Operations Research and Economics Division
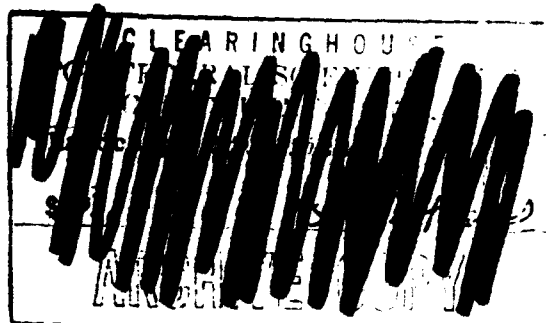
SENSITIVITY ANALYSIS OF CIVIL DEFENSE SYSTEMS AND COMPONENTS

FINAL REPORT VOLUME II

R-OU-157

A SENSITIVITY ANALYSIS OF SELECTED PARAMETERS

BASED ON 8 SMSA'S

Code 1

Prepared for

Office of Civil Defense
United States Department of the Army
under
Office of Civil Defense Contract No. OCD-PS-64-56
OCD Subtask 4113E
RTI Project OU-157

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THE RESEARCH TRIANGLE INSTITUTE

Operations Research and Economics Division

RESEARCH TRIANGLE INSTITUTE
Durham, North Carolina

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H. Rodney Sink

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1 October 1965

FOREWORD

This is Volume II of three separately bound volumes in which are reported the research completed under the general terms of the Office of Civil Defense Subtask Number 4113E, "Sensitivity Analysis of Civil Defense Systems and Components."

The author acknowledges the valuable assistance of Mr. Philip McMullan in completing the research and of Mr. McMulian and Mr. Robert Brooks in preparation of the final report.

ABSTRACT

In order to perform a sensitivity analysis of selected parameters of interest in Civil Defense systems analysis, probable casualties are estimated for 8 SMSA's over a range of fallout environments and shelter utilization patterns. The selected parameters are: SMSA population, population density, and ratio of shelter spaces to population; fallout arrival time and reference intensity; and restrictions on movement of people to shelter, leading to varying patterns of shelter utilization. The SMSA's are selected by "judgment sampling" and range in population from 74,000 to 408,000. The fallout environments used range from a reference intensity of 600 r/hr and 7 hours time of arrival to a reference intensity of 30,000 r/hr and 1 hour time of arrival. The movement-to-shelter restrictions are: (1) movement restricted to the Standard Location (SL) of residence, (2) movement restricted to within two miles of the SL of residence, and (3) unrestricted movement to shelter anywhere within the SMSA. Also, (4) the transportation algorithm is used to determine the optimal (minimum casualty) allocation of people to shelter for each time of arrival and reference intensity combination. This allocation serves as a benchmark of ideality against which to measure other patterns of shelter utilization. Casualties are computed for each of the four movement patterns over the range of attack environments. It is concluded that efficient shelter utilization is very important when shelter spaces exceed population; inefficient utilization can lead to a large number of avoidable casualties. Movement through fallout for a short time in order to reach a better shelter theoretically is warranted in many circumstances.

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Based on 8 SMSA's

I. INTRODUCTION

The purpose of this volume is to analyze the sensitivity of estimates of the effectiveness of fallout shelter systems to changes in movement assumptions and resultant shelter utilization under various fallout environments, shelter/population ratios, and population densities.

Eight Standard Metropolitan Statistical Areas (SMSA's) were chosen representing a range of population densities and shelter/population ratios. Four modes of allocating population to shelters, based on travel restrictions in time or distances, and six types of fallout environment were assumed for each of the SMSA's. Expected casualties were computed for each combination of allocation mode and fallout environment.

The results were then analyzed to answer these and other questions:

(1) How effective are various patterns of shelter utilization in each of the SMSA's?

(2) What trade-offs exist between protection factors and movement in fallout?

II. DEFINING THE MODEL

The four types of movement restrictions considered in the analysis are as follows:

(1) Movement restricted to within each standard location (SL) and no movement in fallout necessary to reach shelter.

(2) Movement restricted to within an SL or to SL's not more than two miles (distances are rectangular distances--rather than straight line--measured between the centers of SL's); no restriction on speed of movement.

(3) Movement unrestricted within the SMSA and no restriction on speed of movement.

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(4) Movement unrestricted within the SMSA and a constant movement speed of two miles per hour beginning with weapon detonation; movement in fallout permitted; casualties minimized using the transportation algorithm (see below).

Assumptions for all cases were as follows:

(1) All standard locations in an SMSA have the same fallout environment;

(2) The fallout intensity increases linearly during the time fallout particles are being deposited;

(3) Maximum Equivalent Residual Dose (ERD) is calculated by a finite differencing method which examines dose accumulation and recovery from time of arrival through the initial shelter period (see Appendix B);

(4) Midpoint values of each Protection Factor (PF) category are used in casualty calculations;

(5) A person experiencing a Maximum ERD of 200r is considered a casualty.

Calculations of casualties for the case with no movement outside the standard location were straightforward. NFSS Phase 1 data [Reference 1] were used for each SL to determine the population and shelter spaces of each PF category, including Category 1. The population was then allocated manually on the basis of utilizing the highest available PF shelter space. Any population in excess of the number of shelter spaces available was considered to have a PF of 2.

In the third type of movement restriction (movement anywhere within the SMSA and no speed restriction), population was allocated to the highest available PF shelter spaces, regardless of their initial locations within an SMSA.

In the case of movement restrictions of two miles, it was necessary to compute the distances between centers of SL's. The rectangular distance was used since it is reasonable that the route to shelters in most cities must follow some right angle street pattern rather than a straight line. The allocation of population to shelters was then done manually, always using all the space with the highest PF within the two-mile movement restriction.

The fourth case of movement restriction, limiting movement speed to two miles per hour, was much more complex. It was necessary to include the possibility of movement in fallout in order to reach a more effective shelter. In order to calculate the movement pattern leading to the minimum number of casualties, it was first necessary to calculate the ERD accumulated in moving from one standard location (S_i) to shelter in another standard location (S_j) of protection factor (k).

When the travel time between standard locations was great enough to require movement in fallout, it was necessary to determine this exposure time and to calculate the dose sustained outside, as well as that sustained while in shelter.

The process of determining the EPD for movement between standard locations under various fallout environments was programmed for the CDC 3600 computer. The generalized matrix that was used for these ERD "costs" is shown below in Table I.

TABLE I

Generalized Matrix for ERD "Costs"

Origins	S_1		S_2					S_j			
	PF_1	PF_2	PF_1	PF_2	..	..	..	PF_1	..	..	PF_k
S_1	S_{111}	S_{112}	S_{121}	S_{122}	..	..	..	S_{1j1}	..	..	S_{1jk}
S_2	S_{211}	S_{212}	S_{221}	S_{222}	..	..	..	S_{2j1}	..	..	S_{2jk}
..	..	..									
..	..	..									
S_i	S_{i11}	S_{i12}	S_{i21}	S_{i22}	..	..	..	S_{ij1}	..	..	S_{ijk}

(e.g., S_{122} is the "ERD" cost to move from origin 1 to destination 2 and enter a PF category 2 space)

With such a matrix, and with the assumption that casualties occur when ERD $\geq 200r$, the transportation problem method of linear programming was used to minimize the number of casualties within each SMSA for each fallout environment. The mathematical description of the transportation model is given in Appendix B.

III. DATA FOR EVALUATION

A. Selection of Local Areas (SMSA's)

Eight SMSA's were selected according to two criteria, shelter/population ratio and population density, by a procedure known as judgment sampling [Reference 2]. Data from judgment samples only suggest or indicate conclusions, which is precisely the purpose intended in this analysis.

Prior to selecting the SMSA's, distribution functions of population density and shelter/population ratio were considered (Figures 1 and 2). The distributions represent 200 of the 213 SMSA's listed in the National Location Code [Reference 3].
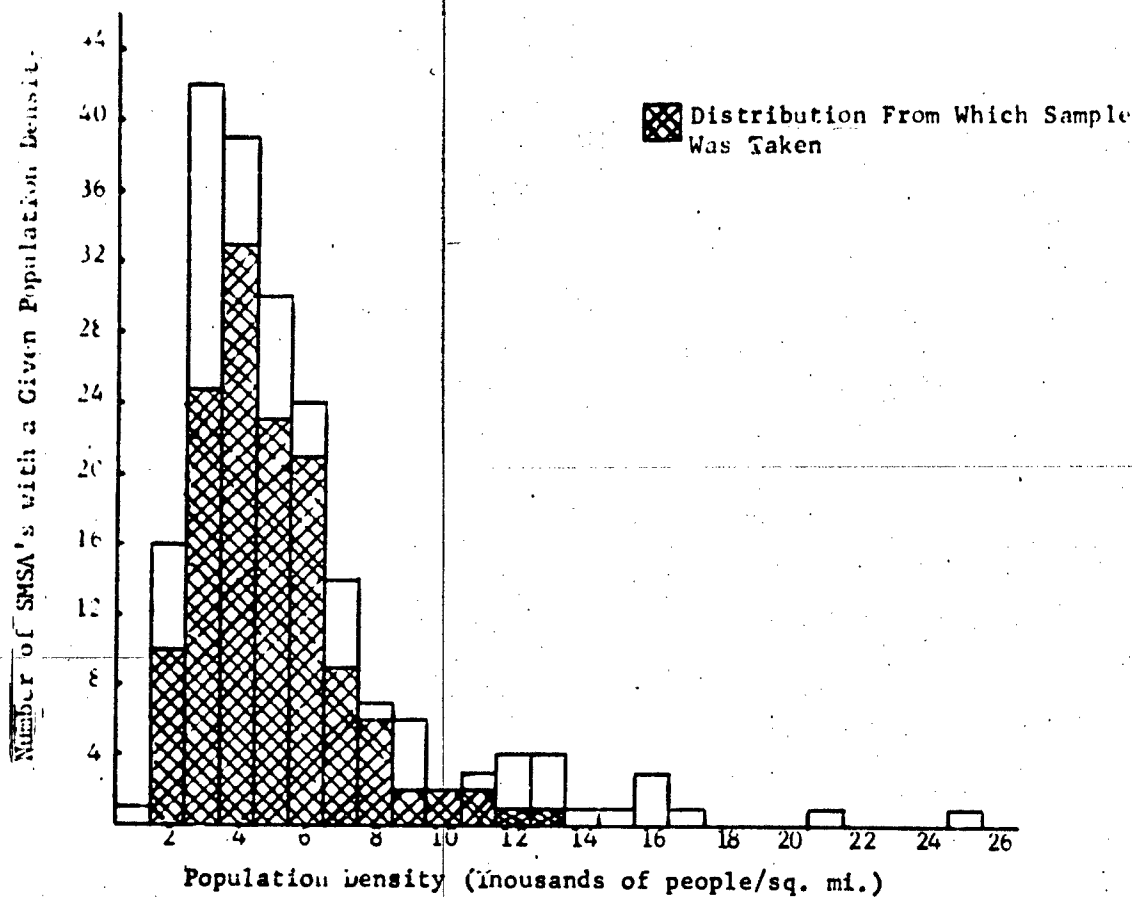
Fig. 1. Distribution of Population Density (200 SMSA's)
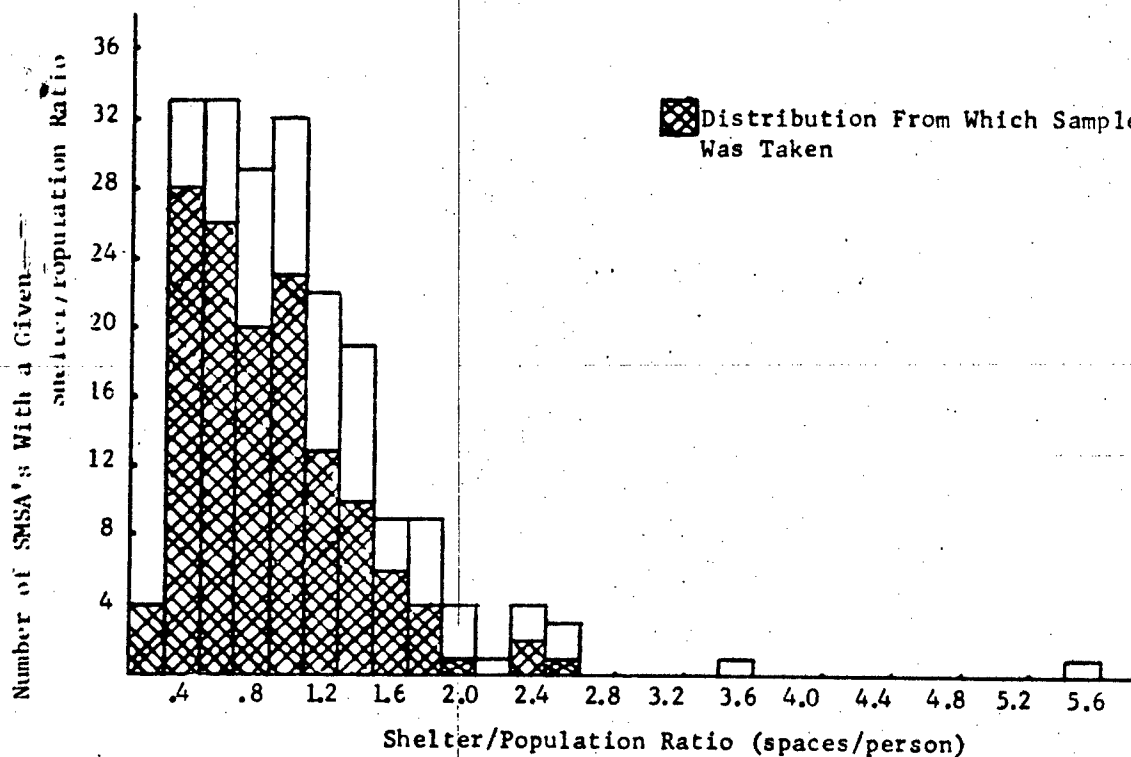
Fig. 2. Distribution of Shelter/Population Ratio (200 SMSA's)

Two constraints were placed on the sampling procedure:

1. SMSA's with population exceeding 500,000 were excluded. This constraint was dictated by the time required to solve the algorithm used to allocate people to shelter.

2. Multiple SMSA's (e.g., Greensboro-High Point, N. C.) were excluded. In most cases, these areas require special consideration because of complex movement restrictions.

The shaded portion in Figures 1 and 2 shows the distribution (after elimination of multiple SMSA's and SMSA's with population greater than 500,000) from which the judgment sample was taken. The characteristics of the selected SMSA's are listed in Table II, <u>Residential Population and Fallout Shelter Characteristics for Eight SMSA's</u>.

In order to visualize the characteristics of the selected SMSA's and their relationships, consider the joint distribution of population density and shelter/population ratio as shown in Figure 3, Joint Distribution of Population Density and Shelter/Population Ratio for 200 SMSA's. If we consider the sample to represent all SMSA's lying within the boundaries formed by the line segments connecting each selected SMSA, then 146 of the 200 will be represented. (It should be pointed out, however, that all SMSA's within the boundaries described do not satisfy the population constraint of being less than 500,000; also some multiple SMSA's are included.)

B. <u>Selection of Fallout Environments</u>

One form of available data providing reference intensity (I_o) and associated arrival times for fallout (T_A) for all SMSA's is the RISK war game analysis [Reference 4]. In order to use representative numbers for the fallout environment, data from an OCD study in a form similar to that described in Reference [4] were used to derive distribution functions for both I_o and T_A (Appendix A). Figures 4, Cumulative Distribution Function for Reference Intensity, and 5, Cumulative Distribution Function for Time of Arrival of Fallout, relate the probability of occurrence at each level of I_o and T_A, respectively, for the OCD study data. The sample size (N) was 20,000; i.e., 100 attacks on each of 200 SMSA's. The available data were aggregated in such a way that it would be inaccurate to associate a joint probability of occurrence of I_o and T_A. However, we have assumed a lower limit on the probability of occurrence of a given combination of I_o and T_A to be the product of their individual probabilities. By assuming complete dependence, we can arrive at some upper limit on the probability of occurrence for the same combination. Thus, we can describe some probability of ._ terval within which the joint probability of I_o and T_A must lie.

TABLE II

Residential Population and Fallout Shelter Characteristics for Eight SMSA's

SMSA	Residential Population	Population Density (People/Mi^2)	Shelter Population Ratio Categories 1-8*	Spaces with at Least 100PF (% of Total Population)	Improvable Spaces (% of Total Population)	Average Cost Per Space Improved** ($)
Orlando, Fla.	263,540	4170	0.20	5	7	6.50
Tucson, Ariz.	265,660	3000	0.24	6	16	7.50
Charleston, S. C.	216,382	12930	0.33	7	6	8.44
Mobile, Ala.	273,942	1320	0.48	15	9	6.90
Macon, Ga.	141,249	4650	0.50	20	14	4.75
Pittsfield, Mass.	73,839	1420	0.66	32	35	5.57
Waterloo, Iowa	122,482	2120	1.10	26	34	6.52
Richmond, Va.	408,494	5950	1.60	49	17	10.73

* PF 20 to > 1000.

** Excludes shelter-stocking costs.
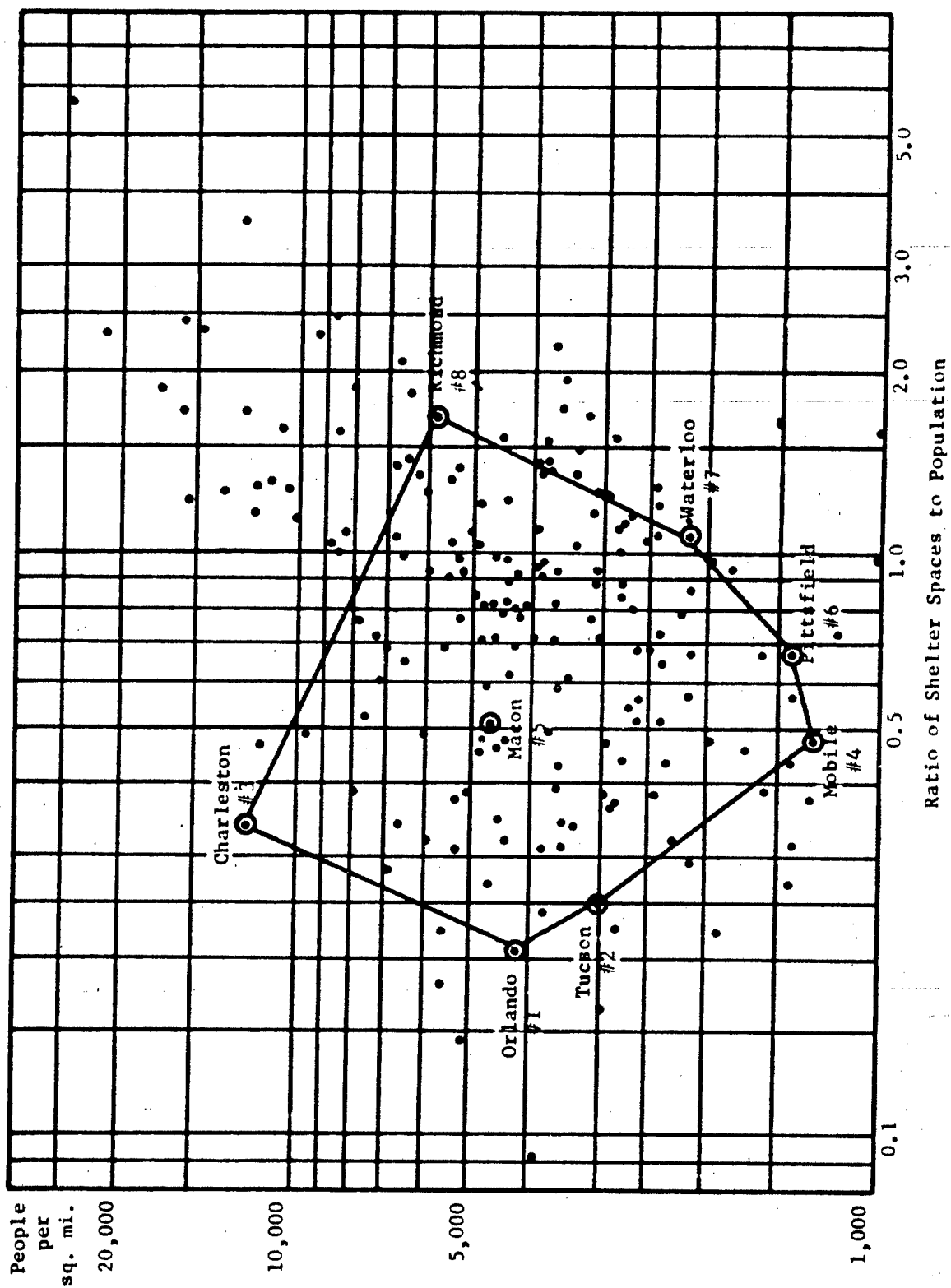
Fig. 3. Joint Distribution of Population Density and Shelter/Population Ratio for 200 SMSA's

Fig. 4. Cumulative Distribution Function for Reference Intensity

All Calculated T_A's Above 12 Hours Were Combined in the Category (> 12 hrs.)

Sample Size = 20,000

Time of Arrival, T_A (hours)

Cumulative Frequency of Occurrence
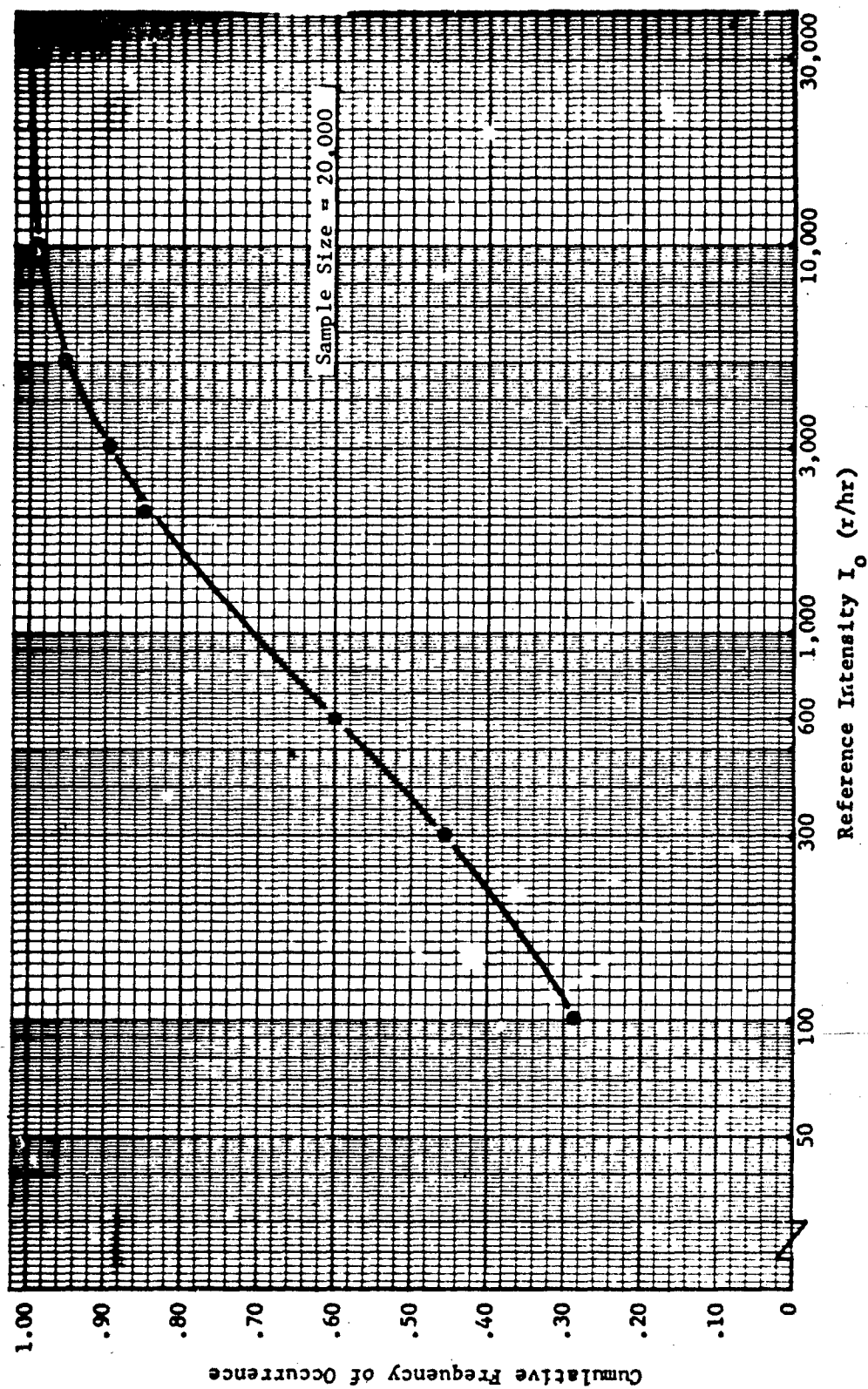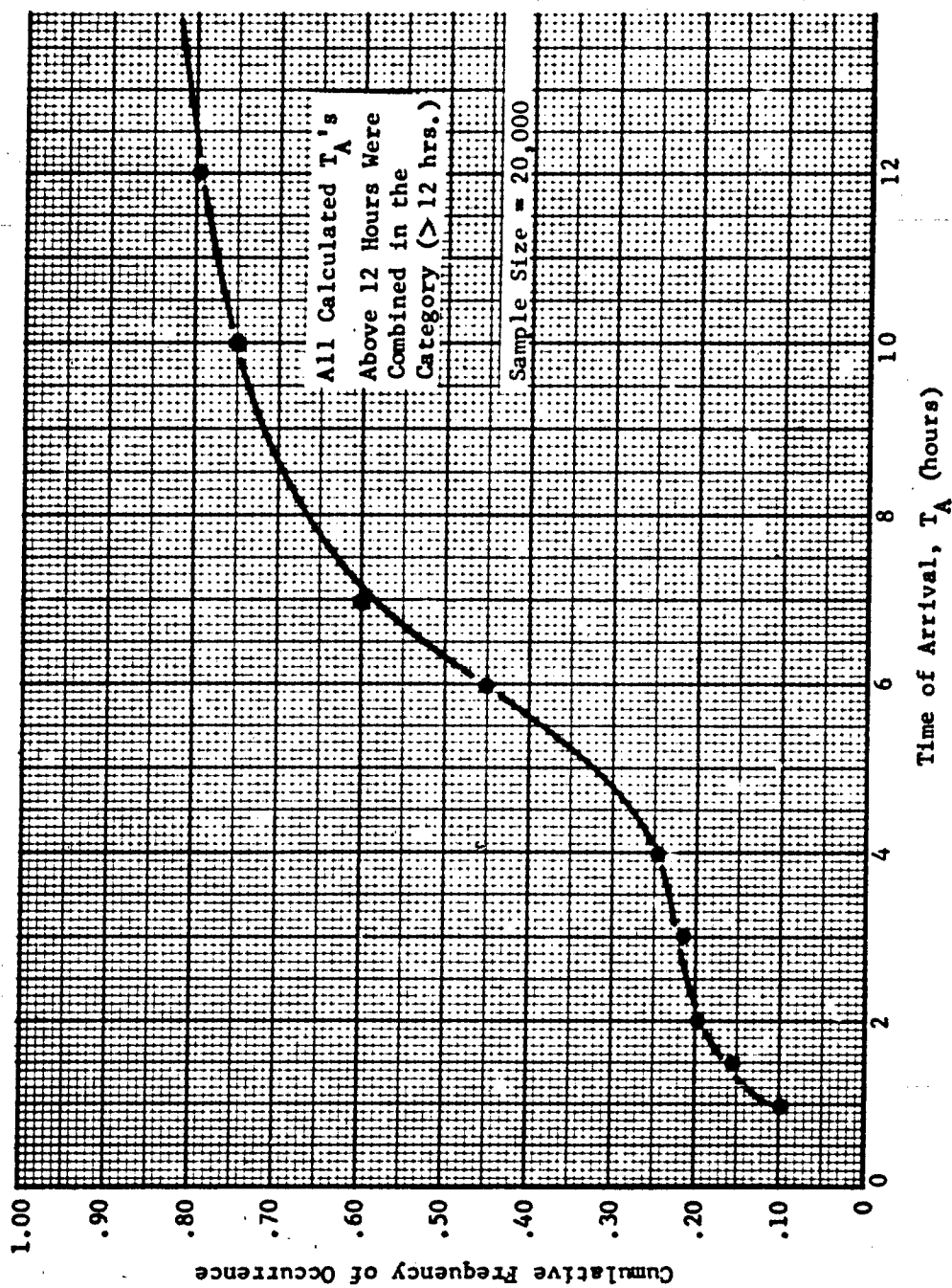
Fig. 5. Cumulative Distribution Function for Time of Arrival of Fallout

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For example, the fallout environment will be $I_o \leq 3000$ r/hr and $T_A \geq 1$ hour between 81 percent and 90 percent of all occurrences (see Table III for method of computing).

Six fallout environments (combinations of T_A and I_o) were selected and used to test the effectiveness of various shelter systems (see Table III).

TABLE III

Fallout Environments Used in 8 SMSA Analyses

I_o (r/hr)	T_A (hr)	Approximate Range of Cumulative Probability	
$\leq$ 600	$\geq$ 5.5	36%[*]	60%[**]
2000	1.5	72%	85%
3000	1	81%	90%
5000	1[***]	86%	95%
10000	1[***]	89%	95%
30000	1[***]	90%	99.9%

[*] Lower Bound: Since it is generally true that late arrival times correspond to low values of I_o, it approximately can be said that:

$$P\{T_A \geq t \mid I_o \leq i\} \geq P\{T_A \geq t\}$$

so that

$$P\{I_o \leq i, T_A \geq t\} = P\{I_o \leq i\} \cdot P\{T_A \geq t \mid I_o \leq i\} \geq P\{I_o \leq i\} \cdot P\{T_A \geq t\}$$

for example:

$$P\{I_o \leq 600, T_A \geq 5.5\} \geq P\{I_o \leq 600\} \cdot P\{T_A \geq 7\} \geq (.60)(.60) \geq .36$$

[**] Upper Bound: Since a probability is always ≤ 1, it is true that:

$$P\{I_o \leq i, T_A \geq t\} = P\{I_o \leq i\} \cdot P\{T_A \geq t \mid I_o \leq i\} \leq P\{I_o \leq i\} \cdot 1 \; ;$$

and similarly

$$P\{I_o \leq i, T_A \geq t\} \leq 1 \cdot P\{T_A \geq t\}$$

so that

$$P\{I_o \leq 600, T_A \geq 5.5\} \leq \min\left[P\{I_o \leq 600\}, P\{T_A \geq 7\}\right] \leq .60$$

[***] In some cases $P\{T_A \geq t\}$ was not known. In this case, the upper bound

$$P\{I_o \leq i, T_A \geq t\} \leq P\{I_o \leq i\} \quad \text{should be used.}$$

IV. SMSA ANALYSIS

A. Casualty Computations and Shelter Utilization Assumptions

The model of SMSA's described in the previous sections was used to calculate the number of casualties in each SMSA at each of the fallout environments described in Table III. (The term "casualty" in this report refers to anyone receiving a Maximum ERD greater than 200r.) Casualties were computed for each of the four movement and shelter allocation schemes and were used to rank their relative effectiveness.

Only one of the four movement-to-shelter procedures allowed for movement in fallout. In each of the four procedures, those persons not sheltered in NFSS spaces (including PF Category 1) were given a PF of 2. Residential basements were not employed in these analyses.

It is recognized that residential basements afford adequate protection in low intensity fallout environments. However, excluding these spaces will only affect the casualty computations in one fallout environment of our analysis; i.e., at reference intensity equal to 600r/hr and time of arrival equal to 5.5 hours, residential basements afford adequate fallout protection. Three SMSA's of the sample have shelter in residential basements for more than 10% of the population--Pittsfield, Waterloo, and Richmond [Reference 5]. Of the three, only Pittsfield has a shelter deficit. Therefore, in the analysis presented here, only in Pittsfield could the total number of casualties be reduced significantly by using residential basement data, and then only in the least severe fallout environment.

B. Analysis of the 8 SMSA's

The following paragraphs present a casualty analysis for each of the 8 SMSA's. They are presented in ascending order of shelter spaces to population ratio. Casualties for the four movement assumptions and eight fallout environments are presented, with and without spaces obtainable in NFSS shelter through added ventilation or shielding. An analysis is made for each SMSA of the effect on casualties of the four movement assumptions.

1. Orlando, Florida

The SMSA has a residential population of 263,540 and a population density of 4170 people per square mile. The population density is slightly less than the average of the 200 SMSA's.
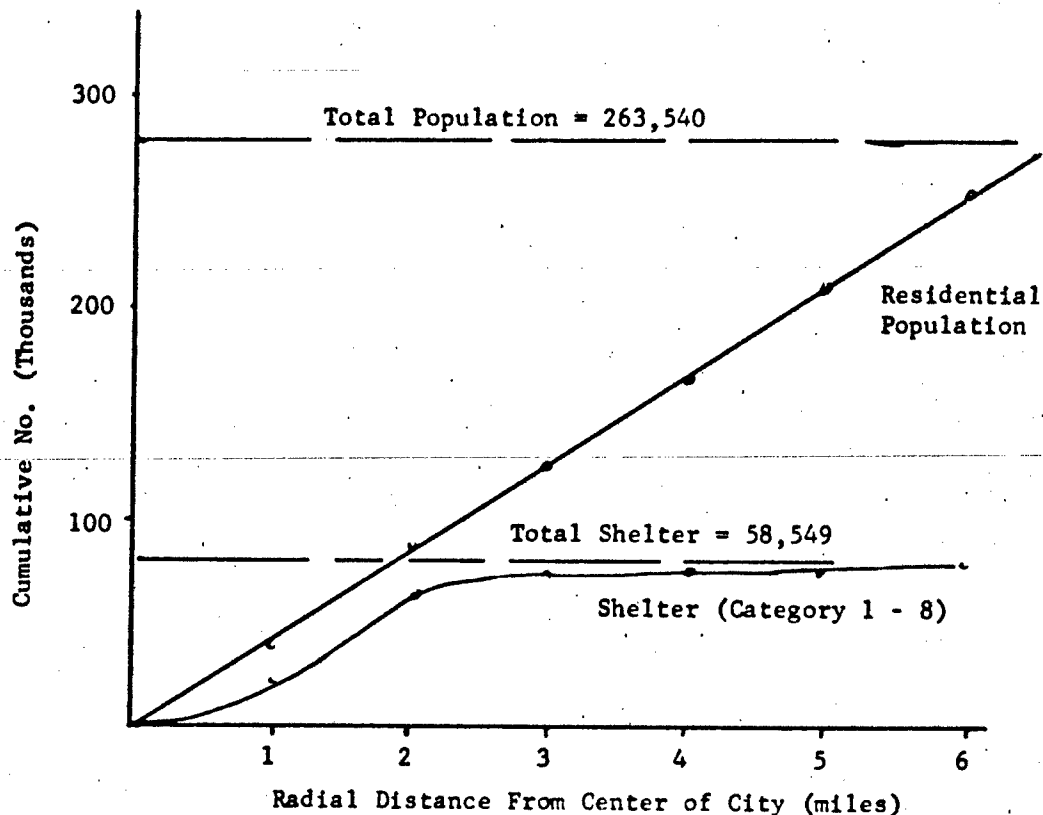
Fig. 6.   Cumulative Distribution of Population and Shelter
in Orlando, Florida

Approximately 20 percent of the population can be sheltered in spaces
located in Phase 1 of the NFSS. Only 5 percent of the population can be
sheltered in spaces having a protection factor of at least 100 and minimum
volume requirements (500 cubic feet per person with no ventilation or 10 square
feet with adequate ventilation).

The plot of the cumulative distribution of population and shelter as a
function of radial distance from the city center shown in Figure 6 indicates
a shelter deficit throughout the SMSA; further, almost no shelter spaces exist
beyond a two-mile radius of the population center. Due to the small number of
available shelter spaces, both the allocation restricting movement to two
miles and the constant movement speed restriction result in the same number of
casualties as that if movement were unrestricted.

Casualty computations are significantly affected by the assumption of
movement restricted to within the SL; at least this is true for the less
severe fallout environments. The expected number of casualties at each fallout

environment is shown in Table IV. Figure 8, Percentage of Casualties for Each Fallout Environment in Orlando, Florida, shows expected casualties from Table IV as a percentage of the total SMSA's population.

TABLE IV

Expected Casualties for Each Fallout
Environment in Orlando, Florida

Fallout Environment		Expected Casualties (%)			
Reference Intensity (r/hr)	Arrival Time (hr)	Movement Restricted to own SL	Movement Restricted to 2 Mi.	Constant Movement Speed	Movement Unrestricted
600	5.5	94	78	78	78
2000	1.5	94	78	78	78
3000	1	96	89	89	89
5000	1	98	93	93	93
10000	1	98	98	98	98
30000	1	99	99	99	99

Data from Phase II of the NFSS survey [Reference 6] points up that approximately 7 percent of the population could be sheltered in improvable spaces. The cost of improvement would be $91,000, or approximately $6.50 per space. A graphical representation of the shelter status is presented in Figure 7, Percentage of Population Sheltered for Each PF Category in Orlando, Florida.

It is quite obvious that this area would suffer severely in any fallout environment. Also, only slight advantage would be gained by improving existing spaces. The only solution appears to be an accelerated shelter development program.

2. Tucson, Arizona

Tucson has a residential population of 265,660, about the same as Orlando, Florida. The population density of 3000 people per square mile is below the 200 SMSA average. A look at the relative location of population and shelter indicates much the same posture as Orlando (Figure 9, Cumulative Distribution of Population and Shelter in Tucson, Arizona).

Fig. 7. Percentage of Population Sheltered for Each PF Category in Orlando, Florida (Total Population = 263,540)

Legend (Fig. 7):

■ Percentage of Population Sheltered in Improvable Spaces*

□ Percentage of Population Sheltered in Existing Spaces

*The term "Improvable Spaces" as used in this and all following figures refers to spaces which may be obtained through added ventilation or shielding--as indicated by NFSS Phase 2 data.

Fallout Environment

No.	I_o (r/hr)	T_A (hr)
1	600	5.5
2	2000	1.5
3	3000	1
4	5000	1
5	10000	1
6	30000	1

■ Casualties Avoided by Assuming Improvable Spaces are Improved and Utilized.

* Excluding the SL Movement Restriction

Fig. 8. Percentage of Casualties* for Each Fallout Environment in Orlando, Florida (Total Population - 263,540)
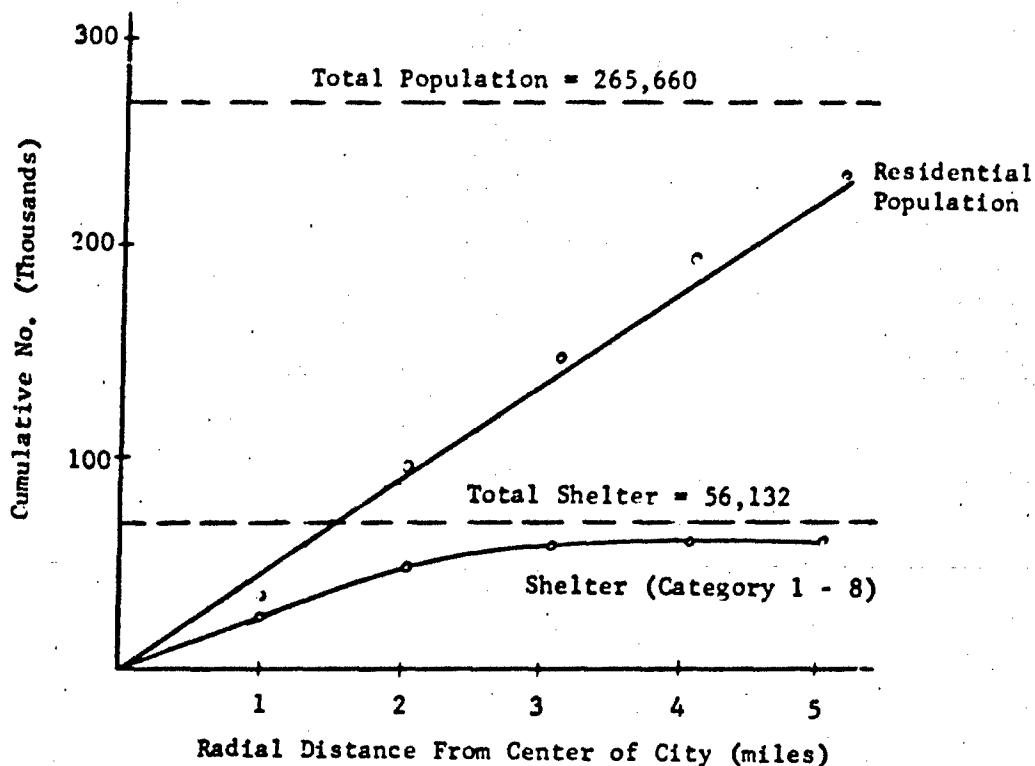
Fig. 9. Cumulative Distribution of Population and Shelter in Tucson, Arizona

According to NFSS Phase 1 data, 24 percent of the population can be sheltered in spaces with protection factors ranging from 20 to 1000. Only a small number, 6 percent of the population, can be sheltered in spaces with PF $\geq$ 100 and the required area and volume. However, improving the existing spaces would provide shelter for an additional 16 percent with protection factor of at least 100. The cost of the improvements would be approximately $522,000, or $7.50 per space.

Figure 10, Percentage of Population Sheltered for Each PF Category in Tucson, Arizona, shows the shelter status of existing and improvable spaces. Although the fallout shelter status in Tucson is somewhat better than Orlando, the effect of movement alternatives is the same. (See Table V, Expected Casualties for Each Fallout Environment in Tucson, Arizona.) There just aren't enough shelter spaces available, even if improvement alternatives are incorporated and spaces in PF Categories below 4 are accepted.

Figure 11, Percentage of Casualties for Each Fallout Environment in Tucson, Arizona, again illustrates the reduction in casualties expected from assuming improvable spaces are improved and utilized.
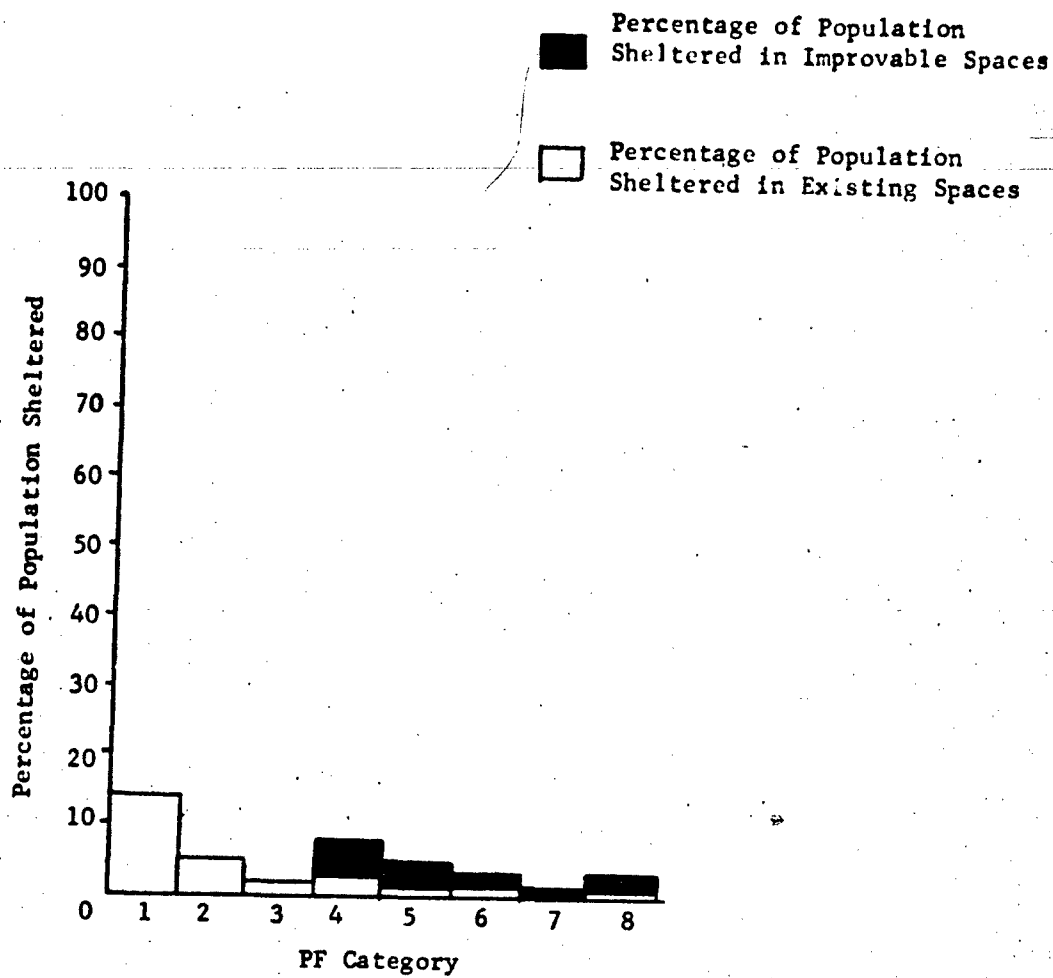
Fig. 10.   Percentage of Population Sheltered for Each PF Category
in Tucson, Arizona (Total Population = 265,660)

100
90
80
70
60
50
40
30
20
10

Percentage of Casualties

Fallout Environment

1 2 3 4 5 6
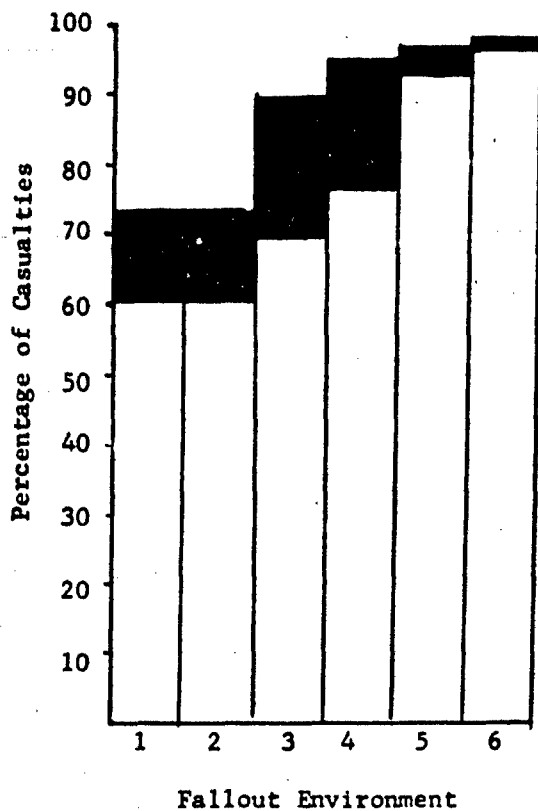
Casualties Avoided by Assuming Improvable Spaces are Improved and Utilized.

No.	Fallout Environment	
	I_o (r/hr)	T_A (hr)
1	600	5.5
2	2000	1.5
3	3000	1
4	5000	1
5	10000	1
6	30000	1

* Excluding the SL Movement Restriction

Fig. 11. Percentage of Casualties* for Each Fallout Environment in Tucson, Arizona (Total Population = 265,660)

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TABLE V

Expected Casualties for Each Fallout
Environment in Tucson, Arizona

Fallout Environment		Expected Casualties (%)			
Reference Intensity (r/hr)	Arrival Time (hr)	Movement Restricted to own SL	Movement Restricted to 2 Miles	Constant Movement Speed	Movement Unrestricted
600	5.5	89	74	74	74
2000	1.5	89	74	74	74
3000	1	94	90	90	90
5000	1	97	95	95	95
10000	1	98	97	97	97
30000	1	99	98	98	98

3. Charleston, South Carolina

This SMSA is somewhat atypical in that the population density--12,930 people per square mile--is very large and the shelter population ratio of 0.33 is rather low. The general trend is for high population densities to be associated with a relatively high shelter/population ratio (see individual points in Figure 3). Despite the combination of high population density and low shelter/population ratio, the relative location--with respect to the population center--of the population and shelter is essentially the same as in Orlando and Tucson. The shelter deficit exists throughout the SMSA (Figure 12, Cumulative Distribution of Population and Shelter in Charleston, South Carolina). As might be expected, except for the SL restriction, there is no variation in the number of expected casualties regardless of the method used to allocate people to shelters. The expected casualties are shown in Table VI, Expected Casualties for Each Fallout Environment in Charleston, South Carolina and Figure 14, Percentage of Casualties for Each Fallout Environment in Charleston, South Carolina.

The NFSS indicates that approximately 33 percent of the population can be sheltered in existing spaces (including Category 1). However, as in Orlando and Tucson, the great majority of spaces provide a protection factor of less than 100. Only 7 percent of the population in Charleston can be sheltered in spaces of 100 PF or better. Adding possible improvements would provide
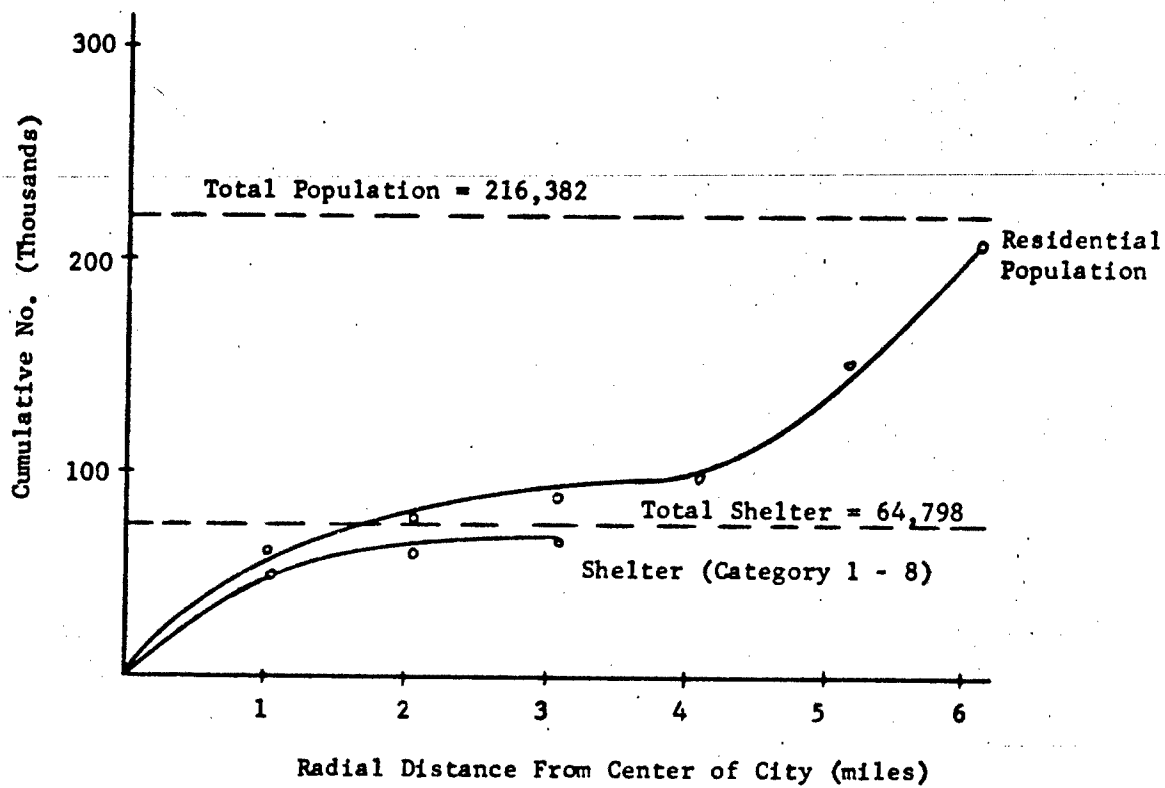
Fig. 12.   Cumulative Distribution of Population and Shelter in
Charleston, South Carolina
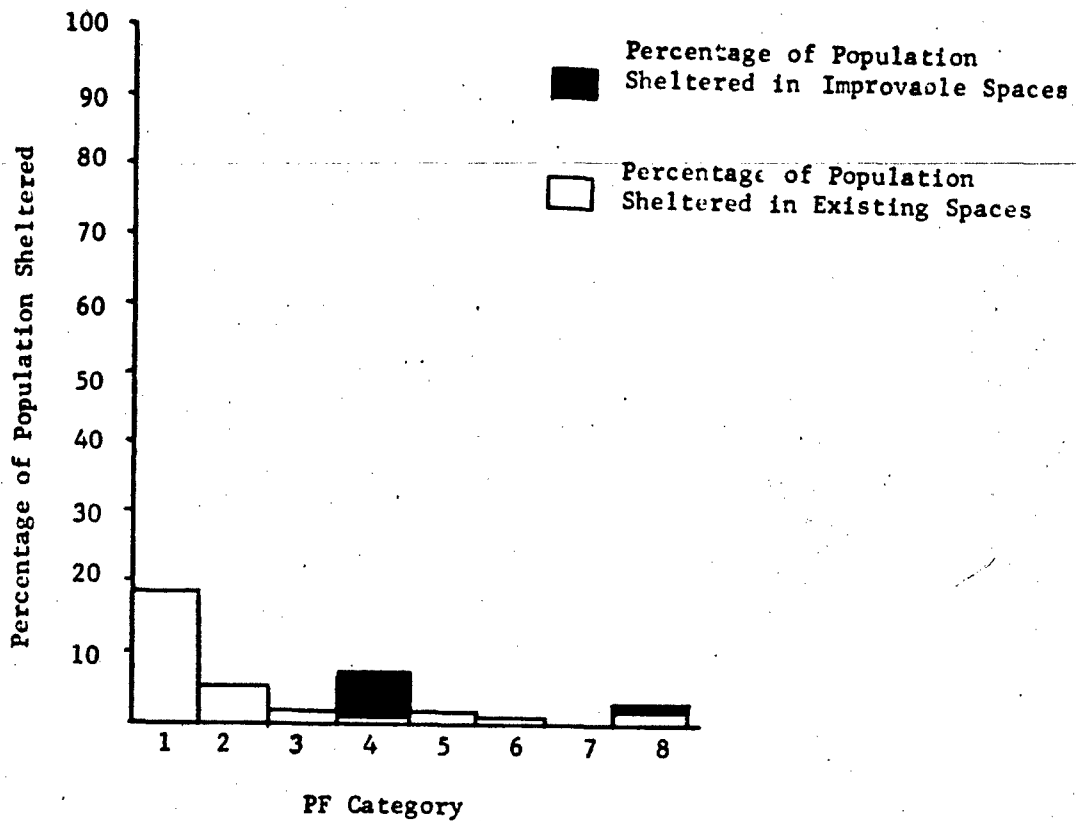
Fig. 13. Percentage of Population Sheltered for Each PF Category
in Charleston, South Carolina (Total Population = 216,382)
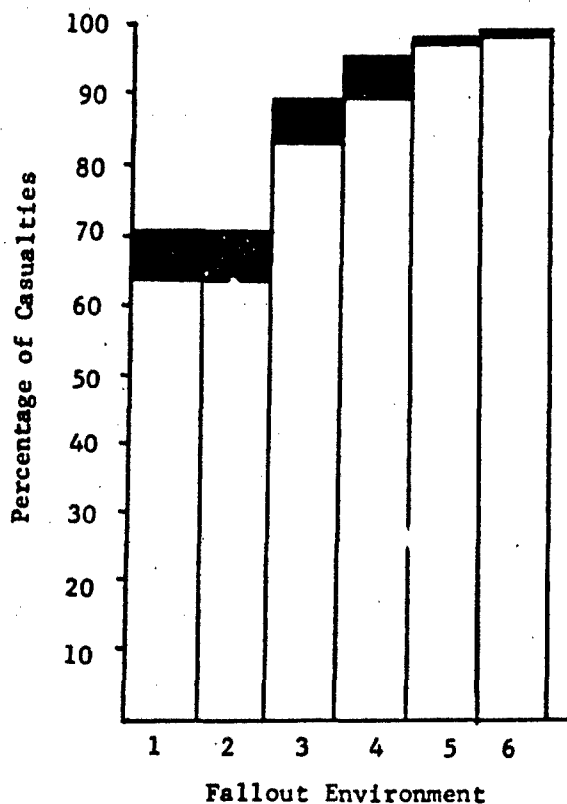
Percentage of Casualties (y-axis, values 10-100)
Fallout Environment (x-axis, 1-6)

Casualties Avoided by Assuming Improvable Spaces are Improved and Utilized

No.	I_o (r/hr)	T_A (hr)
1	600	5.5
2	2000	1.5
3	3000	1
4	5000	1
5	10000	1
6	30000	1

Fallout Environment

* Excluding the SL Movement Restriction

Fig. 14. Percentage of Casualties* for Each Fallout Environment in Charleston, South Carolina (Total Population = 216,382)

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TABLE VI

Expected Casualties for Each Fallout
Environment in Charleston, South Carolina

Fallout Environment		Expected Casualties (%)			
Reference Intensity (r/hr)	Arrival Time (hr)	Movement Restricted to own SL	Movement Restricted to 2 Miles	Constant Movement Speed	Movement Unrestricted
600	5.5	83	70	70	70
2000	1.5	83	70	70	70
3000	1	92	89	89	89
5000	1	97	95	95	95
10000	1	99	98	98	98
30000	1	99	99	99	99

shelter for another 6 percent of the population. The total cost of improvements would be $130,000 or $8.44 per space.

4. Mobile, Alabama

Mobile has a residential population of 273,942, which is the second largest of the eight SMSA's being considered. The population density is the lowest at 1320 people per square mile. Although the SMSA has an overall shelter deficit of 54 percent, it is different from the previous three SMSA's in that a shelter surplus does exist within a two-mile radius of the population center (Figure 15, Cumulative Distribution of Population and Shelter in Mobile, Alabama). In fact, the area outside the two-mile radius has shelter for only 8 percent of the population, and 62 percent of the total population is located in the same region. Therefore, about 6 percent of the population must e moved "downtown" to the available shelter spaces. The expected numbers of casualties for the various movement restrictions are shown in Table VII, Expected Casualties for Each Fallout Environment in Mobile, Alabama. As can be seen, there is little variation in casualties according to the method of allocating people to shelter, with the exception of the extreme case where the population is restricted to its own standard location.

Using spaces located by the NFSS, 48 percent of the population can be sheltered in spaces with PF ranging from 20 to 1000. (Figure 16, Percentage of Population Sheltered for Each PF Category in Mobile, Alabama). Approximately
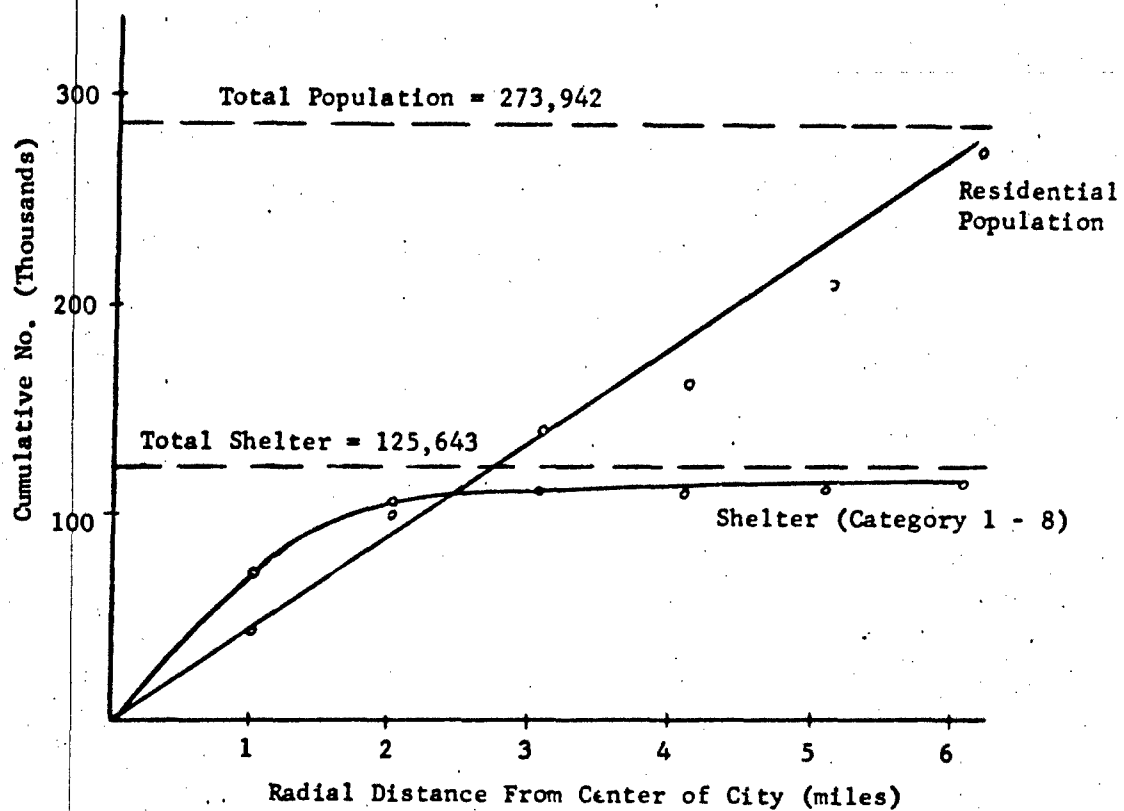
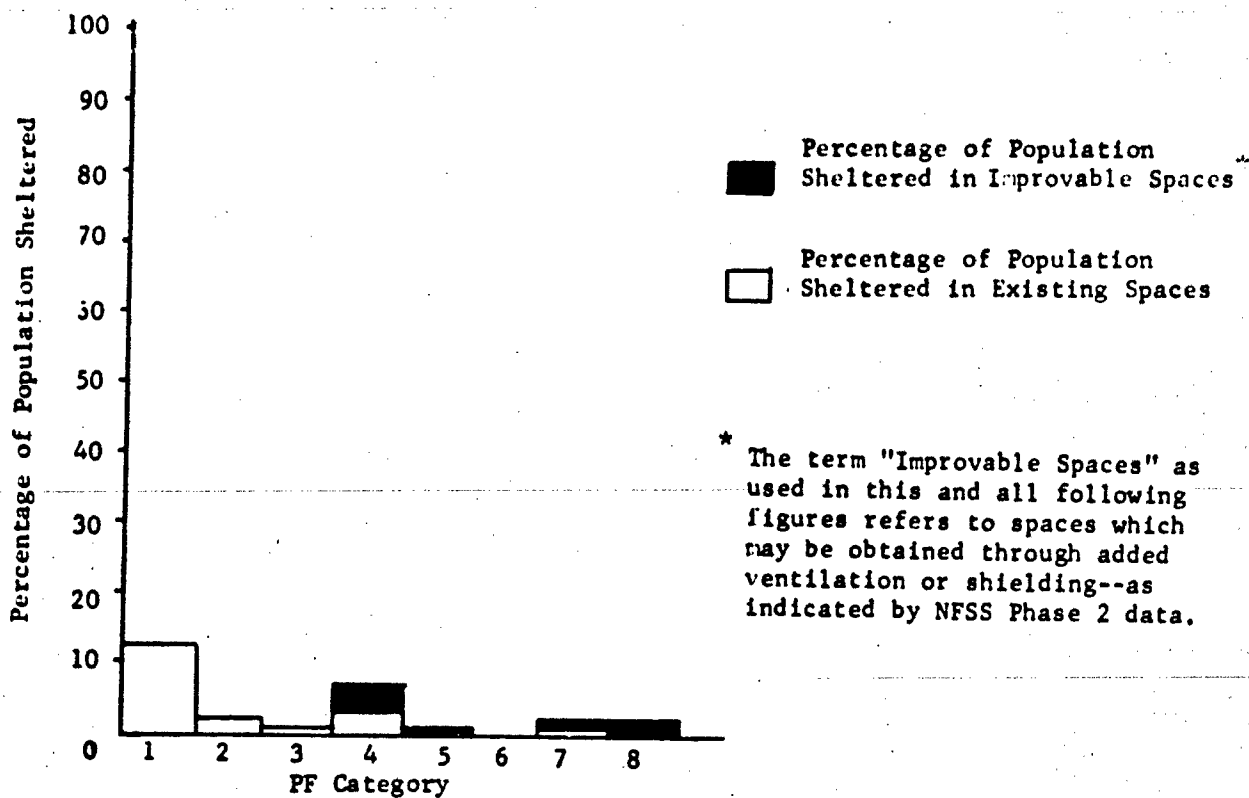Fig. 15.   Cumulative Distribution of Population and Shelter in
           Mobile, Alabama
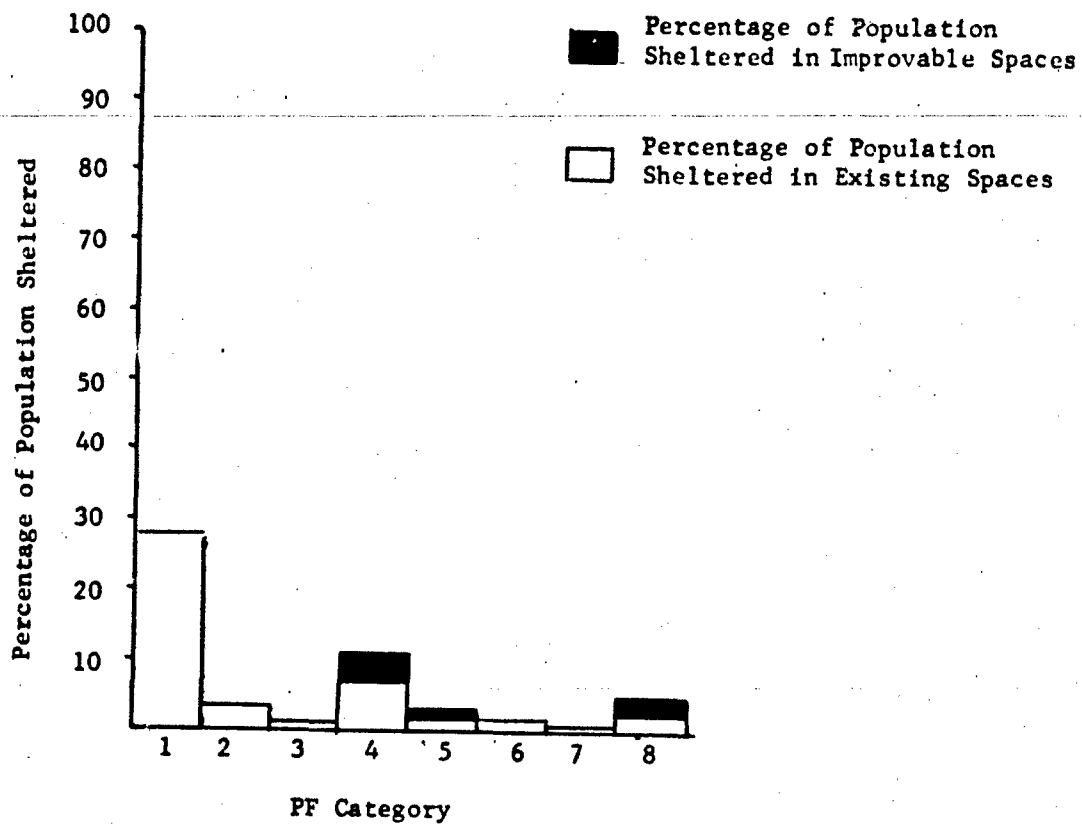
Fig. 16. Percentage of Population for Each PF Category in Mobile,
Alabama (Total Population = 273,942)
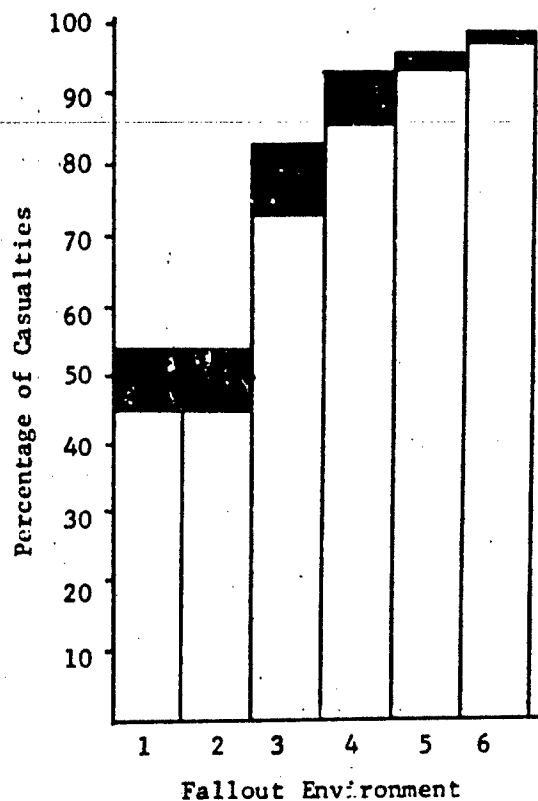
Fig. 17. Percentage of Casualties[*] for Each Fallout Environment
in Mobile, Alabama (Total Population = 273,942)

TABLE VII

Expected Casualties for Each Fallout Environment in Mobile, Alabama

Fallout Environment		Expected Casualties (%)			
Reference Intensity (r/hr)	Arrival Time (hr)	Movement Restricted to own SL	Movement Restricted to 2 Miles	Constant Movement Speed	Movement Unrestricted
600	5.5	78	54	54	54
2000	1.5	78	54	54	54
3000	1	91	83	83	83
5000	1	96	93	93	93
10000	1	97	96	96	96
30000	1	99	99	99	99

15 percent of the population can be sheltered in spaces having PF of at least 100. Improving existing spaces would provide shelter for an additional 9 percent of the population at a cost of $170,000 or $6.90 per space.

5. Macon, Georgia

Macon has very nearly the same shelter/population ratio, 0.50, as Mobile; however, the population density is much higher. The total population is 141,249, and the population density is 4650 people per square mile. Macon, like Mobile, has a shelter surplus near the population center of the SMSA and very few spaces outside a two-mile radius of the center (Figure 18, Cumulative Distribution of Population and Shelter in Macon, Georgia).

According to NFSS data, 50 percent of the population can be sheltered, and 20 percent of the population would have at least a PF of 100. An additional 14 percent of the population could be sheltered in improvable spaces. The cost of the improvements would be $94,000 or $4.75 per space.

The distribution of shelter spaces by PF category shows an increase in the fraction of spaces having a PF of 100 or better over SMSA's previously described (Figure 19, Percentage of Population Sheltered for Each PF Category in Macon, Georgia). As was the case for all previously examined SMSA's, the largest increase in casualties, for all movement restrictions--as shown in Table VIII, Expected Casualties for Each Fallout Environment in Macon, Georgia--occurs when

Fig. 18. Cumulative Distribution of Population and Shelter in Macon, Georgia

Fig. 19. Percentage of Population Sheltered for Each PF Category in Macon, Georgia (Total Population = 141,249)
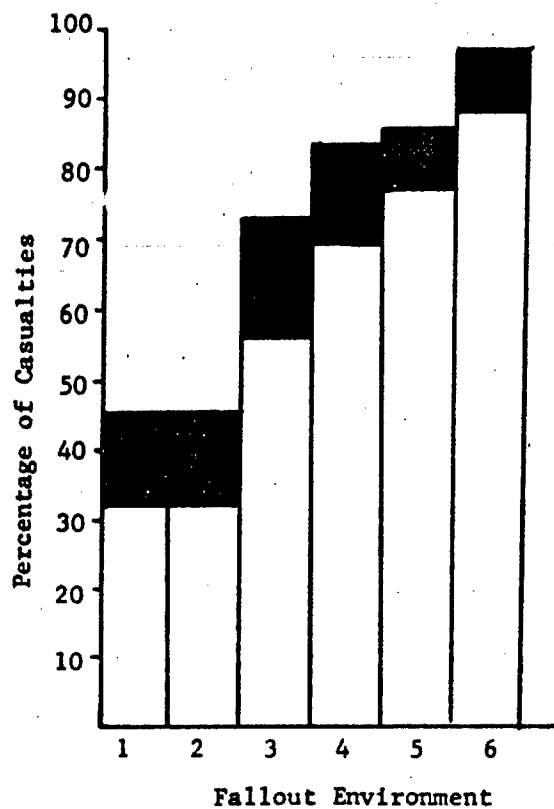
Casualties Avoided by Assuming Improvable Spaces are Improved and Utilized.

No.	Fallout Environment I_O (r/hr)	T_A (hr)
1	600	5.5
2	2000	1.5
3	3000	1
4	5000	1
5	10000	1
6	30000	1

* Excluding the SL Movement Restriction

Fig. 20. Percentage of Casualties* for Each Fallout Environment in Macon, Georgia (Total Population = 141,249)

TABLE VIII

Expected Casualties for Each Fallout Environment in Macon, Georgia

Fallout Environment		Expected Casualties (%)			
Reference Intensity (r/hr)	Arrival Time (hr)	Movement Restricted to own SL	Movement Restricted to 2 Miles	Constant Movement Speed	Movement Unrestricted
600	5.5	77	46	46	46
2000	1.5	77	46	46	46
3000	1	85	73	73	73
5000	1	87	84	84	84
10000	1	90	86	86	86
30000	1	97	97	97	97

the fallout reference intensity changes from 2000 r/hr to 3000 r/hr. The reason for the sharp increase is due to the ineffectiveness of Category 1 spaces at 3000 r/hr. Of the total number of spaces available, more than half of them are Category 1 spaces. A characteristic of Macon not encountered in the previously considered SMSA's is the increase in casualties at the 30,000 r/hr fallout reference intensity. The SMSA's, previously considered, experienced rather constant marginal increases over the range from 3000 r/hr to 30,000 r/hr. Macon, however, has a relatively large number of Category 5 and 6 spaces (enough for 12 percent of the population) which are ineffective at reference intensity of 30,000 r/hr, thereby causing the increase in casualties when I_o = 30,000 r/hr.

6. Pittsfield, Massachusetts

Pittsfield has the smallest population in the sample (73,839), and the second smallest population density (1420 people/square mile); however, its shelter/population ratio is the third largest (0.66). A shelter surplus exists within a one-mile radius of the population center (Figure 21, Cumulative Distribution of Population and Shelter in Pittsfield, Massachusetts). It is also the only SMSA with enough improvable spaces to erase the shelter deficit. By using the improvable spaces, 47 percent of the population could be sheltered in spaces having a PF of at least 100. (Figure 22, Percentage of Population Sheltered for Each PF Category in Pittsfield, Massachusetts).

- 30 -
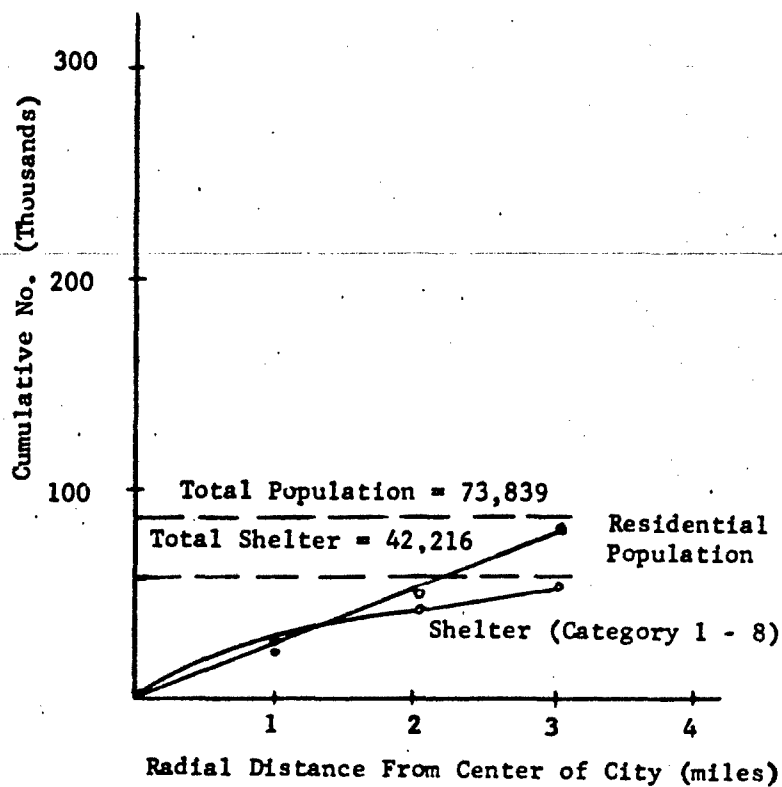
Fig. 21. Cumulative Distribution of Population and
Shelter in Pittsfield, Massachusetts
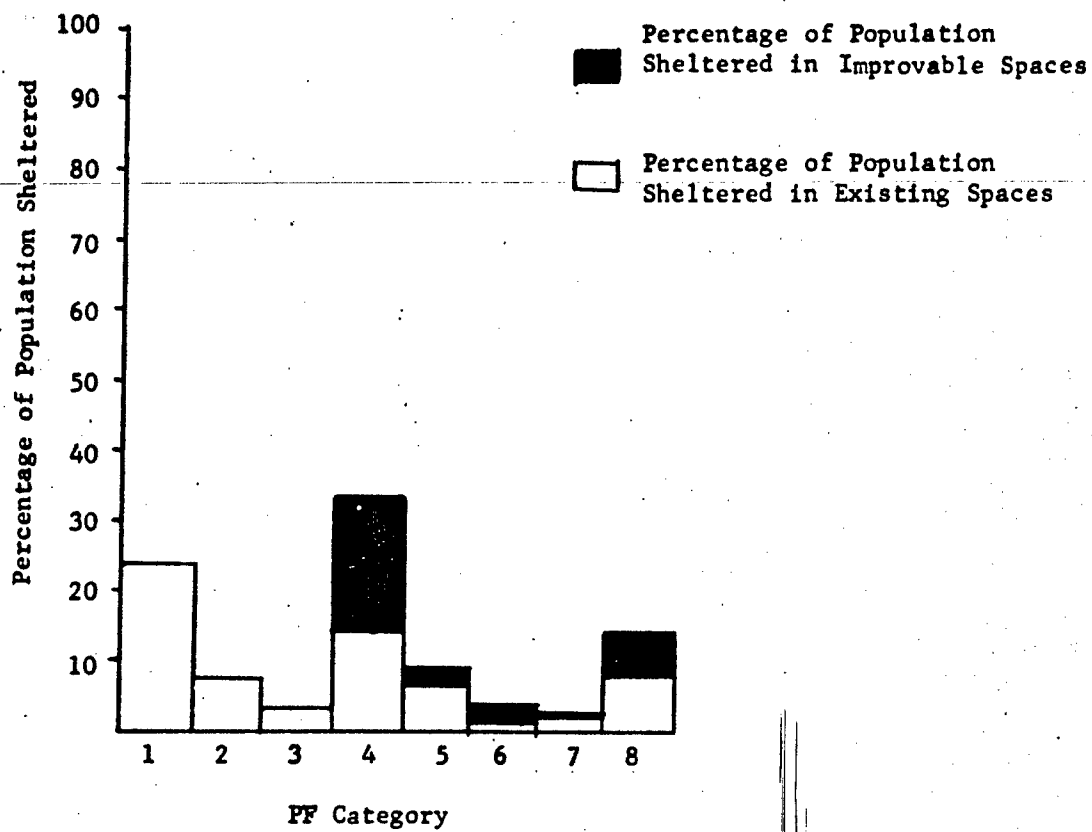
Fig. 22. Percentage of Population Sheltered for Each PF Category in Pittsfield, Massachusetts (Total Population = 73,839)
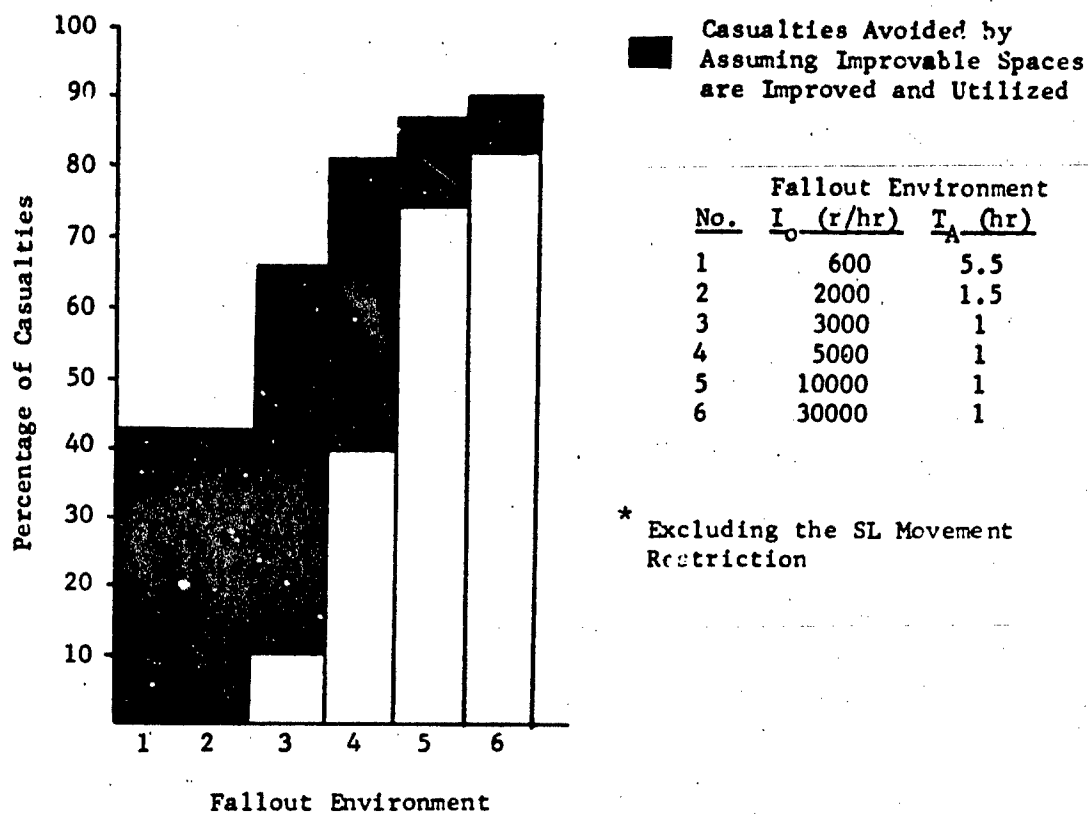
Fig. 23. Percentage of Casualties* for Each Fallout Environment
in Pittsfield, Massachusetts (Total Population = 73,839)

As in all the other SMSA's, intense fallout environments produce a high casualty rate as shown in Table IX.

TABLE IX

Expected Casualties for Each Fallout
Environment in Pittsfield, Mass.

Fallout Environment		Expected Casualties (%)			
Reference Intensity (r/hr)	Arrival Time (hr)	Movement Restricted to own SL	Movement Restricted to 2 Miles	Constant Movement Speed	Movement Unrestricted
600	5.5	64	43	43	43
2000	1.5	64	43	43	43
3000	1	72	66	66	66
5000	1	81	81	81	81
10000	1	87	87	87	87
30000	1	90	90	90	90

The variation in expected casualties is quite large when comparing conditions where some movement is allowed and those conditions where movement is restricted to the SL. For example, in the fallout environment which would be exceeded in only about 15-30 percent of the attacks (i.e., I_o = 2000 r/hr, T_A = 1.5 hrs), approximately 64 percent of the population become casualties if movement is restricted to within the SL while only 43 percent are casualties with any other movement restriction. The point being made is that casualty computations are sensitive to movement restrictions in the majority of expected fallout environments.

Thus far the sensitivity has been evident only when movement is restricted to the SL compared to movement outside the SL. In the remaining SMSA's, casualties become sensitive to all four movement restrictions.

7. Waterloo, Iowa

Waterloo is characterized by a shelter surplus over the entire SMSA (Figure 24, Cumulative Distribution of Population and Shelter in Waterloo, Iowa). The characteristics of Waterloo are: population--122,482; population density--2120; shelter/population ratio--1.10. Being fortunate enough to have enough spaces, however, also creates new problems. In all the previously discussed
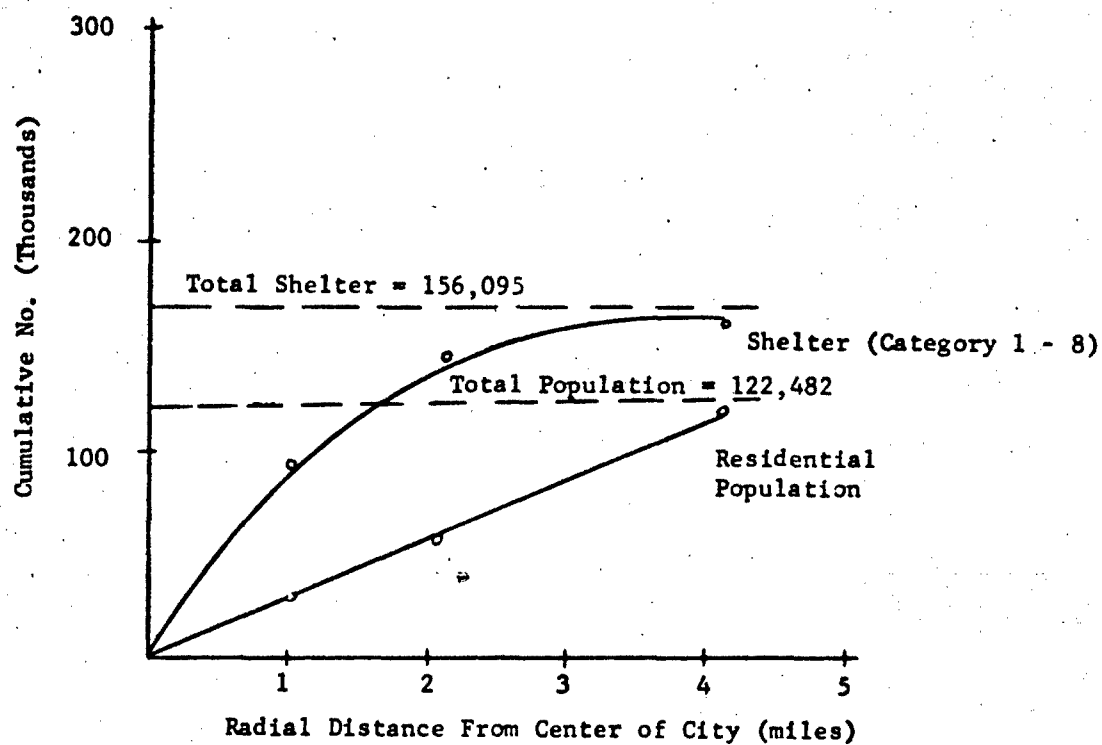
Fig. 24. Cumulative Distribution of Population and Shelter in Waterloo, Iowa
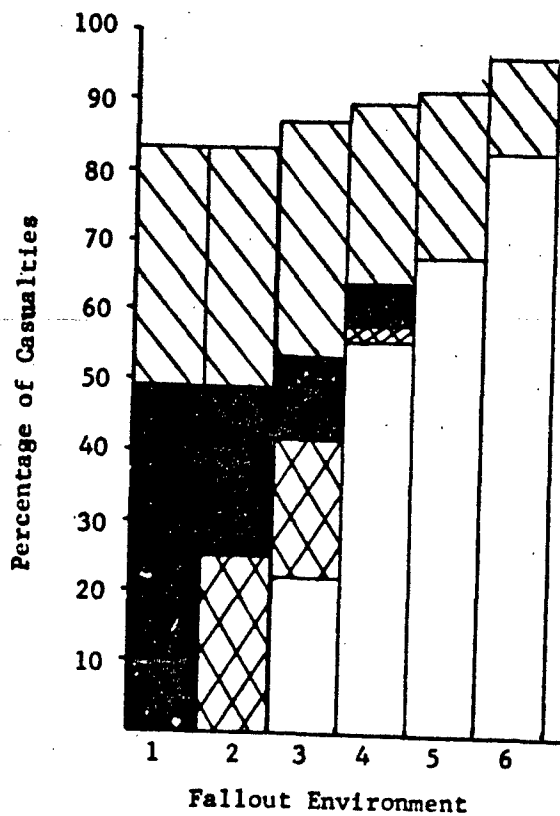
No.	I_o (r/hr)	T_A (hr)
1	600	5.5
2	2000	1.5
3	3000	1
4	5000	1
5	10000	1
6	30000	1

Fallout Environment

□ No Movement Restriction, No Movement in Fallout.

▨ Casualties Added--Movement Restricted to 2 MPH, Movement in Fallout is Allowed.

■ Casualties Added--Movement Restricted to 2 Miles, No Movement in Fallout.

◨ Casualties Added--Movement Restricted to Own SL, No Movement in Fallout.

Fig. 25. Sensitivity of Casualty Calculations to Movement Restrictions--Waterloo, Iowa (Total Population = 122,482)
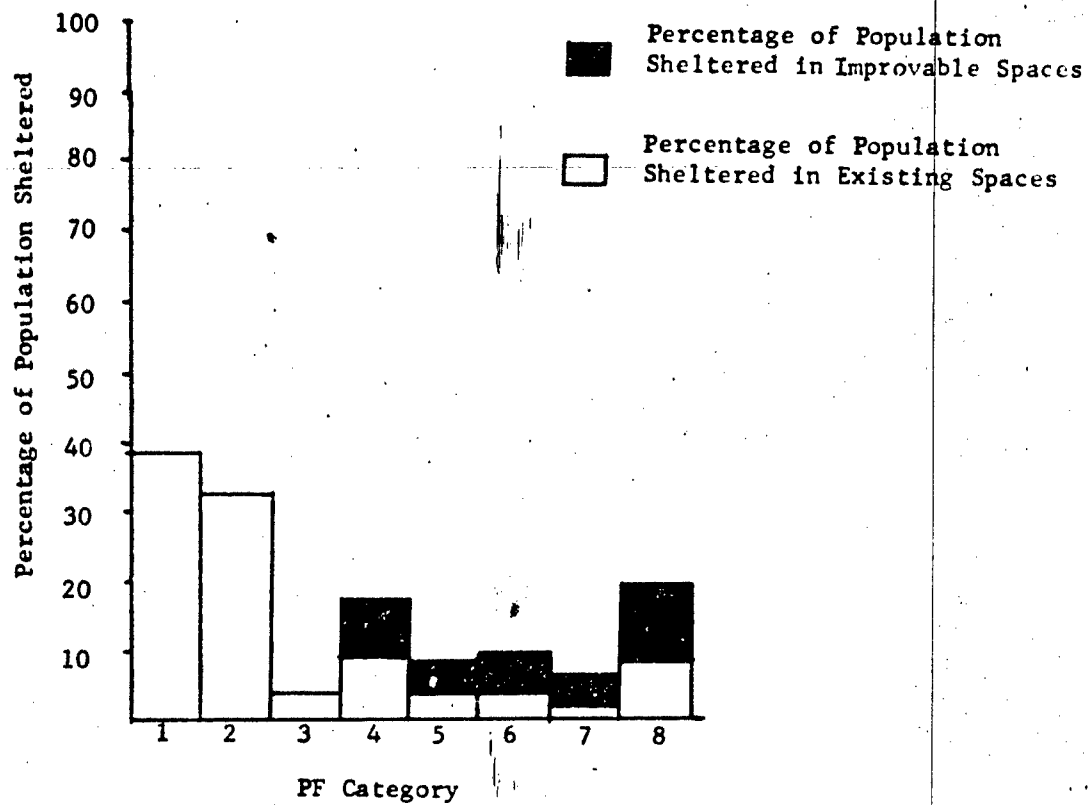
Fig. 26. Percentage of Population Sheltered for Each PF Category
in Waterloo, Iowa (Total Population = 122,482)
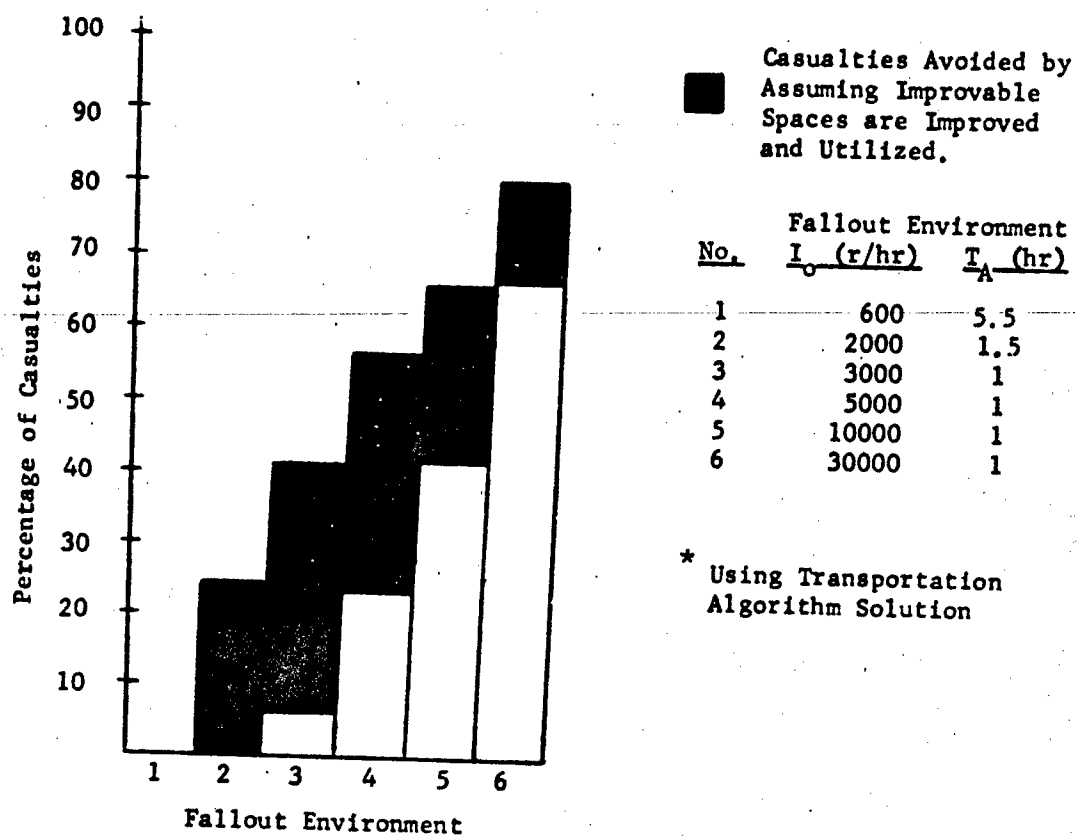
Fig. 27. Percentage of Casualties* for Each Fallout Environment in Waterloo, Iowa (Total Population = 122,482)

SMSA's, the shelter deficit was such that there was no serious problem in utilizing all the spaces. In fact, the available shelter could be treated as if the population has unrestricted movement within the SMSA. In Waterloo, with its shelter surplus, the expected number of casualties is quite sensitive to any change in movement restrictions. For example, consider the results of the allocation model as shown in Table X. Only in the most severe fallout environments are the casualty calculations insensitive to the movement restrictions.

TABLE X

Expected Casualties for Each Fallout
Environment in Waterloo, Iowa

Fallout Environment		Expected Casualties (%)			
Reference Intensity (r/hr)	Arrival Time (hr)	Movement Restricted to own SL	Movement Restricted to 2 Miles	Constant Movement Speed	Movement Unrestricted
600	5.5	83	49	0	0
2000	1.5	83	49	25	0
3000	1	87	54	42	22
5000	1	89	64	58	57
10000	1	91	68	68	68
30000	1	96	83	83	83

These same results are shown graphically in Figure 25, Sensitivity of Casualty Calculations to Movement Restrictions--Waterloo, Iowa. Quite obviously, some movement is necessary in order to utilize shelters and avoid large numbers of casualties. As will be shown later (in Section V and Figure 31), because of the gradual buildup of fallout particles, some movement in a fallout field is permissible for reference intensities as high as 5000 r/hr. Restricting movement seriously degrades the effectiveness of existing shelter spaces.

8. Richmond, Virginia

This SMSA has the largest population (408,494) of all of the SMSA's in the sample. It also has a 60 percent shelter surplus, (Figure 28, Cumulative Distribution of Population and Shelter in Richmond, Virginia); and by incorporating shelter improvements, approximately 60 percent of the population could be sheltered in spaces having PF of at least 100. Here, as in Waterloo, casualty
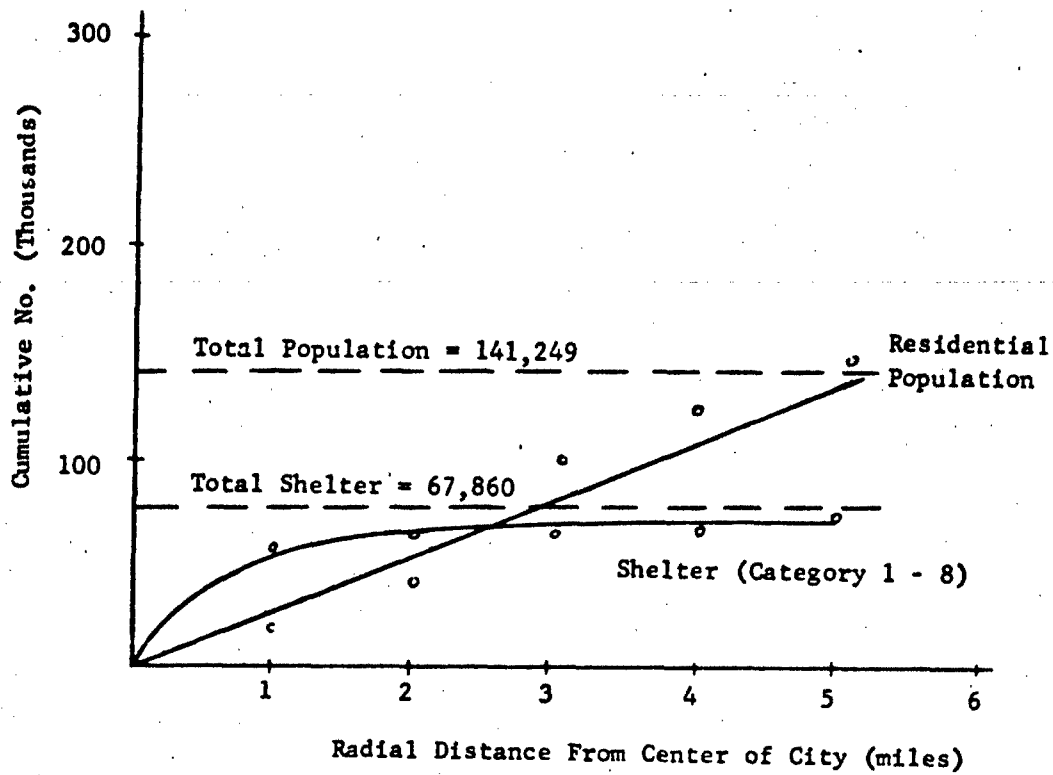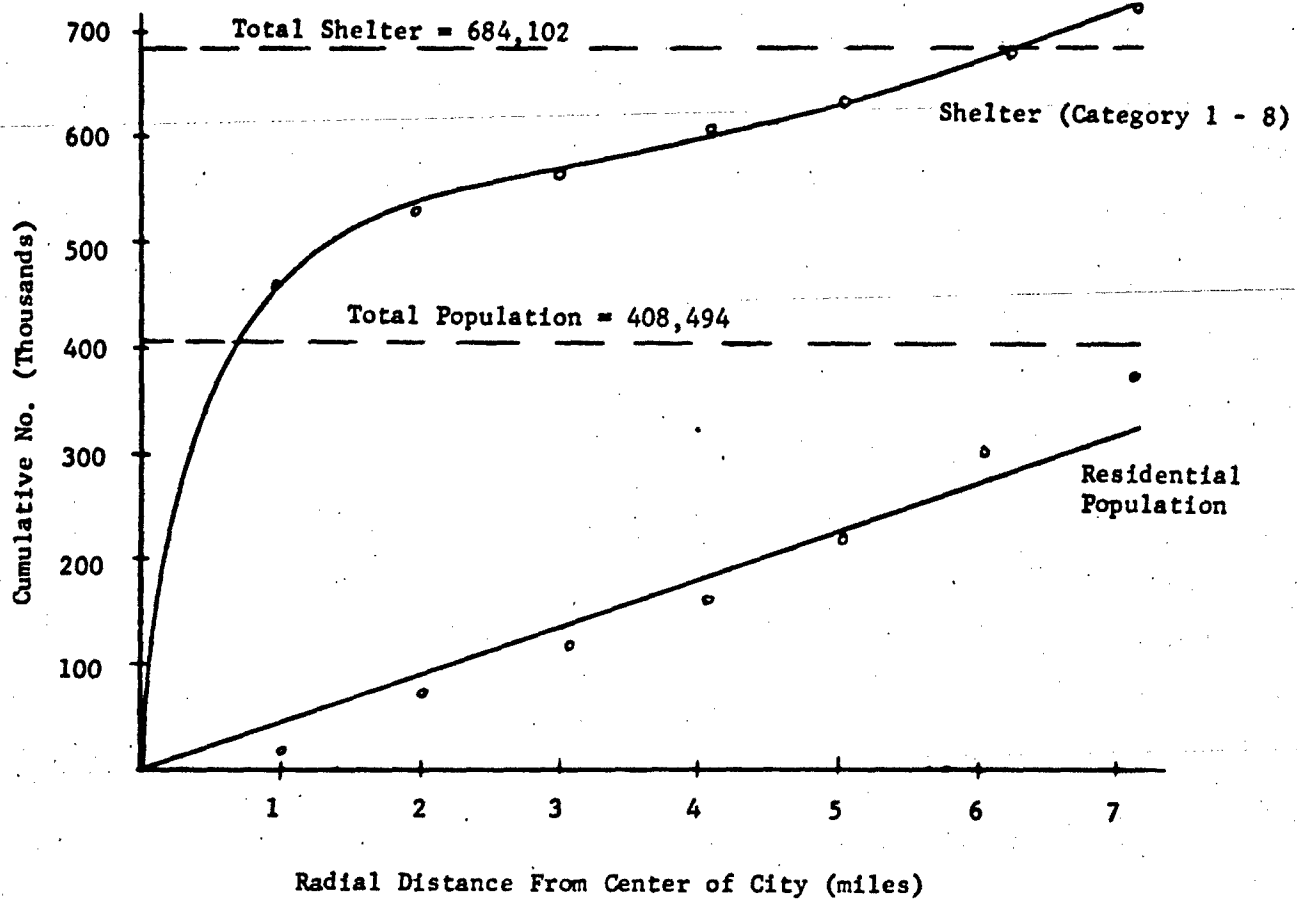
Fig. 28. Cumulative Distribution of Population and Shelter in
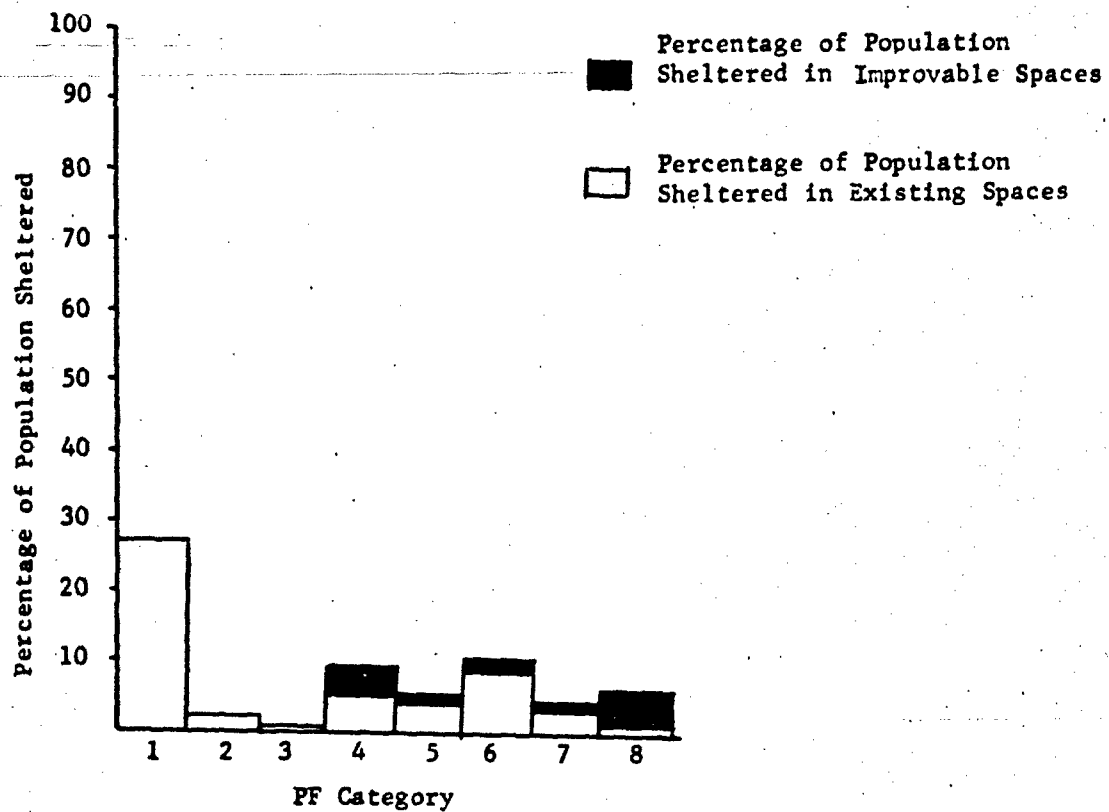Richmond, Virginia
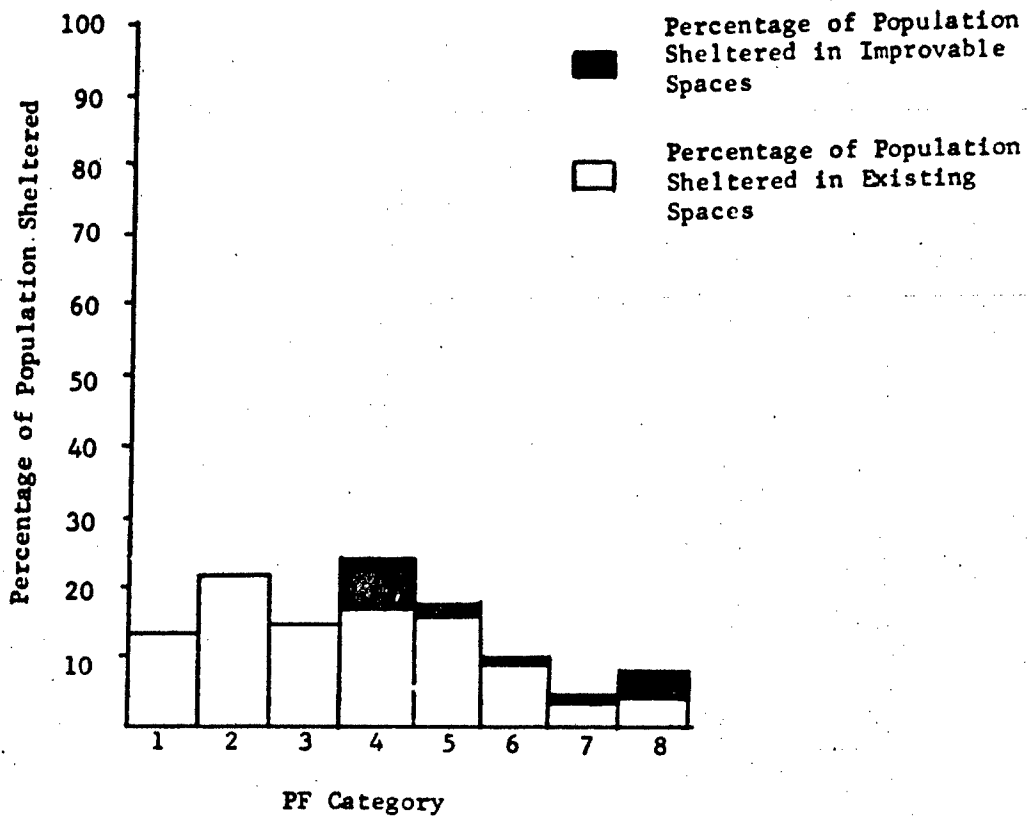
Fig. 29. Percentage of Population Sheltered for Each PF Category in Richmond, Virginia (Total Population = 408,494)

100 — Casualties Avoided by
        Assuming Improvable Spaces
90 —   are Improved and Utilized.

80 —

Percentage of Casualties

70 —   Fallout Environment
                        No. I_o (r/hr) T_A (hr)
60 —
                         1   600   5.5
50 —   2   2000   1.5
                         3   3000   1
40 —   4   5000   1
                         5   10000   1
30 —   6   30000   1

20 —
                        * Using Transportation
10 —   Algorithm Solution

     1   2   3   4   5   6

        Fallout Environment
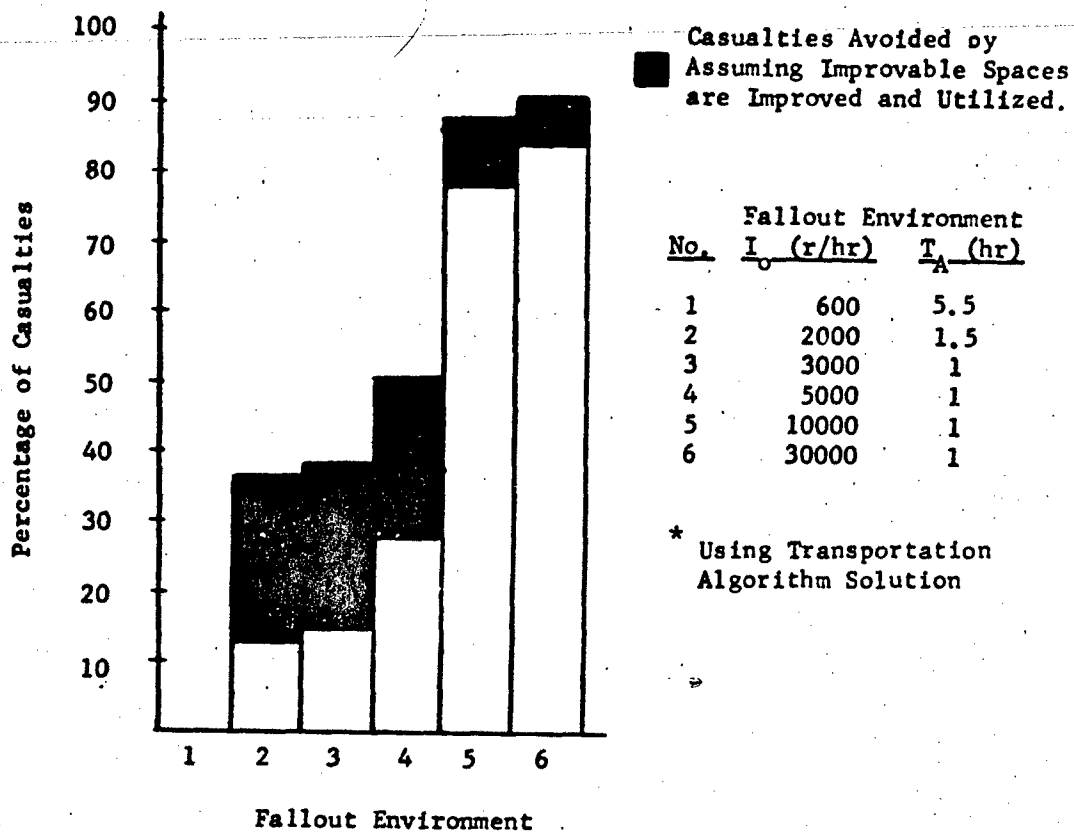
Fig. 30. Percentage of Casualties* for Each Fallout Environment
          in Richmond, Virginia (Total Population = 408,494)

calculations are sensitive to proper shelter utilization. For example, consider a fallout environment, I_o = 3000 r/hr, T_A = 1 hour. If movement is restricted to within standard locations, the expected casualties will be 81 percent. However, if movement is unrestricted (i.e., assume strategic warning) there will be one percent casualties. Obviously, these are extreme examples. Using an optimum allocation plan, such that casualties are minimized subject to a movement speed restriction, would result in approximately 38 percent casualties. Using the two-mile restriction, which is similar to the optimal plan except that it allows no movement in fallout, would result in 68 percent casualties-- a 30 percent increase. The significance of limited movement in fallout is quite evident. The expected casualties at various other fallout environments are shown in Table XI.

TABLE XI

Expected Casualties for Each Fallout
Environment in Richmond, Virginia

Fallout Environment		Expected Casualties (%)			
Reference Intensity (r/hr)	Arrival Time (hr)	Movement Restricted to own SL	Movement Restricted to 2 Miles	Constant Movement Speed	Movement Unrestricted
600	5.5	66	47	0	0
2000	1.5	66	47	36	0
3000	1	81	68	38	1
5000	1	88	81	50	45
10000	1	90	88	87	70
30000	1	93	91	90	90

V. DATA ANALYSIS

A. The Relationship Between Time in Fallout and Protection Factors

An analysis of ERD shows interesting trade-offs between time in fallout and the protection factor of the shelter that is entered. Even when the reference intensity is 5000 r/hr and the time of fallout arrival is only one hour, considerable time in fallout can be compensated for by a relatively small increase in the protection factor of the shelter eventually entered. For example, a person traveling 15 minutes in such a fallout field (at 2 mph) and reaching a fallout shelter with a PF

of 91 would sustain no more dose than a person who was in a shelter with a PF of 70 at the time fallout commenced. Of course, this type of comparison considers only gamma radiation. Other types of radiation might also have to be taken into consideration, but their effect should be negligible if inhalation of particles is avoided.

Figure 31, Trade-Off Between PF and Time in Fallout, shows the trade-offs of PF and time in fallout for the cases where the reference intensities are 5000 r/hr, 3000 r/hr, and 2000 r/hr. The latter has an associated time of arrival of 1.5 hours; the others have a time of arrival of one hour. The curves are based on a buildup time of twice the time of arrival and a linear rate of intensity buildup.

In the case of reference intensity of 10,000 r/hr, there is little opportunity for trade-off between PF and travel in fallout. A person unsheltered in such an environment would receive a dose greater than 200r ERD if he were outside as much as ten minutes, regardless of the type of shelter he eventually entered.

B. Relationship Between Reference Intensity, Protection Factor, and Maximum ERD

The ERD calculations also provide a means for comparing reference intensity, protection factor, and Maximum ERD. Figure 32, Trade-Offs Between PF and Fallout Environment, shows these relationships for the reference intensities considered in this volume. The dashed lines show the effect of times of arrival of more than one hour.

VI. CONCLUSIONS AND RECOMMENDATIONS

A. Discussion

Shelter utilization analyses necessarily include assumptions concerning variables that are difficult to measure. These variables affect utilization. Among the more significant variables are:

1. Knowledge on the part of people about the shelter which they should use (shelter assignment plan, discipline, crowd control, etc.).

2. Time required to reach shelter (warning time, start-up time, travel time, searching time, interference of traffic flow, etc.).

3. Distance to shelter (influences both time and knowledge, for the knowledge may be less if distances are long).

In a complete analysis, relations among these three and other variables must be derived (for they are obviously not independent), and these in turn related to the shelter utilization pattern.
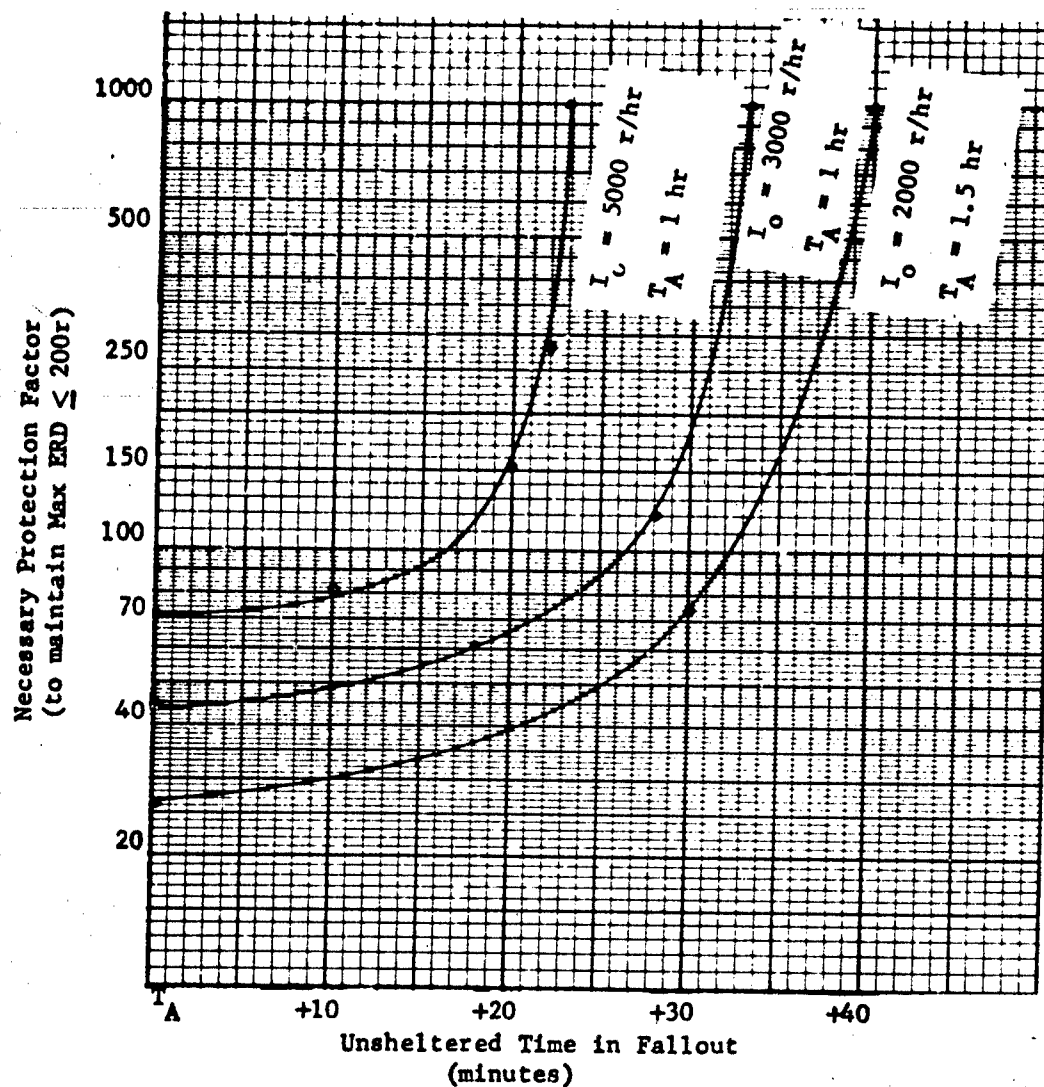
Fig. 31.   Trade-Off Between PF and Time in Fallout
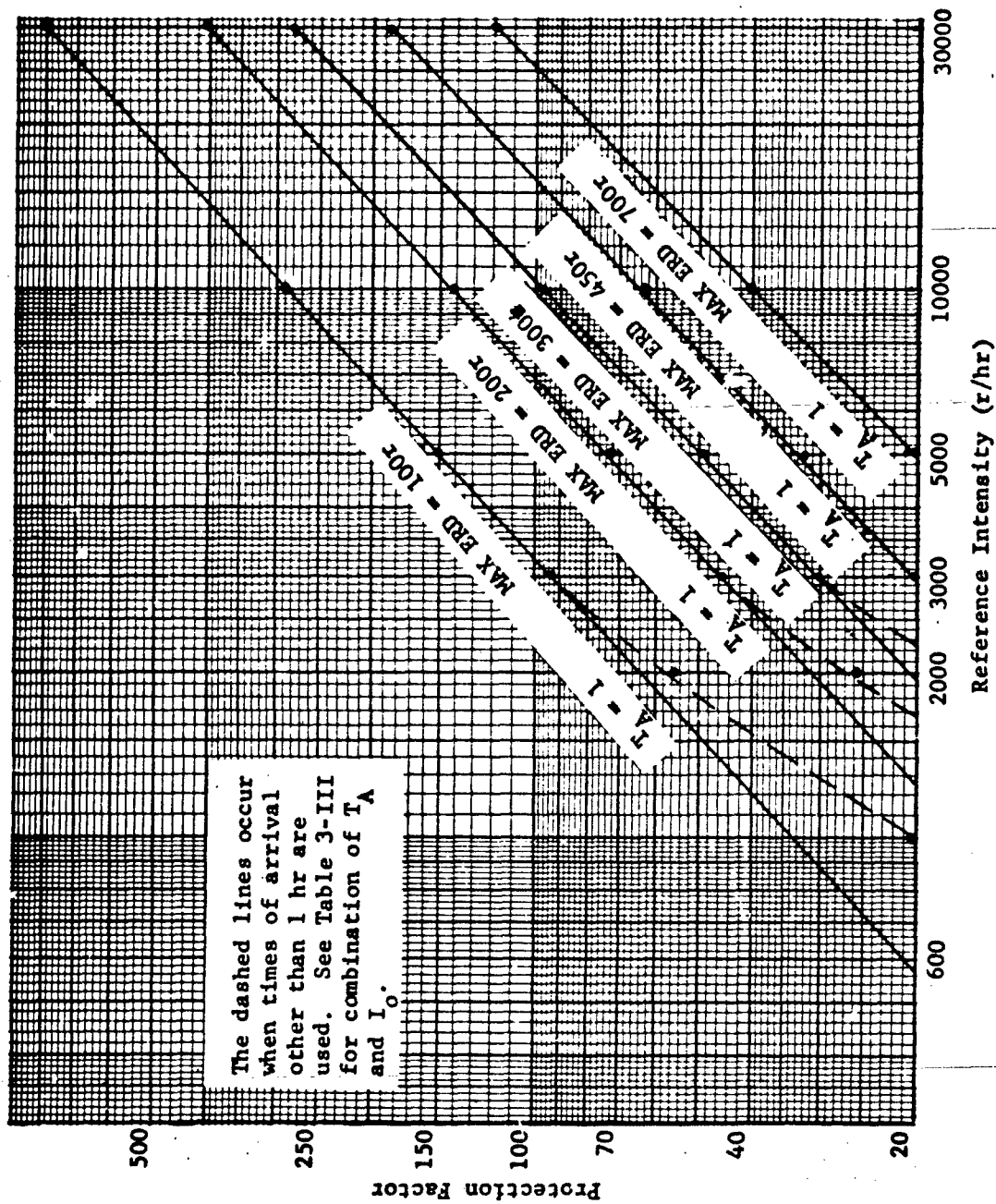
Fig. 32. Trade-Off Between PF and Fallout Environment (No Movement in Fallout)

In the analyses reported here, knowledge, time, and distance to the shelter were introduced in a semi-quantitative way by varying "movement restrictions" as follows:

1. Movement Restricted to Own SL

Knowledge very great, and time and distance allowance great enough to allow best shelter utilization within one's own SL.

2. Movement Restricted to 2 Miles From Own SL

Knowledge very great, and time and distance allowance great enough to allow best utilization of any shelter within one's Standard Location (SL), or a SL not more than two miles away (rectangular distance).

3. Movement Unrestricted Within SMSA

Knowledge very great, and time allowance great enough to allow best shelter utilization, at long distances anywhere in the SMSA.

4. Optimum Shelter Utilization (Transportation Algorithm)

Knowledge exact, to allow optimal shelter utilization (minimum casualties) anywhere within the SMSA, including a prior calculation of dose received during transit in fallout and in the primary shelter, all before or during fallout arrival. Speed was restricted to 2 mph.

We have a mathematically optimum solution in Movement Restriction 4. A similar shelter utilization pattern could be generated by other assumptions, operationally more realistic--as seen in Table XII, Summary of Casualty Estimated (% of Population) for Reference Intensity of 2000 r/hr and Time of Arrival of 1,5 Hours--for unrestricted movement, for example. For more severe environments, the two casualty figures (hence shelter utilization) become identical. This case and unrestricted movement offer a benchmark of ideality against which to measure other shelter utilization patterns.

. Major Conclusions

Efficient shelter utilization appears to be a critical problem when the shelter spaces exceed population; inefficient utilization can lead to a large number of avoidable casualties. This was concluded from the observation of the rapid increase in casualties for a specified attack environment as one restricts movement progressively from the SMSA down to the SL in which the shelteree finds himself at the time of warning. For the most shelter-abundant cities (Waterloo and Richmond in Table II), the percentage of casualties under a 2000 r/hr fallout environment is

progressively reduced from a two-city average ranging between 75% and 30% for limited movement (SL and Constant Movement Restriction in Table XII) to zero for movement unrestricted within the SMSA.

TABLE XII

Summary of Casualty Estimates (% of Population) for
Reference Intensity of 2000 r/hr and Time of Arrival of 1.5 Hours

SMSA	Shelter/ Population Ratio (%); Categories 1 and Better	Movement Restricted To Own SL; Movement Completed Before Fallout	Constant Movement Speed of 2 mph Restriction Movement Permitted in Fallout (Trans- portation Algorithm)	Movement Unrestricted Within SMSA; Movement Completed Before Fallout
Orlando	20	94	78	78
Tucson	24	85	74	74
Charleston	33	83	70	70
Mobile	48	78	54	54
Macon	50	77	46	46
Pittsfield	66	64	43	43
Waterloo	110	83	25	0
Richmond	160	66	36	0

For the most shelter-poor cities (Orlando and Tucson), the corresponding reduction is from a two-city average of 91% casualties to a two-city average of 76% casualties, a feasible savings of 15% of the population who would otherwise be casualties. This is to be compared to the 75% savings to the more shelter-abundant cities. The lack of sensitivity to movement restrictions in shelter-poor cities generally is due to the fact that there are enough people in any standard location to completely utilize available shelter in that SL. Thus, even the most restrictive shelter utilization constraint leads to good utilization.

Within broad limits, the higher the ratio of shelter is to population, the greater is the payoff in casualties saved by shelter utilization planning.

Insofar as movement distance restrictions are derived from time available for sheltering, one can deduce the substantial payoff potential in effective warning means, shelter planning, and indoctrination of the population--particularly in shelter-abundant areas.

C.   Secondary Conclusions

1.   Movement in fallout to a better shelter theoretically is warranted in many circumstances. The quantitative trade-offs between movement time in

fallout and protection factor of the shelter are shown in Figure 31. The feasibility of applying this principle in the transattack environment is questionable, however. It is a special case of remedial movement, but with a very short decision time and a changing environment.

2.   Neither city size nor population density (one of the city selection criteria), which might be supposed to have an effect on juxtaposition of people and shelter, could be shown to be significant in this analysis. This is concluded from examining the difference in casualties in each attack environment, between Movement Restriction 4, (movement in fallout, but limited movement speed), and Restriction 3 (complete freedom) as a function of city size and population density. Small effects which likely exist either are swamped by the more critical shelter/population ratio, or are undetectable from the "noise" of variable PF distributions in cities otherwise similar (size and population density). The casualties differ between Restrictions 3 and 4 only for Waterloo (low density, small size) and Richmond (high density, large size) at the intermediate attack environments.

D.   Recommendations

This analysis has shown the critical sensitivity of casualty estimates to shelter utilization, and therefore, to the corresponding movement-to-shelter assumptions, particularly for shelter-abundant areas. Accordingly, further research is recommended to give a more quantitative insight into the problem of movement-to-shelter (time, training and discipline, and distance to move). Better understanding can lead to more effective operational plans and programs in terms of preattack shelter assignment planning, warning requirements, training, etc.

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Appendix A

Development of Probabilistic Fallout Environments

I. INTRODUCTION

A. Cumulative Distributions Mathematically Defined

Given a simulated nuclear attack, the pattern of the attack is used to compute, on a probability basis, the severity of the fallout environment at each of 200 SMSA's throughout the U. S. One-hundred attack patterns comprise one RISK attack. Thus for one RISK attack, each SMSA will be subjected to 100 possible fallout environments.

Let I_o and T_A dnote the Reference Intensity and Time of Arrival, respectively. Each component is divided into subgroups:

A similar distribution is derived for time of arrival T_A:

i	I_o (r/hr)	T_A (hr)
1	0-100	0-1
2	101-300	1-2
3	301-1000	2-3
4	1001-3000	3-4
5	3001-10000	4-8
6	10001-30000	8-12

If X_{ij} denotes the number of times I_o occurs in the ith interval for the jth SMSA then the probability of occurrence for the ith interval is estimated by

$$P\ (\overline{X}_i) = \frac{\sum\limits_{j=1}^{200} X_{ij}}{200} \cdot f, \quad j=1, \ldots, 6 \qquad (A-1)$$

where f represents the number of attack patterns. Similarly, if Y_{ij} denotes the number of occurrences of T_A in the ith interval for the jth SMSA, we have

$$P(\bar{Y}_i) = \frac{\sum\limits_{j=1}^{200} Y_{ij}}{200} \cdot f, \quad i=1, \ldots, 6 \qquad (A-2)$$

The discrete cumulative distribution function for each variable is developed by summing the individual probabilities.

Appendix B

The Population to Shelter Algorithm

I. INTRODUCTION

A. Expression of Content

This appendix describes in detail the model used to estimate casualties within an SMSA. Also included is the computer program used in calculating the Maximum ERD associated with movement between standard locations.

1. Development of a Mathematical Model to Calculate Maximum Equivalent Residual Dose (Stage 1)

The Model and Program described in this section is a modified version of the Mainline Model and Program discussed in Appendix of Volume III, "A Generalized Sensitivity Analysis of CD Systems." The greatest difference between this algorithm and the Mainline Model of Appendix B of Volume III is in the input/output part of the program. By necessity each being oriented to a different research objective.

The equation describing ERD at t hours is the sum of the reparable and irreparable dose over finite time increments.
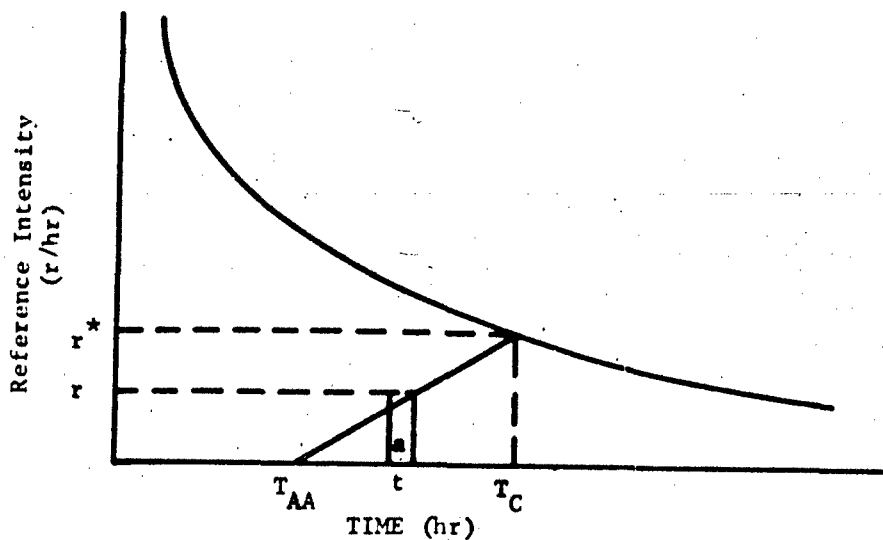
Fig. B-1. Illustration of Finite Different Formulation

T_A and T_c denote the time of arrival and time of cessation of fallout respectively.

Let D_p^* represent the reparable dose, and D_p^{**} the irreparable dose for the pth interval. Then

$$D_p^* = [1 - (a)(b)] D_{p-1}^* + (1-f) \frac{(a)(r)}{PF} \qquad (B-1)$$

$$D_p^{**} = D_{p-1}^{**} + (f)(r)(a) \qquad (B-2)$$

where

(1) a is the constant time increment in hours.

(2) b is the recovery rate (0.1%/hr.).

(3) f is the nonreparable part of the dose.

(4) PF is the protection factor for the shelter used.

And:

$$r = \frac{r^*(t - a/2 - T_A)}{T_A} \quad , \; T_A \le t \le T_c \qquad (B-3)$$

$$T_c = 2T_A$$

$$r = a \, t^{-1.2} \qquad , \; t > T_c \; . \qquad (B-4)$$

The ERD for the pth time increment is

$$D_p = (D_p^* + D_p^{**}) \, I_o \, , \qquad (B-5)$$

and the Maximum ERD occurs when $D_p > D_{p+1}$.

The previous derivation is based on the assumption that a person enters a shelter with protection PF before fallout arrives; i.e., if the time required to move from standard location i to j is T_{ij}, then the assumption is that $T_{ij} \le T_A$. If $T_{ij} > T_A$, then in Equation B-1, PF must equal 1 for $T_{ij} > t$. When T_{ij} becomes less than or equal to t , ($T_{ij} \le t$) the appropriate PF is employed and the original derivation is valid.

The computer program for Stage 1 is described in Sections 3, 4, 5 of this Appendix.

2. The Assignment Model (Stage 2)

The assignment model is based on a linear programming technique called ... ... This technique is most commonly employed in ... ... the cost of shipping a homogeneous product manufactured in "n" mills, each in a different geographical location, and shipped to consumers at "m" different destinations. The analogy is made that people represent the product located in "n" standard locations and fallout shelter spaces represent the warehouse capacities at "m" standard locations. The cost variable is the equivalent residual dose received if one moves from standard location i to standard location j where j has a protection factor of k.

Symbolically, the model formulation is:

Let s_{ijk} represent the ERD defined previously:

$$s_{ijk} = f(R, T_A, V, S_{ij}, PF_k) \qquad (B-6)$$

$R \sim$ fallout reference intensity (r/hr)

$T_A \sim$ arrival time of fallout (hr)

$V \sim$ movement speed (mi/hr)

$S_{ij} \sim$ distance from SL i to SL j (mi)

$PF_k \sim$ protection factor.

The model which calculates s_{ijk} is defined in Section A.1. Then assume the ERD obtained in moving from any SL i ($i = 1, \ldots, n$) to any SL j ($j = 1, \ldots, m$) with a protection factor category k ($k = 1, \ldots, 8$) is known. Thus, we have a 3-dimensional matrix ($n \times m \times 8$) with each element representing a "cost" or Maximum ERD. To simplify the matrix, let jk represent the jth destination and k^{th} protection category. What this means is that each protection category is treated as a separate and distinct destination, where

$$jk = 8(j-1) + k . \qquad (B-7)$$

For example, let the cost matrix be represented by D and let $s_{3,5,8}$ represent the Maximum ERD for a person leaving standard location 3, moving to standard location 5, and entering a protection factor category 8. The element in D corresponding to $s_{3,5,8}$ is $s_{i(jk)}$ where

$$i = 3$$

$$jk = 8(5-1) + 8 = 40 . \qquad (B-8)$$

Therefore,

$$s_{3,5,8} \equiv s_{3,40} \text{ and } s_{3,40} \quad D.$$

To summarize briefly the derivation of the cost matrix:

(a) The maximum ERD is calculated in Stage 1 of the model for each element of a 3-dimensional matrix where s_{ijk} represents each element in the matrix.

(b) In order to fit the 2-dimensional cost matrix scheme of the transportation algorithm, a linear transformation was performed on each element whereby s_{ijk} became $s_{i(jk)}$.

With the cost matrix in the desired form, the constraint equations and objective function may be defined:

(a) The population allocated from origin i to destination $jk(X_{i(jk)})$ must not exceed the initial population at the origin, A_i.

$$\sum_{jk=1}^{8m} x_i(jk) \le A_i, \quad (i = 1, \ldots, n) \qquad \text{(B-9)}$$

$$x_{i(jk)} \ge 0.$$

(b) The population sheltered at destination jk must not exceed the shelter capacity at the destination, $B_{(jk)}$.

$$\sum_{i=1}^{n} x_{i(jk)} \le B_{(jk)}, \quad (jk = 1, \ldots, 8m) \qquad \text{(B-10)}$$

$$x_{i(jk)} \ge 0.$$

(c) The objective function to be minimized is the number of casualties, subject to the previously defined population and shelter space constraints.

$$\min z = \sum_{i=1}^{n} \sum_{jk=1}^{8m} c_{i(jk)} \, x_{i(jk)}$$

$$c_{i(jk)} = \begin{cases} 0, & d_{i(jk)} \le 200r \\ 1, & d_{i(jk)} > 200r \end{cases} \qquad \text{(B-11)}$$

3. Glossary of Terms for Computer Program

ISL	Number of standard locations in the SMSA
LMAX	Maximum number of PF categories
Z	Radiation decay constant
R1	Reference intensity
TA	Arrival time of fallout
VEL	Movement speed
B	Recovery rate
F	Recoverable fraction
DMAX	Maximum acceptable ERD
PF1	Primary PF
PF2	Secondary PF
PF3	Equivalent PF in third shelter period
PF4	Equivalent PF in fourth shelter period
T1	Time in primary shelter
T2	Time in secondary shelter
T3	Time in third shelter
III	SMSA code
IP	Number of populated standard locations
IS	Number of standard locations with shelter spaces
IC	IS x IP
RMAX	Peak reference intensity of buildup function
D1	Reparable portion of total dose
D2	Irreparable portion of total dose
DD	Equivalent Residual dose (ERD)
DP	Maximum ERD
TMM	Cumulative time since time of arrival
L	PF category.

4. Flow Charts for Computer Program

```
                              ┌─────────┐
                              │  BEGIN  │
                              └────┬────┘
     ( 1 )                         │
                                   ▼
   ┌────────┐              ┌───────────────┐
   │ RETURN │─────────────▶│    INPUT      │
   │  FROM  │              │ ISL, LMAX, Z  │
   │   2    │              └───────┬───────┘
   └────────┘                      │
                                   ▼
   ┌────────┐   0, NEG.     ╱───────────╲
   │  END   │◀──────────────  TEST  ISL  ╲
   └────────┘                ╲───────────╱
                                   │ POS.
                                   ▼
                          ┌───────────────┐
                          │    INPUT      │
                          │ R1, TA, VEL   │
                          │ B, F, DMAX    │
                          └───────┬───────┘
                                  │
                                  ▼
                          ┌───────────────┐
                          │    INPUT      │
                          │ PF1, PF2, PF3,│
                          │ PF4, T1, T2, T3│
                          └───────┬───────┘
                                  ▼
                             ╭─────────╮
                             │  WRITE  │
                             │STANDARD │
                             │ OUTPUT  │
                             │  TAPE   │
                             ╰────┬────╯
                                  ▼
                          ┌───────────────┐
                          │    INPUT      │
                          │ SMSA  IDENT.  │
                          └───────┬───────┘
                             ╭────┴────╮
                        ╭────────╮ ╭────────╮
                        │ OUTPUT │ │ STAND. │
                        │  TAPE  │ │ OUTPUT │
                        │   9    │ │        │
                        ╰────────╯ ╰────────╯
                                  │
                                  ▼
                          ┌───────────────┐
     ( 2 )                │    INPUT      │
                          │ III, IP, IS, IC│
                          └───────┬───────┘
                                  ▼
```

```
                                        ┌──────────────┐
┌──────────────────┐                    │      IS      │
│   CALC. DOSE     │       YES          │   TIME IN    │
│ ACQUIRED BEFORE  │◄───────────────────│ F.O. GREATER │
│    ENTERING      │                    │     THAN     │
│    SHELTER       │                    │      0       │
└──────────────────┘                    └──────────────┘
         │                                     │ NO
         │                                     ▼
         │                           ┌──────────────────┐
         │                           │    ADD. DOSE     │
         └──────────────────────────►│ ACQUIRED DURING  │
                                     │    BUILD-UP      │
                                     │   (SHELTERED)    │
                                     └──────────────────┘
                                              │
                                              ▼
                                     ┌──────────────────┐
                                     │    ADD. DOSE     │
                                     │ ACQUIRED (AFTER  │
                                     │   BUILD-UP) IN   │
                                     │ PRIMARY SHELTER  │
                                     └──────────────────┘
                                              │
                                              ▼
                                     ┌──────────────────┐
                                     │    ADD. DOSE     │
                                     │   ACQUIRED IN    │
                                     │    SECONDARY     │
                                     │     SHELTER      │
                                     └──────────────────┘
                                              │
                                              ▼
                                     ┌──────────────────┐
                                     │    ADD. DOSE     │
                                     │   ACQUIRED IN    │
                                     │ THIRD & FOURTH   │
                                     │ SHELTER PERIODS  │
                                     └──────────────────┘
                                              │
                                              ▼
                                     ┌──────────────────┐
                                     │      CALC.       │
                                     │ (1) SUBSCRIPTS   │
                                     │ (2) PROB. OF     │
                                     │     FATALITY OR  │
                                     │     CASUALTY     │
                                     └──────────────────┘
                                              │
                            ┌─────────────────┴─────────────────┐
                            ▼                                   ▼
                     ┌────────────┐                      ┌────────────┐
                     │  OUTPUT    │                      │   STAND.   │
                     │   TAPE     │                      │   OUTPUT   │
                     │    9       │                      │            │
                     └────────────┘                      └────────────┘
                            └─────────────────┬─────────────────┘
   ┌───┐                                      ▼
   │ 2 │                            ┌──────────────────┐
   └───┘                            │    INITIALIZE    │
   ┌───────┐                        │  VARIABLES FOR   │
   │ GO TO │◄───────────────────────│    NEXT F.O.     │
   │   1   │                        │   ENVIRONMENT    │
   └───────┘                        └──────────────────┘
```

```
              │
              ▼
   ┌──────────────────────┐
   │ ╭────────╮  ╭────────╮│
   │ │ OUTPUT │  │ STAND. ││
   │ │        │  │        ││
   │ │ TAPE 9 │  │ OUTPUT ││
   │ ╰────────╯  ╰────────╯│
              │
              ▼
          ╱ IS  ╲
        ╱ THIS FIRST ╲──── NO ────┐
        ╲ F.O. ENVIR. ╱           │
          ╲    ╱                  │
            │ YES                 │
            ▼                     │
   ┌──────────────────┐           │
   │      INPUT       │           │
   │    SL COORD.     │           │
   └──────────────────┘           │
            │                     │
            ▼◄────────────────────┘
        ╭──────────╮
        │  CALC.   │
        │          │
        │  RMAX    │
        ╰──────────╯
            │
            ▼
        ╭──────────╮
        │  STAND.  │
        │          │
        │  OUTPUT  │
        ╰──────────╯
            │
            ▼
   ┌──────────────────┐
   │ BEGIN LOOP       │
   │ TO CALCULATE     │
   │ MAX. ERD FOR     │
   │ MOVEMENT FROM    │
   │ SL(i) TO SL(j)   │
   └──────────────────┘
            │
            ▼
   ┌──────────────────┐
   │ CALC.            │
   │ (1) DISTANCE     │
   │     TRAVELED     │
   │ (2) TIME IN      │
   │     F.O.         │
   └──────────────────┘
            │
            ▼
          Exit
```

5. Fortran Listing

* .. ..BCONEY SINK _ RII-OCD

* XEG
    SECTICN 1 - CALCULATICN OF MOVEMENT TIMES

    DIMENSICN X(100),Y(1CC),C(10),D1(10),C2(10),CP(1C),TM(10)
    DIMENSICN PF1(10),PF2(10),S(10CC),JRSAC(100)
    DIMENSICN DDP(4C,4C,8),TERM(4C,4C) ,P(100)
    REWINC 9
    IGNCRE=C
 1 CCNTINUE
    II=1
    REAC INPUT TAPE 5,3C1,ISL,LMAX,Z
    IF(ISL)714,714,2
 2 READ INPUT TAPE 5,5C1,R1,TA,VEL
    REAC INPUT TAPE 5,5C2,B,F,DMAX
 1C CCNTINUE
    READ INPUT TAPE 5,4,PF1(1),PF1(2),PF1(3),PF1(4),PF1(5)
    READ INPUT TAPE 5,4,PF1(6),PF1(7),PF1(8),PF1(9),PF1(1C)
    REAC INPUT TAPE 5,4,PF2(1),PF2(2),PF2(3),PF2(4),PF2(5)
    RFAC INPUT TAPE 5,4,PF2(6),PF2(7),PF2(8),PF2(9),PF2(1C)
    READ INPUT TAPE 5,4,PF3,PF4,T1,T2,T3
 3C1 FCRMAT(2I5,F1C.2)
 5C1 FCRMAT (3F1C.2)
 5C2 FCRMAT (3F1C.5)
  4 FCRMAT (5F1C.2)
    WRITE CUTPUT TAPE 6,8C1,R1,TA,VEL,PF1(1)
 8C1 FCRMAT (4F12.2)
    REAC INPUT TAPE 5,7C7
 707 FCRMAT(4CH1   )
    WRITE CUTPUT TAPE 9,7C7
    WRITE CUTPUT TAPE 6,707
    READ INPUT TAPE 5,7C5,III,IP,IS,IC
    WRITE CUTPUT TAPE 6,7C6,IP,IS,IC
    WRITE CUTPUT TAPE 9,7C6,IP,IS,IC
 7C5 FCRMAT(I7,I13,I1C,I1C)
 7C6 FCRMAT(7HC211113I13,I1C,I1C)
    IF(IGNCRE)7C61,7061,7C62
 7C61 DC 703 M=1,ISL
    REAC INPUT TAPE 5,701,JRSAC(M),X(M),Y(M)
 701 FCRMAT(I8,F12.C,F10.0)
 7C3 CCNTINUE
 7062 CCNTINUE
    RMAX = (2.0*TA)**(-Z)
 7C8 CONTINUE
    WRITE CUTPUT TAPE 6,8CC
 8CC FCRMAT(55H1   I   J   PF   JJ   PRCB   MAX ERD   TIME)
    DC 305 I=1,ISL
    DC 305 J=1,ISL
 5C9 DC = C
    D11 = C
    D22 = C
    TMM = C
    DPP = C
    T = (SCRTF((X(I)-X(J))**2)+SQRTF((Y(I)-Y(J))**2))/VEL
    T = T*0.C62
 590 CCNTINUE
 5C4 CCNTINUE
 5C8 CCNTINUE

- B-9 -

```
                 T = T-TA
1                SECTION I - CALCULATION OF MOVEMENT TIMES

                 IF (T)507,508,508
     507 T = 0.
     508 CONTINUE
                 IF(T) 599,599,510
     510 TMM = TMM+0.1
                 RM =(RMAX*(TMM-0.05)/TA)*0.1
                 IF((RM*10.)-RMAX)515,515,514
     514   A1=TMM**(1.-Z)
                 A2=(TMM-.1)**(1.-Z)
                 RM=(A1-A2)/(1.-Z)
     515   D11 = ((1.0-0.1*B)*D11)+((1.0-F)*RM)
                 D22 = D22+(F*RM)
                 CC = (D11+D22)*R1
                 IF(DD-DPP) 513,511,511
     511 DPP = CC
                 IF(DPP-DMAX)513,599,599
     513 IF(TMM-(T-0.05)) 510,599,599
     599 CONTINUE
     C       SECTION III
     5       CONTINUE
     7       DO 101 L = 1,LMAX
                 D(L) = DD
                 D1(L) = D11
                 D2(L) = D22
                 DP(L) = DPP
                 TM(L) = TMM
                 IF(DP(L)-DMAX)19,999,999
     19  IF(TMM-TA) 20,30,30
     20  TM(L) = TM(L)+0.5
                 RML =(RMAX*((TM(L)-0.25)/TA))*0.5
                 D1(L) = (1.0-B/2.0)*D1(L)+(1.0-F)*RML/PF1(L)
                 D2(L) = D2(L)+F*RML/PF1(L)
                 D(L) = R1*(D1(L)+D2(L))
                 IF(D(L)-DP(L)) 22,22,21
     21  TERM(I,J)=TM(L)
                 DP(L) = D(L)
                 IF(DP(L)-700.)22,999,999
     22 TAL = TA-0.25
                 IF(TM(L)-TAL)20,30,30
     30 TM(L) = TM(L) +6.0
                 A1 = TM(L)**(1.0-Z)
                 A2 = (TM(L)-6.0)**(1.0-Z)
                 RML = (A1-A2)/(1.0-Z)
                 D1(L) = (1.0-6.*B)*D1(L)+(1.0-F)*RML/PF1(L)
                 D2(L) = D2(L)+F*RML/PF1(L)
                 D(L) = R1*(D1(L)+D2(L))
                 IF(D(L)-DP(L))32,32,31
     31 TERM(I,J)=TM(L)
                 DP(L) = D(L)
                 IF(DP(L)-700.)32,999,999
     32 IF(TM(L)-T1)30,40,40
     40 CONTINUE
     401 TM(L) = TM(L)+24.0
                 A1 = TM(L)**(1.0-Z)
                 A2 = (TM(L)-6.0)**(1.0-Z)
                 RML = (A1-A2)/(1.0-Z)
1                SECTION I - CALCULATION OF MOVEMENT TIMES
```

```
                 D1(L) = (1.C-24.Q*B)*D1(L)
                 D1(L) = D1(L)+((1.C-F)*RML)/PF2(L)
                 D2(L) = D2(L)+F*RML/PF2(L)
                 D(L) = R1*(D1(L)+C2(L))
                 IF(D(L)-DP(L))42,42,41
          41     TERM(I,J)=TM(L)
                 DP(L) = D(L)
                 IF(DP(L)-70C.)42,999,999
          42 TAL = T1+T2
                 IF(TM(L)-TAL) 4C1,49,49
          49 IF(T3)999,999,50
          5C TM(L) = TM(L)+168.0
                 A1 = TM(L)**(1.C-Z)
                 A2 = (TM(L)-6.0)**(1.C-Z)
                 RML = (A1-A2)/(1.C-Z)
                 D1(L) = (1.C-168.C*B)*D1(L)+(1.C-F)*RML/PF3
                 D2(L) = D2(L)+F*RML/PF3
                 D(L) = R1*(D1(L)+C2(L))
                 IF(C(L)-DP(L))52,52,51
          51 TERM(I,J)=TM(L)
                 DP(L) = D(L)
                 IF(DP(L)-700.)52,999,999
          52 TAL = T1+T2+T3
                 IF(TM(L)-TAL)50,59,59
          59     CONTINUE
          6Q TM(L) = TM(L)+720.
                 A1 = TM(L)**(1.C-Z)
                 A2 = (TM(L)-6.0)**(1.C-Z)
                 RML = (A1-A2)/(1.C-Z)
                 D1(L) = (1.0-720.C*B)*C1(L)+(1.C-F)*RML/PF4
                 D2(L) = D2(L)+F*RML/PF4
                 D(L) = R1*(C1(L)+D2(L))
                 IF(D(L)-DP(L))62,62,61
          61 TERM(I,J)=TM(L)
                 DP(L) = D(L)
                 IF(DP(L)-70C.)62,999,999
          62     CONTINUE
                 GC TO 6C
          999 DCP(I,J,L)=DP(L)
          1C1 CCNTINUE
          3C5 CCNTINUE
                 DC 90 J=1,ISL
                 DC 90 I=J,ISL
                 DC 90 L=1,LMAX
                 DCP(I,J,L) = DDP(J,I,L)
                 TFRM(I,J) = TERM(J,I)
          9C  CCNTINUE
                 DC 91 I=1,ISL
                 DC 91 J=1,ISL
                 DC 91 L=1,LMAX
                 JJ=(J*LMAX)-(LMAX-L)
                 PROB=(DCP(I,J,L)-20C.)/50C.
                 IF(PRCB)93,94,94
          93 NPRCB=C
                 GC TO 95
          94  IF(PRCB-1.)942,941,941
                 SECTICN I - CALCULATICN OF MOVEMEAT TIMES

          941  NPRCB=1000
```

```
            GC TO 95
    942     NPROB=PROB*1OCC.
     95     WRITE OUTPUT TAPE 6,709,I,J,L,JJ,NPROB,DDP(I,J,L),TERM(I,J)
            WRITE OUTPUT TAPE 9,720,I,JJ,NPROB
    709     FCRMAT(1CH               415,I10,2F1C.3)
    72C     FCRMAT(10HB              I5,I5,I10)
     91     CCNTINUE
            WRITE OUTPUT TAPE 6,71C
            WRITE OUTPUT TAPE 9,71C
     71C    FCRMAT(10HB              * )
            N=1
            DO 75C M=1,ISL
            IF(IGNORE)7101,71C1,71C2
    7101    CCNTINUE
            READ INPUT TAPE 5,751,P(M),S(N),S(N+1),S(N+2),S(N+3),S(N+4),
           1 S(N+5),S(N+6),S(N+7),S(N+8),S(N+9)
    7102    CCNTINUE
            N=N+LMAX
            KP=P(M)
            WRITE OUTPUT TAPE 6,752,M,KP
            WRITE OUTPUT TAPE 9,752,M,KP
    751     FCRMAT(F1C.C,1CF5.0)
    752     FORMAT(I5HS               I5,I1C)
    75C     CONTINUE
            WRITE OUTPUT TAPE 6,753
            WRITE OUTPUT TAPE 9,753
    753     FCRMAT(11HS              * )
            K=LMAX*ISL
            DC 754 N=1,K
            KS=XFIXF(S(N))
            WRITE OUTPUT TAPE 6,755,N,KS
            WRITE OUTPUT TAPE 9,755,N,KS
    755     FCRMAT(15HD               I5,I1C)
    754     CCNTINUE
            WRITE CUTPUT TAPE 6,756
            WRITE CUTPUT TAPE 9,756
    756     FCRMAT(11HD              * )
            T4=T4+1.
            II = II
            DO 759 I=1,ISL
            DC 759 J=1,ISL
            DC 759 L=1,LMAX
            DDP(I,J,L)=C.
    759     TERM(I,J)=0.
            IGNORE=1
            GC TO 1
    714     CONTINUE
            WRITE CUTPUT TAPE 6,757
            WRITE OUTPUT TAPE 9,757
    757     FORMAT(17H   END CF PROBLEM )
            WRITE OUTPUT TAPE 6,758
            WRITE OUTPUT TAPE 9,758
    75E     FCRMAT(1HC)
            END FILE 9
            REWINC 9
1           SECTICN I - CALCULATICN OF MOVEMENT TIMES

            WRITE OUTPUT TAPE 6,713
    713     FORMAT (18H PROBLEM CCMPLETED )
            CALL EXIT
```