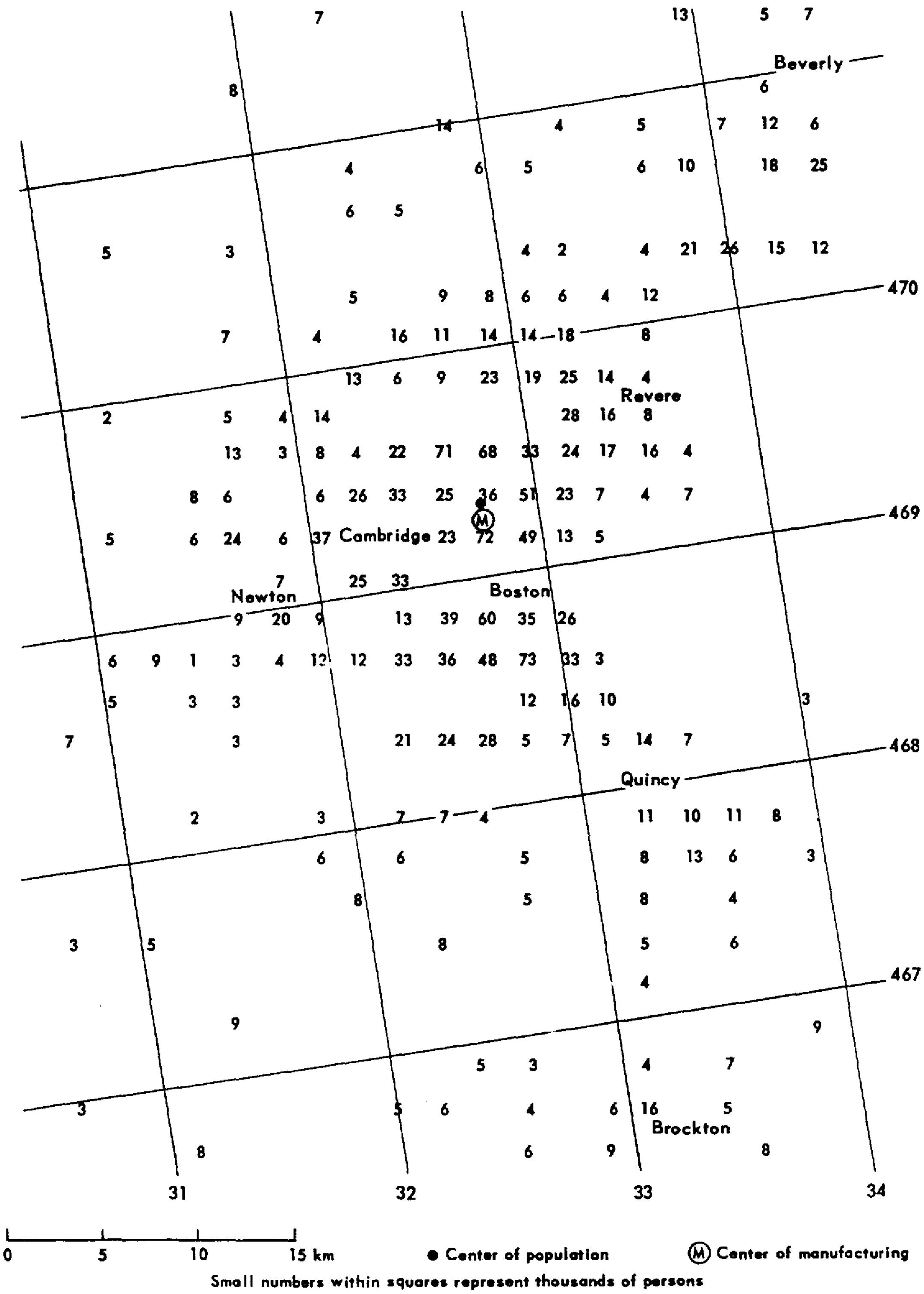

Fig. 3 — Resident Population of Boston Target

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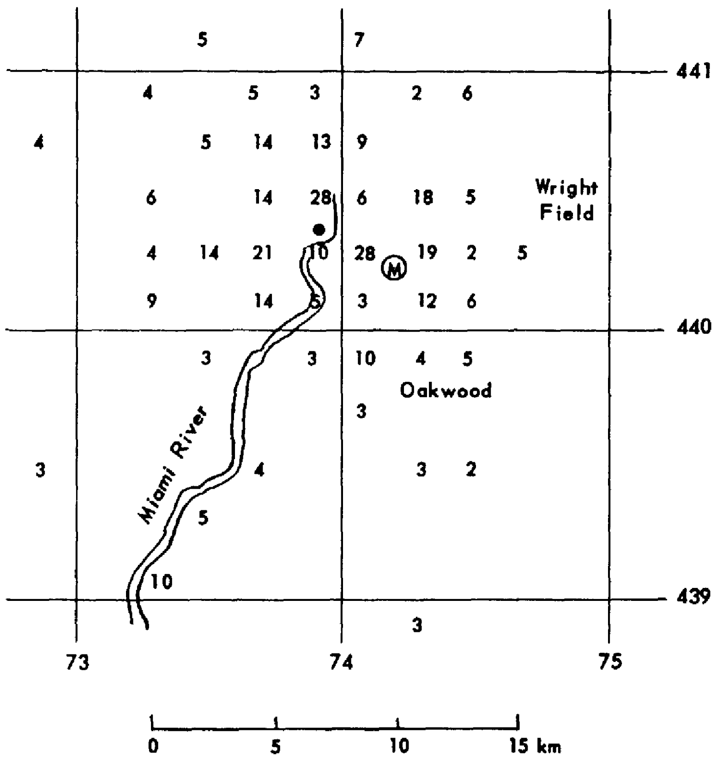
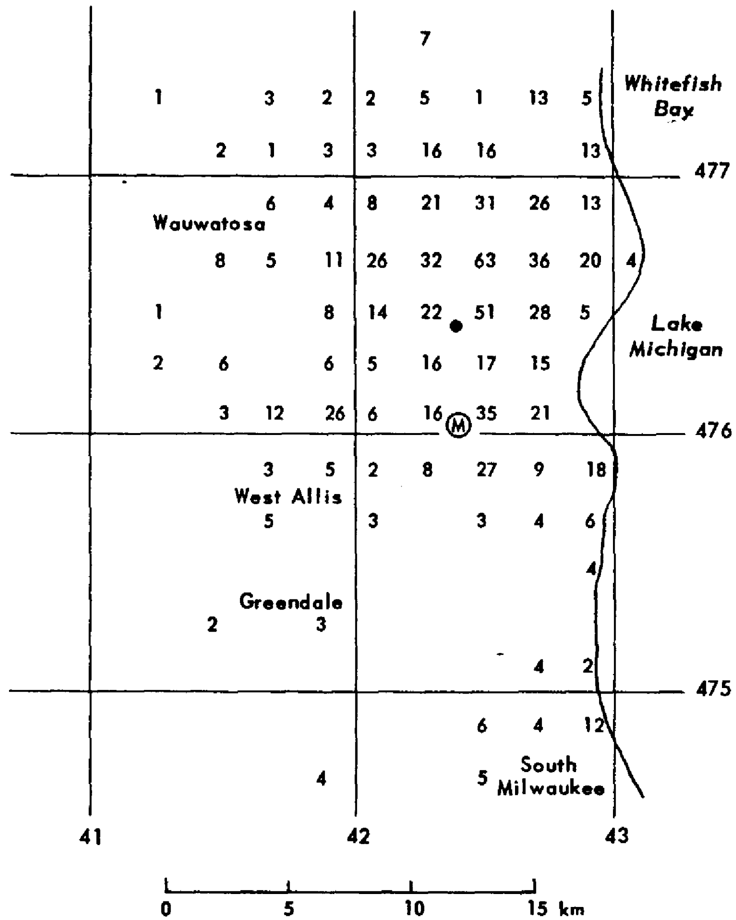


● Center of population (M) Center of manufacturing
Small numbers within squares represent thousands of persons

Fig. 4 — Resident Population of Dayton Target



● Center of population (M) Center of manufacturing
Small numbers within squares represent thousands of persons

Fig. 5 — Resident Population of Milwaukee Target

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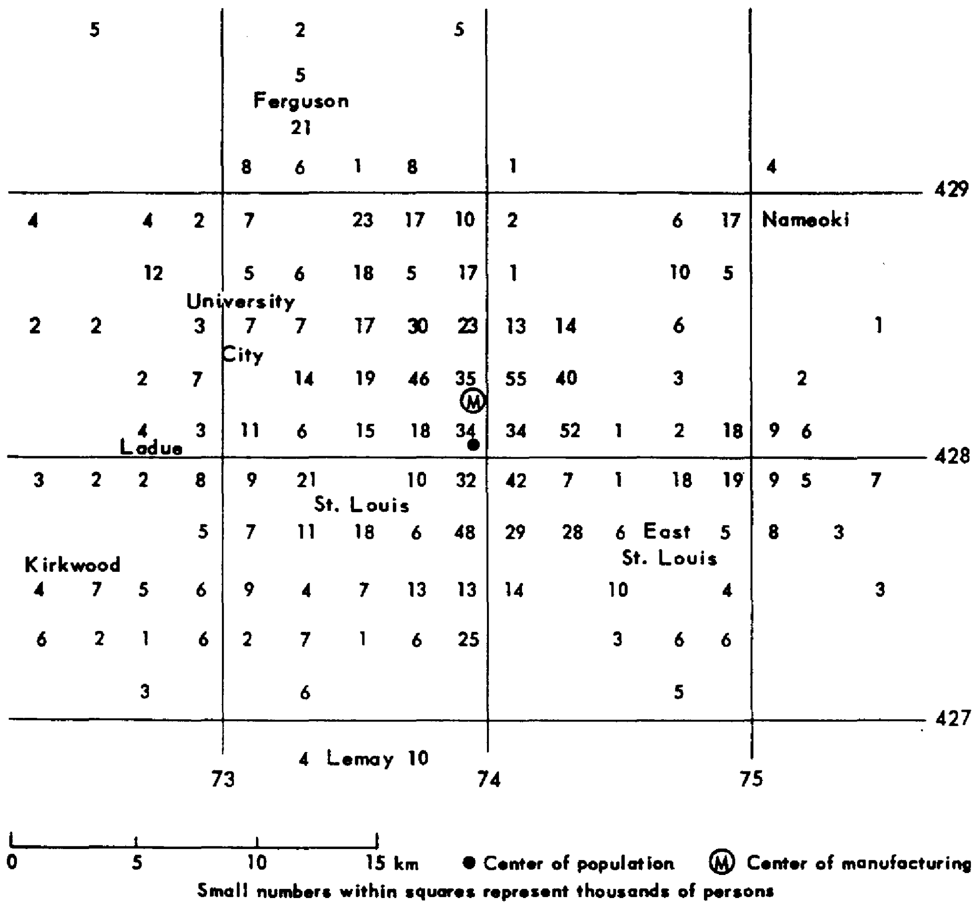

Fig. 6 — Resident Population of St. Louis Target

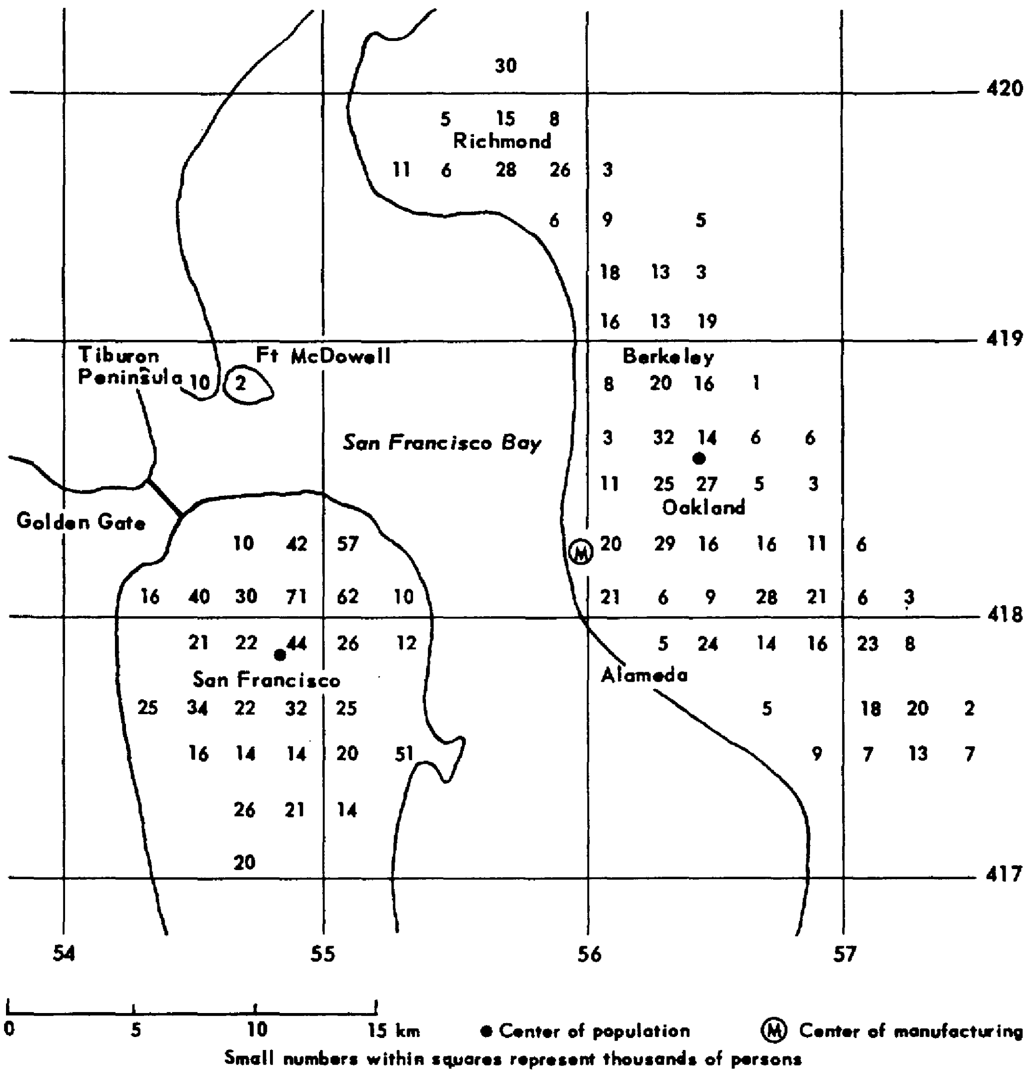

Fig. 7 — Resident Population of San Francisco Bay Area Target

It was thought that heads of government might provide a desirable target for the enemy under some attack conditions. In order to discover whether or not there might be some separate aiming point if such people were the target, the nighttime location of Senators, Representatives, and heads of executive agencies was plotted. It was found that this special group was distributed among the population at large, although there was a greater tendency to live closer to the center of population. No separate aiming point emerged.

INDUSTRY AS A TARGET

Figures 3 to 7 also show the point at which a 10-Mt attack could inflict maximum damage on "manufacturing value added" in the five targets containing appreciable industry (see App A of this report).[4] In all except San Francisco the aiming point for the destruction of industry and that for inflicting maximum casualties on population tend to coincide. San Francisco, in addition to a separate center of manufacturing, has two population "best aiming points." Washington contains no appreciable industry; however, the center of population and the center of the government-building group nearly coincide.

AIMING POINTS WITHIN URBAN COMPLEXES

On the basis of the information gathered, only one of the six targets considered, San Francisco, exhibits more than one optimum aiming point as a function of enemy intentions to destroy nighttime or daytime populations, special groups within the population, or industry.

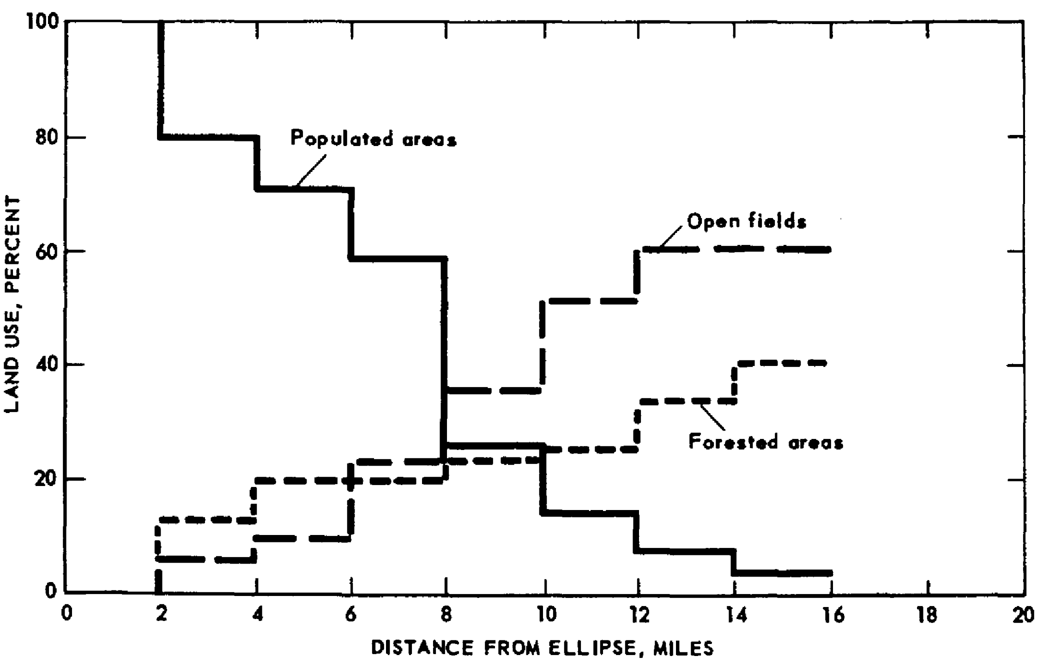

Fig. 8 — Percentage Developed, Wooded, and Cleared Land in Washington Target

LAND USE

Figure 8 shows, for Washington, radially outward from the Ellipse by 2-mile zones, the percentage of land that is developed, cleared, and wooded. It is clear that developed areas that could provide shelter from both the initial and fallout hazards of atomic weapons begin to drop off sharply at about 8 miles.

The types of buildings in these areas are also important because of the shelter they might afford from both immediate effects and fallout. In Washington, although the survey by the District of Columbia is incomplete, there would seem to be adequate shelter space in reinforced-concrete and steel-frame buildings *within* 4 miles of the Ellipse, based on the fact that recent civil defense tests have revealed no overcrowding in the designated shelter areas. *Outside* this 4-mile circle the amount of shelter space in buildings of these types is clearly inadequate. Table 2 lists the number of people who could be accommodated in existing approved shelter between the 4-mile circle and the District line in the four quadrants of the city. In every case there is a deficiency of space for the numbers of persons in the area both during the day and night. The deficiency is somewhat less severe in the northwest quadrant, with its many multistoried steel-frame and reinforced-concrete apartment buildings. No shelter survey has been completed in adjacent suburban areas.

TABLE 2

SHELTER CAPACITY NOW AVAILABLE BETWEEN 4 MILES FROM THE CENTER OF WASHINGTON AND THE DISTRICT LINE

Quadrant	Population		Shelter capacity[a]	Shelter deficiency	
	Day	Night		Day	Night
NW	62,471	83,391	45,376	17,095	38,015
NE	37,370	62,489	6,462	30,908	56,027
SE	35,795	75,968	1,391	34,404	74,577
SW	3,031	7,325	400	2,631	6,925

[a]Based on FCDA standards for Category I and II shelter.

On the basis of the study of land use and the existing shelter surveys, it would seem that in the Washington target shelter of all grades diminishes as distance from the city's center increases. Similar studies have not been made of the other target cities. However, aerial photographs of these cities indicate that multistoried buildings tend to be clustered near the population center of the city, with construction of all kinds giving way to forested and cleared areas as distance from the city's center increases.

ROAD NETWORK

Figure 2 shows the number of traffic lanes leaving the 4-, 8-, 12-, and 16-mile circles in the Washington target. Not only does the number of lanes diminish (from 149 to 101) but the quality of the roads (in terms of width, alignment, etc.) also diminishes as distance from the city's center increases. This tendency for the number of traffic lanes to diminish as distance from the center of population increases holds true for all the other targets studied except San Francisco.* There are, however, marked differences from one target to another in the ratio of available traffic lanes to the population that they must

*The Bay area does not conform to the other city patterns in many respects. The road network between the two population centers of San Francisco and Oakland, although severely limited in numbers of lanes, is constant.

serve. Table 3 shows the ratio of the number of lanes leaving the target area to the population of the area. It can be seen that Washington and Dayton have twice the road capacity of Milwaukee and St. Louis and slightly more than twice that of Boston.

TABLE 3

TRAFFIC LANES SERVING POPULATIONS OF FIVE URBAN TARGETS

Target	Lanes leaving target	Persons enclosed, thous	Ratio, lanes/thous of persons
Boston	60	2200	0.025
Dayton	22	350	0.06
Milwaukee	26	800	0.03
St. Louis	45	1400	0.03
Washington	101	1700	0.06

The urban complex as a target seems to be characterized by a single center that contains the best shelter, the best road network, and the most value to the economy. People ebb and flow from this point by night and day but the location of the point does not shift. The cities under consideration seem to differ most markedly in the extent of their road network and in their geographical locations, which affect the relative freedom of their populations to leave the target area.

THE ENEMY ATTACK

For the purposes of this study a massed attack of high-altitude bombers is assumed. It is assumed that the attack may come over Canada and also approach both coasts directly. The raid size is assumed to be sufficient to successfully explode from one to four 10-Mt weapons on the targets under consideration.

LETHAL RANGE

The mortality coefficients vs distance of a 10-Mt weapon as used in this study are presented in Fig. 9. For comparison, mortality vs distance curves as used by the FCDA[3] and SRI[4] are also presented. All three curves are based essentially on Hiroshima-Nagasaki data and have been modified to account for the longer positive-pulse phase associated with

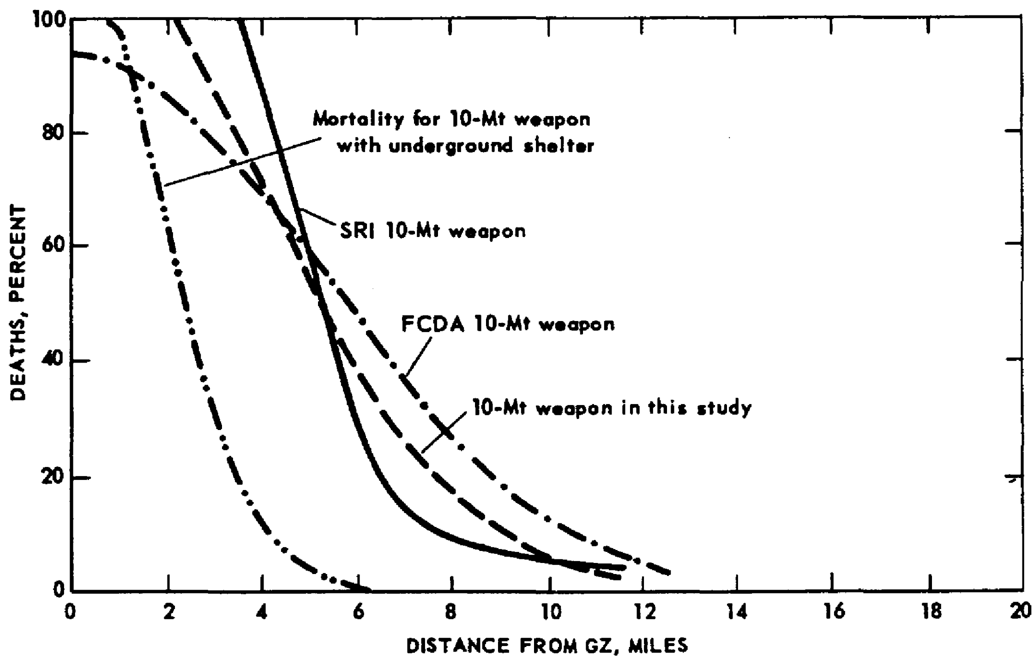

Fig. 9 — Population Lethality Contours for 10-Mt Ground Burst

high-yield weapons. The curve used in this study was the best approximation to Hiroshima data that would meet the purposes of the study; like the SRI curve it has a region of 100 percent mortality to meet the requirements of cratering associated with ground bursts.

Figure 9 also gives the mortality coefficients for populations in shelters with 3 ft of earth cover. The 100 percent mortality "plateau" extends to the limits of the crater and lip that would be created by a 10-Mt ground burst and then drops off at the same rate as for populations exposed above ground. None of the mortality curves presented here include the probabilities of death from indirect ionizing radiation (fallout). The mortality rates associated with various patterns of fallout are discussed in the section "Effectiveness of Civil Defense Actions."

ACCURACY

Delivery accuracy of the enemy attack is of extreme importance to civil defense planning, especially if movement of the population away from some assumed aiming point is one of the passive maneuvers under consideration. Since this is one of the most debatable aspects of the attack, this study uses a range of circular probable errors (CEP) from 4000 to 12,000 m (CEP of 0 were also computed for comparison purposes but are not cited in this appendix since they do not differ appreciably in their effects from CEP of 4000 m).

Many factors enter into the accuracy with which a high-altitude bomber can attack some point in a metropolitan complex. The random fall of the weapon and inaccuracies of the bombsighting mechanisms are probably minor, although these are the bases for the usual computations of CEP. Other factors, largely unexplored, may contribute to CEP of many miles as opposed to the few hundred feet that practiced crews over friendly territory can sometimes achieve. Some of these factors may be as follows.

Effect of Defender Action. Local point defenses may destroy the aircraft but not the bomb. This might result in a ground burst many miles from the desired ground zero (DGZ).*

Failure To Identify Aiming Point. Although it is presumed that enemy crews will be well briefed on their mission, it is also true that they have not had the advantage of seeing the actual target on radarscopes until the time of the attack. At least one study[5] indicates that it may be important to distinguish between aiming-point misidentification and being "lost." The latter behavior is typified by incomplete orientation in which the operator apparently feels compelled to find some point that at least resembles the desired aiming point. As the pattern deteriorates, the operator chooses another point further ahead. In one case cited, a "lost" operator made four different selections of target area in the course of one bomb run.

Intelligence Errors. An FCDA report states that: "By analysis of population and industrial concentrations within any target area, we are able to assume what we believe to be a logical aiming point for enemy attack. However, we do not know how complete the enemy's information may be or whether his attack assumptions are the same as ours."[6]

This is but a partial list of the factors that may contribute to very large aiming errors. An ORO[7] study concerned with predicting safe distances of friendly troops from DGZ suggests the term "tactical CEP (TCEP)" to describe more realistically the dispersion of aimed weapons around a point.

This paper does not propose to answer the question of how accurately high-altitude bombers can deliver thermonuclear weapons on defended targets. It is suggested, however, that the TCEP, as opposed to the CEP attained by friendly crews on practice runs, may be very large.†

WARNING TIME

The amount of warning time of enemy attack places severe restrictions on possible civil defense maneuvers. Table 4 summarizes the warning times that the six targets under

*Appendix H of this report discusses the possibility of destroying the bomb as well as the carrier. Should this tactic be adopted, this factor would not contribute to CEP.

†An Air Force press release of 15 June 1956 indicates that a bomber in the Pacific Proving Grounds Tests missed the DGZ by "less than four miles."

consideration may expect in the years 1956–1959 (see App D of this report).[8] These times are based on the expected completion dates of the McGill, Pinetree, and distant-early-warning (DEW) networks and the seaward extensions; flying speeds of enemy aircraft are assumed to be 550 mph by 1959. These figures are not firm but serve to indicate that targets face varying warning conditions depending on their location. The possibility of complete surprise, for coastal cities at least, may always remain high.

TABLE 4

WARNING TIME OF BOMBER ATTACK

City	Warning time, hr			
	1956	1957	1958	1959
Boston	0.5	0.5	1.0	1.0
Washington, D.C.	0.5	0.5	1.0	1.0
St. Louis	2.0	2.5	2.5–4.0	2.5–4.0
Dayton	1.5–2.0	2.0–2.5	2.0–4.0	2.5–4.0
San Francisco	0.5	0.5	1.0	1.0
Milwaukee	1.0–2.0	2.0–2.5	2.5–4.0	2.5–4.0

In order to compare the effects of alternative civil defense actions, this study has assumed a massed attack by bomber-type aircraft. However, it should be pointed out that attack from ballistic missiles launched from submarines affords no warning before the first missile, and little warning before any remaining missiles. The maximum warning time from attack by ICBMs has been estimated at 15 min.

It should also be pointed out that the time span of the attack has important civil defense implications; depending on the success of the initial attack and other factors, urban populations could be subjected to subsequent attacks from ballistic missiles or aircraft over periods of days or weeks. Some civil defense actions may leave them more vulnerable to follow-up attacks than others.

POSSIBLE CIVIL DEFENSE ACTIONS AND FEASIBILITY

Opposing the enemy attack are a variety of civil defense actions cities can take. These may be broadly categorized as changing the population configuration or changing the population vulnerability or combinations of these.

The population configuration can be changed by mass evacuation of the city as a whole from some assumed aiming point to beyond the assumed lethal radius of a thermonuclear weapon; evacuation of the congested core of the city (partial evacuation); selective evacuation of the aged, infirm, children, etc., prior to warning of actual attack; or reduction of population vulnerability through long-range dispersal programs.

The population vulnerability may be changed by a policy of seeking the best shelter now available in the target; seeking shelter in public or private underground shelters; preparing improvised shelter; designing and constructing blast-resistant buildings; or constructing underground installations.

A combination of these two methods may call for mass evacuation of the city to public shelters in the periphery; evacuation of the congested core of the city to shelter elsewhere within the target; or evacuation of the city population to smaller towns and villages.

In this study the alternatives of mass radial evacuation, seeking the best shelter now available, seeking underground shelter, and seeking shelter in surrounding towns and villages are considered. Dispersal programs, blast-resistant designs, and underground installations are treated separately in Annex B of this appendix.

MASS EVACUATION

Determining Feasibility

Ideally the feasibility of evacuating large urban targets could be determined by practice evacuations. Although there have been practice evacuations of some cities, such as Spokane,[9] Mobile,[9] Erie, Pa.,[10] and Portland, Ore.,[11] the results have had little bearing on the problem of the feasibility of this tactic. In every case a relatively small portion of the target was evacuated, and in every case a relatively small proportion of the population in the evacuated area participated in the exercise. It may be reasonable to conclude that those persons who did choose to participate represent the population that would create the fewest problems in evacuation; perhaps those who did not participate were the aged, infirm, mothers with small children, and noncooperative persons, who might create special problems.

In any event, in the tests conducted so far the size of the areas being evacuated has been too small and the number of participants too few to permit any conclusions regarding the feasibility of this civil defense maneuver.

In the absence of valid experiential data, an evacuation model was designed, based on the assumption that the number of traffic lanes leading out of the target would be a prime limiting factor to carrying out a mass evacuation within a given period of time. The Washington area was used as a model. As described in Fig. 2, the number of traffic lanes diminishes from 149 at 4 miles from the city's center to 101 at 16 miles from the city's center. The model is designed to set an upper limit on evacuation feasibility, and assumes that immediately on warning of attack all vehicles will start moving radially outward at a rate of 1000 vehicles per lane per hour.* It is further assumed that all vehicles will be used to optimum advantage (the population of each ring distributed evenly throughout the number of vehicles in the ring), and that each vehicle will contain five passengers.

Table 5 shows how the population is distributed after 1, 2, 3, and 4 hr of evacuation. At the end of 4.5 hr the target is empty. Figure 10 shows the same data in terms of ring density after 1, 2, and 3 hr of evacuation. For comparison this figure assumes that evacuees might be held in the 16- to 20-mile ring; it will be noted that under these conditions density is optimally uniform after about 3 hr of evacuation.

TABLE 5

POPULATION DISTRIBUTION OF WASHINGTON FOR VARIOUS EVACUATION TIMES

FCDA damage zone	Zone radius, miles	Traffic lanes leaving city	Population, thous				
			No movement	1-hr evac	2-hr evac	3-hr evac	4-hr evac
A	0–4	149	647	0	0	0	0
B	4–8	120	748	996	577	19	0
C	8–12	112	218	239	286	409	0
D	12–16	101	64	100	136	236	200
Outside	16–20	—	—	342	678	1013	1477

The approximate times required to empty the six remaining targets under consideration (based on the number of traffic lanes leaving the target area) are as follows: Boston, 8.0 hr; Dayton, 3.3 hr; Milwaukee, 6.7 hr; St. Louis, 6.0 hr; and San Francisco, 11+ hr.

A comparison of the times required to evacuate totally the six urban targets assuming the probable warning times expected for them through 1959 (Table 4) reveals that only one, Dayton, can complete mass evacuation within the expected period of warning. Against attack with ballistic missiles, with perhaps 15-min warnings, such a tactic is completely impossible.

It should be further emphasized that these figures represent the minimum times required. The figures given would have to be degraded by many factors, including the following.

(a) There is some loss in starting time, e.g., losses in making the warning public (probably 12 min), 11 or more min to empty large office buildings under normal well-practiced circumstances (recent air-raid drills), and 20 min and upward to empty parking lots, depending on their size. The time required to reunite fathers, mothers, and school-age children for evacuation purposes would also degrade this figure by some large factor, and additional starting losses would be created as prospective evacuees loaded their automobiles with needed supplies.†

*Lane capacities as high as 2300 vehicles per lane per hour have been measured on some limited-entry-egress highways; other highways have capacities as low as 600 vehicles per lane per hour. A capacity of 1000 was chosen as an all-road, all-season, day-night average.

†An SRI study[12] of three California floods indicated that 70 percent of the population had left their homes within 30 min of the warning. After the first 30 min, the remaining population responded slowly; at 4 hr from the warning only an additional 15 percent had evacuated.

(b) Egress from evacuation routes to relocation sites would slow the evacuation rate. If open fields were used under muddy conditions, egress from evacuation routes might be impossible.

( ) Behavioral factors would further degrade the rate: elevator operators and parking-lot attendants might flee their posts. Drivers might collide and create roadblocks. Some cars may be without sufficient gasoline, etc.

(d) The times based on 1000 vehicles per lane per hour presume a well-practiced plan, with well-marked routes, adequate traffic controls, and some all-over control system for the maneuver. None of these conditions now exist.

A mass evacuation plan cannot be considered feasible unless realistic, widespread, and frequent practice of the plan is feasible. Some additional points limiting the feasibility of such practice are as follows.

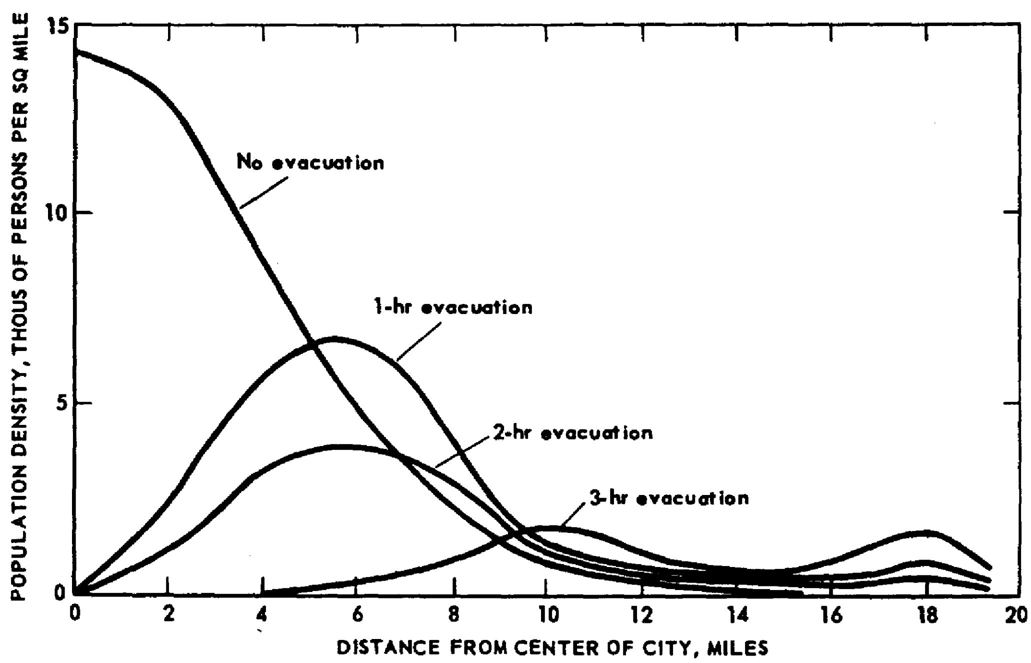

Fig. 10 — Population Density of Washington Target as Function of Distance from Center of City for Three Evacuation Times

(a) Practice evacuations are very costly. Indirect losses to the economy through loss of production and consumption of fuel and materiel are difficult to assess, but in the Washington target would probably not be less than $1 million per practice, with perhaps two practices per year required. In addition there might be widespread damage to real estate, crops, vehicles, etc.

(b) In many targets there is no legal basis for ordering a practice evacuation.

(c) Social problems might arise that although undoubtedly minor in time of war might limit the possibility of continuing practice drills in time of peace. In the Washington target such problems might arise when predominantly Negro populations were evacuated to predominantly white areas.

(d) As mentioned previously, practice evacuations have shown that large numbers of people do not participate anyway, and that these may be the people who most need the practice if they are to carry out such a maneuver under threat of attack.

Limitations to Evacuation Movement

As pointed out previously in this paper, shelter of all kinds diminishes rapidly as one moves outward from the center of the city. Shelter is imperative due to dangers from immediate blast and thermal effects, fallout radiation, and debris of all kinds from defender action. In the Washington target 8 radial miles seems to be the limit of adequate shelter. In addition to shelter, the public air-raid alert system that could warn evacuees to take shelter is rapidly outrun.

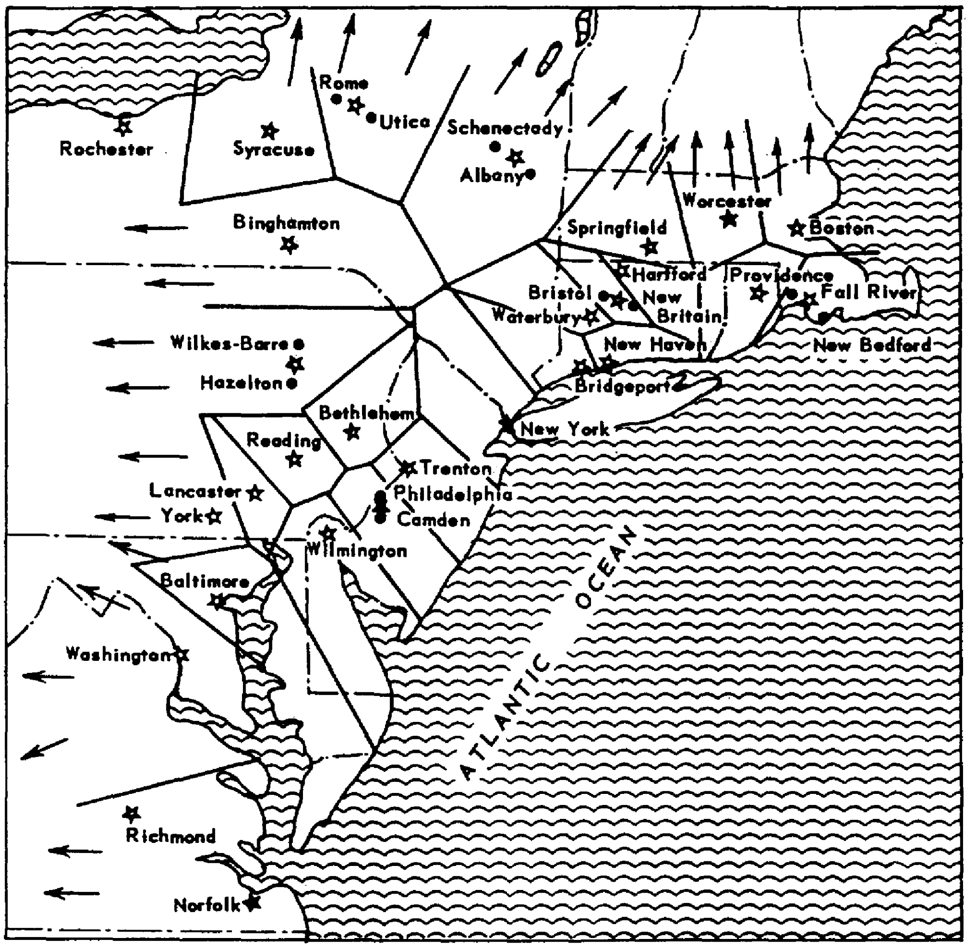

Fig. 11 — Barriers to Distant Evacuations Created by Terrain and Adjacent Targets along the Eastern Seaboard

A third factor limiting evacuation is the presence of physical barriers, such as coasts and mountains and the proximity of other targets. Figure 11 indicates evacuation limitations for 25 critical target areas along the Eastern Seaboard.[13] The solid lines indicate the point halfway between one target and the next adjacent target, or the point at which an evacuee from one city would be in equal jeopardy from a weapon aimed at an adjacent city. This device would not be useful for planning purposes, since it assumes equal value for targets and weapons of equal lethality, but it does serve to indicate that the targets face varying restrictions on maximum evacuation distances. Boston, for example, is limited to about 20 miles of movement to the east, south, and west by the proximity of the seacoast and the Worcester, Providence, and Fall River targets, whereas Washington is relatively unlimited, being bounded for all practical purposes only by the proximity of Baltimore and the coast.

The proximity of other targets and physical barriers also set upper limits on the amount of dispersion that can take place. For example, although population density along the East Coast averages about 370 persons per square mile, many of the targets, limited by the afore-mentioned barriers, would still have concentrations many times that figure even if the population within the target could be evenly dispersed in the area allotted to it. New York, for example, would have concentrations of 2500 and Philadelphia 1500 persons per square mile.

Evacuation Roads and the National Highway Program

The feeling has been expressed by civil defense planners that the recently enacted public roads program would make mass evacuation possible or that the program could be modified to make such a tactic feasible.* Figure 12 shows the proposed highway system. It is clear that this 40,000-mile system is designed to connect major cities and is not a system of radial routes emanating from congested urban areas into the surrounding countryside. It is not considered desirable to substitute radial routes for the intercity system. The latter routes were selected in cooperation with the military as being of first importance to the national defense, and are vital to the successful operation of plans for mutual aid in the postattack period that have been developed by the various cities.

It has been estimated that an expenditure of $10 billion is needed to provide for the evacuation of every person in the 23 largest target areas to beyond a 15-mile radius in 1½ hr.

An evacuation-highway program would in no way substantially reduce the requirement for a shelter program to protect evacuees from fallout, and the cost of the entire evacuation-highway-to-shelter program might be of the order of $18 billion.

Should Congress consider a program to construct evacuation highways, the earliest year they could consider it would be 1957. Congressional action in 1957 would probably occur too late for enactment of cooperative state legislation that year so it would normally be carried over until the 1959 session. If states were urged to call special sessions, state legislation could probably be speeded up by 1 yr. Regardless, it is evident that enactment of legislation affecting highways requires several years.

Getting highway construction under way after legislation is enacted takes additional time. Routes must be selected, surveys made, land and property condemned, structures built, and pavements laid. This process normally takes at least 3 yr for each section of highway.

By the time highway legislative and construction processes are completed and highways are made available for evacuation, the US might well be into the intercontinental ballistic missile (ICBM) era.

Feasibility

In view of the probable short warning times of attack, the long times required for evacuation of targets, additional hazards that may further slow evacuation routes, the limitations on realistic practice of mass evacuations, dispersion limitations due to geographic

*See, for example, the testimony of Governor Peterson in hearings before the Senate Committee on Armed Services.[14]

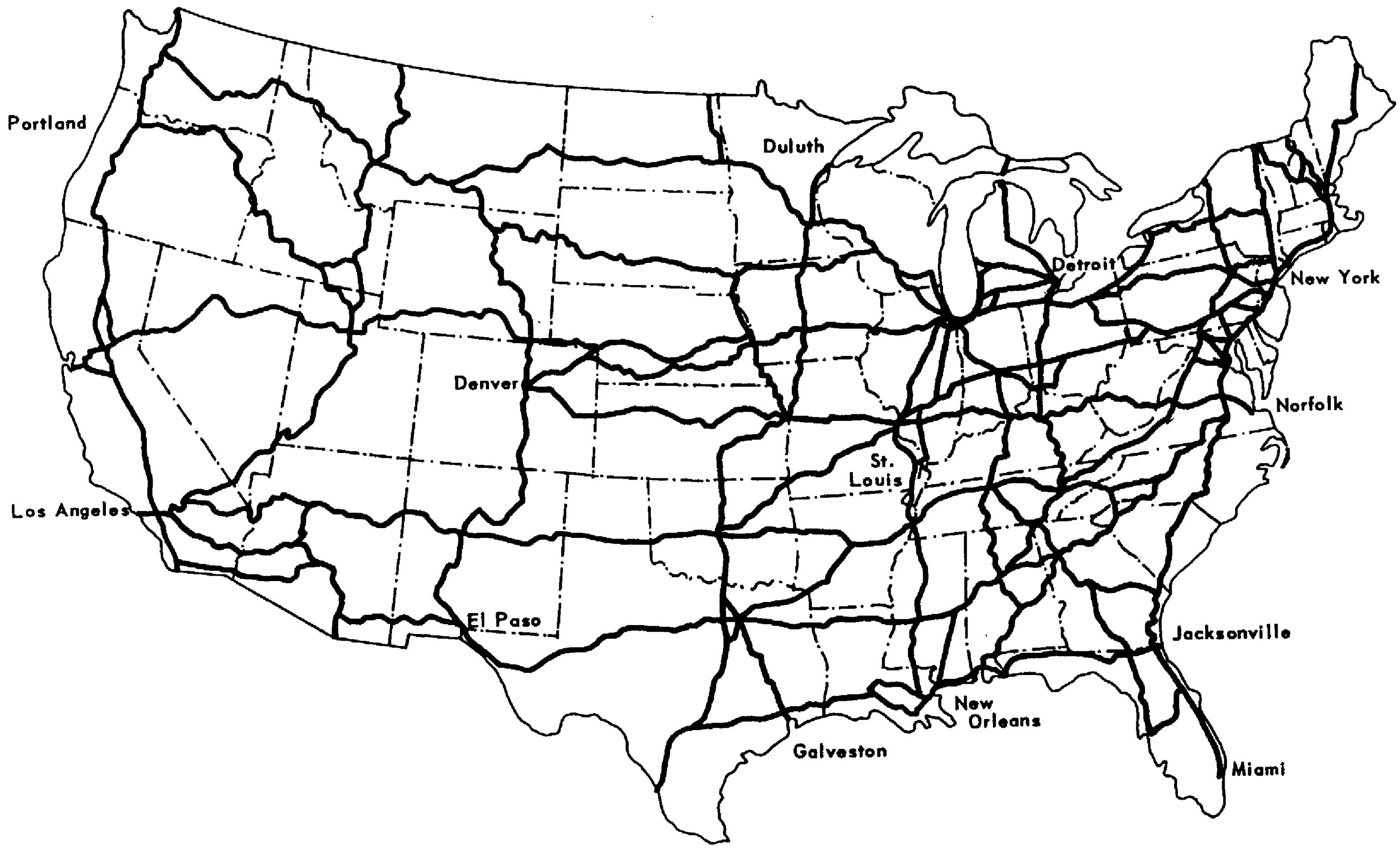

Fig. 12 — Proposed National System of Interstate Highways

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barriers, and the small likelihood that the highway system can be measurably improved during the time period considered in this appendix, it would seem that the feasibility of mass evacuation of large targets is highly questionable. Some small inland cities, such as Dayton, may be in a position to consider this tactic along with the other passive moves open to them.

MASS EVACUATION TO EXISTING SHELTER IN SMALLER TOWNS AND FARMS

Determining Feasibility

It has been suggested that residents of critical targets might evacuate and seek shelter in the basements and cellars of houses well outside the target area. To test the feasibility of such a tactic an area of approximately 8400 sq miles, including Washington and Baltimore, was inspected. This area was bounded on the north by the Pennsylvania state line, on the east by Chesapeake Bay, on the west by a straight line drawn to include Hagerstown, Md., and Warrenton, Va., and on the south by a straight line extending west from Smith Point, about 20 miles north of Richmond. The area northeast of Baltimore was not included, owing to the proximity of the Wilmington, Lancaster, and York targets.

The population of this area is 3.3 million, of whom 2.7 million live in the two critical targets. Of the remaining 0.6 million, 134,000 live in small towns that are not part of the target complex, an estimated 157,000 live on farms, and the rest live in suburbs adjacent to the targets.

Below-Grade Shelter Available. In the absence of an actual survey it is assumed that 50 percent of the dwellings might have below-grade shelter equivalent to 750 sq ft.* On this basis the towns alone could provide approximately 5½ sq ft of shelter for each inhabitant of the two critical targets.† The towns and farm buildings together could perhaps provide 10.7 sq ft of below-grade shelter for each evacuee. These figures exceed the minimum of 5 sq ft per person recommended by the FCDA.

Times Required. The number of traffic lanes leading from Baltimore and Washington to open country or smaller towns is 28 and 26 respectively. (These numbers do not include the lanes that lead only from Baltimore to Washington, the lanes that go from Baltimore northeast, or the lanes that lead only to the cities' suburbs.) Using the figure of 1000 vehicles per lane per hour, at least 9.5 and 13 hr, respectively, would be required to empty the target areas. An additional 2 hr would be required for the last vehicle to reach the median town, 70 miles distant. These times are well in excess of the 0.5 to 1.0 hr of warning time predicted for the two targets.

The three largest towns in the evacuation area were considered in detail. Table 6 shows their population, the below-grade shelter space available after the needs of the local residents have been subtracted, the number of evacuees who could be sheltered at the rate

*Along the Bay and in the Eastern Shore region below-grade shelter is negligible because of the high water table. It is estimated that in older inland towns and on farms up to 75 percent of the dwellings may have cellars, but many of these would be "root cellars" with far less than 750 sq ft. However, many farms have "bank barns," where one-half the structure is partly below grade. Many newer dwellings (up to 80 percent in some areas) are built on concrete slabs and have no available shelter. As a reasonably good over-all estimate, 50 percent was selected. (Information provided the author by the Maryland Civil Defense Administration.)

†This figure includes total basement space. It is presumed that in the event of emergency any basement space presently used for storage would be cleared.

of 5½ sq ft per person, the times required to enter the host town area, and the new population created. Since the times required to enter these towns are less than those required to leave the critical target areas, it seems clear that they would not constitute a further bottleneck.

TABLE 6

SOME EFFECTS OF EVACUATING MAJOR TARGET POPULATIONS TO SMALLER TOWNS

Town	Population	Basement shelter available to evacuees, thous of sq ft	Evacuees who could be sheltered	Time required to enter host town, hr	New population of host town
Frederick	18,142	1900	349,000	7.0	367,000
Hagerstown	36,260	3800	698,000	7.8	734,000
Fredericksburg	12,156	1300	234,000	5.9	246,000

Feasibility

The claim of feasibility of such a scheme is more vulnerable when one considers the traffic problem a town with normal provision for 5000 cars would have in trying to provide egress and storage for 70,000 additional vehicles. Bumper-to-bumper parking could be provided for this number of vehicles on approximately 350 acres of land (needless to say, these acres would have to be dry and unblocked by fences, ditches, etc.). The control and practice required to make such a scheme workable is probably beyond capability.

An even more serious problem is constituted by the new targets presented. Any civil defense plan must be public to be effective, and hence known in advance to the enemy. These three towns, beyond the range of present point defenses, would have new populations — 367,000, 734,000, and 246,000, respectively — concentrations worthy of the attention of enemy target analysts. Furthermore these populations are now so highly concentrated that a single 10-Mt weapon can place the entire sheltered population in the crater or lip, with resulting 100 percent lethality.

In view of the times required to carry out this tactic (11.5 to 15 hr), the magnitude of the planning and practice required, and the high vulnerability of the new configurations created, the tactic of evacuating critical targets to satellite towns is not considered feasible.

On receipt of a strategic alert of perhaps 24 hr such a plan might be carried out, if only time is considered. This would not alter the fact that new, highly vulnerable targets have been created. It should further be pointed out that people in shelters for a long period of time require many times the 5 to 10 sq ft of space allotted them in this study. It does not seem advisable to attempt to augment existing space with sheds, tents, barns, etc., or any structure that will attenuate less than 0.9 of the radiation effects. Figure 13 shows fallout conditions created by 10-Mt ground bursts on all the FCDA-designated critical targets within a 300-mile radius of Washington. The method of computation is described later in this paper. At least sometime during the 36-day sample of fallout conditions, Hagerstown and Frederick were exposed to 500 to 1600 r, and Fredericksburg to 100 to 500 r.

It seems clear that only below-grade shelter could be used. On the basis that at least 20 sq ft per occupant would be necessary, only approximately one-fourth of the evacuees that this study estimates the towns could shelter could actually stay there for extended periods, and then only after advance preparation of supplies, toilet facilities, etc.

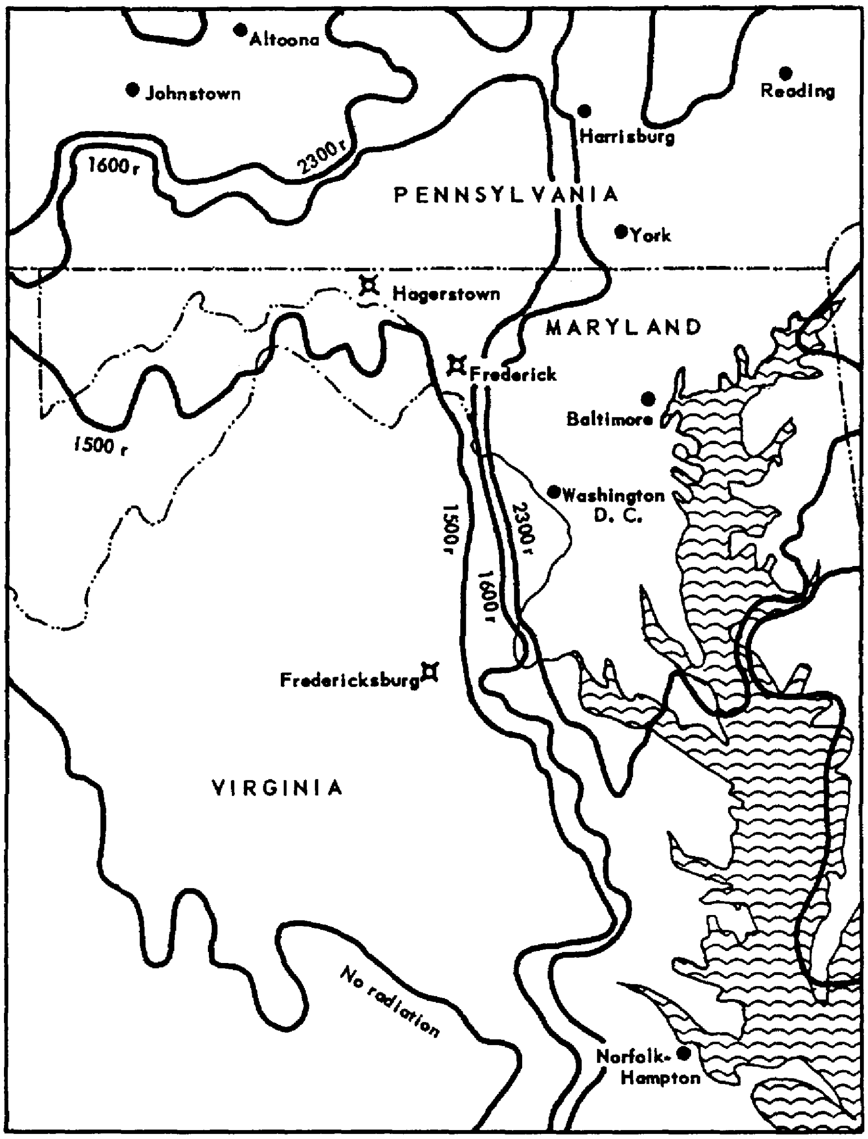

Fig. 13 — Possible Fallout Conditions in Host Towns

PRIVATE AND PUBLIC SHELTERS

The feasibility of constructing both family and public shelters capable of withstanding blast overpressures up to 100 psi has been adequately demonstrated at atomic test sites under the auspices of FCDA and others.[15] The serious problems relating to the feasibility of this tactic are largely in the field of motivation. To date, efforts on the part of FCDA and other civil defense organizations to motivate the public to build home shelters have been met with apathy. Efforts to promote the construction of public underground shelters have likewise been unsuccessful. The effect of a consistent program of public education along these lines is problematical.

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A second problem related to shelter construction is the shortage of land in those areas of the city where the population is most concentrated. Apartment dwellers and day workers in the heart of the city must rely on public shelters. In the Washington target, land for such purposes would have to be acquired by condemnation procedures or by the use of space now devoted to public parks. The use of parks for any purpose other than recreation has been bitterly contested; condemnation is a very expensive and time-consuming procedure.

It is probable, however, that with continuing deterioration of international relations, motivation to take protective action may increase to the point where both the problem of public apathy and unwillingness to use public land for shelter construction may disappear, as was the case in WWII in Europe. In any event there seems to be insufficient evidence at this time for ruling out public and private shelters as one possible civil defense action.

EFFECTIVENESS OF CIVIL DEFENSE ACTIONS

In this section the desirability of one civil defense action over another is considered through comparing the proportions of the target populations that would be killed by enemy attacks with various numbers of 10-Mt ground-burst weapons delivered with various CEP when the civil defense action is (a) to seek the best shelter now available, (b) to seek shelter with 3 ft of earth cover, and (c) mass evacuation.

DEATHS FROM IMMEDIATE EFFECTS

Method of Study

Resident population data for 1950 were distributed into cells 2000 by 2000 m each and variances were computed for the cities as binormal surfaces. These data are shown for Boston, Dayton, Milwaukee, St. Louis, and San Francisco in Figs. 3 to 7. For the Washington target, 1955 population data were obtained and were arrayed in cells 2 by 2 miles each. Weapons with the population lethality rates shown in Fig. 9 were then aimed at the centers of population * and cumulative deaths were computed. Where mass evacuation was the civil defense action the variances were increased at the rates indicated by the Washington evacuation model (Table 5 and Fig. 10), and for Boston, Dayton, Milwaukee, and St. Louis were modified on the basis of the number of lanes leaving the target areas (Table 3). Since evacuation was not considered feasible for San Francisco (evacuation model indicated that 11+ hr would be required to carry out this tactic), that area is not given further consideration. The minimum times assumed to be spent in evacuating the target were taken as equal to the warning times expected now, and the maximum as equal to the warning times expected by the end of 1959 (Table 4).† Further methodological details are given in Annex A.

Results

The results of these comparisons are given in Table 7 and Figs. 14 to 28. Figures 14 to 18 compare deaths from immediate effects from a single 10-Mt weapon for different courses of civil defense action when the CEP of the attack varies to 12,000 m; Figs. 19 to 28 compare the deaths resulting from different courses of action for 4000- and 12,000-m CEP attacks when one to four 10-Mt weapons are employed.

*Although this study is limited to single aiming points, it should be pointed out that for all practical purposes an attack with CEP as large as 12,000 m can be considered an attack with random aiming points throughout the target.

†Even though no warning time or 0.5-hr warning time is indicated now for coastal cities, 1 hr was granted them in this study, on the basis that evacuation would not be considered with only a 0.5-hr warning available. In addition, for Washington and Boston 3 hr was used for comparative purposes, even though it is unlikely that such times will be available.

Several patterns emerge from inspection of these data.

(a) In every case, increased CEP of the attack favors the defender; this may be a function of the decreasing probability of hitting the highly concentrated city center plus the probability of the weapon landing outside the target.

(b) With increased CEP of the attack the difference in immediate deaths as a function of taking one civil defense action or another is markedly reduced.

TABLE 7

PERCENTAGE TARGET POPULATION KILLED IN ATTACKS OF VARIOUS SIZE AND CEP FOR VARIOUS CIVIL DEFENSE ACTIONS

Target and defender action	Deaths, percent											
	10-Mt weapons, CEP 4000 m				10-Mt weapons, CEP 8000 m				10-Mt weapons, CEP 12,000 m			
	1	2	3	4	1	2	3	4	1	2	3	4
Boston												
Best available shelter	36	55	66	73	27	46	60	69	19	34	47	58
Underground shelter	10	17	23	28	6	12	18	23	4	8	12	16
Minimum evacuation (1 hr)	31	47	58	64	24	41	54	63	17	32	43	53
Maximum evacuation (3 hr)	19	30	37	42	16	28	37	44	13	23	32	40
Dayton												
Best available shelter	66	92	—	—	40	66	83	94	25	44	59	71
Underground shelter	24	43	56	67	11	21	30	38	6	11	17	22
Minimum evacuation (1.5 hr)	13	20	26	29	11	20	27	33	10	18	25	31
Maximum evacuation (4 hr)	6	9	12	14	5	9	13	15	5	9	13	17
Milwaukee												
Best available shelter	62	87	99	—	39	65	81	92	24	43	58	70
Underground shelter	22	39	52	62	11	20	29	36	6	11	16	21
Minimum evacuation (1 hr)	27	43	52	59	22	37	49	58	16	29	40	50
Maximum evacuation (4 hr)	10	17	21	24	9	17	22	27	8	15	21	26
St. Louis												
Best available shelter	54	78	91	98	35	59	75	86	23	41	55	67
Underground shelter	17	30	41	49	9	18	26	33	5	10	15	20
Minimum evacuation (2 hr)	16	26	32	37	14	25	33	40	11	21	30	37
Maximum evacuation (4 hr)	10	16	20	23	9	16	21	26	10	15	21	26
Washington												
Best available shelter	48	71	84	92	33	56	71	82	21	39	53	64
Underground shelter	14	26	35	42	8	16	23	29	5	10	14	19
Minimum evacuation (1 hr)	13	22	28	32	12	20	28	34	10	18	25	32
Maximum evacuation (3 hr)	6	10	13	15	6	10	14	17	5	10	14	18

(c) Increased CEP of the attack favors shelter policies rather than a policy of evacuation; in every case where shelter is not preferable to evacuation regardless of CEP there is some critical CEP where a "stay put" policy results in fewer casualties than the amount of evacuation available for the next few years. Thus for Boston, even seeking the best shelter now available is preferable to evacuation when the CEP reaches 10,000 m (Fig. 14). For the Dayton target, evacuation is less effective than underground shelter at CEP above 8000 m (Fig. 15). The same situation exists for St. Louis after 5000 m (Fig. 17) and for Washington above 6000 m (Fig. 18).

(d) When the CEP reaches 12,000 m, evacuation is preferable to underground shelter for only one target, Dayton (Fig. 22), and even then only for the maximum warning time.

(e) Increasing the number of weapons used in the attack exaggerates the difference in numbers of persons killed as a function of taking different civil defense actions. Thus for Boston the difference in the percentage of population killed as a result of taking the least

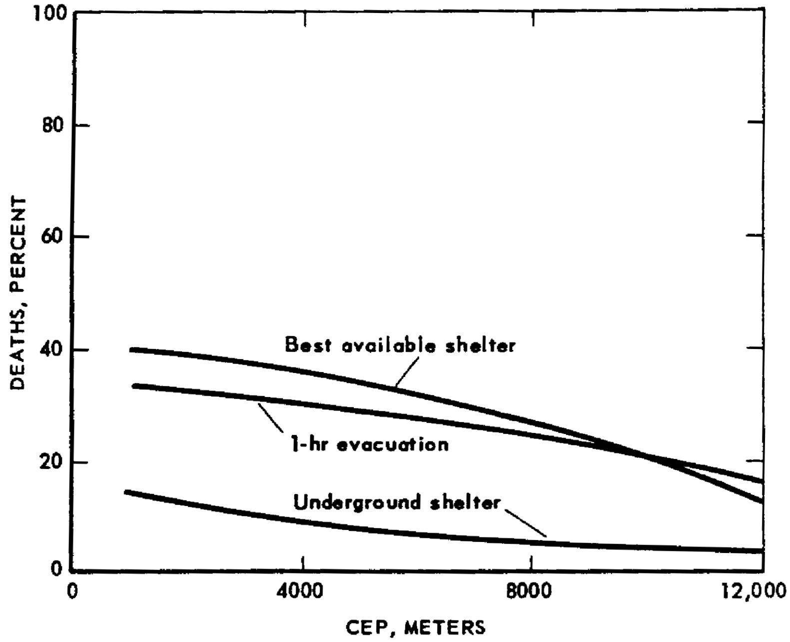

Fig. 14 — Percentage Boston Resident Population Killed by Single 10-Mt Weapon, CEP to 12,000 m

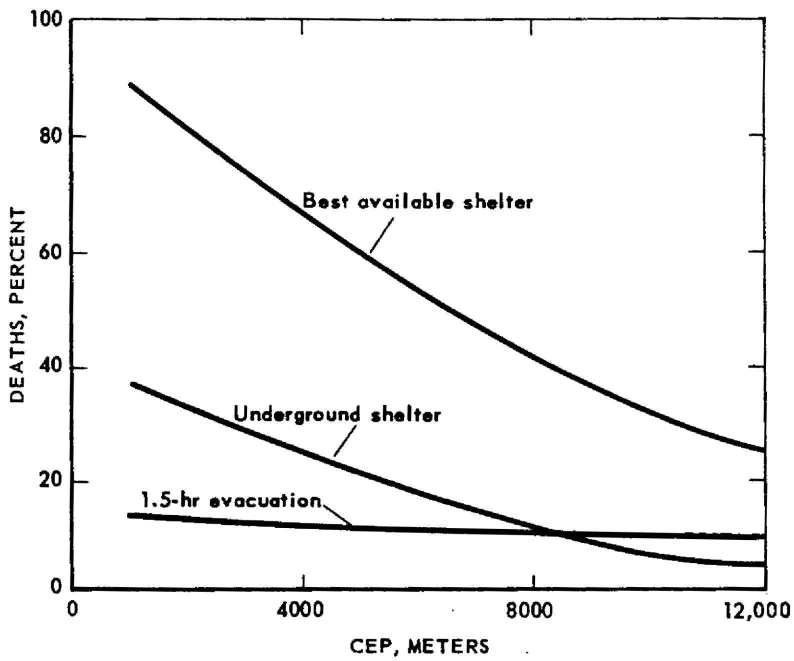

Fig. 15 — Percentage Dayton Resident Population Killed by Single 10-Mt Weapon, CEP to 12,000 m

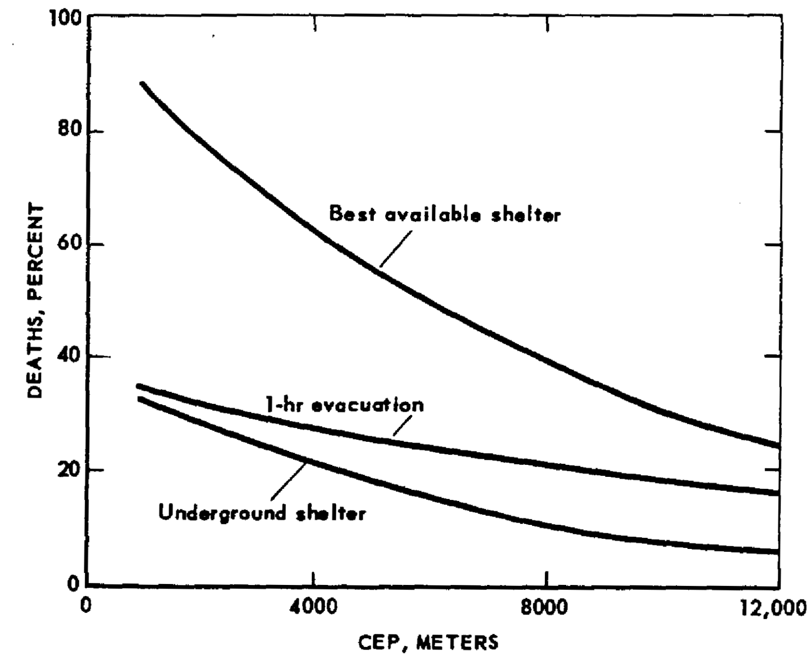

Fig. 16 — Percentage Milwaukee Resident Population Killed by Single 10-Mt Weapon, CEP to 12,000 m

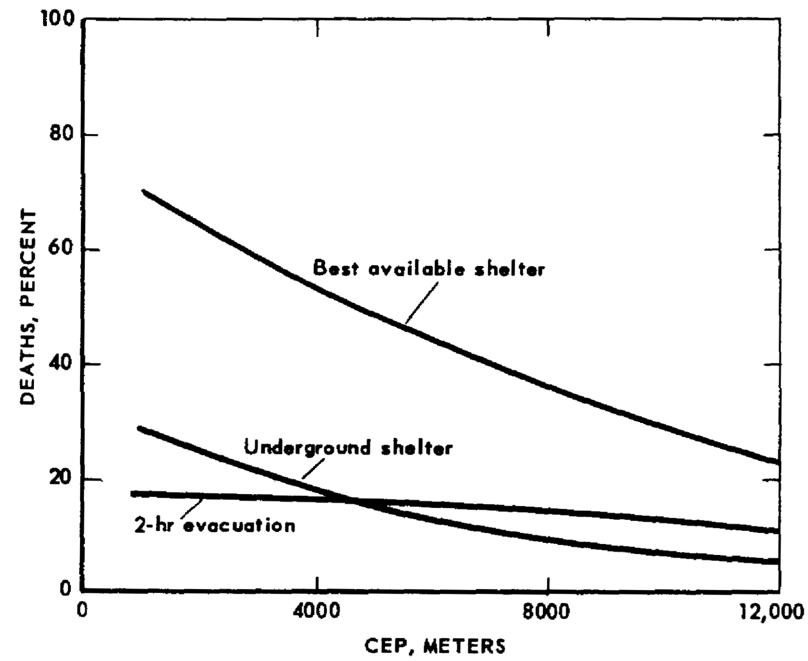

Fig. 17 — Percentage St. Louis Resident Population Killed by Single 10-Mt Weapon, CEP to 12,000 m

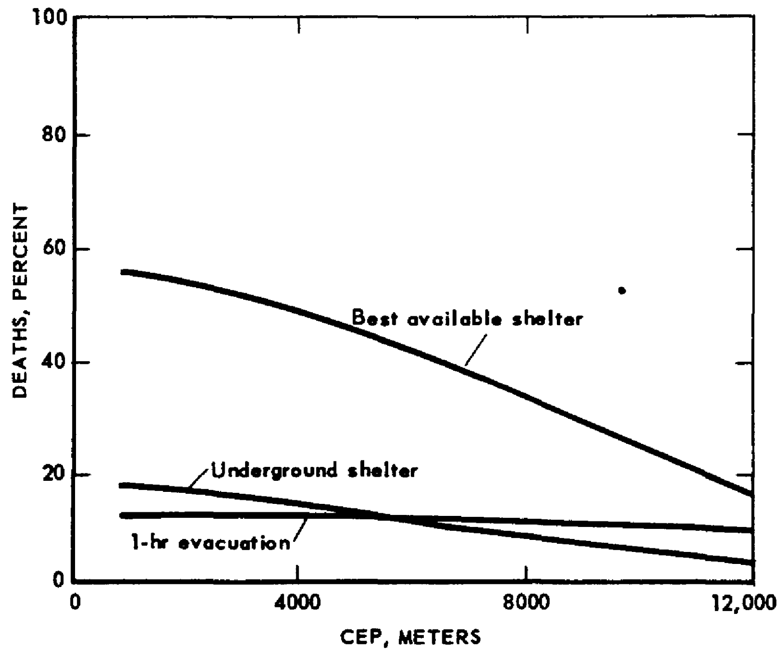

Fig. 18 — Percentage Washington Resident Population Killed by Single 10-Mt Weapon, CEP to 12,000 m

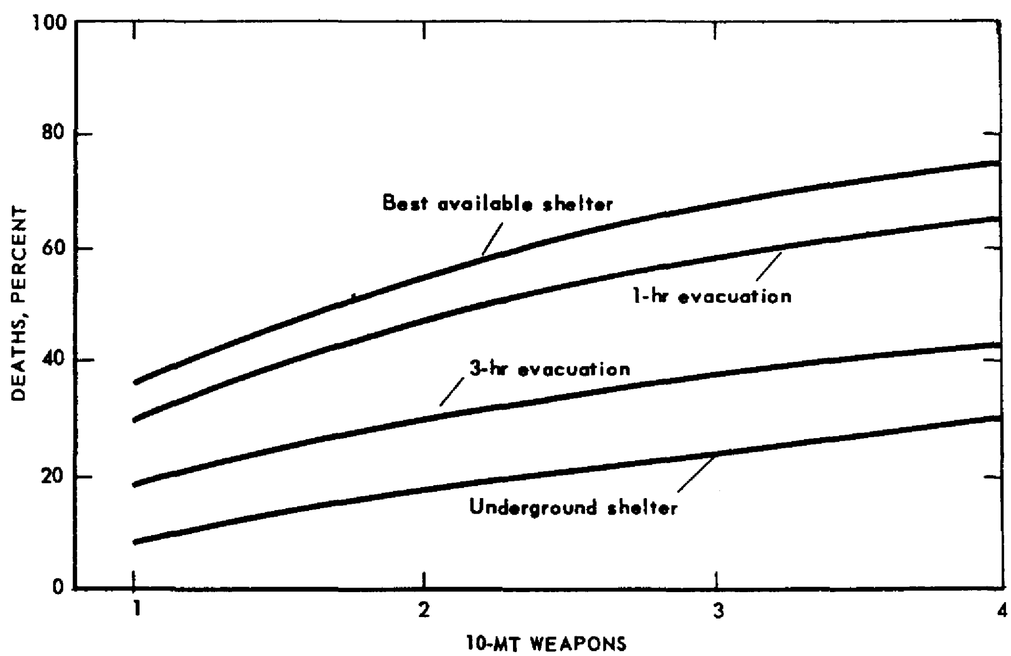

Fig. 19 — Percentage Boston Resident Population Killed by One to Four 10-Mt Weapons, CEP 4000 m

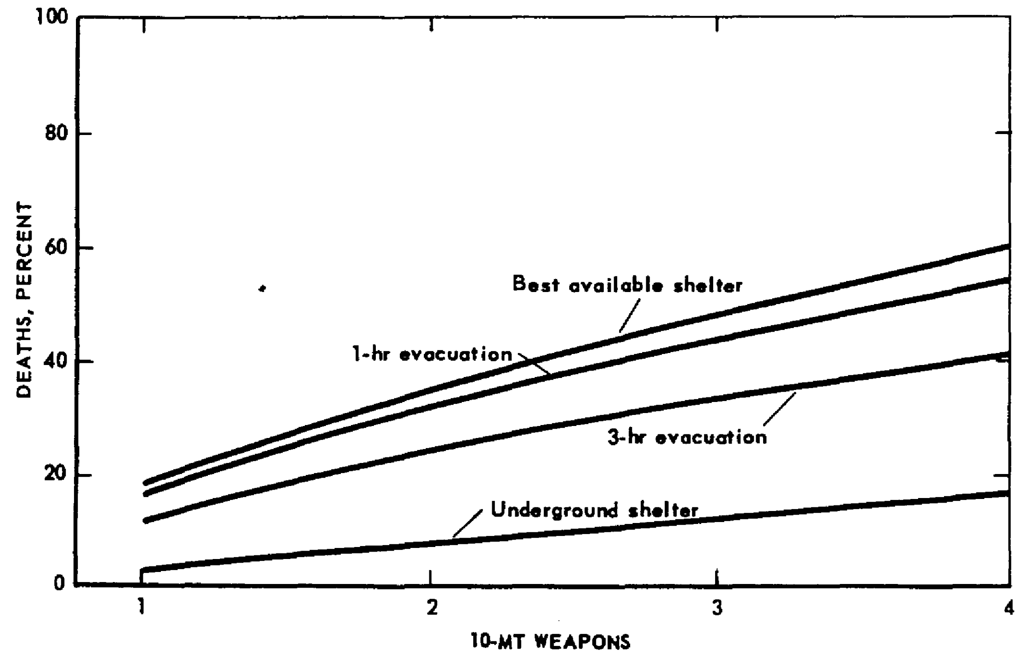

Fig. 20 — Percentage Boston Resident Population Killed by One to Four 10-Mt Weapons, CEP 12,000 m

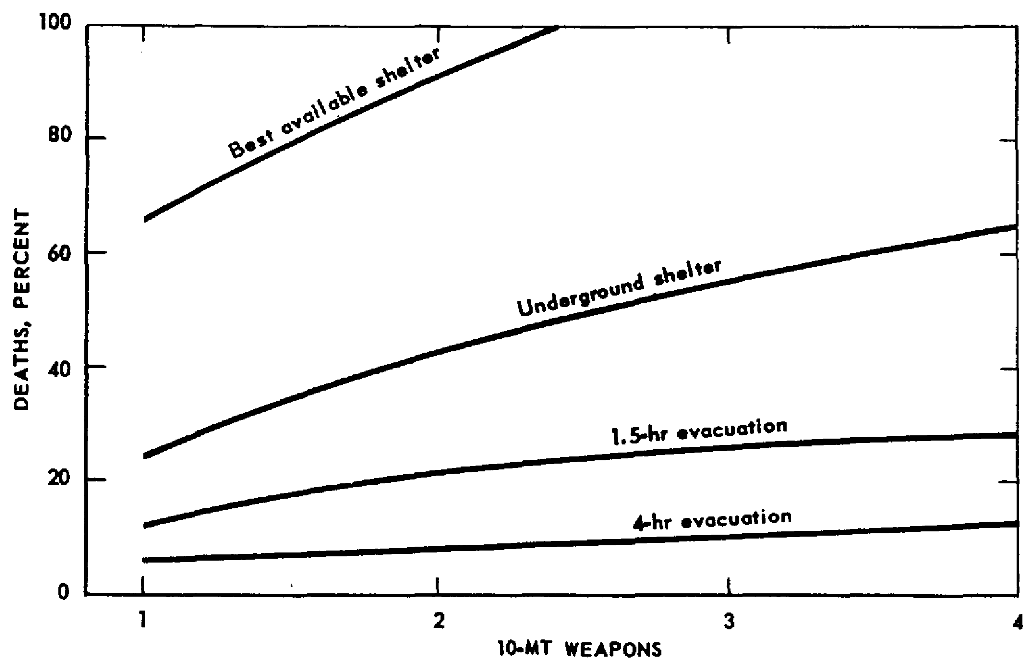

Fig. 21 — Percentage Dayton Resident Population Killed by One to Four 10-Mt Weapons, CEP 4000 m

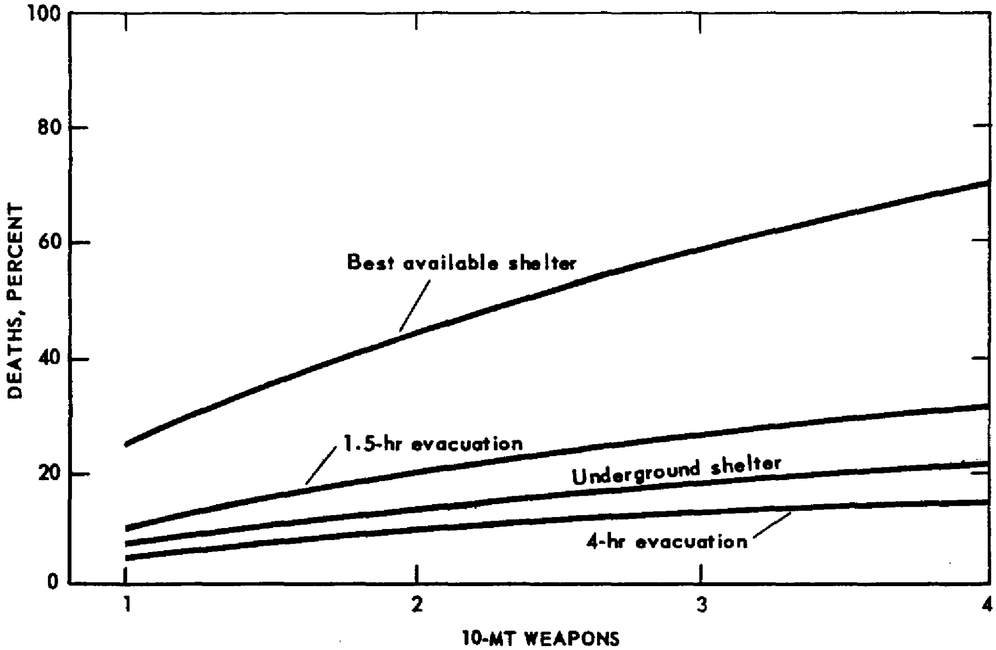

Fig. 22 — Percentage Dayton Resident Population Killed by One to Four 10-Mt Weapons, CEP 12,000 m

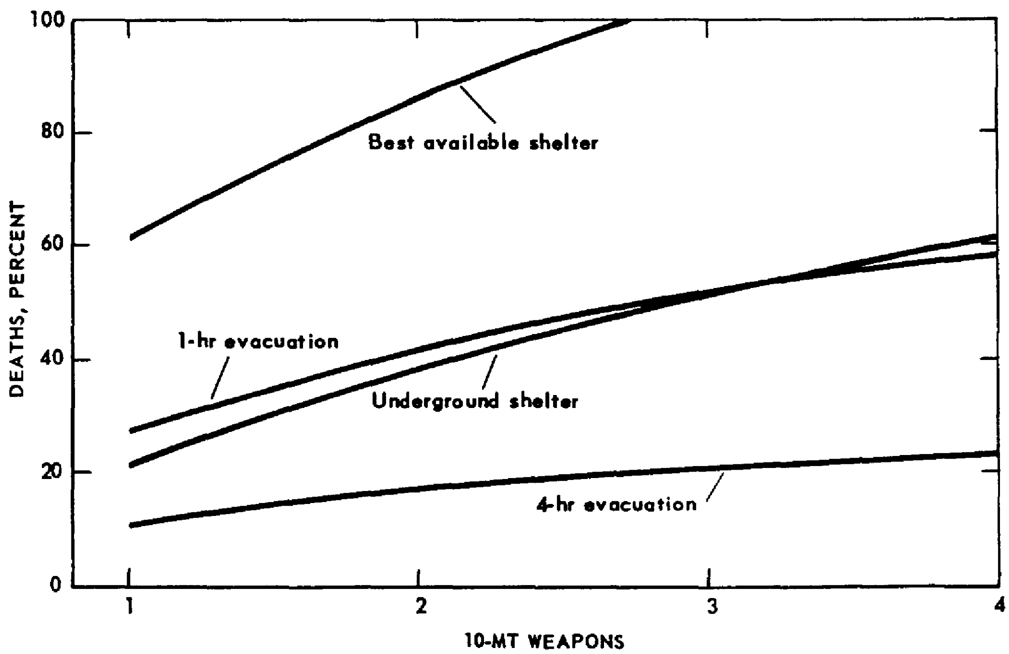

Fig. 23 — Percentage Milwaukee Resident Population Killed by One to Four 10-Mt Weapons, CEP 4000 m

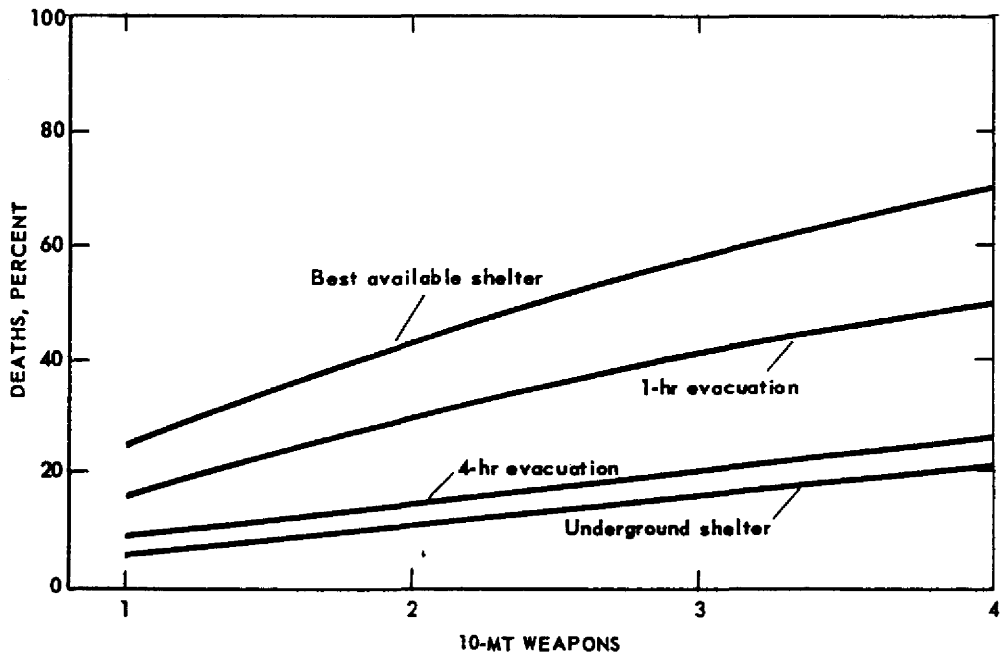

Fig. 24 — Percentage Milwaukee Resident Population Killed by One to Four 10-Mt Weapons, CEP 12,000 m

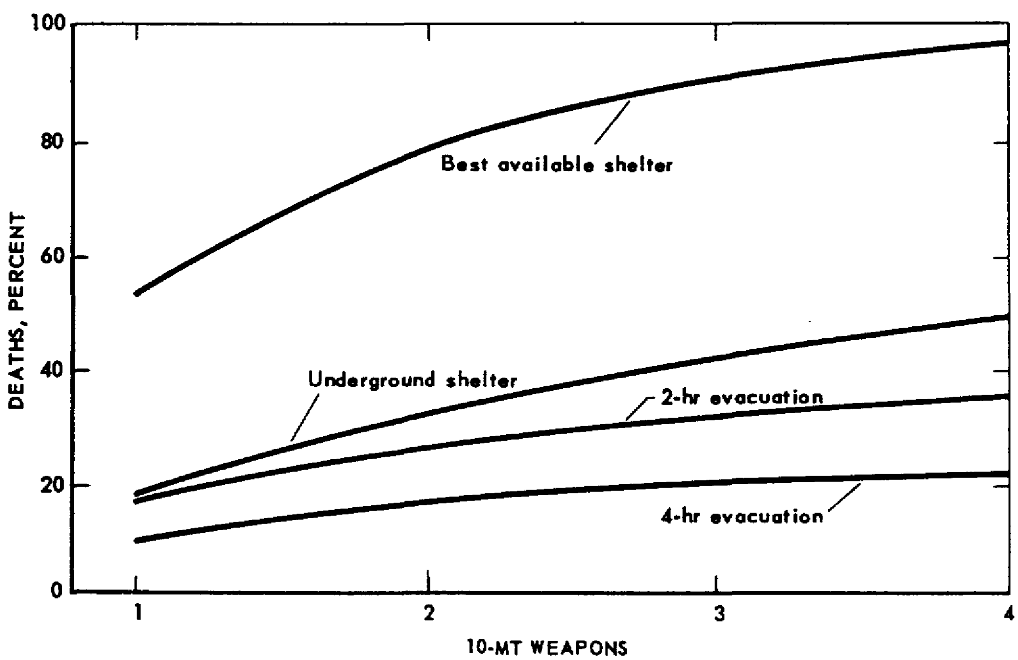

Fig. 25 — Percentage St. Louis Resident Population Killed by One to Four 10-Mt Weapons, CEP 4000 m

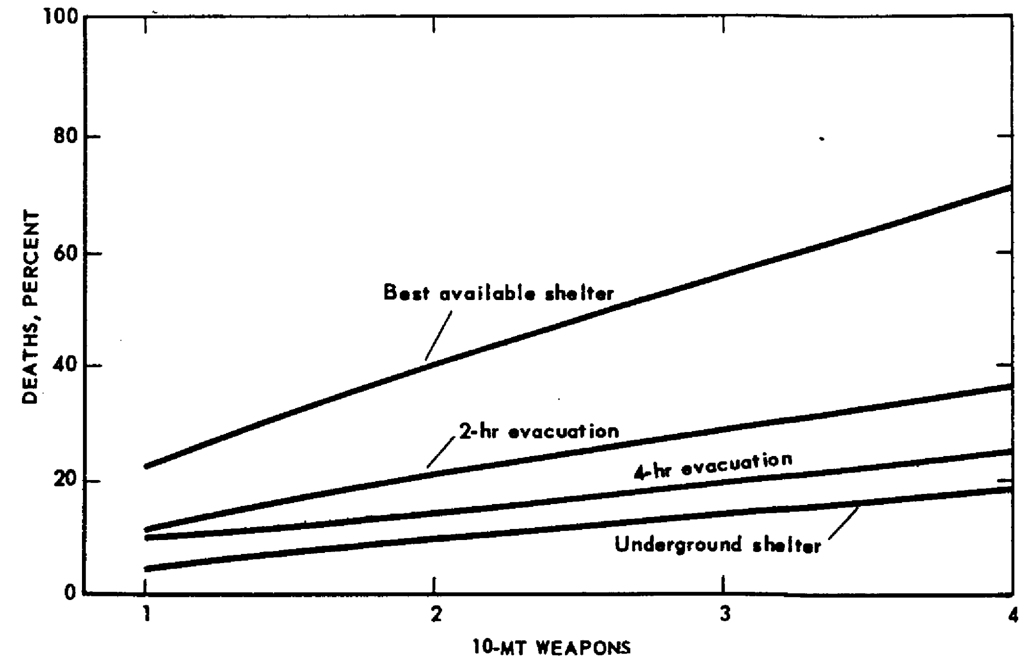

Fig. 26 — Percentage St. Louis Resident Population Killed by One to Four 10-Mt Weapons, CEP 12,000 m

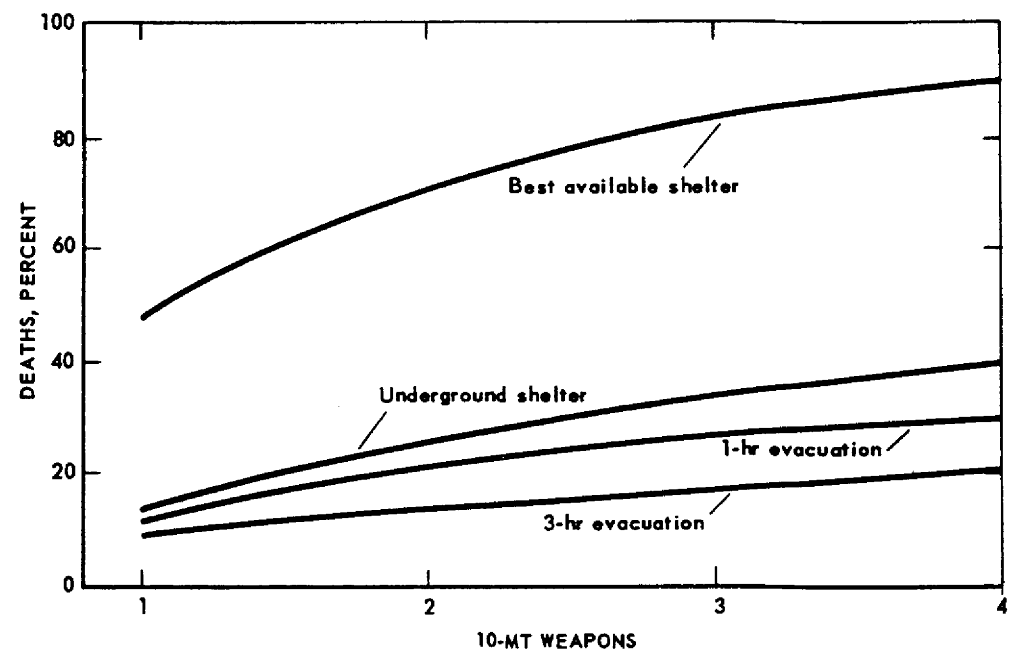

Fig. 27 — Percentage Washington Resident Population Killed by One to Four 10-Mt Weapons, CEP 4000 m

or most desirable course of action is about 25 percent for a single weapon but about 50 percent when four weapons are employed (for a 4000-m CEP, Fig. 19). When the CEP is 12,000 m (Fig. 20) the differences are 15 percent for one bomb but 45 percent for four bombs.

(f) Perhaps the most outstanding finding from these comparisons is that cities differ in the optimum civil defense action they can take. The relative effectiveness of these actions varies with their size, population distribution, road net, and probable warning time. Thus for Boston underground shelter results in fewer casualties under all conditions of CEP and attack size (Figs. 19 and 20), whereas for Dayton minimum or maximum evacuation is preferable for small CEP, and 4-hr (but not 1.5-hr) evacuation for large CEP (Figs. 21 and 22). For the remaining targets, evacuation seems preferable when the CEP is small, and underground shelter best when the CEP is large; however, the magnitude of differences due to taking one or another civil defense action is by no means uniform.

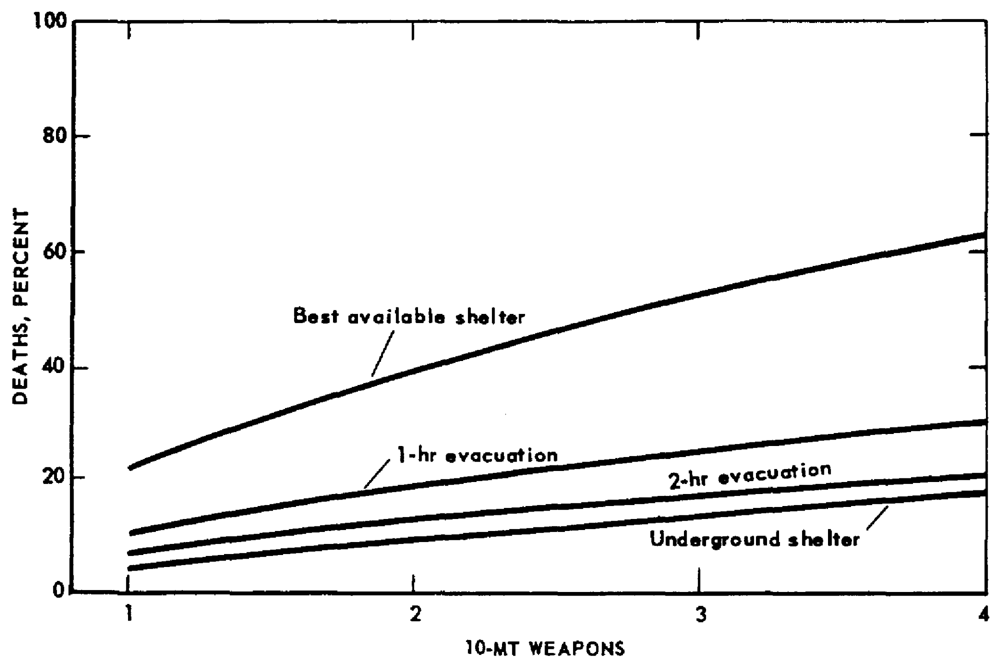

Fig. 28 — Percentage Washington Resident Population Killed by One to Four 10-Mt Weapons, CEP 12,000 m

DEATHS FROM FALLOUT

Method of Study

It should be emphasized that none of the preceding comparisons consider the probabilities of additional deaths from indirect radiation (fallout). To afford some insight into the dimensions of this threat a model attack was developed that delivered from two to four 10-Mt weapons on the Washington-Baltimore targets.

A sample of 137 upper wind readings was drawn at random from 1955 US Weather Bureau teletype information. The sample composed about three-fifths of the available readings. These were separated into summer and winter readings and into low-, medium-, or high-speed winds according to a system developed by Technical Operations Incorporated, as described in another ORO study.[16]

Briefly, this system considers the distance to which a 100-μ particle will travel from a height of 60,000 ft. A "low" wind-speed pattern results from the particle traveling 30 miles or less; a "medium" pattern, 31 to 150 miles; and a "high" pattern, 150 or more miles.

Tabulation of readings by season, wind speed, and bearing (see Table 8) indicated that in the winter months high wind patterns could be expected 63 percent of the time, and that 40 percent of the time the most likely bearing would be 80 deg. During the summer months the modal pattern was moderate winds (67 percent of the time), 26 percent of the time with a bearing of 110 deg. There was considerably more variability both as to speed and bearing of upper winds during summer months. During summer months the 100-μ particle could be expected to fall to the west of GZ (between 180 and 360 deg) 21 percent of the time, whereas in the winter sample this occurred only 3 percent of the time.

TABLE 8

WIND PATTERN AND BEARING AS FUNCTION OF SEASON

Bearing, deg	Distribution of wind patterns					
	June through September			October through March		
	Low	Moderate	High	Low	Moderate	High
0–30		2				1
31–60		3	1		6	2
61–90	5	12	2		2	21
91–120	2	17	2		7	11
121–150	4	5	1		4	1
151–180	2	5				
181–210		5				
211–240	3	1			1	
241–270	2					
271–300	2	1			1	
301–330		1				
331–360		2				
Total	20	54	6		21	36

Four GZ for weapons aimed at the center of Washington and three GZ for weapons aimed at the population center of Baltimore were selected on a probability basis for attacks with CEP of 4000, 8000, and 12,000 m. Fallout contours were then drawn over a population map and the number of expected deaths for the corrected 48-hr cumulative dose * were computed by multiplying the population enclosed by the mortality coefficients shown in Fig. 29.[17]

*It was assumed that on the Eastern Shore shelter would be available that would attenuate radiation by a factor of 0.5 and on the mainland by a factor of 0.9 (the high water table on the Eastern Shore precludes most below-grade construction). Overlapping fallout contours were considered to be directly additive. Deaths due to close-in or stem fallout around GZ are not included in these comparisons. (The limits of collapse to wood-frame dwellings extend nearly to the 500-r limit. Deaths in this area are presumed to be from blast and thermal injury and from the combined effects of radiation, fractures, lacerations, and burns.)

Two attacks were postulated — a winter attack using a high wind pattern and a bearing of 80 deg and a summer attack with a moderate wind pattern and a bearing of 110 deg. Fallout contours for attacks with CEP of 4000 and 12,000 m are illustrated in Figs. 30 and 31.

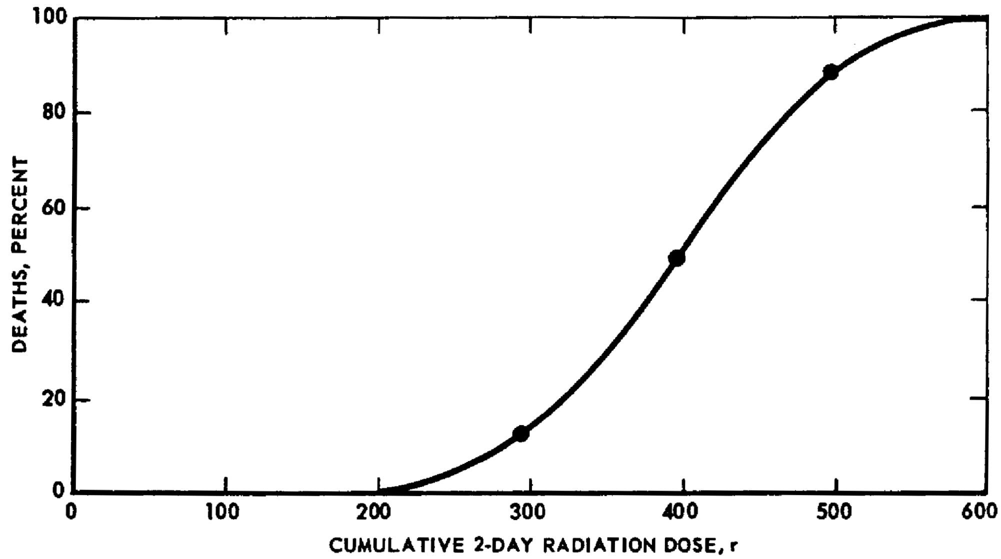

Fig. 29 — Percentage Deaths as Function of Cumulative 2-Day Radiation Dose

Results

Table 9 shows the expected deaths from these attacks. Several points emerge.

(a) It can be seen that although the number of deaths increases with the number of weapons, the increase is by no means linear. When the GZ are concentrated (CEP 4000 m), the greatest increase occurs as a function of dropping two weapons rather than one on each target, resulting in an increase for most of the target from a corrected dose (dose received in shelter with 0.9 attenuation) of 250 r, which kills only 5 percent of the population, to a corrected dose of 500 r, which can be expected to kill 88 percent. The smaller increase in the number of deaths resulting from dropping a total of seven weapons rather than four can be attributed to the fact that few new populations are encountered and the increase can come only from the remaining 12 percent of the population not killed by the previous attack. When the CEP is large (12,000 m), the increase in deaths with increase in number of bursts tends to be more uniform, since fallout occurs over larger areas and new populations are encountered.

(b) Although the winter fallout pattern is of less intensity and smaller area than the summer pattern, more people are killed by the winter pattern when the number of bursts is large enough to create lethal concentrations. This seems to be almost entirely due to the winter bearing of 90 deg, which carries the fallout over the more densely populated northern peninsula, including the Atlantic City area.

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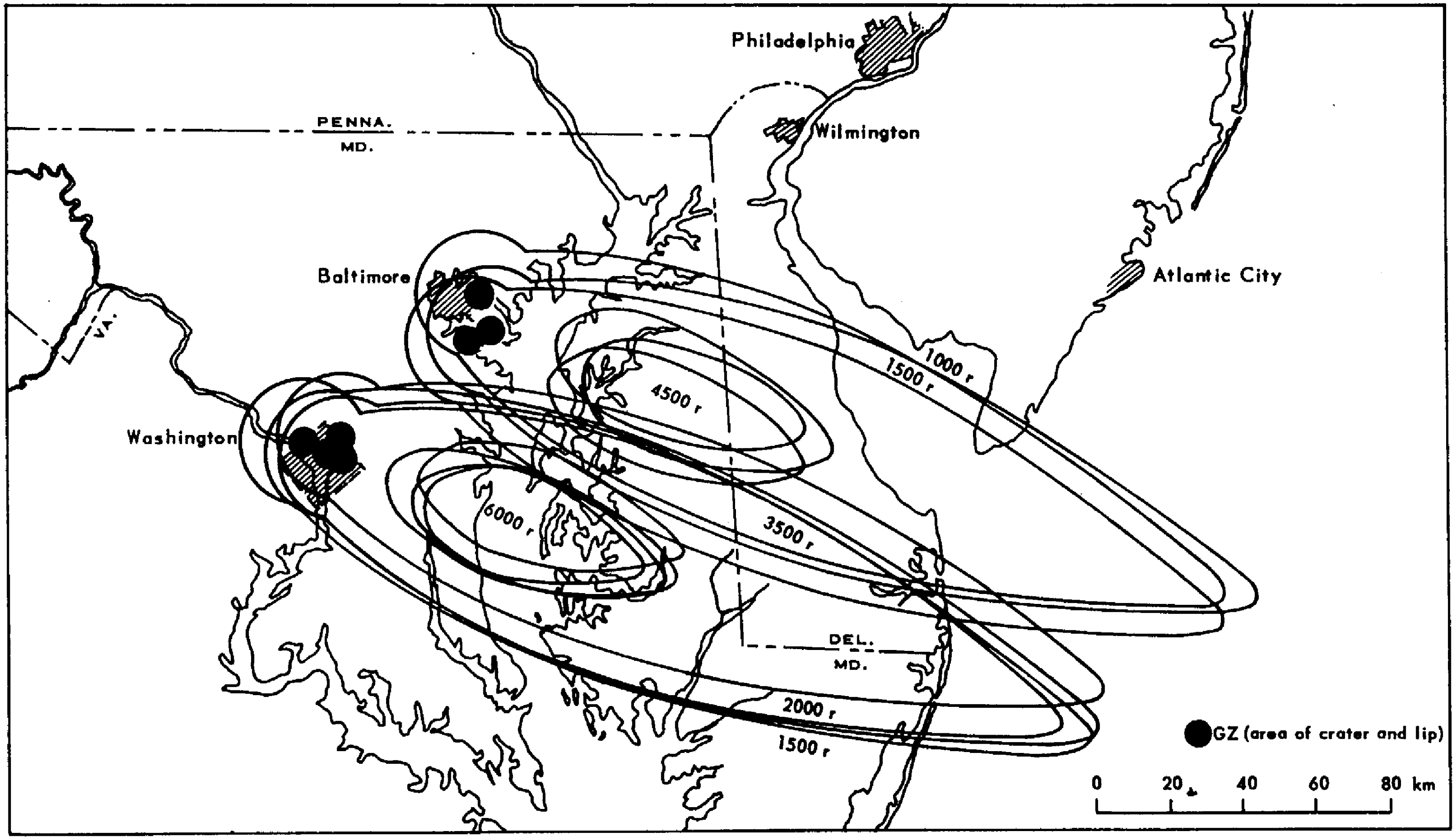

Fig. 30 — Fallout Contours for Washington-Baltimore Attack with Seven 10-Mt Weapons, CEP 4000 m
Moderate-speed wind, bearing 110 deg; cumulative 2-day radiation dose.

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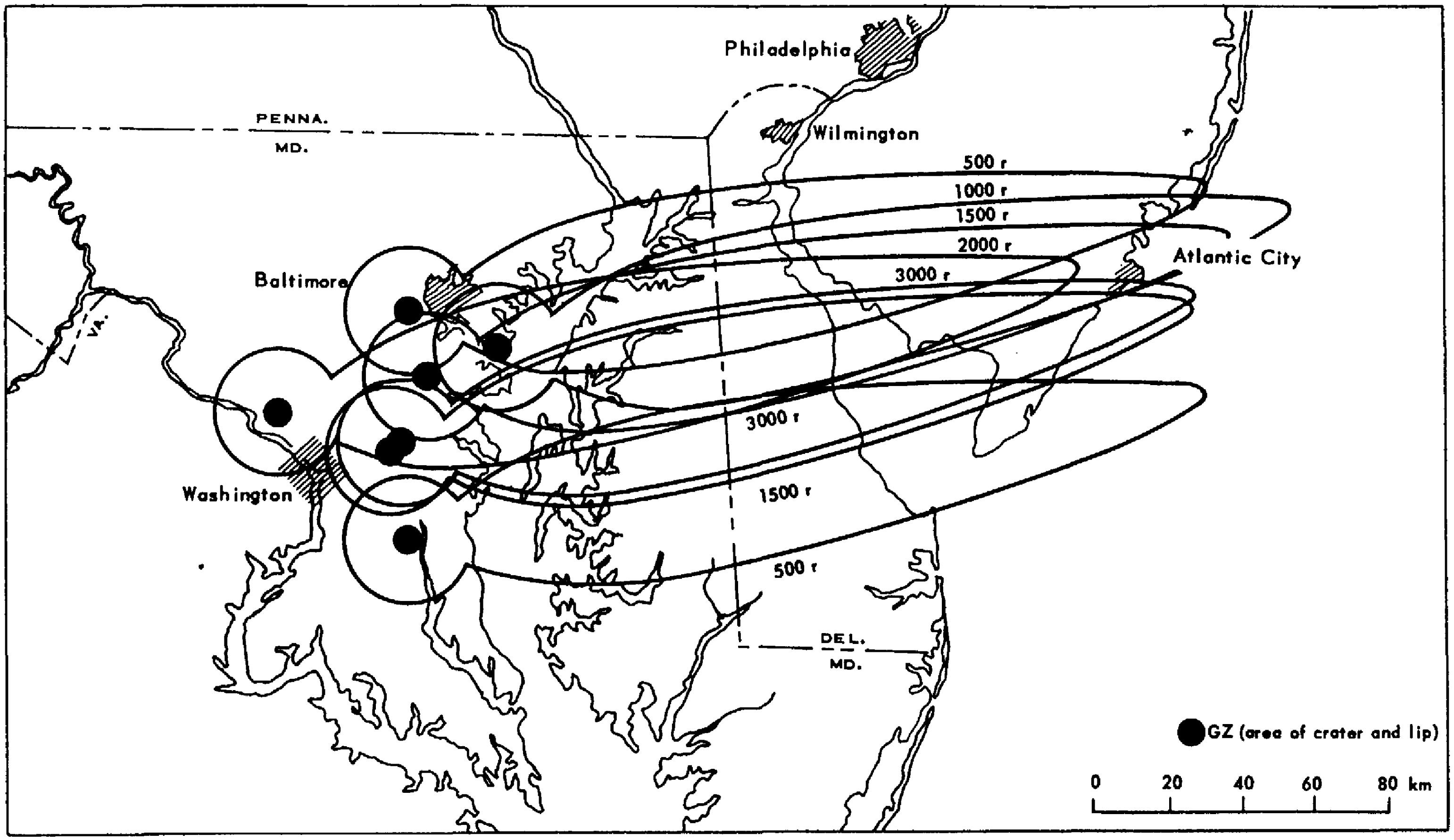

Fig. 31 — Fallout Contours for Washington-Baltimore Attack with Seven 10-Mt Weapons, CEP 12,000 m
High-speed wind, bearing 80 deg; cumulative 2-day radiation dose.

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(c) Although the proportion of deaths from fallout increases slightly with the CEP of the attack, the deaths from fallout alone are a very small proportion of the deaths from the attack as a whole. This finding is borne out also in App C of this report.

It should be emphasized that the figures cited here assume no evacuees from urban targets, but are based on the relatively sparse rural and small town populations residing in the area.

TABLE 9

DEATHS FROM FALLOUT AS FUNCTION OF ATTACK SIZE, CEP, AND SEASON

Bombs	Deaths, thous		
	CEP 4000 m	CEP 8000 m	CEP 12,000 m
	Summer		
2	73	78	72
4	220	200	103
7	262	261	246
	Winter		
2	12	76	22
4	490	138	245
7	470	282	323
Additional from blast and thermal effects, any season			
2	2361	1742	510
4	3001	2574	1056
7	3401	3438	1214

FALLOUT AND EVACUATION

It is now possible to estimate the number of additional deaths from fallout that can be expected as a function of 1- or 3-hr evacuation radiating outward from the city.

Figure 27 indicates that for a 4000-m CEP attack 12 percent of Washington's population would be killed by a single weapon when the civil defense tactic was 1-hr evacuation, and 9 percent when the tactic was 3-hr evacuation. Figures 30, 32, and 33 show actual GZ for a 4000-m CEP summer attack of one, two, and four bombs on the Washington target. Using Fig. 10 as a guide to the new population concentrations created by 1-hr evacuation, it is apparent that approximately 33 percent of the city's population who were not killed by blast and thermal effects would be exposed to a dose of 500 r. Allowing an attenuation factor of 0.5 for shelter equivalent to an automobile or shed-type building, and applying a mortality coefficient of 0.05 for the corrected dose of 250 r, a new estimate of at least 14 percent instead of 12 percent is appropriate when 1-hr evacuation is the civil defense tactic.

The disadvantages of evacuation become striking when the number of bombs increases. Figure 33 indicates that for two bombs per target approximately the same percentage of the evacuating population would be exposed to 500 r as for one bomb, resulting in a revised estimate — 51 percent mortalities instead of the 22 percent computed when fallout was not considered. With four 10-Mt ground bursts, as indicated in Fig. 30, all but perhaps 15 percent of the population of Washington is destroyed by either blast or thermal effects or lethal degrees of radiation.

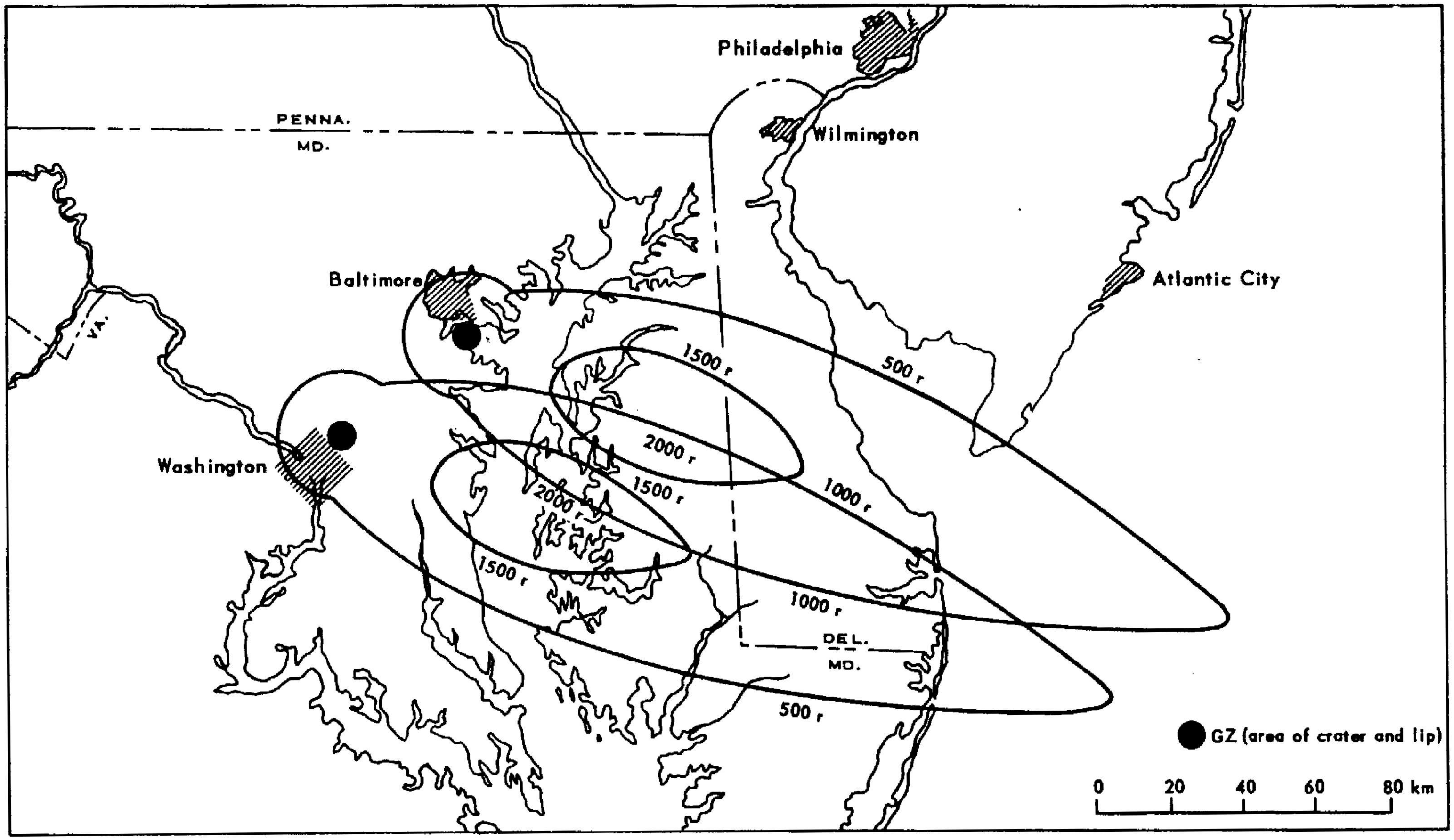

Fig. 32 — Fallout Contours for Washington-Baltimore Attack with Two 10-Mt Weapons, CEP 4000 m
Moderate-speed wind, bearing 110 deg; cumulative 2-day radiation dose.

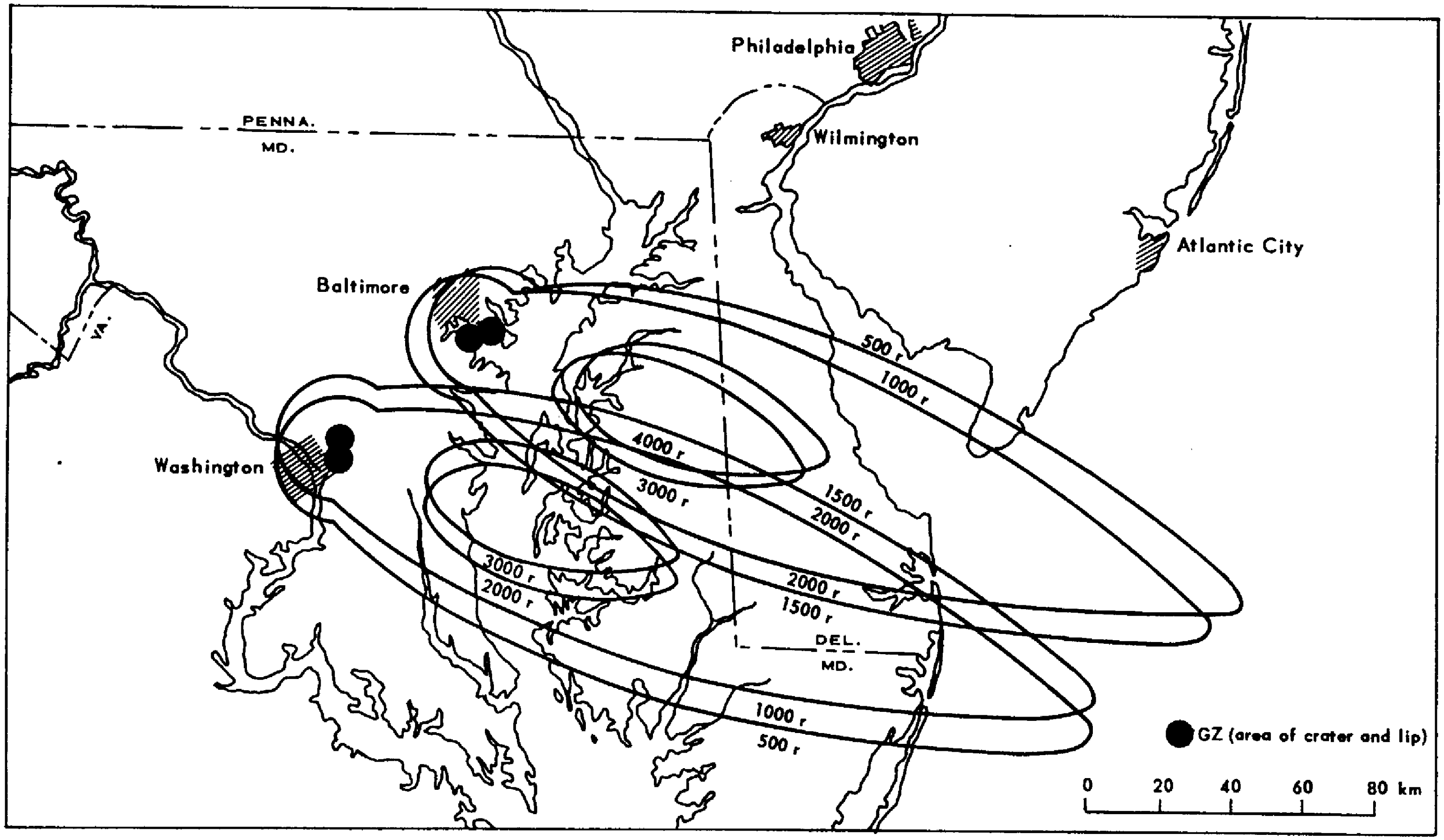

Fig. 33 — Fallout Contours for Washington-Baltimore Attack with Four 10-Mt Weapons, CEP 4000 m
Moderate-speed wind, bearing 110 deg; cumulative 2-day radiation dose.

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Similarly, with 3-hr evacuation it is found that approximately 37 percent of the population who are not killed by blast and thermal effects would be exposed to 250 r (0.05 lethality) and a few more than that exposed to 500 r (0.88 lethality).

Figure 31 shows some actual GZ for an attack with a CEP of 12,000 m. The main population centers of Baltimore and Washington happen to remain almost untouched by primary effects in this particular attack, but the areas in which large numbers of evacuees would be located have radiation levels up to 3000 r in addition to suffering heavy damage from primary blast and thermal effects. It would seem clear that under these conditions (large CEP) up to 50 percent lethalities in the evacuated population could be expected.

Figure 34 summarizes the revised estimates for an attack with a CEP of 4000 m. It is clear that for realistic attack assumptions (multiweapon large-CEP attacks involving fallout) underground shelter is the preferable civil defense tactic.

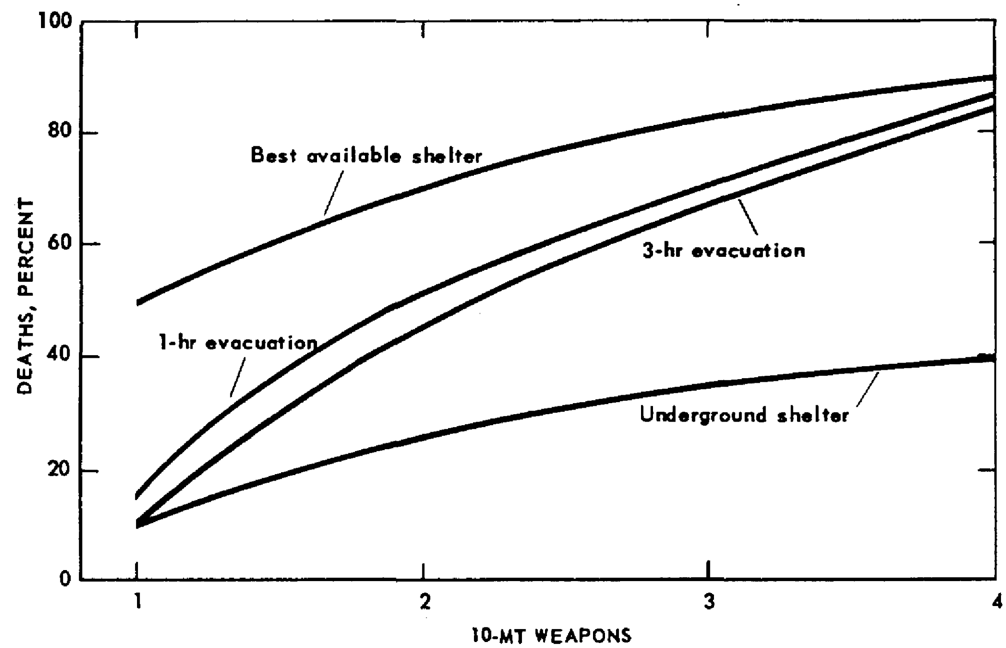

Fig. 34 — Percentage Washington Resident Population Killed by Direct Effects plus Fallout from One to Four 10-Mt Weapons, CEP 4000 m

It is possible for a target population to evacuate from anticipated attack only to find itself in the path of fallout from an adjacent target. Figure 35 shows fallout-contaminated areas for a mock attack on 5 Aug 55 in which no weapons were actually exploded on the Washington target but were on a large number of nearby targets. It will be noted that a fallout-free proposed reception area exists only toward the southwest, 25 miles distant; most of the proposed reception areas received a cumulative 2-day dose ranging up to 2200 r.

EFFECT OF WIDESPREAD ATTACK[18]

Since an attack on Washington and Baltimore alone markedly reduced the effectiveness of mass evacuation, the effectiveness of mass evacuation under a widespread attack on many targets was considered.

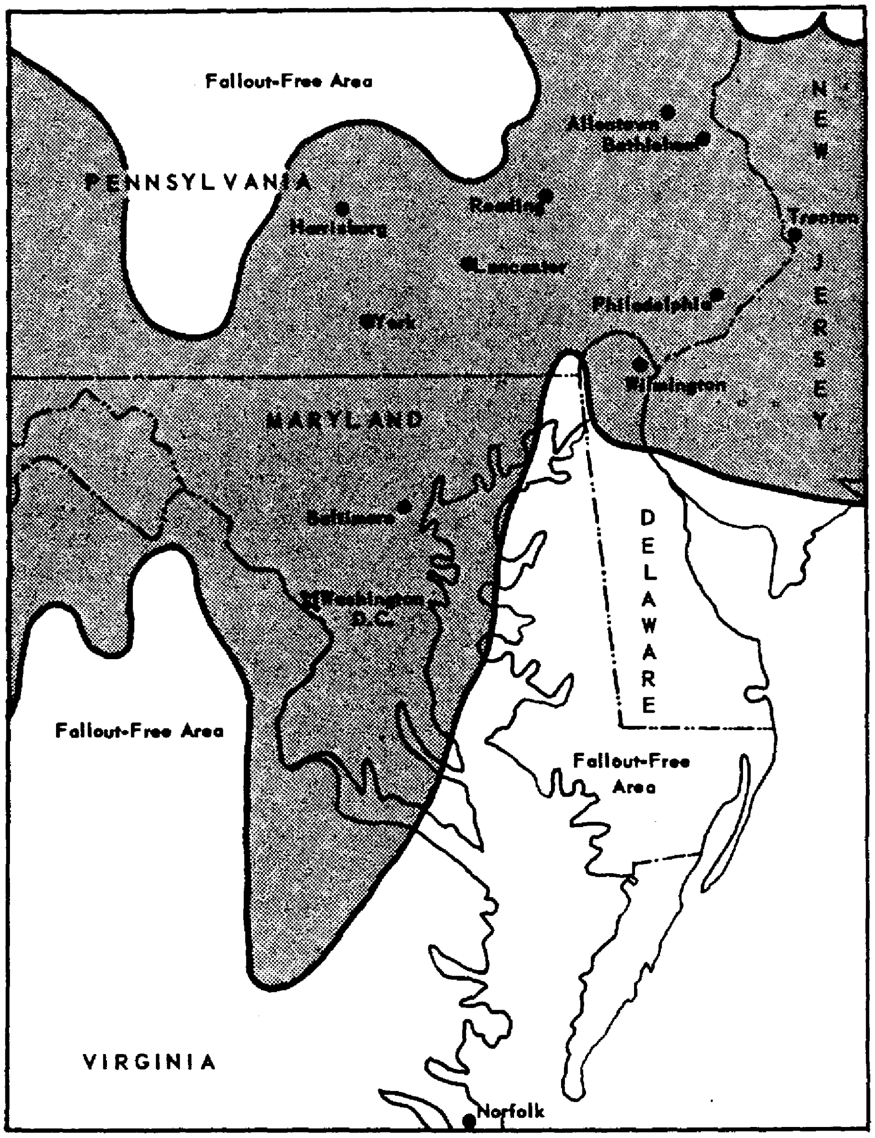

Fig. 35 — Fallout Conditions Following Attack on 5 Aug 55

A random sample of 36 days (3 days per month) was selected from available upper wind fallout (UF) readings. These data were used to select appropriate fallout contours and bearings as described in the section on deaths from fallout. Ten-Mt ground bursts were exploded on all the FCDA-designated critical targets within 300 miles of the Washington target. The weapon was exploded over the center of population in each target except Washington and Baltimore, where expected GZ for a CEP of 4000 m were used. The targets and the number of weapons assigned (roughly on a population basis) are given in Table 10.

The area shown in Fig. 36 was then examined for the cumulative 2-day radiation dose received on each of the 36 days of the attack. Contour lines were drawn for radiation conditions that existed 100 percent of the time, 70 percent of the time, and 50 percent of the time in the sample; the results appear in Figs. 36 to 38. Thus Fig. 36 would be read as follows: at no time in the sample did the areas outside the zero contour receive fallout; at no time did the area between zero and the 500-r contour receive more than 500 r, etc. Figure 37 would be interpreted in the same manner: for 70 percent of the days in the sample the area outside the zero contour was fallout free; for 70 percent of the days in the sample the area between 0 and 500 r received less than 500 r (conversely, 30 percent of the time it

TABLE 10

TARGETS AND NUMBER OF WEAPONS IN MOCK WIDESPREAD ATTACK

Target	Weapons
Allentown-Bethlehem-Easton	1
Baltimore	2
Harrisburg-Lancaster-York	3
Johnstown-Altoona	2
New York-NE New Jersey	7
Norfolk-Portsmouth-Newport News	1
Philadelphia	1
Pittsburgh	2
Reading	1
Scranton–Wilkes-Barre	1
Trenton	1
Washington, D.C.	2
Wilmington	1
Wheeling-Steubenville	1

received more than 500 r), etc. Figure 38 would be similarly read, and, since it shows the conditions that would exist 50 percent of the time, represents the median case. These findings hold several implications for selection of a civil defense tactic:

(a) If planning is to be done at the 100 percent confidence level (no possibility of a given level of radiation being exceeded based on the present sample), movement to the north and east and short movement to the south is precluded, since these areas at sometime receive cumulative 2-day radiation doses in excess of 2300 r. Movement of approximately 25 miles to the west places evacuees in relative safety (50 to 250 r, 0.5 attenuation) and movement to the south and west of 125 and 225 miles, respectively, places them in fallout-free areas. However, due to limitations in direction of movement and because of the distances involved, the number of available lanes is reduced, and it now requires 20 hr to move into the 100- to 500-r zone and 25 to 30 hr to move to fallout-free areas — hours many times in excess of the warning periods anticipated.

(b) Limited movement of the type planned in the Washington area (3-hr mass radial evacuation) could result in 100 percent lethality in the evacuated population.

(c) If civil defense planners are willing to accept a 70 percent level of risk, movement in an eastward direction (20 to 120 deg) is still precluded by high indirect radiation conditions, but shorter movements to the west and south of 15 and 30 miles, respectively, may be indicated. From 8 to 12 hr would be required to carry out this tactic — times still in excess of expected warning times.

(d) If civil defense planners are willing to take a 50–50 chance (one-half the time the radiation level will exceed that shown for a given area in Fig. 38, one-half the time it will be less), the situation is not appreciatively changed from the 70 percent confidence situation. An appreciable sector east of Washington receives 500 to 1000 r; 15 to 20 miles of movement west and south, and to a limited degree toward the northwest, is necessary. The times required would still exceed expected warning times by a factor of 6 or 8.

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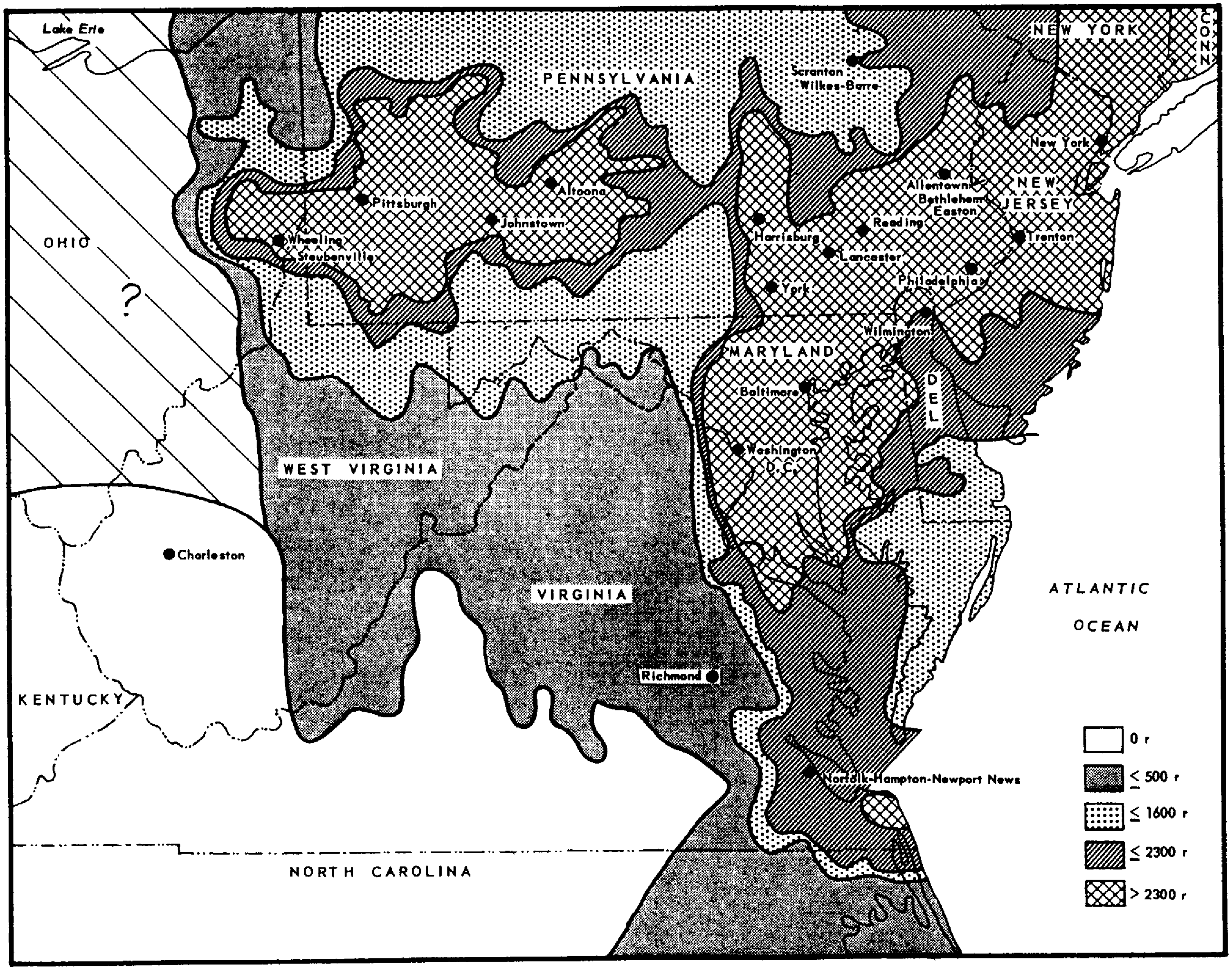

Fig. 36 — Radiation Levels Never Exceeded in Sample for Widespread Attack

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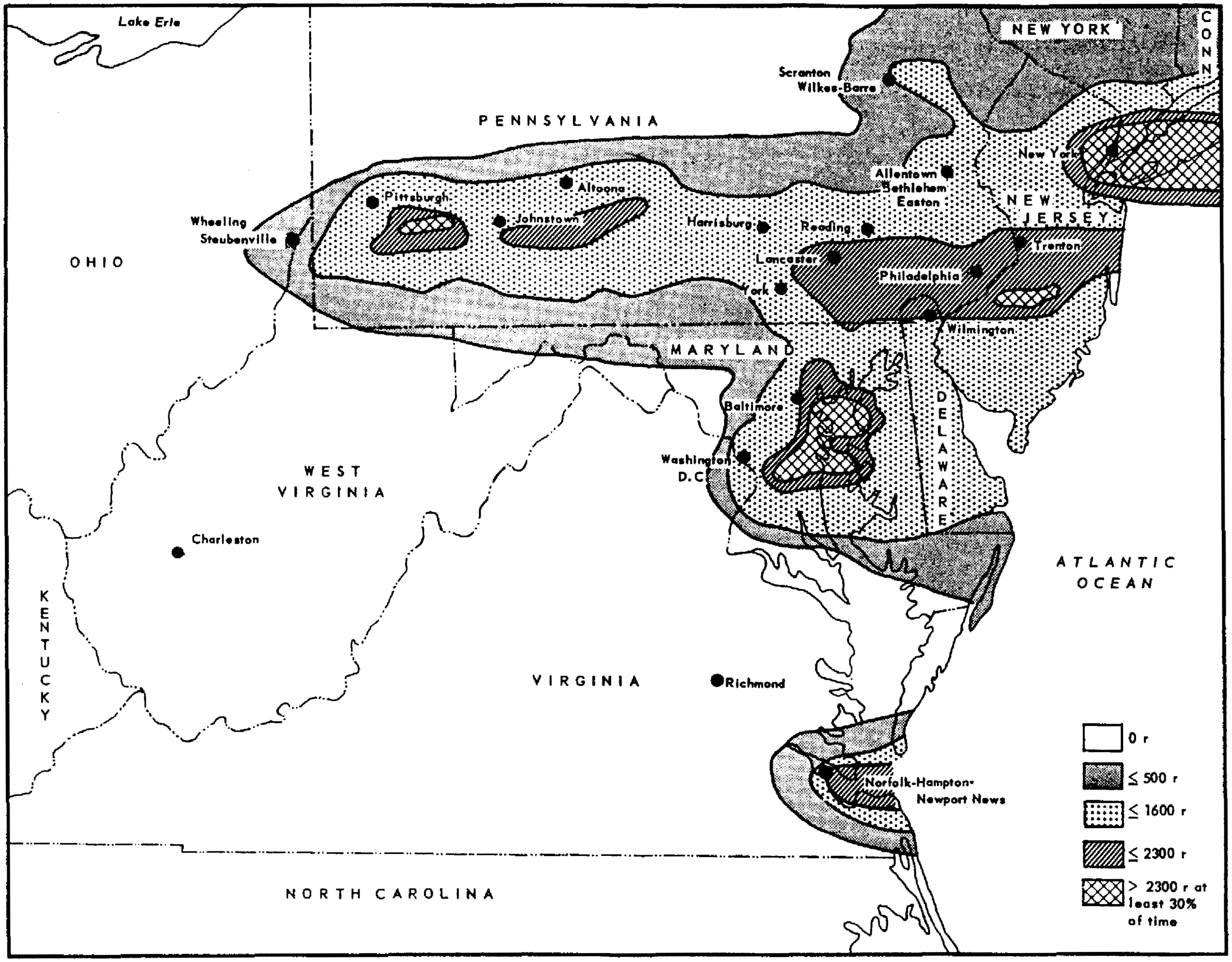

Fig. 37 — Radiation Levels Occurring 70 Percent of Time in Sample for Widespread Attack

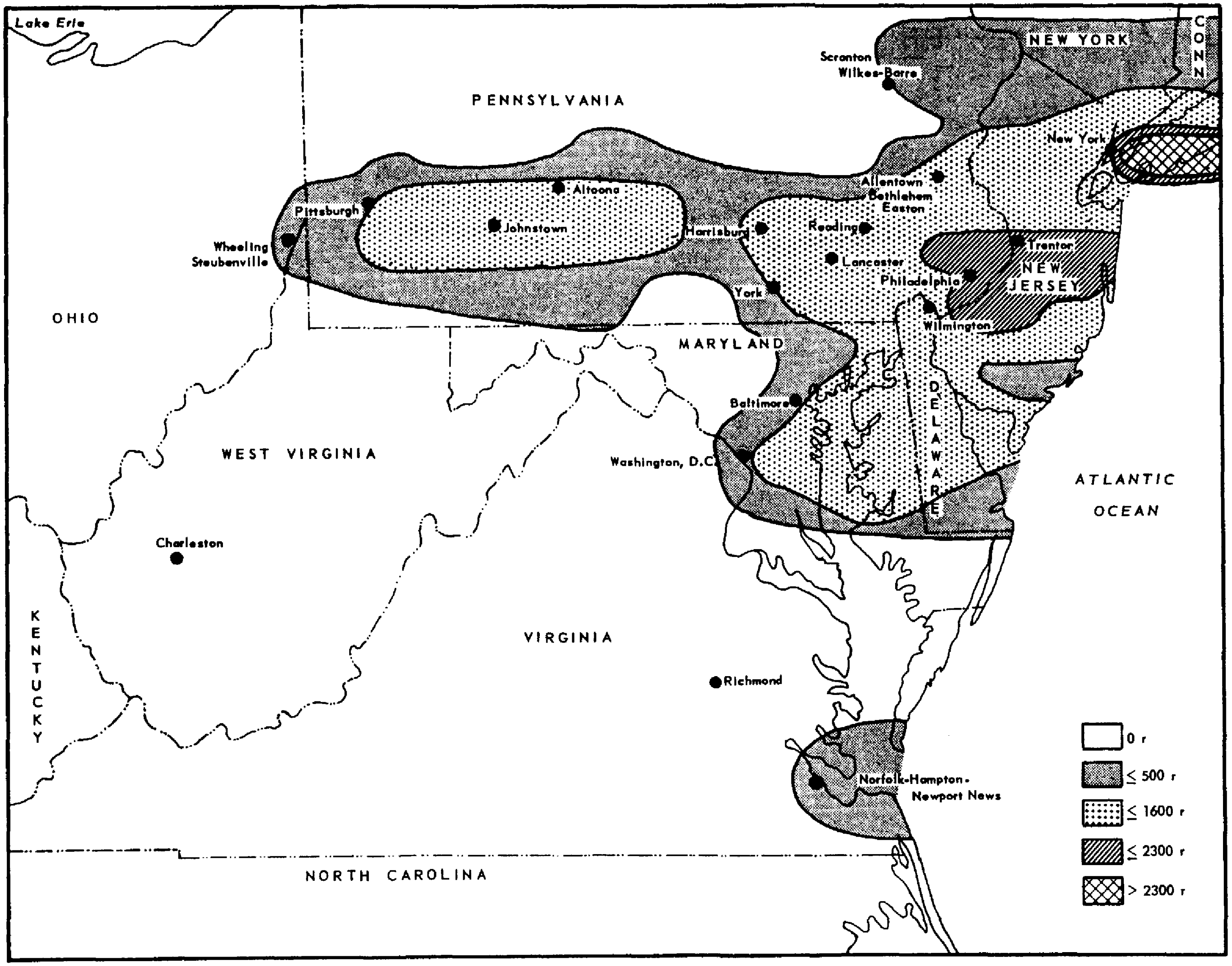

Fig. 38 — Radiation Levels Occurring 50 Percent of Time in Sample for Widespread Attack

FALLOUT AND TRADITIONAL CIVIL DEFENSE

To gain better insight into the civil defense problem, 1 day from the 36-day sample was drawn at random and the local radiation picture examined in more detail. From data supplied to the Washington Survival Plan Committee by the AEC, close-in fallout (pre-

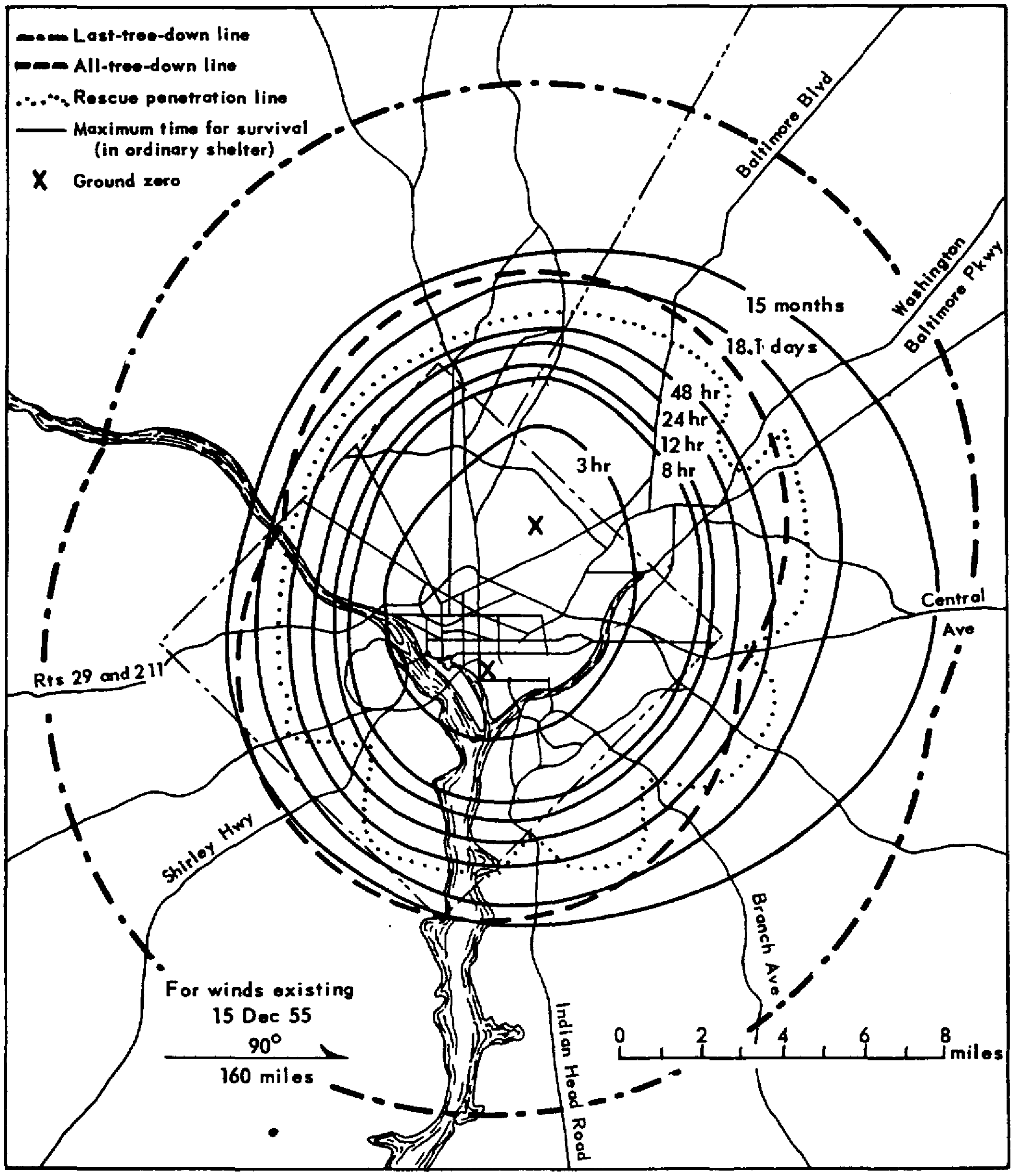

Fig. 39 — Radiation Effects of Two 10-Mt Ground Bursts on Washington

sumably very heavy particles from the stem and cloud) was superimposed on the previously computed fallout contours. Figure 39 shows the results of this calculation. The solid lines indicate the number of hours a person can be in shelter attenuating 0.9 radiation before acquiring an LD_{50} dose. These times range from 3 hr at 2 to 3 miles from GZ to 48 hr at 7 miles from GZ, and do not include any direct radiation that may have been received.

Seven miles is roughly the outer edge of the Civil Defense B (severe) damage ring, a ring in which civil defense traditionally expects to conduct rescue, fire fighting, and other post-attack services.

Figure 39 also shows the distance at which some trees would be blown down and the distance at which all trees will be blown down. It is clear that to reach people who will die in 48 hr rescue teams will have to clear their way through 6 miles of downed trees and rubble. Furthermore the debris problem is most severe where the radiation dose rates are highest.

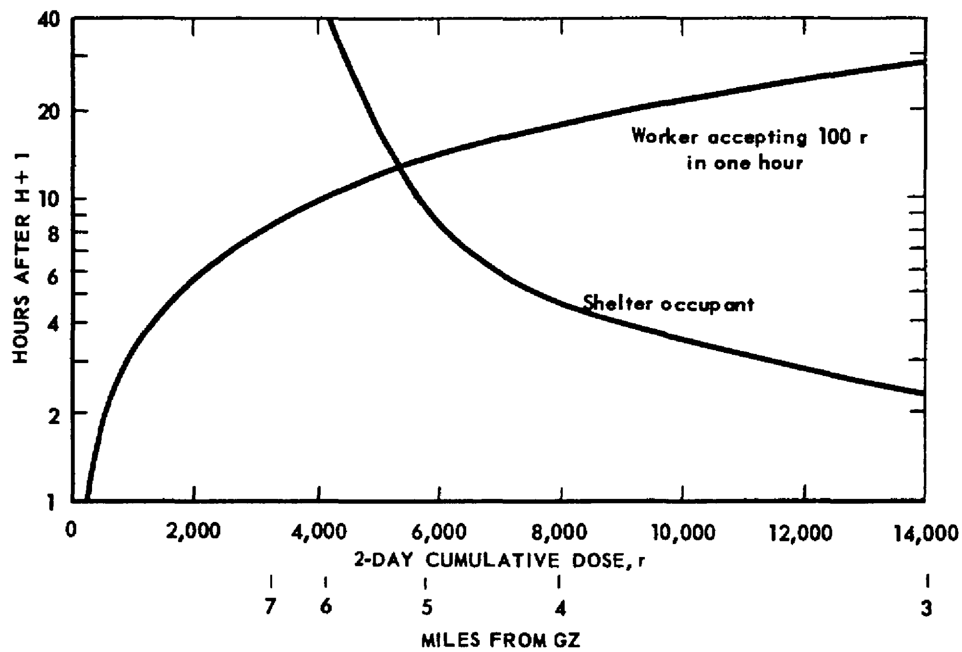

Fig. 40 — Hours of Life in Ordinary Shelter and Waiting Time for Rescue as Function of Distance/Dose

Figure 40 shows the hour after H+1 at which a shelter occupant will receive an LD_{50} dose plotted against the 2-day accumulated dose for the area in which the shelter is located. This figure also shows the area (in terms of 2-day dose) in which a rescue worker can work for 1 hr receiving 100 r in that hour (perhaps the maximum permissible one-shot emergency dose). Since the two curves intersect at 12 hr, any shelter occupant who is located in an area in which he will receive an LD_{50} dose in less than 12 hr (cumulative 2-day dose of 5500 r) cannot be rescued (by these standards). In this particular attack, this would be within 4 to 6 miles of GZ.

This radius, however, does not take into account the debris-clearance problem, nor does it allow for the radiation received by a worker in the course of entering and leaving the area. It could represent the minimum distance from GZ at which a rescue worker could work if transported by air or possibly by a shielded vehicle along a debris-clear freeway, such as the Shirley Highway. The dotted line in Fig. 39 represents the limit of penetration of the area by rescue workers on the ground.* Over most of the attacked area it

*The data comprising this line consist of the best estimate of an urban planner familiar with the road system and potential debris near the roadways.

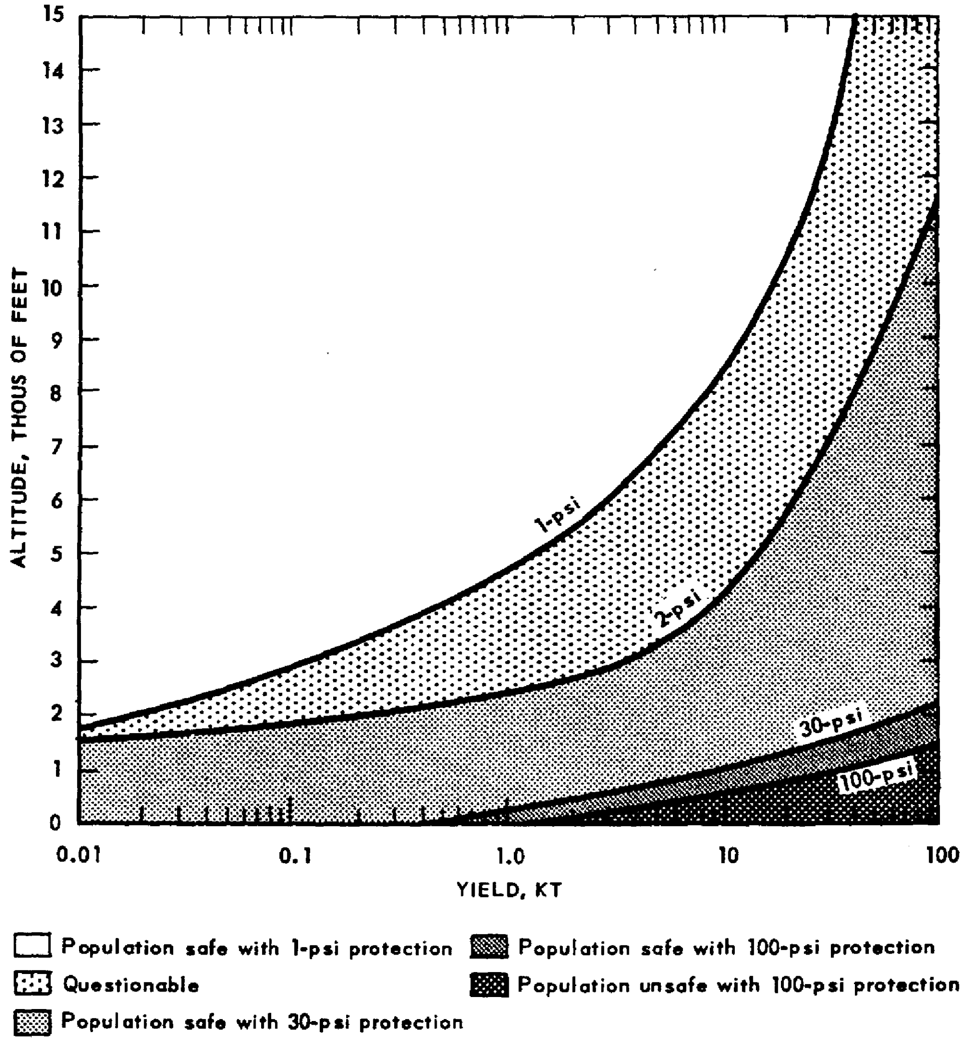

Fig. 41 — Altitudes at Which Friendly Commander Could Use Nuclear Warheads of Various Yields for Various Levels of Population Protection

exceeds the distance at which people in shelter will exceed an LD_{50} dose in 48 hr (about 4000-r cumulative 2-day dose, at a distance from GZ ranging to 8 miles).

It seems clear that basement shelter attenuating radiation by 0.9 is not enough protection for urban dwellers, since they can receive LD_{50} doses before rescue workers, impeded by debris and high radiation dose rates, can reach them. It also seems clear that the traditional civil defense postattack services will not be possible over most of the attacked area.

Since preattack evacuation is neither feasible nor desirable in view of fallout, the only alternative would seem to be large shelters capable of sustaining life for days or weeks and attenuating all radiation effects. In a shelter system postattack measures would consist of working from the inside out (once radiation levels had fallen to tolerable limits) rather than the present civil defense practice of attempting to clear roads into the damaged area.

Effect of Passive Measures on Active Defenses

If the bomb carrier is killed but not the weapon itself, there is a strong likelihood that intolerable levels of fallout might result (App H). One solution to killing the bomb is the use of nuclear warheads in the defending missiles. Figure 41 indicates that there is a safe corridor of altitudes for attacking aircraft. At these altitudes or below, the use of high-yield warheads is denied the ground commander because of the danger of inflicting death or injury to personnel in best shelter available on the ground. This corridor is based on the assumption that 1-psi overpressure on the ground would constitute a "safe" limit, and that 2 psi would be the absolute maximum peak overpressure that could be sustained by the population.

For personnel in shelter capable of withstanding 30 and 100 psi the size of this corridor is reduced to academic proportions (Fig. 41); 10-kt warheads could be used at practically any altitude feasible for the attacking aircraft. The corridor for any likely yield in the defending missile is less than 1000 ft. Thus a program of shelter construction could be utilized to deny the attacking aircraft a corridor in which he could have assumed that nuclear warheads could not be used against him.

CIVIL DEFENSE COSTS

CURRENT COST

Costs of the present civil defense policy (seeking the best shelter now available) are probably of the order of $200 million per year; one-half of this amount is appropriated by the Federal government.

EVACUATION PROGRAM

The cost of an evacuation program for 170 major cities would be of the order of $50 million in direct costs for plans, maps, and traffic signs and for recruiting, training, and equipping traffic control personnel. Indirect costs due to the loss of wages, output, and profits are not included in this estimate. Civil defense officials feel that two practice alerts per year would be a minimum requirement for a workable plan. The cost to the economy of each practice alert for the District of Columbia has been estimated at not less than $1 million. The cost of two practice alerts per year for each of the 170 major metropolitan areas has been estimated to be of the order of $400 million a year, or, cumulated for the 8-yr period through 1965, $3 billion. If the cost of a road-building program (which would be necessary to make evacuation feasible with a 2.5-hr warning) is added to this figure, the cost might be upward of $23 billion. Should the enemy adopt "spoofing" tactics the cost to the economy would be inestimable.

SHELTER PROGRAM

The type and size of shelter and shelter "mix" (proportion of public shelters to family shelters) will vary from target to target, depending on density of population, available sites, and anticipated urban growth. This section describes the types and costs of shelters currently available that could constitute the ingredients of the shelter program.

Table 11 lists some public and private shelter types and estimates the cost of sheltering the residents of 170 major metropolitan areas. With respect to public shelters, some of the differences in cost estimates reflect differences in construction techniques. The community redoubt is the most expensive since it is designed to afford protection even in the crater and lip. The difference in the cost between the 40-person and 100-person shelters reflects a general savings in moving machinery onto the site, etc.

The public shelter of the American Machine and Foundry Co. is less costly, by a factor of 2, than any of the others. This is partly a function of its large size and partly because the poured-in-place concrete dome offers more resistance to shock waves than an equivalent amount of concrete in some other form. This reinforced-concrete arched-dome shelter is 250 ft in diameter and has 3 ft of earth cover at the apex of the dome. The shelter area

TABLE 11

COSTS OF PUBLIC AND FAMILY SHELTERS

Firm or source	Shelter type	Occupants	Space per occ, sq ft	Facilities	Psi	Cost: Shelter, thous of dollars	Cost: Per occ, dollars	Cost: 25 major cities, billions of dollars	Cost: 170 metro areas, billions of dollars	Remarks
Cleveland Twist Drill Co.	Public, below grade	2000	10	Toilets, self-contained power, forced filtered air	100	300	150	9	12	Actually built and in use
FCDA (Fig. 42)	Public, below grade	40	6	Ventilation, self-contained power, sand-filled escape passage	100	15–16	375–400	22–24	32–34	Only public shelter subjected to proving-ground test; sand-filled shaft attenuates radiation while still providing emergency egress
Ammann and Whitney Co.	Public, below grade	100	6	Ventilation, self-contained power	100	25–30	250–300	15–18	22–26	—
American Machine and Foundry Co.	Public, dome type, below grade	14,000 (long stay)	10	Ventilation, self-contained power, crude toilets	100	875	62.50	3.6	5.3	Company estimates entire urban population could be sheltered for $8 billion
Lehigh University	Family, underground	6	6	Power, crude toilet	10–15	.9	150	9	12	Tested at given overpressures
Portland Cement Association	Family, bathroom	6–10	Varies	Toilet facilities	5–10	.5	50–83	3–5	4–7	Reinforced concrete provided during construction of home
FCDA	Family, underground, 90-in. pipe	4–5	Sitting or standing space only	None	5	.15	35	2.1	3.0	Overpressures built up inside shelter during tests, dummies damaged
Portland Cement Association	Reinforced-concrete first-story floor	150	10	None	5–10	1	127.00	.7	1.6	Can be provided only in new construction
—	Community redoubt	20,000	10	Ventilation, self-contained power, toilets	1000	10,000	500–625	30–39	43–53	—
Stanford Research Institute	Corrugated metal arch	Varies	10	None	22	Varies	40–60	2.4–3.6	3.4–5.1	—

within the dome is on three tiers that can be compartmentalized to reduce panic potential. Eighteen entryways equipped with sliding doors permit entry of the population within 10 min. Figure 43 shows a dome-type shelter design.

The American Machine and Foundry Co. has estimated that the entire target-area population of Milwaukee could be sheltered in 150 dome-type shelters varying in size (according to available land sites) up to 250 ft at a cost of $65 million, or about $65 per inhabitant, exclusive of land costs.* No shelter was farther than a 30-min walk from

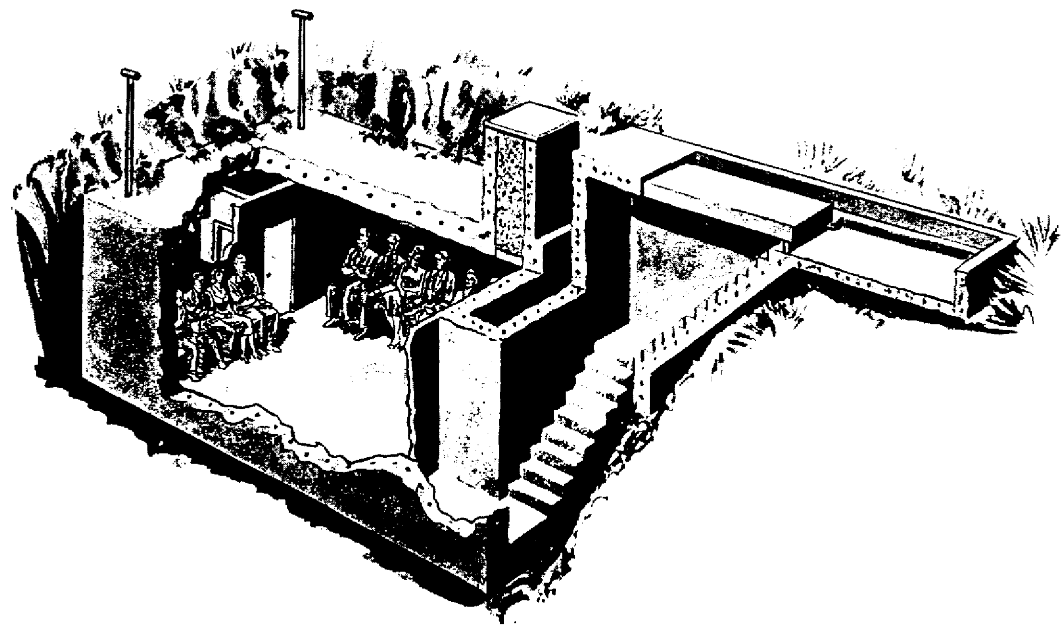

Fig. 42 — FCDA 40-Person Shelter

the location of any inhabitant. It is of interest to compare this figure with the estimate of $78 million required to improve Milwaukee's road net so as to allow evacuation within 1.5 hr.[19] To reduce the time of walking to shelter to 20 min would require twice as many shelters, or about $130 million. These costs rise markedly if enough shelters are provided to enable everyone to be within a 15-min walk; four times as many shelters would be required, a cost of $260 million. Admittedly the shelters could be smaller and hence less expensive (if one planned ahead to this extent), but tending to balance this factor would be increased land costs as the supply of less expensive sites became exhausted.

It should be pointed out that this type of shelter does not exist even in prototype and has never been exposed to tests, although it is scheduled for testing in the 1957 Nevada series. The Chief of Protective Construction Branch, Office of Chief of Engineers, US Army, testifying before a House Committee, questioned the cost estimates and had reservations about the available air supply and the ability of the structure to maintain a tolerable heat level without expensive refrigeration equipment.[20]

Figure 44 shows another relatively inexpensive public shelter designed to resist 22-psi overpressures. Essentially a buried corrugated metal arch erected on a concrete slab, it should cost $40 to $60 per occupant, allowing each 10 ft of shelter space.[21]

*FCDA has estimated the cost of this shelter at $100 per occupant.

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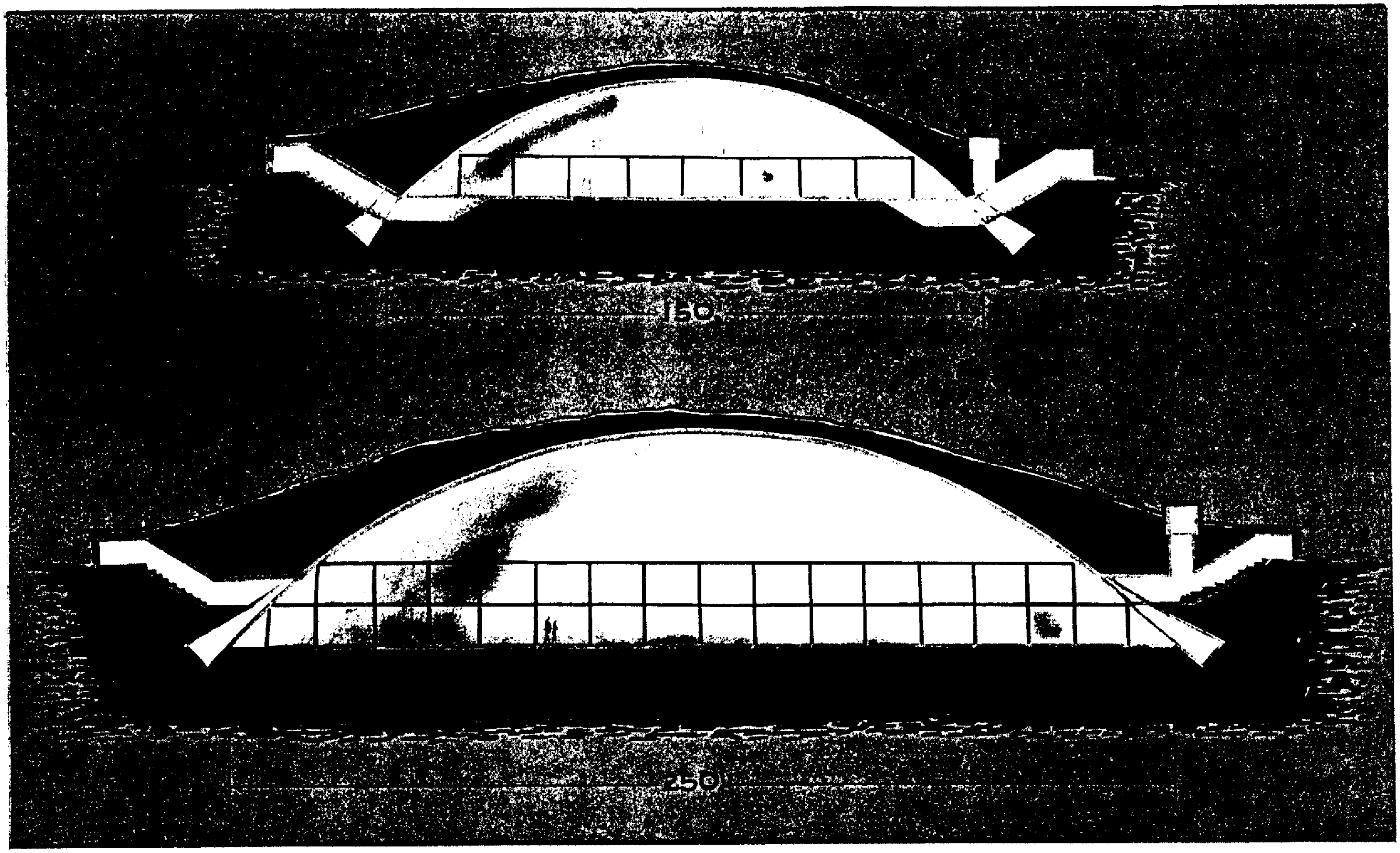

Fig. 43 — Proposed Shelters of American Machine and Foundry Co.

The 150-ft shelter will accommodate 3000 persons for a long stay, 5000 for a short stay; the 250-ft shelter will accommodate 14,000 persons for a long stay, 23,000 for a short stay.

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One other public shelter design that has been given serious consideration by research agencies is the deep underground community redoubt, described as:

> . . . built at a depth of 200 to 400 ft in a network or honeycomb fashion so as to provide a capacity of on the order of 20,000 each. They will almost necessarily be built on a large scale to spread the heavy initial cost involved in penetrating to such depths. These shelters will be assumed to be capable of supporting life for a period of a week or 10 days in almost complete isolation from the surface, being provided with food, water, air, sanitation, and fuel. They would be constructed by mining techniques, and either interconnected or provided with multiple entrances and exits. They are assumed to be vulnerable only within 1.5 crater radii of GZ. For the deep shelters geological conditions may sometimes create problems, but it is believed that the freedom to select, within certain limits, both site and depth may minimize these (as compared with, e.g., mining or subway tunneling, which are in the nature of the case more constrained as to locus). The chief problems that may arise are excessive wetness, weak soil structure in certain strata (sand, mud, or fill), and rock pressure. Remedies for all these exist, but of course may seriously increase costs of construction.[22]

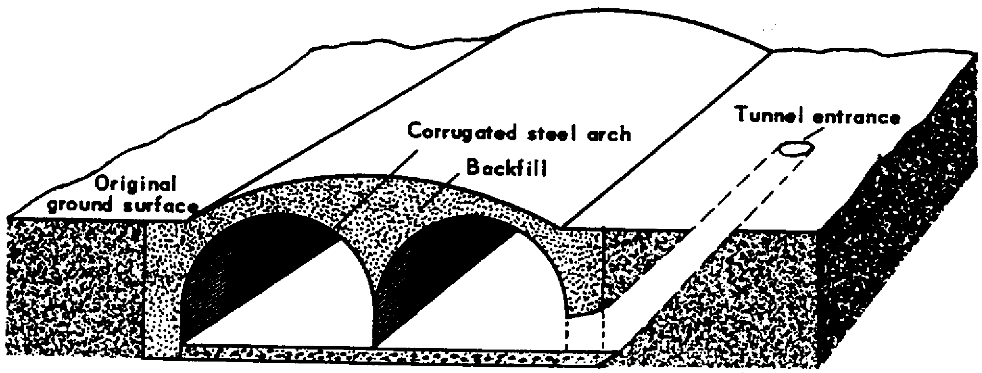

Fig. 44 — SRI Public Shelter (Showing Vertical Section)

The cost of such a shelter system is estimated at $500 per occupant where the number of occupant spaces is in excess of 20,000 and $625 per occupant where the number of spaces is less than 20,000.[22]

For sheltering the entire population this would be the most expensive shelter program of all. Furthermore such a shelter system would have little or no auxiliary value, such as the large dome-type shelters could have (as auditoriums, skating rinks, public garages, etc.). The community redoubt, however, does offer maximum protection, and included in its total cost are the costs of entryways serving every ¼ sq mile, which means that this shelter might be accessible during the ICBM period.

The shelter of the Cleveland Twist Drill Company is of special interest since it has actually been built and is completely stocked. Hence its cost, $300,000, is based on experience rather than builders' estimates. The only other public shelter that has been constructed in this country (by the Cincinnati Milling Machine Co.) was built above grade at relatively high cost ($425 per occupant). It is believed the cost of the below-grade shelter may be more applicable in estimating the costs of the shelter types considered here.

Among home-type shelters (discounting the below-grade 90-in. pipe shelter, which did not seem to offer good protection in Nevada tests), one type seems to offer unusually cheap protection. The Portland Cement Association has designed a house with a reinforced-concrete floor that is designed to prevent the wood-frame structure from collapsing into the basement. This concrete floor should also protect people in the basement from secondary fires. If contractors could be persuaded to build some new houses of this type, each house could offer protection from low overpressures to 20 families. At the present home-building rate of approximately a million units a year, this could provide relatively cheap protection for people in suburban areas (where most new building is taking place). Among the disadvantages to this and to the bathroom-type home shelter shown in Fig. 45 are that they are limited to new construction (hence only certain newer sections of cities) and have not been subjected to proving-ground tests.

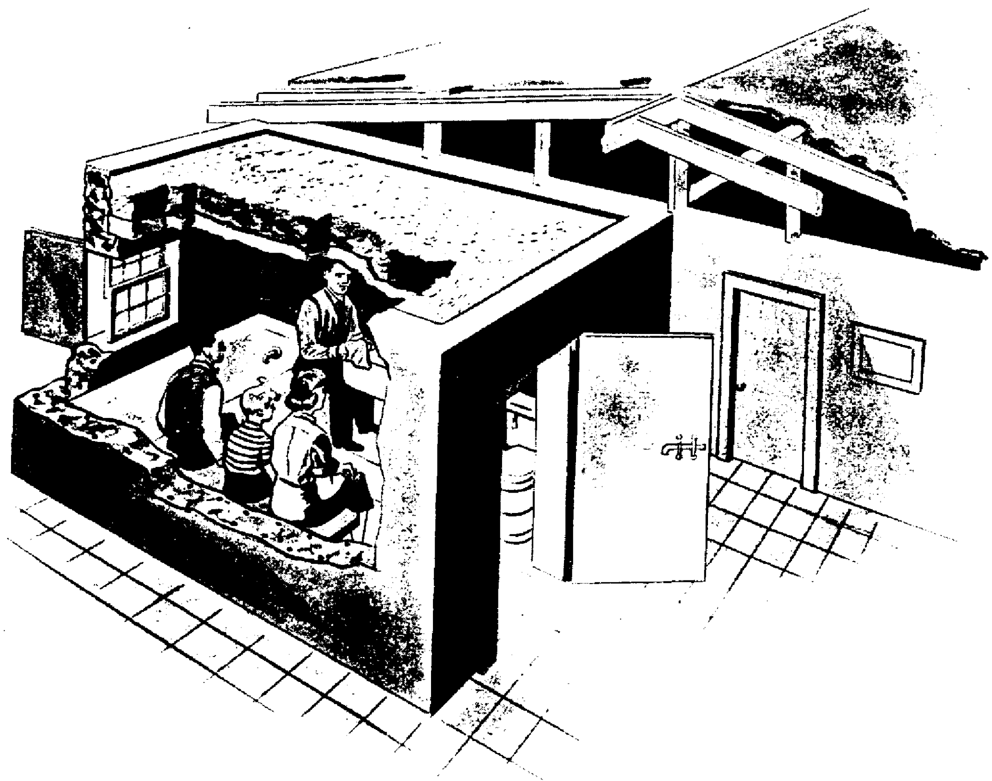

Fig. 45 — Reinforced-Room Shelter

A mixed shelter program is probably necessary, since people near the center of the city have no land for family shelters. One possible mix would be shelter for one-half the population in dome-type shelters at the center of the city, ¼ in family underground shelters (Fig. 46), and ¼ in buildings with reinforced-room or reinforced-concrete-floor construction. Such a mix for the 25 major targets would cost $3.3 billion, and for all 170 major cities $4.7 billion. However, since shelter space cannot be optimally used because of the day-night ebb and flow of the cities' population to and from the center, these costs have to be increased by about ⅓, or to $4.4 billion for the 25 cities and $6.3 billion for the 170. These costs do not include land costs, which vary greatly.

Another possible mix might be one-half community redoubts, one-eighth family underground shelters, one-eighth reinforced-room or reinforced-floor shelters, and the remaining one-fourth the foxhole device discussed subsequently (for cities where mass evacuation is proven feasible). Such a mix, after allowing for the day-night ebb and flow, would cost $24 billion for the 25 cities and $33 billion for the 170. Many other combinations are possible, and a shelter program should be undertaken only after careful consideration of local needs.

Subways, modified so as to permit quick entry and so as to permit closing entryways, not only provide good shelter but can provide protected movement away from the target area. The initial cost of subway systems would be greater than that for other types of shelters, but might well be offset by operating revenue.

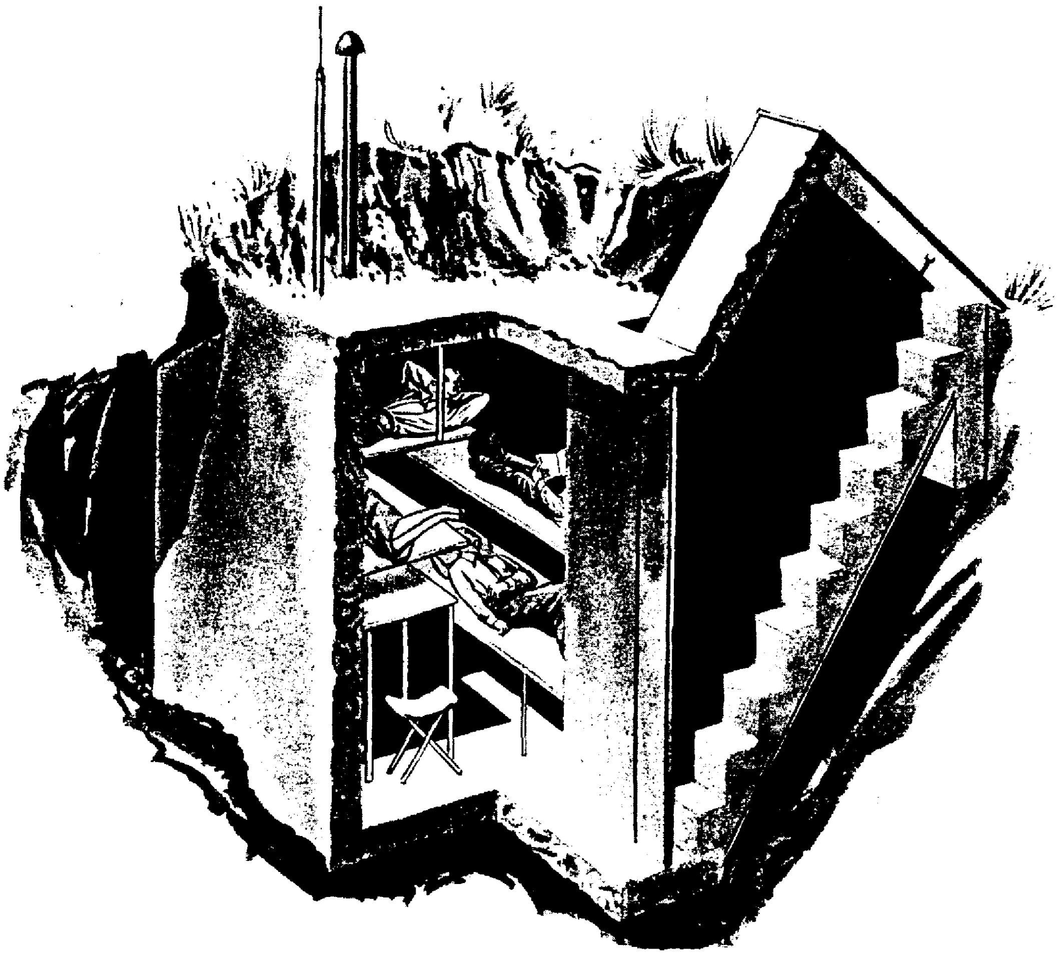

Fig. 46 — Family Outdoor Shelter

Improvised Shelter

Should Congress and the public remain apathetic to shelter programs, the Engineer Research and Development Laboratory, Ft Belvoir, has in prototype stage a device that could be adapted to civil defense needs with relatively little difficulty, according to the designer. This device (Fig. 47) was originally developed for digging foxholes quickly to protect

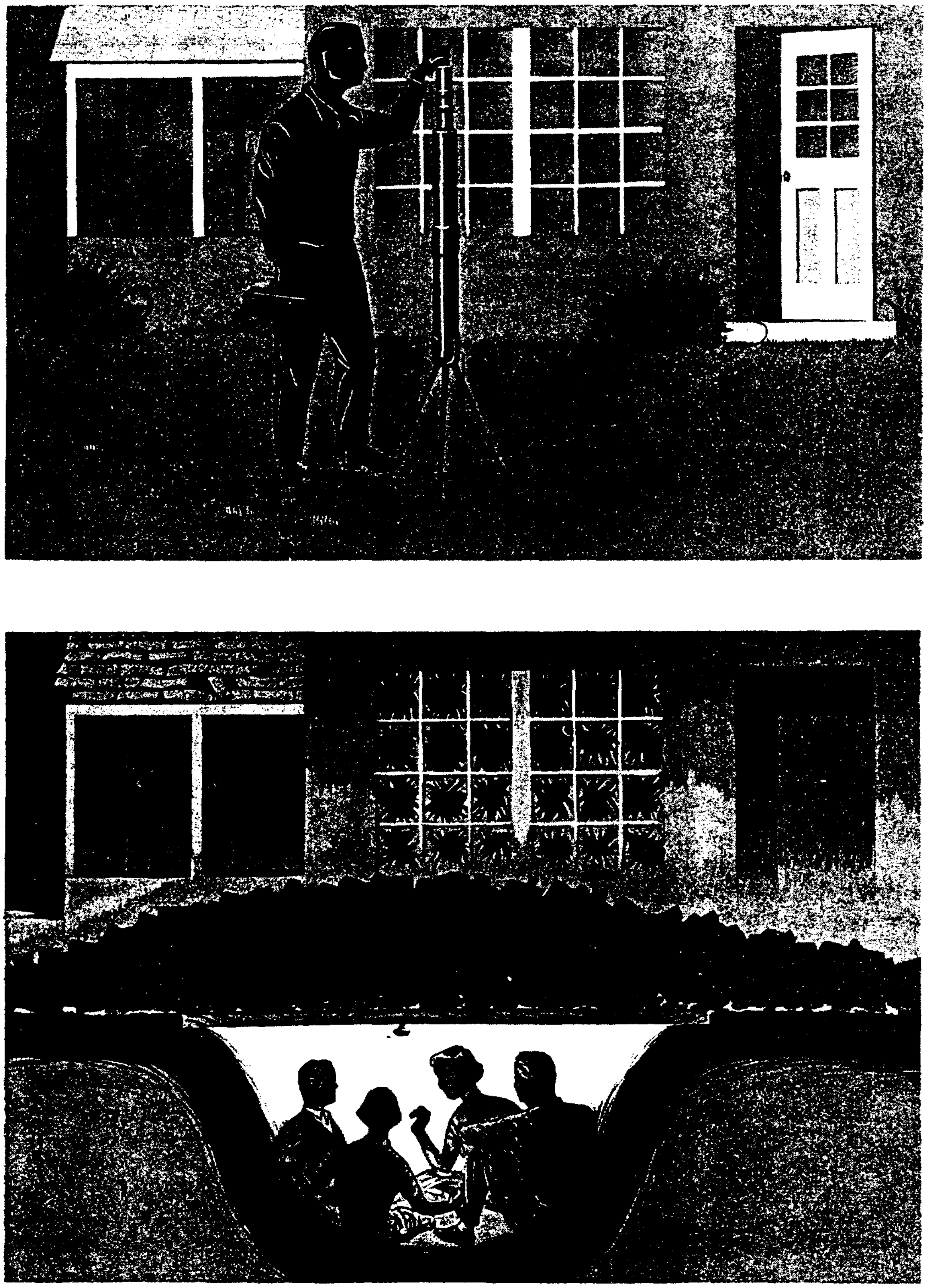

Fig. 47 — Improvised Family Shelter
Above, sketch of foxhole-digging device; below, vertical section of foxhole shelter.

troops under threat of atomic attack. A miniature mortar drives a propelling charge into the earth, where an excavating charge blasts out the foxhole. The entire device weighs less than 5 lb, and the cost is estimated at less than $10.

For civil defense purposes somewhat larger devices based on this principle could be stored in advance of attack in neighborhoods and communities. On receipt of a yellow or strategic alert these devices could be distributed quickly and the householder could excavate a family shelter, roof it with doors, etc., and spread the excavated earth over the improvised roof. This type of improvised shelter should provide nearly perfect protection from primary thermal and secondary blast effects. The extent to which it attenuated radiation would be determined by the amount of earth cover, but could be close to unity. For cities where evacuation may be feasible (such as Dayton in this study) such a device could provide a means for providing fallout cover in the reception areas. The cost of enough devices to shield the entire US population would be of the order of $700 million.

TIME REQUIRED AND AVAILABILITY OF MATERIAL

Mass evacuation plans could perhaps be developed in 6 months, but as yet no city has completed satisfactory plans, and many have been working on them for up to 3 yr. An additional 12 months would probably be required to implement and practice a city's plan to the point at which it could be considered adequate.

To construct shelters for a large-scale shelter program would require at least 12 months — up to 24 months if land had to be acquired through condemnation procedures. The Cincinnati Milling Machine Co. shelters, however, were completed in 7 months. There is no shortage of concrete or reinforcing steel (the major materials used in shelter construction), but the shelter program and the proposed road programs might find themselves in competition for these materials.

IMPLEMENTING THE SHELTER PROGRAM

It is true that each community will have varying shelter needs, but some general principles can be stated:

(a) The first shelters should be constructed outside the congested urban core but within walking distance. This distance will vary. For coastal cities this might be within a walking time of ½ hr. Inland cities may be able to disperse their shelters even more.

(b) Planning must ultimately look forward to having a shelter entrance within a 10-min walking distance of each inhabitant.

(c) The shelter program must be accompanied by a program of reduction in urban vulnerability through dispersal. Shelters built to conform to present population distributions would still result in very large numbers of people being in the crater or lip in a daytime attack.

Problems of implementation are treated in detail in Annex B of this appendix.

CONCLUSIONS AND RECOMMENDATION

CONCLUSIONS

Feasibility

1. The feasibility of mass evacuation has not been proven by actual test in any large city. There are serious difficulties facing realistic practice on the necessary scale. Current survival plan projects in a number of large cities may find ways of overcoming the difficulties.

2. Mass evacuation of large cities to smaller villages and towns is not feasible within expected warning times of air attack.

3. Radial roads to permit the mass evacuation of major cities could not be built in time for this tactic to have any value.

4. The feasibility of an underground shelter construction program has not been proven to the point of stimulating Congress to provide public funds. The technical know-how for large shelter construction exists, although one of the most promising and inexpensive designs has not been tested.

Effectiveness

5. In the Washington area, against attack with one to four 10-Mt ground-burst weapons all aimed at the population center with a 4000-m CEP, results were as follows:

a. Use of underground shelter, evacuation with 1959 warning time, and evacuation with 1956 warning time are all more effective civil defense measures than use of existing shelter.

b. Use of underground shelter and evacuation with 1959 warning time are more effective than evacuation with 1956 warning time.

c. Use of underground shelter is more effective against several weapons than evacuation with 1959 warning time, and is as effective as such evacuation against a single weapon.

6. In the Boston area, against attack with 10-Mt ground-burst weapons aimed at the population center, use of underground shelter is more effective than any other civil defense measure for all weights of attack from one to four weapons and for all CEP from 4000 to 12,000 m, even when effects of fallout are completely ignored; the superiority of underground shelter is further increased when fallout is considered.

7. In the Milwaukee and St. Louis areas, against attack with 10-Mt ground-burst weapons, when effects of fallout are ignored, evacuation with 1959 warning time is the most effective measure for a CEP of 4000 m, and underground shelter is the most effective measure for a CEP of 12,000 m. When fallout is considered, the superiority of evacuation with 1959 warning time for a CEP of 4000 m is reduced and perhaps eliminated, depending on the local and regional fallout pattern, and the superiority of underground shelter for a CEP of 12,000 m is further increased.

8. In the Dayton area, against attack with 10-Mt ground-burst weapons, when effects of fallout are ignored, evacuation with 1959 warning time is the most effective measure for

all CEP from 4000 to 12,000 m. When fallout is considered, the superiority of evacuation is reduced and perhaps eliminated, depending on the local and regional fallout pattern.

9. Any increase in radiation effects resulting from attacks on other nearby targets will increase the effectiveness of underground shelter relative to the other possible civil defense tactics. This relative superiority will be most drastic when the total fallout intensity reaches a level where the 0.9 protection factor of best shelter now available permits occupants to receive a lethal dose.

10. Shelter that will attenuate radiation effects by 0.9 (ordinary basement shelter) is not adequate in urban targets:

a. At 2 to 4 miles from ground zero, individuals in basement shelters would receive an LD_{50} dose in 3 hr, at 4 to 5 miles, in 6 hr. At these distances fallen trees and other debris in a high radiation field would make rescue operations impossible within the hours of life left to occupants of basement shelters.

b. At distances that might be relatively debris-free (7 to 8 miles), LD_{50} doses would be received by occupants of basement shelters after 24 hr. Evacuation by shielded vehicles would be imperative to preserve life.

11. Since immediate postattack rescue and evacuation efforts may be impossible because of high radiation levels, public and private shelters need to be designed and stocked to permit survival within the shelter for periods as long as 10 days.

12. With widespread attack on many targets, mass evacuation tactics could result in 100 percent lethality among the evacuated population. This could be true even if the evacuated city were not itself successfully attacked.

Costs

13. The cost of an evacuation program for 170 major cities should not exceed $50 million in direct costs for plans, maps, and traffic signs and recruiting, training, and equipping traffic control personnel. Indirect costs due to loss of wages, output, and profits are not considered in this estimate and would be very high, especially if the enemy developed "spoofing" tactics.

14. The cost of combination public-private shelter programs is largely dependent on the degree of protection desired. Two programs considered in this appendix are estimated at $6 billion and $33 billion each for 170 major cities.

RECOMMENDATION

1. The Army should support the following activities:

a. A start should be made on a reduction-of-vulnerability plan and an underground shelter plan for each metropolitan target area, looking toward reduction of target values in the core area and a spacing of underground shelters to match future population distribution at the expected date of ultrashort warning for ICBM.

b. Construction of underground shelters should be started as soon as firm long-range shelter needs in any geographical subdivision of the metropolitan target area can be determined. The current "survival studies" being undertaken by various cities with federal funds should be utilized to determine local shelter needs rather than to designate evacuation routes.

c. The entire civil defense concept of postattack operations should be reexamined in light of probable high radiation levels that may render traditional rescue, medical, fire fighting, and other services at or near the site of the attack impossible.

d. Intensive R&D effort should be expended on testing existing shelter designs and on the design of multipurpose and improvised shelter.

Annex A

STOCHASTIC MODEL FOR ESTIMATING EFFECTIVENESS OF BOMBING OF AGGREGATED TARGETS

CONTENTS

INTRODUCTION

In order to estimate the proportion of a city's population that will be casualties of a thermonuclear weapon it is necessary to construct a model of the bombing of a city. With the resultant casualties as a measure, the effectiveness of various courses of action open to the belligerents can be examined and assigned numerical values, so that the desirability of one course over another can be determined.

There are three independent components of the problem: the aiming point or points selected by the aggressor, together with the errors inherent in his aim — in short, the frequency distribution according to which the bombs are laid down; the proportion of casualties as a function of distance from GZ for any given bomb — in other words, the performance of the individual bombs; and the geographical distribution of the population of the city. The last factor contains time as one of its parameters when evacuation is considered.

A mathematical model of this problem should extract from each of the components some characteristic or characteristics, preferably numbers (rather than graphs, for example), and afford a way of combining these to obtain the measure of effectiveness. In this way each of the components can be varied separately, and the interactions of the components can be determined without resetting every component every time.

The formulas and approach should be as simple and time-saving as is consistent with a realistic analysis. Here a word is in order about the statistical milieu of the problem.

The expected level of casualties that an air raid will inflict on a city is determined in the following manner: if the same raid, under precisely the same conditions, were mounted a very large number of times, then on the average a certain proportion of the population would prove casualties; this proportion is called "the expected level." It would be enlightening to know the likeliest level of casualties as well, and even more to know the function by which the casualty levels are distributed; but if a single number is required, the expected level is the most natural one to take.

This expected value is obviously an idealization. The raid, if it occurs at all, will only occur once. Suppose the expected level of casualties has been determined to be 40 percent, yet the actual raid kills 50 percent of the population. This fluctuation would not be surprising, since 40 percent is only a mean value and it is reasonable to expect a certain amount of fluctuation (although a fluctuation to 10 percent or 90 percent might be cause for alarm).

In brief, the situation being investigated here is one in which no more than a rough index of what may happen can be asked for. In light of this it would be pointless to develop tedious and laborious equations or to calculate to very great accuracy.

It is felt that the method presented here fulfills the requirements of both flexibility and simplicity. The most time-consuming step in the process is the reduction of the population data, but once the prerequisite map study has been made, the reduction can be performed on an ordinary desk calculator in a few hours at the most, and of course need not be redone until the population distribution undergoes a marked change.

The formulas developed can be quickly evaluated on a slide rule equipped with a scale of negative exponentials. It is hoped that these features will recommend the approach developed here to both local civil defense authorities and SAC.

The treatment is meant to be indicative rather than exhaustive. It should perhaps be stated explicitly that the annex aims to be clear enough to be applied by those who are not particularly interested in the details and detailed enough to be of interest to those who are not specifically concerned with the applications.

BOMB DISTRIBUTION

It is commonly assumed that bombing errors follow a binormal distribution; i.e., that in a suitably chosen coordinate system the number of bombs falling in a rectangle dx by dy situated at (x, y) is proportional to

$$(1/2\pi\sigma_B\tau_B)\exp\left[-(x^2/2\sigma_B^2)-(y^2/2\tau_B^2)\right], \tag{A1}$$

where σ_B and τ_B are the standard deviations, the distribution has been rotated to remove the cross-product term, and the origin has been taken at the mean. If, as seems very likely, the errors are the resultants of a great number of independent causes, then Eq. A1 is in fact a consequence of the Central Limit Theorem. Of course there may be several distributions corresponding to Eq. A1 and having different means; e.g., the various aircraft on a bombing mission might be given their own aiming points in an attempt not to overkill at the center of the city. There is no need to consider a covariance term in these distributions unless it is anticipated that an attack might be mounted against the city from several directions simultaneously, a situation that for simplicity will be disallowed in this discussion. Similarly there is no a priori reason for supposing that the attacker's accuracy of aim would vary from point to point in a massed attack. It is therefore assumed that σ_B and τ_B remain constant from distribution to distribution. Indeed, later in the analysis, it will be further assumed that $\sigma_B = \tau_B$, and τ_B will be suppressed in later equations.

BOMB EFFECTIVENESS

Examination of any atomic-weapon curve showing proportion of people killed or injured at "ground r" (i.e., distance r from GZ), indicates that the curve might be adequately approximated by a suitably scaled normal distribution. Suppose in fact that the curve were really given by

$$c\cdot\exp\left[-(\lambda/2)r^2\right]. \tag{A2}$$

Here c is a scalar, the proportion of casualties at GZ, and λ is measured in inverse square feet and is in fact the reciprocal of the variance. Thus a small value for λ represents a spread-out distribution and indicates a bomb effective out to a large radius; large λ indicates an ineffective bomb. Perhaps the clearest way of characterizing these parameters is through the concept of lethal area. The lethal area of the weapon described by Eq. A2 is

$$\int_0^{2\pi}\int_0^{\infty} c\cdot\exp\left[-(\lambda/2)r^2\right]r\,dr\,d\theta = 2\pi c/\lambda. \tag{A3}$$

What remains is to fit the empirical curve by a curve of the form of Eq. A2. This is done by the method of moments. Indeed, for Eq. A2

$$\mu_0 \equiv \int_0^{\infty} c\cdot\exp\left[-(\lambda/2)r^2\right]dr = \sqrt{(\pi/2)}\cdot(c/\lambda^{1/2}),$$
$$\mu_2 \equiv \int_0^{\infty} c\cdot\exp\left[-(\lambda/2)r^2\right]r^2\,dr = \sqrt{(\pi/2)}\cdot(c/\lambda^{3/2}),$$

and solving for c and λ gives Result 1.

Result 1. To determine the parameters c and λ, which characterize the bomb, compute the zeroeth and second moments of the empirical distribution and set

$$c = \sqrt{(2/\pi)} \cdot (\mu_0^{3/2}/\mu_2^{1/2}),\ \lambda = \mu_0/\mu_2.$$

Before considering the joint implications of Eqs. A1 and A2 it is instructive to note a possible improvement of the latter in the case of a ground burst. Owing to the so-called "crater effect" the observed curve of bomb effectiveness will be very flat at the origin. Now $\exp[-(\lambda/2)r^2] = 1 + 0(r^2)$, but

$$[1/(\lambda - \kappa)][\lambda \exp(-\kappa r^2) - \kappa \exp(-\lambda r^2)] \tag{A4}$$

$= 1 + 0(r^4)$ is flatter at the origin and should in this case give a better fit. If the curve is fitted by the first and third moments, a particularly simple expression results:

$$\mu_1 \equiv \int_0^\infty [1/(\lambda - \kappa)][\lambda \exp(-\kappa r^2) - \kappa \exp(-\lambda r^2)] r\, dr = \tfrac{1}{2}[(1/\lambda) + (1/\kappa)],$$

$$\mu_3 \equiv \int_0^\infty [1(/\lambda - \kappa)][\lambda \exp(-\kappa r^2) - \kappa \exp(-\lambda r^2)] r^3\, dr = \tfrac{1}{2}[(1/\lambda^2) + (1/\lambda\kappa) + (1/\kappa^2)],$$

so that

$$2\mu_3 - 3\mu_1^2 = \tfrac{1}{4}[(1/\lambda^2) - (2/\lambda\kappa) + (1/\kappa^2)],$$

and from the first and last of these equations,

$$\lambda, \kappa = 1/(\mu_1 \pm \sqrt{2\mu_3 - 3\mu_1^2}). \tag{A5}$$

By making the coefficients in Eq. A4 independent parameters, instead of having them depend on the exponents, a better fit yet may be realized, at the expense of a more complicated analysis. Equation A2 rather than Eq. A4 will be used throughout the sequel, since it results in simpler expressions. Any results based on Eq. A2 may easily be extended to the analogous expression for Eq. A4.

Suppose now that a bomb of the form Eq. A2 is delivered according to the distribution Eq. A1. If the bomb lands at (x, y) the proportion of casualties at another point (ξ, υ) will be

$$c \cdot \exp\{-(\lambda/2)[(x - \xi)^2 + (y - \upsilon)^2]\};$$

however, the probability of this occurring is given by Eq. A1, and hence the expected level of casualties at (ξ, υ) is

$$c/(2\pi\sigma_B\tau_B)\int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} \exp\{-(x^2/2\sigma_B^2) - (y^2/2\tau_B^2) - (\lambda/2)[(x - \xi)^2 + (y - \upsilon)^2]\}\, dx\, dy. \tag{A6}$$

This is typical of the sort of expression that must be evaluated repeatedly in the course of the problem: the definite integral of the negative exponential of an inhomogeneous quadratic form in several variables. Fortunately a single calculation can be done.

Write the integral as

$$\int_{-\infty}^{+\infty} \exp(-XAX' - 2LX')\, dX, \tag{A7}$$

where $X = (x_1, x_2, \cdots, x_n)$, $\int_{-\infty}^{+\infty} dX$ means $\int_{-\infty}^{+\infty} \cdots \int_{-\infty}^{+\infty} dx_1 \cdots dx_n$, A is a symmetric positive definite matrix, and L is a (row) vector. It is well known that for such A there exists a real nonsingular matrix P such that $A = PP'$ and hence $A^{-1} = P'^{-1}P^{-1}$ and $|P| = \sqrt{|A|}$.

Equation A7 can now be evaluated by completing the square in n-space. Write

$$Y = XP + LP'^{-1};$$

this represents an affine transformation, with Jacobian $| P |$. Also,

$$\begin{aligned} YY' &= (XP + LP'^{-1})(P'X' + P^{-1}L') \\ &= XPP'X' + XL' + LX' + LP'^{-1}P^{-1}L' \\ &= XAX' + 2LX' + LA^{-1}L', \end{aligned}$$

and Eq. A7 becomes

$$\int_{-\infty}^{+\infty} \exp\,(-\,YY' + LA^{-1}L')dY/| P |$$

$$= (\exp LA^{-1}L')/\sqrt{| A |} \int_{-\infty}^{+\infty} \cdots \int_{-\infty}^{+\infty} \exp\,(-y_1^2 - \cdots - y_n^2)\, dy_1 \cdots dy_n,$$

so that

$$\int_{-\infty}^{+\infty} \exp\,(-\,XAX' - 2LX')\, dX = (\pi^{n/2}/\sqrt{| A |}) \exp LA^{-1}L'. \qquad \text{(A8)}$$

Application of Eq. A8 to Eq. A6 leads to Result 2.

Result 2. If a bomb characterized by Eq. A2 is delivered according to the distribution Eq. A1 the expected level of casualties at a point with coordinates (ξ, υ) with respect to the axes of Eq. A1 is given by

$$[c/\sqrt{(1 + \lambda\sigma_B^2)(1 + \lambda\tau_B^2)}] \exp\,(-(\lambda/2)\{[\xi^2/(1 + \lambda\sigma_B^2)] + [\upsilon^2/(1 + \lambda\tau_B^2)]\}).$$

It may be noted that when $\sigma_B = \tau_B$ this becomes a function of the radius $\sqrt{\xi^2 + \upsilon^2}$ alone; and when $\sigma_B = \tau_B = 0$, which represents pin-point bombing, this result reduces to Eq. A2.

POPULATION DISTRIBUTION

Suppose, for concreteness, that a square 20 by 20 miles that contains most of the population of the city has been divided into 100 squares 2 by 2 miles each, and that the nighttime population within each of these squares has been determined to the nearest thousand. One might compute the expected level of casualties as follows. Take the center of any one of these squares and find its coordinates (ξ, υ) with respect to the assumed bomb pattern, Eq. A1; then from Result 2 compute the expected level of casualties in that square; finally, multiply by the number of people in the square. Complete the same processes for each square, and sum over all 100 squares, to arrive at the total number of casualties expected. The problem of several bombs dropped at different points could be treated in like manner.

Such numerical integrations are, however, lengthy and tedious. It would seem natural to assume normal distributions here in order to eliminate these integrations, but the implications of such a step should be considered.

In the first place such a step does not testify to any sort of conviction about the true nature of the distribution of the population. It is merely an analytic device that experience suggests may prove applicable within certain wide limits, although results so obtained could be as bad as the point of worst fit of the city by the surface. It is only necessary to choose that point as the aiming point and set λ, σ_B, and $\tau_B = 0$; the bomb will always land at that point and its effect will be felt only at that point — in short, that worst point will be the only one to enter into consideration. Thus if the fitted surface assigns twice as many people to that point as are actually there, the formulas will "kill" twice as many people as they should.

The difficulties here lie in the fact that the surfaces of population distribution and distribution of bomb damage have not been made to mesh properly. For example, in the case of one bomb drop the ideal fit for the population of the city would be best at the aiming point and so weighted as to give diminishing importance to points farther out, in accordance with Result 2. To this extent, then, the three components of the problem discussed at the outset are not independent. They will of course be treated as if they were, and the city will be fitted only once with a binormal surface; thus circumspection must be exercised in the use of the formulas if they are not to be pushed beyond their proper range of validity.

Since the expected level of casualties springs from integrating Result 2 over the entire city, inaccuracies of fit should be smoothed out in the process. The numerical details involved in getting the fit to the city are postponed until the next section; assume now that it has been obtained and that the map has been rotated so that the principal axes of the city are aligned E-W and N-S, i.e., the city is the frame of reference. If its standard deviations are σ_c and τ_c its distribution function is

$$(1/2\pi\sigma_c\tau_c) \exp [-(x^2/2\sigma_c^2) - (y^2/2\tau_c^2)]. \tag{A9}$$

Assume for simplicity that a bomb is aimed at its center, with standard deviations σ_B and τ_B, and tilted through an angle ω with respect to the urban population (see Fig. A1). Determining the effectiveness of this attack, although a straightforward application of Eq. A8, involves some rather lengthy algebra; only the answer is given here.

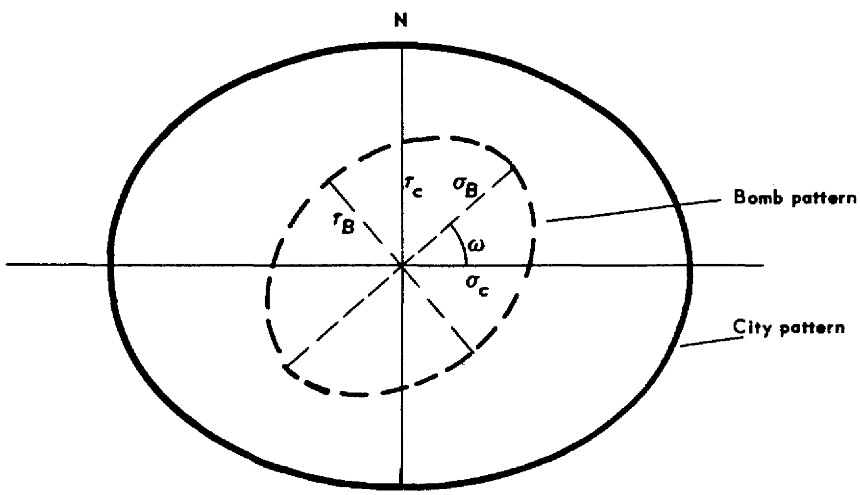

Fig. A1 — Relation of Bomb Pattern to City Pattern when Bomb Is Aimed at Center of City

Result 3. If one bomb characterized by Eq. A2 is delivered according to the setup pictured in Fig. A1 the expected level of casualties is

$$c \cdot \{[1 + \lambda(\sigma_B^2 + \sigma_c^2)][1 + \lambda(\tau_B^2 + \tau_c^2)] + \lambda^2(\sigma_B^2 - \tau_B^2)(\sigma_c^2 - \tau_c^2) \sin^2 \omega\}^{-1/2}.$$

It is perhaps worth noting that when $\sigma_B > \tau_B$ and $\sigma_c > \tau_c$ this result is greater than

$$c \cdot \{[1 + \lambda(\sigma_B^2 + \tau_c^2)][1 + \lambda(\tau_B^2 + \sigma_c^2)]\}^{-1/2} \tag{A10}$$

and less than

$$c \cdot \{[1 + \lambda(\sigma_B^2 + \sigma_c^2)][1 + \lambda(\tau_B^2 + \tau_c^2)]\}^{-1/2} \tag{A11}$$

Equation A10 corresponds to the case in which the city and bomb patterns are completely out of phase ($\omega = 90$ deg); Eq. A11 to the case in which they are completely in phase ($\omega = 0$ deg). By letting λ and the different standard deviations assume various special values, e.g., 0 and ∞, it is easy to see that Result 3 and Eqs. A10 and A11 withstand inspection.

When the center of the bomb pattern is not coincident with the center of the city the effect is to degrade Result 3 by a certain negative exponential: the exponent is a homogeneous quadratic form in the coordinates of the aiming point with respect to the frame of reference determined by the city. Consequently the locus of points such that a bomb aimed at them under these conditions gives rise to a fixed expected level of casualties — in brief, the equicasualty contours — is an ellipse. This too is an observation that agrees with experience, at any rate toward the center of a city. Away from the center of the city the bomb begins to pick out casualties in neighboring cities; hence the contours for the lower casualty levels wander about, enclosing more than one center of population.

PROCEDURE FOR OBTAINING BINORMAL FIT TO CITY

A hypothetical population breakdown of a city into squares 2 by 2 miles each is shown in Fig. A2 (0 to 9 columns and rows). Any standard work on statistics may be consulted on the question of computing the means, variances, and covariance. The interest in such

y ↓ \ x →	0	1	2	3	4	5	6	7	8	9	A	B	C	
0	1	2	1	3	0	3	5	1	0	2	18	83	101	
1	1	1	5	4	6	13	18	14	6	1	69	375	444	
2	0	3	15	21	17	29	27	22	15	3	152	772	924	
3	1	11	30	43	35	54	61	19	11	6	271	1251	1522	
4	2	12	28	60	45	112	31	7	5	4	306	1299	1605	
5	0	10	25	41	72	80	64	27	13	1	333	1557	1890	
6	2	0	16	27	51	65	30	15	9	0	215	999	1214	
7	3	5	13	20	29	33	24	10	6	2	145	652	797	
8	6	2	6	8	11	18	14	11	8	5	89	442	531	
9	1	1	0	2	3	5	9	6	1	3	31	175	206	
a	17	47	139	229	269	412	283	132	74	27	1629	7605	40847	57686
b	102	198	597	1004	1309	1891	1240	580	323	127	7371	34322		
c	119	245	736	1233	1578	2303	1523	712	397	154	39389			
											55760			

Fig. A2 — Hypothetical Distribution of Urban Population
Thousands of persons per 4 sq miles.

works, however, usually extends to further quantities that are of no concern here, and the effect may be somewhat confusing. Consequently the method developed and employed for this study is given here in full, and the results are shown in the A, B, C columns and a, b, c rows of Fig. A2. One of the advantages of the method is that there is a check on every computation immediately after it is made. The following instructions were given with no further comment to computers without previous experience in this work; the results were quite satisfactory.

1) Compute the sum of all the entries in each row and enter it in column A $(1 + 2 + 1 + 3 + \cdots + 0 + 2 = 18$, etc.).

2) Do the same for each column $(1 + 1 + \cdots + 6 + 1 = 17$, etc.).

3) Sum column A and row a; these should be equal $(18 + 69 + \cdots + 31 = 1629 = 17 + 47 + \cdots + 27)$. Enter total.

4) In the first row, compute the cumulative sum of each entry multiplied by the corresponding x-value $(1 \cdot 0 + 2 \cdot 1 + 1 \cdot 2 + 3 \cdot 3 + 0 \cdot 4 + \cdots + 2 \cdot 9 = 83)$. Enter in column B.

5) In the first row, compute the cumulative sum of each entry multiplied by the next higher x-value $(1 \cdot 1 + 2 \cdot 2 + 1 \cdot 3 + 3 \cdot 4 + \cdots + 2 \cdot 10 = 101)$. Enter in column C. Should be equal to sum of corresponding values in columns A and B $(101 = 83 + 18)$.

6) Do the same for each of the rows and each of the columns. Note that the figures in column C are just check-sums, and are not used further in the work. They need not even be written down once they check.

7) Compute the sum of column B $(83 + 375 + \cdots + 175 = 7605)$.

8) In row a, compute the cumulative sum of each entry multiplied by the corresponding x-value $(17 \cdot 0 + 47 \cdot 1 + \cdots + 27 \cdot 9 = 7605)$. This should equal the number computed in the previous step. Enter total.

9) Compute the sum of row b $(102 + 198 + \cdots + 127 = 7371)$ and check that it is the same as the cumulative sum of each entry in column A multiplied by the corresponding y-value $(18 \cdot 0 + 69 \cdot 1 + \cdots + 31 \cdot 9 = 7371)$. Enter total.

10) In column A, compute the cumulative sum of each entry multiplied by the square of the corresponding y-value $(18 \cdot 0 + 69 \cdot 1 + 152 \cdot 4 + 271 \cdot 9 + \cdots + 31 \cdot 81 = 39389)$. Enter total.

11) In column A, compute the cumulative sum of each entry multiplied by the square of the next higher y-value $(18 \cdot 1 + 69 \cdot 4 + 152 \cdot 9 + 271 \cdot 16 + \cdots + 31 \cdot 100 = 55760)$. This should equal the figure in cA plus twice the figure in bA plus the figure in aA $(55760 = 39389 + 2 \cdot 7371 + 1629)$. It is just a check-figure and is not used again.

12) In row a, compute the cumulative sum of each entry multiplied by the square of the corresponding x-value $(17 \cdot 0 + 47 \cdot 1 + 139 \cdot 4 + \cdots + 27 \cdot 81 = 40847)$ and enter total; compute the sum with each entry multiplied by the square of the next higher x-value $(17 \cdot 1 + 47 \cdot 4 + 139 \cdot 9 + \cdots + 27 \cdot 100 = 57686)$. As a check: $57686 = 40847 + 2 \cdot 7605 + 1629$.

13) In column B, compute the cumulative sum of each entry multiplied by the corresponding y-value $(83 \cdot 0 + 375 \cdot 1 + 772 \cdot 2 + \cdots + 175 \cdot 9 = 34322)$.

14) In row b, compute the cumulative sum of each entry multiplied by the corresponding x-value $(102 \cdot 0 + 198 \cdot 1 + 597 \cdot 2 + \cdots + 127 \cdot 9 = 34322)$. This should be equal to the value obtained in the last step. Enter total.

15) Of the values so far computed we retain only the triangular array in the lower right-hand corner:

1629	7605	40847
7371	34322	
39389		

From these the parameters of the population are computed according to the scheme:

$$\bar{x} = 7605/1629 \qquad \bar{y} = 7371/1629$$

$$\sigma_x^2 = (40847/1629) - \bar{x}^2 \qquad \sigma_y^2 = (39389/1629) - \bar{y}^2$$

$$\sigma_{xy} = (34322/1629) - \bar{x}\,\bar{y}$$

$$\rho = \sigma_{xy}/\sigma_x\sigma_y$$

Thus, in this case, $\bar{x} = 4.67$, $\bar{y} = 4.52$, $\sigma_x = 1.81$, $\sigma_y = 1.93$, $\sigma_{xy} = -0.054$, and $\rho = -.015$. It should be recalled that x and y are assumed to be measured in units of 2 miles, and these are therefore the units in the results (i.e., actually $\sigma_x = 3.62$ miles).

16) The transformation to the principal axes, σ_c and τ_c, is accomplished by means of the equations

$$(\sigma_c + \tau_c)^2 = \sigma_x^2 + \sigma_y^2 + 2\sigma_x\sigma_y\sqrt{1-\rho^2},$$
$$(\sigma_c - \tau_c)^2 = \sigma_x^2 + \sigma_y^2 - 2\sigma_x\sigma_y\sqrt{1-\rho^2}.$$

In solving for σ_c and τ_c, take $\sigma_c - \tau_c > 0$ when $\rho > 0$ and $\sigma_c - \tau_c < 0$ when $\rho < 0$.

17) The angle α through which the principal axes are inclined is given by

$$\tan 2\alpha = [2\rho\sigma_x\sigma_y/(\sigma_x^2 - \sigma_y^2)](\sigma_x \neq \sigma_y)$$

and

$$\alpha = 45^\circ\ (\sigma_x = \sigma_y).$$

It is to be noted that $90^\circ - \alpha$ is also a solution of this equation; i.e., the equation alone does not tell which of the axes the angle is measured toward.

This procedure tacitly assumes that the city is not markedly bimodal. If it is, it is probably safe to assume that it is because of some geographical barrier — twin cities separated by a river, or a city like San Francisco, on opposite sides of a bay — since otherwise reasons of commerce and convenience would tend to make the halves coalesce. This barrier can then be used to dissect the city into a pair of unimodal subcities, each of which may be fitted according to the method used here.

BOMBS AIMED AT CENTER OF CITY

For the sake of simplicity it is assumed from now on that the bombs are circularly normally distributed, i.e., that $\sigma_B = \tau_B$. When n bombs of the same characteristics are aimed at the center of the city, the expected level of casualties is given by

$$\frac{1}{2\pi\sigma_c\tau_c}\int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty}\exp\left(-\frac{\xi^2}{2\sigma_c^2}-\frac{v^2}{2\tau_c^2}\right)\left\{1-\left[1-\frac{c}{1+\lambda\sigma_B^2}\exp\frac{-\lambda(\xi^2+v^2)}{2(1+\lambda\sigma_B^2)}\right]^n\right\}d\xi\,dv, \quad \text{(A12)}$$

which works out to be:

Result 4. For n bombs aimed at the center of the city, the expected level of casualties is given by

$$\sum_{\mu=1}^{n}(-)^{\mu-1}\binom{n}{\mu}[c^\mu/(1+\lambda\sigma_B^2)^{\mu-1}]\{[1+\lambda(\sigma_B^2+\mu\sigma_c^2)][1+\lambda(\sigma_B^2+\mu\tau_c^2)]\}^{-1/2}.$$

This is relatively easy to compute from, although the increasing number of terms as n increases is unfortunate. A rather rough one-term approximation can be made as follows. If expected levels of survival rather than casualties are considered, the curve tends to 0 as $n \to \infty$, and moments of all orders exist. From Eq. A12 the zeroeth moment is simply

$$\frac{1}{2\pi\sigma_c\tau_c}\int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty}\exp\left(-\frac{\xi^2}{2\sigma_c^2}-\frac{v^2}{2\tau_c^2}\right)\cdot\frac{1+\lambda\sigma_B^2}{c}\exp\frac{\lambda}{2}\frac{\xi^2+v^2}{1+\lambda\sigma_B^2}\,d\xi\,dv$$
$$= \frac{(1+\lambda\sigma_B^2)^2}{c\sqrt{[1+\lambda(\sigma_B^2-\sigma_c^2)][1+\lambda(\sigma_B^2-\tau_c^2)]}}. \quad \text{(A13)}$$

Now fit this by $\exp(-an)$, whose zeroeth moment is $1/[1-\exp(-a)]$, by equating these moments. Thus

$$\exp(-a) = 1 - \{c\sqrt{1+\lambda(\sigma_B^2-\sigma_c^2)][1+\lambda(\sigma_B^2-\tau_c^2)]}/(1+\lambda\sigma_B^2)^2\}, \quad \text{(A14)}$$

so that the expected level of survival of n bombs is approximately

$$\{1-[c/(1+\lambda\sigma_B^2)^2]\sqrt{[1+\lambda(\sigma_B^2-\sigma_c^2)][1+\lambda(\sigma_B^2-\tau_c^2)]}\}^n. \quad \text{(A15)}$$

It is not difficult to show that the survival probability is really asymptotically proportional to

$$(1/n)\exp\left[-cn/(1+\lambda\sigma_B^2)\right]\ (n\to\infty). \tag{A16}$$

BOMBS AIMED AT DIFFERENT POINTS

Suppose that at each of the points $(x_1, y_1), \ldots, (x_n, y_n)$, the bomb of Result 2 is aimed (with $\sigma_B = \tau_B$). This does not rule out the possibility that certain of these points may coincide; thus the discussion really includes the case of several bombs at each of several points and in particular the case of n bombs aimed at the center of the city. The expected level of casualties is clearly given by

$$\begin{aligned}1-\frac{1}{2\pi\sigma_c\tau_c}\int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty}\exp\left(-\frac{\xi^2}{2\sigma_c^2}-\frac{\upsilon^2}{2\tau_c^2}\right)&\left[1-\frac{c}{1+\lambda\sigma_B^2}\exp\frac{-\lambda}{2}\cdot\frac{(\xi-x_1)^2+(\upsilon-y_1)^2}{1+\lambda\sigma_B^2}\right]\\ &\times\left[1-\frac{c}{1+\lambda\sigma_B^2}\exp\frac{-\lambda}{2}\cdot\frac{(\xi-x_2)^2+(\upsilon-y_2)^2}{1+\lambda\sigma_B^2}\right]\\ &\times\cdots\times\left[1-\frac{c}{1+\lambda\sigma_B^2}\exp\frac{-\lambda}{2}\cdot\frac{(\xi-x_n)^2+(\upsilon-y_n)^2}{1+\lambda\sigma_B^2}\right]d\xi\,d\upsilon.\end{aligned} \tag{A17}$$

When this expression is expanded and integrated, there result $2^n - 1$ terms, of which the first n are of the form

$$\frac{c}{\sqrt{[1+\lambda(\sigma_B^2+\sigma_c^2)][1+\lambda(\sigma_B^2+\tau_c^2)]}}\exp\frac{-\lambda}{2}\left[\frac{x_1^2}{1+\lambda(\sigma_B^2+\sigma_c^2)}+\frac{y_1^2}{1+\lambda(\sigma_B^2+\tau_c^2)}\right], \tag{A18}$$

the next $\frac{1}{2}n(n-1)$ of the form

$$\begin{aligned}&\frac{c^2}{1+\lambda\sigma_B^2}\cdot\frac{1}{\sqrt{[1+\lambda(\sigma_B^2+2\sigma_c^2)][1+\lambda(\sigma_B^2+2\tau_c^2)]}}\\ &\qquad\times\exp\frac{-\lambda}{2}\left[\frac{(1+\lambda\sigma_B^2+\lambda\sigma_c^2)(x_1^2+x_2^2)-2\lambda\sigma_c^2x_1x_2}{(1+\lambda\sigma_B^2)(1+\lambda\sigma_B^2+2\lambda\sigma_c^2)}+\textit{ditto}\ y_1,y_2\right],\end{aligned} \tag{A19}$$

and so on, the terms growing progressively more complicated. If, however, only two or three aiming points are considered, the resultant formulas are still practicable. It is interesting to remark that the terms in Eq. A18 are what would result if the casualties from one bomb might be compounded with those of another by simple addition; the terms in Eq. A19 may be considered "first-order corrections," and so on.

EVACUATION

It would be well to close with a brief examination of the effect of evacuation efforts. Many cities have detailed plans about where they will transfer their populations and how long they will need to do so. From the point of view of this annex such reallocations of population constitute new cities for which a new bivariate analysis must be performed in order to arrive at casualty estimates.

In this annex it is not a controlled evacuation, but rather a more or less unsupervised exodus, that is of interest. Certainly there is no overwhelmingly compelling evidence that this will not be the case, however good the intentions may be.

Assume, then, that there is a uniform outward flow of population governed by the diffusion equation

$$(1/k)(\partial f/\partial t) = (\partial^2 f/\partial x^2) + (\partial^2 f/\partial y^2) \qquad \text{(A20)}$$

and subject to the initial condition that at $t = 0$ the population distribution is given by Eq. A9. Fourier's solution is simply

$$f = (1/\pi)\int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} \exp(-\xi^2 - v^2)\cdot(1/2\pi\sigma_c\tau_c)\exp\{-[(x + 2k\xi\sqrt{t})^2/2\sigma_c^2] - [(y + 2kv\sqrt{t})^2/2\tau_c^2]\}\, d\xi\, dv, \qquad \text{(A21)}$$

which evaluates at once as

$$[1/2\pi\sqrt{(\sigma_c^2 + 2kt)(\tau_c^2 + 2kt)}]\exp\{-[x^2/2(\sigma_c^2 + 2kt)] - [y^2/2(\tau_c^2 + 2kt)]\}. \qquad \text{(A22)}$$

This leads to Result 5.

Result 5. Under a uniform outward flux of population the distribution remains binormal but the variances become linear functions of time. That is, the relative position and orientation of the city do not change; the distribution surface simply becomes flatter and flatter.

The constant k is found from the network of roads and streets the city possesses. Actually there are more traffic lanes near the center of the city than in the outskirts and therefore the center should drain out relatively quickly. Rather than a flattening hummock, the population distribution would probably resemble an expanding doughnut.

If concentric circles are taken about the center of population and people are periodically displaced outward through the available traffic lanes, a series of "snapshots" of the diffusing population can be obtained. These can be plotted radially and fitted by

$$(r/\sigma_c^2)\exp(-r^2/2\sigma_c^2). \qquad \text{(A23)}$$

A simple application of Fisher's Method of Maximum Likelihood indicates that the best value to take for σ_c^2 is half the second moment. If these variances are plotted against time it may be seen that Result 5 is an adequate approximation to the truth, unless the road network is very spotty.

Annex B

IMPORTANT FACTORS IN THE DEVELOPMENT OF AN UNDERGROUND SHELTER PLAN FOR A METROPOLITAN TARGET AREA

CONTENTS

INTRODUCTION

The body of this appendix indicates that the most effective method of minimizing urban population casualties under thermonuclear attack is the use of underground shelters providing a high level of resistance to peak blast overpressure and adequate shielding against initial and residual radiation. The long-range inferiority of alternative passive defense measures is due to some special characteristic of each. Best existing shelter offers very poor protection against blast and would supply only a few hours of life under local fallout from megaton weapons. Mass evacuation is time-consuming at best and may result in panic at worst; in the case of missile attacks this measure cannot be undertaken, owing to short warning time.

Under most conditions of airborne attack, use of underground shelters would yield more survivors than use of best existing shelter or evacuation. The relative superiority of underground shelter increases as the number of weapons per target increases and as aiming accuracy deteriorates. Furthermore underground shelter is undoubtedly the best passive defense measure under the conditions of short warning time associated with missiles, whether submarine-launched or ICBM, and against the widespread high-intensity fallout from a mass attack.

LIMITATIONS OF UNDERGROUND SHELTER

To be usable under the short warning of missile attack, underground shelter must be located close to where people are, both by day and by night. Construction of a system of underground shelters on a geographical pattern matching the present distribution of daytime and nighttime populations would result in a concentration of shelters itself vulnerable to the cratering effects of megaton weapons and the very high blast pressures just beyond the crater and lip. If the accuracy of enemy bombing were poor, some concentrations of shelters would escape; however, the possibility of a high CEP cannot be relied on to remove the hazard of direct hits on shelter concentrations, and cannot be established by national policy as a passive defense measure. Thus the prime limitation of an underground shelter program is the necessity to spread out the pattern of shelter sites and at the same time keep people close to their shelters.

The second major limitation is cost. Previously proposed shelter programs, such as those recommended to Congress by FCDA during past years, have been summarily rejected by Congressional committees on the grounds of cost. The possibilities of favorable Congressional action are improving and it is entirely possible that the cost of a national program of shelters able to withstand 30 to 100 psi and giving adequate radiation attenuation may soon be acceptable to Congress.

The concentration of shelters in potential crater areas may create a new stumbling block. This limitation might be ameliorated by sinking shelters so deep through use of shafts and tunnels that they would be below any surface-burst crater or lethal underground shock. But again, Congressional appropriations leaders might shy at the cost of this shelter program, which would obviously be much higher than that for shelters just below ground level.

A final limitation of a national underground shelter scheme is construction time. The new highway program will add heavy requirements for steel and cement to already high boom-period demands. During the time required to construct underground shelters on a wide scale, reliance must necessarily be placed on alternative measures.

ESSENTIAL CHARACTERISTICS OF AN UNDERGROUND SHELTER PLAN

It would appear that a detailed study of reduction of vulnerability such as that recently prepared for the Milwaukee Metropolitan area[23] might provide a general framework for the description or detailing of a metropolitan shelter plan. The Milwaukee study was divided into three major parts: preventing further increase in the vulnerability of the central area, aiding new growth to locate in the suburbs, and reducing existing vulnerability in the central area. The problem in a program of construction of new underground shelters, however, is not one of reducing the vulnerability of an existing and growing target but rather one of designing from the ground up a new target system that will have the lowest possible vulnerability to air attack. Thus the most important single aspect of a metropolitan shelter plan is the new target system it proposes. How can this target system be made least vulnerable within the bounds of economic, physical, and political feasibility?

The design objective is of course maximum survival at minimum cost. Considered as a theoretical design problem, assuming raw land, this objective would require finding the most efficient size, shape, design, mechanical equipment, and materials and methods of construction for a single shelter structure, and then spacing duplicates of such a structure at uniform intervals throughout the target area.

The problem is reduced to a practical basis by adding the requirement that working and living places be located near the shelters and then proceeding to analyze the degree to which working and living spaces can be moved, over the period of years needed to carry out the shelter program, to conform to desirable spacing of shelters. This is primarily a matter of economic feasibility, tested within the framework of a comprehensive regional plan for future physical development of the metropolitan target area.

A metropolitan shelter plan should be based on a geographical pattern of shelters incorporating the maximum dispersion possible. Since shelter location must be controlled by the location of daily activities, the maximum dispersion will depend on the degree of dispersion economically feasible for daily activities. This factor should be expressed in terms of the minimum level of activity or concentration that must be maintained in the central area to preserve the essential nature and inherent advantages of a metropolitan complex. It should also be expressed in terms of the maximum level of activity or congestion for which shelters will be provided, both in the central area and in outlying areas.

Local and perhaps federal agencies must decide which of the existing activities in the concentrated central area will be provided underground shelter under the national program. All activities in the congested area should be officially informed as to whether they will receive underground shelter within the congested area or in a less congested outlying area.

Next it should be decided whether activities requiring central locations and due to be provided central shelter are suitably distributed within the central area, or whether some shifts, perhaps into buildings to be vacated by activities not requiring central locations, would be desirable. Concurrently, work should be underway to determine general locations in the outer portions of the metropolitan target zone where activities eventually to be displaced from the center could settle. Where needed, new high-speed freeways should be planned to connect the proposed dispersed development locations with one another and with the central city.

Only after dispersion of activities has been planned is the designer ready to establish construction priorities for specific underground shelter projects. First priority should go to shelters located at dispersed development sites near existing high-speed radial freeways. These shelters should be assigned to central-area activites not due to be furnished shelters in the central area, and movement priorities established by a metropolitan survival plan or nonmilitary defense plan should be assigned to these activities.

Second priority should go to construction of shelters for those activities allotted shelter space in the central area. Those activities whose shelters will be located in the most probable crater area should be so informed. At this point, if it has not been done previously, decision must be made concerning the depth at which shelters in the most probable crater area will be constructed.

Third priority for construction should go to the large zones between the congested central area and the planned dispersed development sites. In this intermediate territory there may be much private activity in strengthening or hardening best existing shelter during the time interval required to reach third-priority underground shelter construction.

Fourth priority for underground shelter construction should go to dispersed development sites that are to be made readily accessible for peacetime intercourse with the central area through construction of new freeways. Shelter construction here should be timed to coincide with freeway construction.

Since the possibility of submarine-launched missile attack with very short warning exists today for coastal cities, it is obvious that first-priority dispersed development site shelters for personnel in central-area activities would not be accessible within the warning time. Therefore for coastal cities central-area shelters should be given equal priority with dispersed development site shelters. This procedure is advocated with reluctance, however, since land for central-area shelters, if purchased, would have to be acquired at prices representing capitalization of income based on existing congestion in the central area, while the national shelter program itself would be operating to spread land values in any metropolitan area over a wider and larger territory, thus tending to reduce present peak land values in the central area. There would be a serious danger that low-value land might be bought at high prices to the detriment of the shelter program as a whole.

UNDERGROUND SHELTER PLAN AS PART OF A METROPOLITAN REGIONAL PLAN

It may be felt that too much trouble and complexity are wrapped up in the proposed shelter plan, and that the problem is a relatively minor one. Are air-raid shelters important enough to justify this much disruption of peacetime economic activity? So much government control would be required to accomplish the plan that the country might lose before a war the very freedom it planned to defend by the war itself. This is indeed a powerful argument. Project EAST RIVER, which has gone furthest in exploring the possibility of reducing vulnerability through use of space, reported opposition to its recommendations:

> 8. In terms of what had been hoped for in the way of progress in carrying out our 1952 Project EAST RIVER recommendations, it may be useful to state certain of our disappointments as of 1955. They can be listed as
>
> a. While Project EAST RIVER placed great stress and considerable emphasis on the reduction of urban vulnerability (Part II–B — Federal Leadership to Reduce Urban Vulnerability, and Part V — Reduction of Urban Vulnerability), it is disappointing to observe that such little progress has been made. It is fair to state that the political and economic obstacles to any such program were underestimated by Project EAST RIVER.[24]

Yet when all the objections have been aired and duly recorded, the hard facts remain. A 10-Mt weapon will inflict A-ring damage out to a radius of 4 miles from GZ with peak overpressures of 19 psi at 4 miles and 6.6 psi at 8 miles. Shelters built to withstand 30 psi might survive at 3½ miles, and shelters built to withstand 100 psi might survive at 2½ miles. These figures are rough estimates given in the absence of authoritative data. The crater of a 10-Mt ground burst would have a radius of 1½ miles. Any unusual concentration of shelters in a potential crater or in a potential shelter destruction zone will surely draw enemy fire as a target of above average reward. If an attack is successful and accuracy of delivery is high, large numbers of people and a very costly investment in shelters will be lost in spite of the expense of a national shelter program. This fact may be a prime argument for regional planning for reduction of urban vulnerability through dispersal.

The heart of a plan for reduction of vulnerability should be a metropolitan regional plan for future development on a dispersed basis. Before a comprehensive plan can be drawn up, a number of staff studies should be made. Many such studies already exist — routine products of city, county, and regional planning commissions; those of recent date need only be reexamined in terms of the general goal of a broader distribution of densities.

Preliminary Staff Studies

For that part of a regional dispersal plan related to spacing of underground shelters certain preliminary staff studies should be made. These studies should include an appraisal and analysis of existing economic activity, with projections and estimates of the future total economic activity and its major components. The size, distribution, and composition of the future population of the metropolitan region at selected time intervals should be estimated. The relative strength of various interrelations among activities in the region should be analyzed to serve as a measure of the feasibility of geographically separating various groups of activities.

Staff studies should also include an analysis of certain physical aspects of the metropolitan area. Existing and potential service zones of the metropolitan center, as bounded or limited by comparable service zones of other metropolitan centers, should be studied. Major physiographic features that would exert influences on future development within the selected dispersed development district should also be studied. The major element is topography, which affects routes and ease of movement, suitability of ground for building sites, possibility of underground construction with access through horizontal as opposed to vertical shafts, possibilities of gravity distribution of raw and treated water, possibilities and economics of developing sewer systems, possibilities of developing water-reservoir sites, etc. Other major elements are size and flow characteristics of waterways; location, capacity, and quality of underground water supplies; soil characteristics, including fertility for crops, porosity for septic-tank sewage disposal, and load-bearing capacity for heavy-building construction; and existing ground cover, particularly forests, rainfall, etc.

A preliminary identification should be made of areas that should be reserved for open space or very-low-density development. Typical low-density land uses would be public or private forests; national, state, or local parks; watersheds; agricultural or residential estates; and summer cottages.

Preliminary identification, later modified by concurrent reappraisal of all area studies, should be made of general areas for location of nuclei of future dispersed development. The basic consideration here must be geographical separation sufficient to remove underground shelters of one nucleus from the potential crater area and high overpressure area of another nucleus.

Potential high-speed transportation routes connecting dispersed nuclei with one another and with the central part of the city should be selected. These routes will be primarily for freeways, but will probably include existing rail routes. Consideration should be given to operating factors affecting scheduled helicopter operations, including air traffic patterns.

Potential sources of water supply, the effect on other potential sources of developing one source of supply, and the effects of various alternative sewer systems on the different water-supply sources should be analyzed. Competition with other metropolitan centers for distant sources of supply must be considered. If more than one system appears desirable, the study should cover possibilities of interconnecting the systems to permit bypassing enemy damage.

Possible methods of sewering the various nuclei and those of their surroundings planned for close development should be studied. Existing sewer systems and existing and planned water-supply systems must be given adequate consideration. Dispersion of treatment facilities through use of package plants might provide ameliorating safeguards against the heavy contamination that could result from successful attack on a single integrated system. Package plants would probably be more economical, too, if a full-bodied pattern of protected open spaces were developed.

Although most communications lie in the sphere of private enterprise, the vital importance of good transportation and communications to any dispersed pattern of activity is so great that special studies might be undertaken in conjunction with private utilities to make certain that needless handicaps are not imposed on the development of communications. Reservation of selected hilltops for public-utility television relay stations is not an impossibility. Image-carrying telephone devices exist now in prototype stage; newer inventions to speed communication are a strong possibility.

A classification and evaluation of the activities in the central (core) area should be made to determine those for which a central location is so clearly in the public interest that central underground shelter should be provided them. These evaluations will involve estimates of target value, alternative facilities, recuperability, economic and physical ties to other core activities, and comparable factors relating to the need for a central location as opposed to the need for continuity of operation during and after attack. At the present time in the Washington area decisions of this kind are actually being made by the heads of federal departments and agencies about to construct new buildings. The first decisions to move to dispersed sites were those of the National Security Agency and the Atomic Energy Commission. The Central Intelligence Agency, the Weather Bureau, the Coast and Geodetic Survey, and the Bureau of Standards have followed suit. The State Department and the Court of Claims plan to build in the core area. Congress is now alerted to the possible need for some check on the discretion of individual agencies. A Washington area regional plan for metropolitan distribution of key federal activities should probably be decided on by the Congress, with some voice given to agency heads and the District Commissioners, and with preliminary staff studies conducted by the Office of Defense Mobilization, the Area Development Division of the Department of Commerce, the National Capital Regional Planning Council, and the National Capital Planning Commission. However, the area of jurisdiction of the National Capital Regional Planning Council, as established at present by the Congress, is not large enough to cover an appropriate dispersed development district for Washington, nor are the presently constituted planning agencies closely conversant with problems of nonmilitary defense and reduction of urban vulnerability.

When existing core activities have been grouped into those that might move outward and those that should remain, a general allocation study should be made to determine location and distribution of the moved agencies throughout the dispersed development district. Something of this kind has already been started by the Office of Defense Mobilization in allocating sectors of territory around Washington to federal agencies for their continuity-of-government activities.

The kinds and general quantities of minor basic employment and secondary or supporting economic activities around suburban nuclei and in the central city should be estimated. These generalized data are needed for broad design decisions in the fields of water supply, sewerage, highway capacity, and areas of land to be devoted to various uses.

A study should be made of methods of preventing excessive concentration of those essential activities planned for long-time retention in the central area. Some shifts to more satisfactory sites or buildings are likely to occur over the years even among permanent in-town activities. For example, in Washington the crater areas of weapons in the single megaton range are so great in relation to the Mall, the Federal Triangle, and the Federal Rectangle that some moves outside this core into other parts of the District of Columbia would be advisable. The Bureau of Standards' current site, which will become available when the Bureau moves, would be safer for an important agency than a new building downtown, and an underground shelter there might survive a weapon that cratered out all shelters in the downtown area.

Shelter needs should be calculated on the basis of planned ultimate redistribution of primary and secondary activities of the metropolitan area. The results of this study should be used in the search for suitable sites for underground shelters. There should be some opening up of land in the central area due to departure of less essential activities, which should reduce costs of land acquisition for the shelter program.

Shelter construction priorities should also be studied. If a massive program were undertaken, some shelters would probably be built in all three zones immediately — central area, suburban nuclei, and intermediate zone. Local priorities would probably be related to importance of persons and activities to a war effort.

Key Plans for Dispersal

The series of staff studies recommended here should produce material from which official plans can be prepared. These plans would be similar to presently used comprehensive or master plans but would be based on an expanded distance scale.

A plan for land use should be established to distinguish between open and close development throughout the dispersed development district. Close development areas should be subdivided into industrial, commercial, and residential areas, with residential further subdivided into principal density categories.

For nonmilitary defense purposes a population distribution plan should be set up for both daytime and nighttime distribution. Nighttime distribution should be a restatement of data on use of residential land, with the data converted to population figures. Daytime distribution should reflect intensity of development planned in industrial and commercial areas, plus residual nonworking population in residential areas.

The backbone of a transportation plan will be a metropolitan system of freeways, composed of existing and proposed routes, extending throughout the dispersed development district. Routes included in the national system of interstate highways will usually form the framework on which freeway spurs and circumferentials reaching the suburban nuclei can be hung. Helicopter routes and major uncontrolled-access highways will probably also be shown. Commuter rail service may survive in some metropolitan areas.

A water supply plan should be drawn up to show impounding, transmission, treatment, storage, and major distribution facilities for the various water-supply systems in the dispersed development district. A sewerage plan is also needed, to show service areas, interceptor and trunk lines, and sewage treatment facilities throughout the dispersed development district.

A shelter plan for the area should show the locations, size, and service area of communal underground shelters, and the areas in which family underground shelters will be used. The latter may be limited to rural areas, owing to the need for mechanical services in shelters that may have to be occupied for many days under conditions of heavy fallout from multiple sources.

A communications plan should show alternate routings available for wire communications in the dispersed development district, together with protected or underground sites for telephone exchanges and radio transmitters.

Administrative Controls

In addition to the various plans there must be appropriate administrative tools for holding development in line with plans. New techniques in zoning must be developed to ensure uniform application of density restrictions over the entire metropolitan area. This might be accomplished by adoption of urban defense zoning regulations at the state level, with interstate uniformity achieved by compact. Another important tool in maintaining standards in areas of new development is the local ordinance regulating subdivision of land. Standards flowing from urban defense requirements might be applied locally under state coordination or might be established directly at the state level.

Major public expenditures are required to stimulate rapid development of dispersed areas. Costs are most burdensome in the fields of highways, water supply, and sewerage. Underground shelters would be a new addition to this list. The physical development plans must be accompanied by a public works construction priority schedule. It is obvious that water and sewer service must be provided first to the nuclei that are first served by freeways. The public works program is usually planned on a 3-, 5-, or 6-yr basis. For a major effort such as dispersal of new underground shelters the period might be extended to 10 yr, or to 13 yr, as for the new national highway program.

Adherence to construction priorities is maintained through the capital budget that covers annually the current year's public works program.

OTHER COMPONENTS OF A METROPOLITAN REGIONAL PLAN

This section briefly treats topics other than those directly connected with shelter that would normally be included in a well-rounded reduction-of-vulnerability program. These topics fall into two broad categories: structural protection, and advance planning by management and government.

Structural protection may be applied to buildings, process equipment, and utilities. A typical field is in hardening buildings to minimize building losses and preserve usable floor space in the face of enemy attack. This aim is distinct from that of preserving life through construction of shelters, but may be related to the latter.

One method of obtaining hardening, probably maximum hardening, is to place installations underground. The Office of the Chief of Engineers, Department of the Army, in recommending that underground construction should at least be planned now has stated:

> The study of the need for underground plants must of course take into account the possibility of dispersion, camouflage, duplication of facilities, stockpiling, and transportation.
>
> However, when all is said and done, nothing affords better protection [of production and production personnel] than a plant located underground in a sound rock formation. A minimum of 50 feet of overhead cover will provide a reasonable degree of protection against all known weapons.[25]

Exhaustive studies of the psychological and morale effects of working in windowless structures, tunnels, bank vaults, underground installations in Sweden, etc., indicate that no work decrement need be expected.[26]

Estimates have been made of the comparative above-grade and underground initial and operating costs for three types of installations: a precision manufacturing plant, a chemical plant, and a storage depot.[27] Consideration was given both to excavating new sites and utilizing existing mines. These costs, expressed as percentages of above-grade costs, appear in Table B1.

TABLE B1

COMPARATIVE CONSTRUCTION AND OPERATING COSTS FOR ABOVE-GRADE AND UNDERGROUND INSTALLATIONS
(Expressed as percentages of above-grade costs)

Costs and site	Precision plant	Chemical plant	Storage depot
Construction			
Above grade	100	100	100
Existing mine	119	134	78
New excavation	144	160	151
Operating			
Above grade	100	100	100
Existing mine	102	104	98
New excavation	103	106	99

It would appear that this type of hardening could provide relatively inexpensive protection. In at least many situations (where the underground installation is located near population centers, or where part of the factory is above grade), and given some warning time of the attack, an additional benefit would be that the underground installation could serve as a shelter area.

Another method of obtaining hardening would be to require that all new structures provide strength adequate to resist blast throughout a portion of their floor area, so that postattack emergency operations could be resumed or continued in a fraction of the floor space available prior to attack. Local building codes might be revised to require that 10 percent of the floor area of any new building within a metropolitan target zone be constructed to withstand some given peak blast overpressure, perhaps 30 psi or more. This 10 percent might be put underground, with a blastproof ceiling. Alternatively it might be a highly reinforced core of the building, with the outer and top portions of the building more fragile. If the entire building had a steel or reinforced-concrete frame the strengthened core would then be braced by the outrigger portions of the frame even though the walls and perhaps the floors of the outer portions were demolished.

Although this requirement for a strengthened portion of each new building would not extend to provision of fallout protection, some building owners might want to combine a strengthened floor area with a shelter area. If blast and radiation protection equivalent to that provided under a federal underground shelter program were designed, federal shelter money might be included in the construction funds. This scheme, in fact, might provide the mechanism so long sought for obtaining dual-purpose shelter areas.

Damage to buildings would also be lessened by general dispersal. In addition to the broad effects that could be achieved by planning a dispersed development district, new zoning standards should be applied to the spacing of new buildings in and around suburban nuclei. These standards might include a maximum percentage of lot occupancy (say, 20 percent) to prevent the kind and degree of coverage of land that is prerequisite to the development of fire storms. Off-street parking should be required on each lot to meet 100 percent of needs. This would provide terminal parking facilities commensurate with the freeway network in the dispersed development district and would prevent overcrowding and congestion of buildings in suburban nuclei, with accompanying concentration of target value.

A maximum floor-area ratio would prevent excessive bulk of building on any given lot and thus maintain standards of relatively low density of population and floor space in newly developed dispersed areas. The floor-area ratio would vary with the land-use zone, but might not rise higher than 0.4 or 0.5.

To reduce building debris in the streets after damage or destruction by blast, a minimum depth of front yard, minimum width of side yard abutting a street, and minimum depth of rear yard abutting a street could be established at some figure, such as one and one-half or two times the height of the building. Also to lessen the blocking of streets, local zoning ordinances could require that no trees be planted or retained and no utility poles be installed or used within some specified distance of the centerline of pavement of any public roadway except a local residential street or an alley. This setback requirement would then apply to freeways, primary and secondary uncontrolled-access highways, primary and secondary urban thoroughfares, and residential collector streets. Since these two restrictions serve the particular needs of rescue teams as well as the general needs of civil defense for accomplishing emergency clearance and restoration of streets and roads, decontamination, fire fighting, and emergency restoration of essential activities, they might be grouped with measures relating to an underground shelter program.

The second broad category of nonshelter measures relates to maintaining continuity of vital functions of society: industrial, governmental, financial, and economic. Advance planning for continuity of industrial production relates to stockpiling of materials and equipment, preparation of federal standby programs for allocating scarce materials and equipment, and individual plant, company, and industry programs for dispersion, protective construction, alternative sources of supply, alternative plants and facilities, and advance plans for repair and reconstruction of damaged plants. Advance planning for continuity of government relates to duplication and dispersed storage of vital records, provision of alternative locations for governmental administration, dispersion of supplies and equipment, protective construction for vital utilities, plans for personnel shelters and evacuation, etc. Advance planning for continuity of financial and economic institutions and activities includes maintenance of the supply of money and credit, maintenance of individual and family incomes, establishment of rationing and of controls on prices, rents, and wages, and compensation for losses due to enemy attack. Since many of these measures must be applied on a uniform national basis, they cannot be initiated by the designers of a metropolitan plan for reduction of vulnerability. When established nationally, however, they could be incorporated into local plans.

Unclassified

LIST OF MATERIALS TO BE PHOTOCOPIED

Name of Researcher Betsy Jorgen Card No. ________ Page Number ________

Collection and/or Series (e.g. OF; PPF; Mitchell Papers)	Box No.	File No. and/or Folder Title (e.g. 41-A; 62-B; Civil Rights)	Correspondents and/or Subject (e.g. Memo, Smith to Jones)	Date of Docs.	Number of Pages
WH Off. 64. Sec Subj Files	5	#15 Representaves Test	Memo - Cooper to Cutler	1/11/55	1 ✓
"	5	"	Ltr - Peterson to Lay	2/26/53	1 ✓
WH Off, NSC OCB Central Files	8	OCB 000.9 (File #2) (9)	Dept - Foreign React to AEC Release...	3/11/55	5 ✓
"	8	" (9)	Memo Staats to OCB	2/21/55	6 ✓
"	8	" (10)	Rept OCB - Overseas Reaction to AEC...	3/2/55	10 ✓
					23
				10/25/94	