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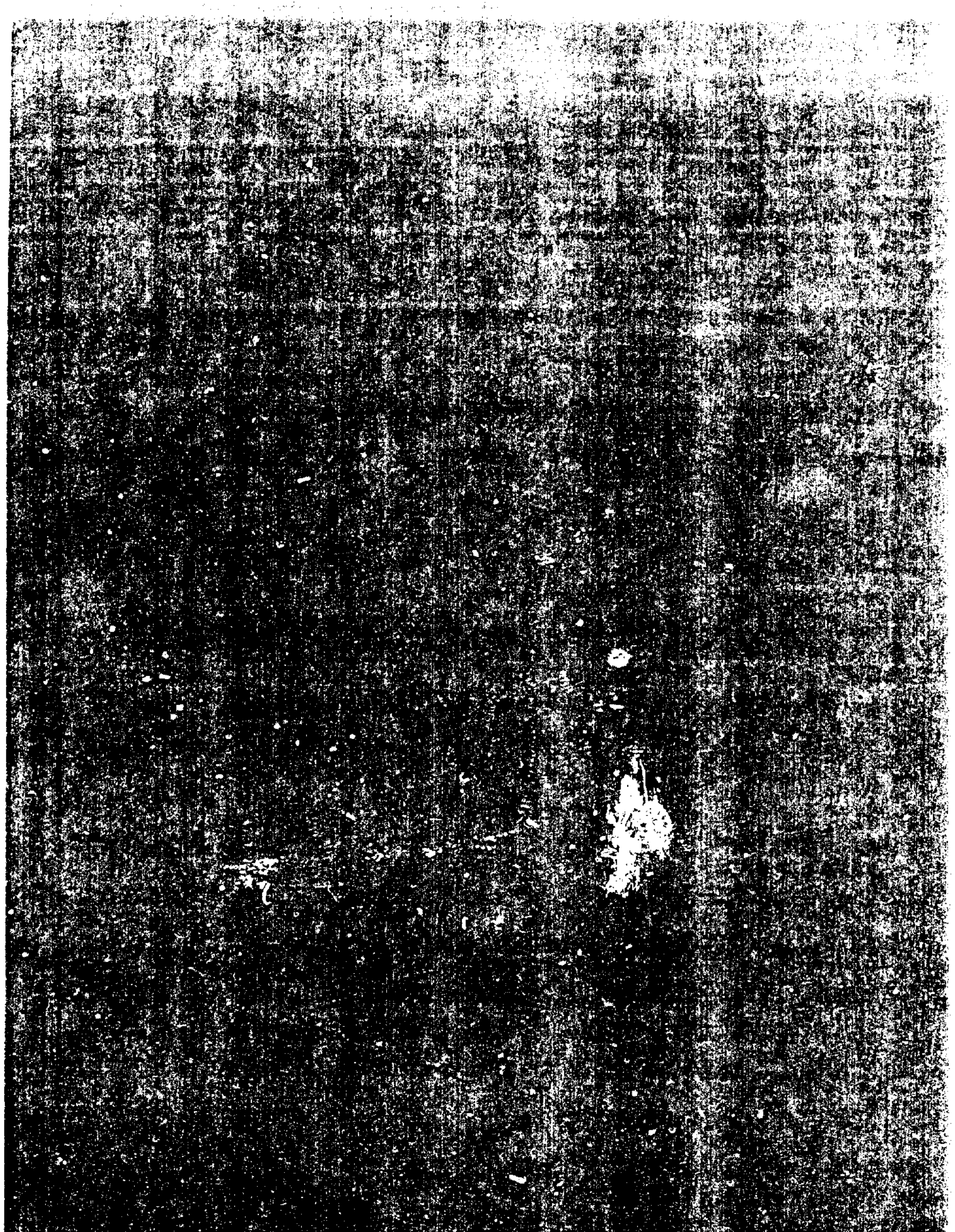
RADIO WARNING STUDIES



NOVEMBER 1965

Prepared for:

OFFICE OF CIVIL DEFENSE
DEPARTMENT OF THE ARMY
WASHINGTON, D.C. 20301

SRI

RADIO WARNING STUDIES

POPULATION IN SHELTER:

A METHOD FOR MEASURING THE EFFECTIVENESS OF RADIO WARNING

By:

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I INTRODUCTION AND SUMMARY

The use of cost-effectiveness analysis and other advanced techniques of economic analysis is becoming increasingly important in evaluating the merit of civil defense programs. Such analyses are usually difficult to prepare both because of problems in selecting proper criteria for evaluating effectiveness and because of difficulties in computing a numerical value for the effectiveness of proposed programs. The purposes of this report are, therefore, to present a method that can be used to compute a numerical value for warning system effectiveness, to show how to compute warning system effectiveness using the method, and to describe the assumptions, computations, and data that lie behind the techniques presented.

This introductory section describes the evaluation criterion selected and shows how the criterion is related to warning system performance. A set of charts and worksheets is presented in the second section. The remainder of the report presents instructions on the use of the charts and the worksheets, and gives an example of the use of a numerical measure of effectiveness. The appendix describes the mathematical model that was used to generate the charts.

Choice of an Evaluation Criterion for Warning Systems

Civil defense programs are established to save lives in case of attack. Therefore, a frequently used measure of the effectiveness of a civil defense system is the number of lives that could be saved with the implementation of the system. However, for the design and evaluation of the subsystems, i.e., warning, shelters, etc., that make up complete systems, other measures may be established which may be easier to use and which, if used to optimize system performance, will usually result in the optimization of the performance in terms of the more desirable measure of lives saved.

The fraction of the population in shelter before fallout arrives has been selected in this analysis as a measure of the effectiveness for warning systems. It is assumed that the number of lives saved will be related to the fraction of the population in shelter, and that maximizing the fraction in shelter will therefore also generally maximize the number of lives saved in a fallout-shelter-based civil defense program. The abbreviated term "fraction of the population in shelter" is used throughout the remainder of this report, and implies that the fraction is measured at the time that fallout arrives. In other words, if the people are better off inside the shelters that have been provided them, the value of the warning system may be measured by the degree to which the system allows utilization of the shelters provided.

Choice of the time at which fraction of the population in shelter is to be measured is complicated by great uncertainty as to the expected allocation of nuclear weapons to targets and as to their arrival times on target. It is known, however, that the first fallout from a nuclear explosion will arrive on the ground about 30 minutes after the explosion. For planning purposes, it has therefore been assumed that all metropolitan areas are potential targets, or are near potential targets for attack, and that the time available for warning the population of these metropolitan areas and for moving them to shelter is 30 minutes plus any time in advance of the detonation in which the warning is received. It has further been assumed for planning purposes that nonurbanized areas will not be subject to nearby nuclear detonations, but that these areas are subject to a fallout threat. Since the nonurbanized areas are not near the explosions, it has been assumed that the fallout will require at least 60 minutes to reach the nonurbanized area, and that the time available to reach shelter will be 60 minutes in addition to any advance warning before detonation. These times, 30 minutes for urbanized areas and 60 minutes for nonurbanized areas, plus any advance warning of the detonation, are the times at which the fraction in shelter has been measured.

While the fraction of the population in shelter before fallout arrives is potentially a complete description of warning system performance in terms of the contribution of the warning system to the life-saving potential of civil defense, two areas of performance have been omitted in the method for computing the measure. Warning system survivability effects are not included in the computations because the attacks under which the warning system must operate are so varied and so uncertain that the reduction of the coverage to that which might be expected over a range of attacks would contain such a large uncertainty as to mask other warning system performance features. The risks of false-alarm and no-alarm failures (due either to equipment failure or to overt action) are quite uncertain, as is the effect of such failures upon subsequent operation of the warning system. In the comparison of alternative warning systems, therefore, these two areas should be subjected to separate analysis.

Relationship Between Warning System Performance and Fraction of the Population in Shelter

A discussion of the relationship between system performance and fraction in shelter introduces the illustrations and examples of the use of fraction of the population in shelter and summarizes the detailed development of the measure described in the appendix. This introduction and summary describes the nature of warning, how it is transmitted, and how warning systems are specified. There follows a description of an individual's actions between the time the alert signal sounds and the time that individual arrives in shelter. The variations in the times required for these individual actions and the factors affecting the times required are examined. Finally, the way in which the fraction of the population in shelter depends upon the warning system specifications is shown.

Civil defense attack warning may be thought of as a public alerting signal followed by a verbal confirmation of the alert. The alerting signal may be generated by an outdoor siren, by a radio loudspeaker, or by any other noisemaker that is capable of attracting public attention. While many combinations of noisemakers and message delivery devices are available, only a limited number have been considered as having a useful application to civil defense warning. For convenience, the combination of the method for delivering the alert signal and the method for delivering the voice message is called a mode. Four modes are considered. They are called: Radio Warning, Indoor Alerting, Siren Alerting, and No Alerting. The sources of the alerting signal and the confirming message for each mode are shown in Table 1.

Warning systems may then be described as collections of hardware and procedures associated with warning the public by one or more of these modes. The performance of each mode may be specified in terms of coverage, response time, and reliability. Coverage is the fraction of the population that can be warned by the mode; response time is defined as the time between initiation of the national warning at the National Warning Center and the beginning of the alert signal sound; and reliability is the factor to which coverage must be reduced because of inoperative equipment in the system when the warning is to be sent out.

Consider the individual who is within the range of the alerting signal. Before he arrives in shelter, he will have performed three distinct kinds of activities.

The first set of activities will be to hear the signal, to recognize the signal, to interpret the meaning of the signal, to seek verification

Table 1

CIVIL DEFENSE WARNING MODES

Name of Mode	Source of Alerting Signal	Source of Confirmation
1. Radio Warning	Radio warning receiver	Radio warning receiver
2. Indoor Alerting	Indoor alerting device (NEAR or radio alert-only receiver)	Commercial radio or TV
3. Siren Alerting	Outdoor sirens	Commercial radio or TV
4. No Alerting	Accidental, word-of-mouth, etc.	Commercial radio or TV

of the validity of the signal, and to decide to act in response to the signal. This set of actions is called the alert verification process, and the time required to complete the process is called the alert verification time.

The second set of activities that the individual must complete is that of gathering personal clothing, blankets, and other items to be taken to the shelter, and of securing his residence before leaving. This process is called movement preparation, and the time required to complete it is called the movement preparation time.

Finally, the individual must travel whatever distance is required to reach a fallout shelter. This travel process is called movement to shelter, and the time required to complete it is called movement time. It may easily be seen that the movement time for all individuals will not be the same, since everyone will not be located at the same distance from the shelter when he begins his move. The movement times for a group of persons must be described by a distribution of movement times for the group. Such a distribution would be a table, curve, or formula describing the numbers of persons who would require, say, exactly 10 minutes to complete their move, 11 minutes to complete their move, and so on for

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Similarly, not all persons will require the same amount of time for alert verification nor will all require the same amount of time for movement preparation. These times must also be described in terms of their distribution for a large group of persons.

For a single individual, the time between the start of the alert signal and his arrival in shelter could be found by adding his alert verification time, movement preparation time, and movement time. Finding the number of persons in shelter before a given time, however, requires that statistical techniques be applied. Using these techniques it is possible to find the expected number in shelter at any time from the distributions of the verification, preparation, and movement times.

The relationship between the warning system performance and the fraction of the population in shelter depends, first, upon the response time of the various modes of the warning system, then upon the relationship of the alert verification, movement preparation, and movement time distributions to the performance of the warning system modes.

The response time of the warning system mode reduces the amount of time available for the population to reach shelter before the fallout arrives. For example, in an urbanized area, fallout will arrive 30 minutes after impact, and warning as much as 15 minutes in advance of the detonation may be available. A system with a 5-minute response time would allow 40 minutes to reach shelter, one with 10 minutes response time would allow only 35 minutes, and so on.

The alert verification times will be primarily dependent upon the mode of warning. The superior audibility and distinctiveness of the alert signal from the radio warning receiver, together with the automatic broadcast of the confirming voice message, result in any given fraction of the radio-warned population having completed the verification process in a shorter time than by any other mode. The rank of speed of responses to the modes is: fastest, radio warning; next fastest, indoor alerting; next, siren alerting; least fast, no alerting. A range of alert verification responses is considered for sirens. This range is necessary because civil defense siren signals are not distinctive--they may be mistaken for sirens on emergency vehicles. The time required to recognize the signal may be reduced by increased awareness on the part of the public either because of an international crisis condition or because of higher levels of effort to inform the public about civil defense. Verification of siren alerting signals can also be speeded up by providing prompt radio broadcast messages following these signals. The combination of public awareness of the sirens and the radio support to sirens gives rise to cases of siren effectiveness within the range of alert verification time for sirens.

The movement preparation time is not considered to be affected by the mode of warning, nor by any other feature of warning system performance.

The movement time distributions depend upon the number and location of shelter spaces relative to the number and location of the people whom these shelters are to protect. Since these factors are expected to change over time, two major cases have been analyzed--one for the resident population as determined by the 1960 census and the location of the shelter spaces that existed in January 1965, which is called the existing shelter posture; the other for the population distribution projected for the 1970 census and the number and location of shelter spaces existing after the implementation of a shelter development program with federal funds. This second situation is called the 1970 shelter posture.

Movement time distributions as well as fallout arrival times will be different for urbanized and for nonurbanized areas. Further, because there are differences between the distribution of people and shelters within urbanized areas, a distinction is made between central city and urban fringe areas of urbanized areas. A major breakdown of movement times for analysis will therefore be made between central cities, urban fringe areas, and nonurbanized areas.

Thus, given a complete shelter situation under which to evaluate a particular system, it may be seen that the fraction of the population in shelter before fallout arrives is dependent upon the response time of each of the modes of the warning system and upon the coverage of each of the modes making up the warning system in central cities, urban fringe areas, and nonurbanized areas.

Conditions under Which Warning Systems May Be Evaluated

In order to preserve the usability of the fraction of the population in shelter as a measure of effectiveness, and to limit the scope of the development of the measure, fraction in shelter can be computed for only a limited number of conditions and warning modes. While it is believed that the applicability of the computation is sufficiently broad to handle almost any problem that may arise, it is nevertheless necessary to describe these limits.

First, only the four warning modes described above can be evaluated. Since siren alerting and no alerting predominate in the existing system and since this study has been made to support analysis of radio warning systems, analysis of other modes such as mobile loudspeakers has been omitted. Alerting resulting from the effects of a nuclear detonation has also received attention as a possible warning mode, but inclusion of a mode based upon such alerting has not been possible within the time available for this analysis.

Since the study is concerned with indoor radio warning, only resident populations have been used--daytime business populations are excluded. The data on the locations of resident population are vastly more abundant and reliable than data on daytime population locations. This implies an assumption that the attack would occur in the late evening or early morning hours. Also implied is that everyone is indoors. The likelihood of attack occurring during the nighttime hours suggested by the indoor resident population is subject to prior determination.

Finally, population shelter data are based upon the coterminous United States (48 states).

II COMPUTATION OF WARNING SYSTEM EFFECTIVENESS

The charts and worksheets used to compute the fraction of the population in shelter are presented and described in this section. Given also in this section are instructions for using the charts and worksheets and an example further illustrating the use of the computational aid. Applications of the use of fraction in shelter problems of cost-effectiveness analysis are presented in Section III.

The charts shown in Figures 1-8 represent the output of a mathematical model that has been used to generate the fraction of the population in shelter as a function of the time after the alert signal sounds. Two sets of charts are included, one for the existing shelter posture and one for the 1970 shelter posture. Each set includes four charts, one for each warning mode to be considered: radio warning, indoor alerting, siren alerting, and no alerting. For each mode, curves showing the fraction of the population in shelter as a function of the time after the alert signal sounds are shown for central city, urban fringe, and nonurbanized areas.

Following the charts is Figure 9, a worksheet for computing the fraction of the population in shelter. The worksheet provides for an orderly arrangement of system environment and performance data, and presents the steps needed to convert the various segments of the population sheltered into a single figure for fraction of the total population in shelter in all areas and as a result of all the modes of the warning system. The worksheet is divided into three parts. Part I, Warning System Environment, contains spaces for entries describing environmental conditions pertinent to the analysis of all warning modes in the system. Part II is a summary of detailed evaluations of the modes of the warning system under analysis, and is structured so that the contribution of each of the modes of the postulated warning system (computed in Part III, below) may be entered and compared. Part II includes the additional step from which the overall warning system effectiveness is determined. Part III contains the structure for detailed computations necessary to compute the population in shelter as a result of each warning mode. Part III consists of four sections, one for evaluating each of the four warning modes considered in this report.

Figure 1

FRACTION IN SHELTER vs TIME

EXISTING SHELTER, RADIO WARNING

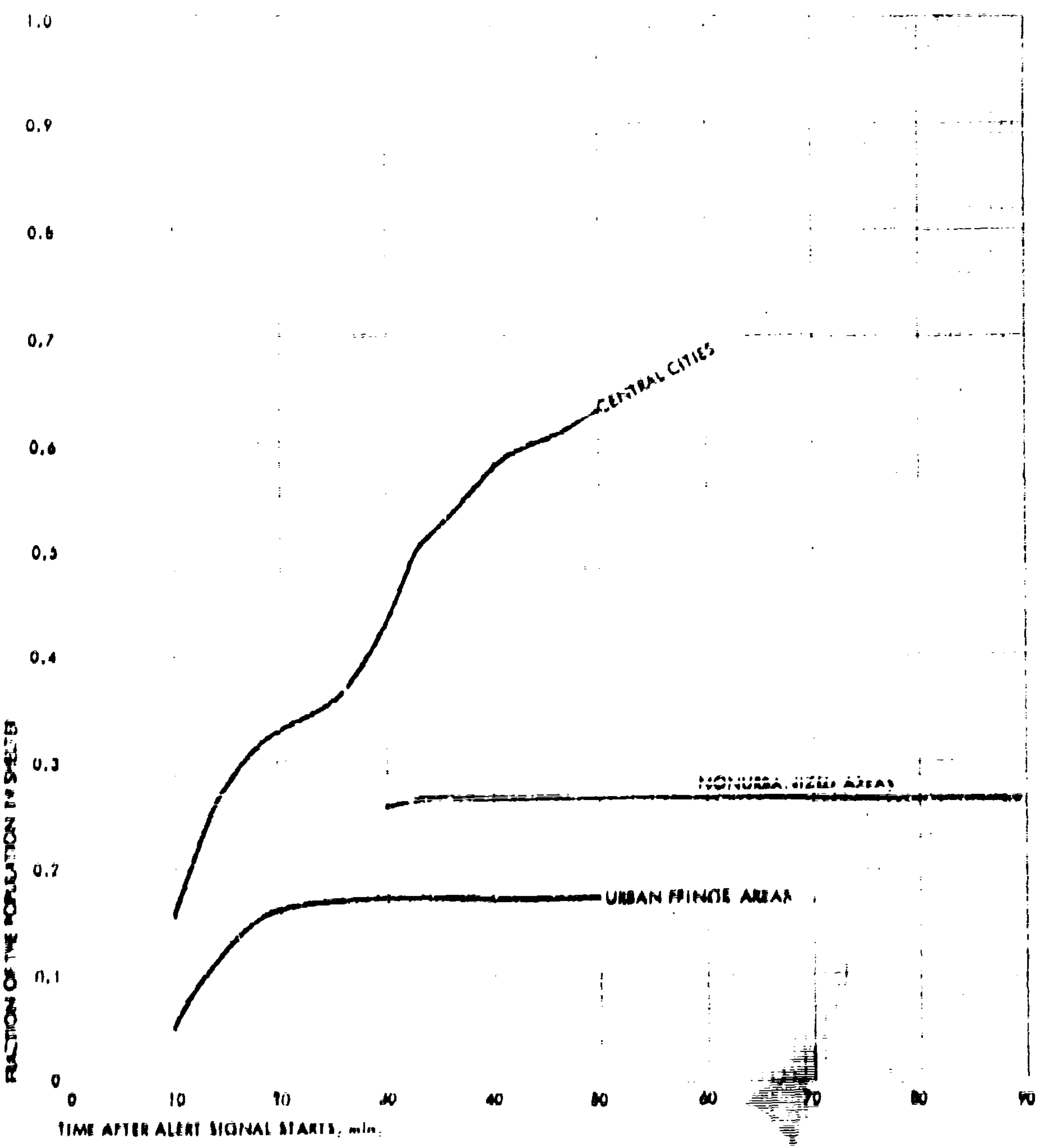

Figure 2

FRACTION IN SHELTER vs TIME

EXISTING SHELTER, INDOOR ALERTING

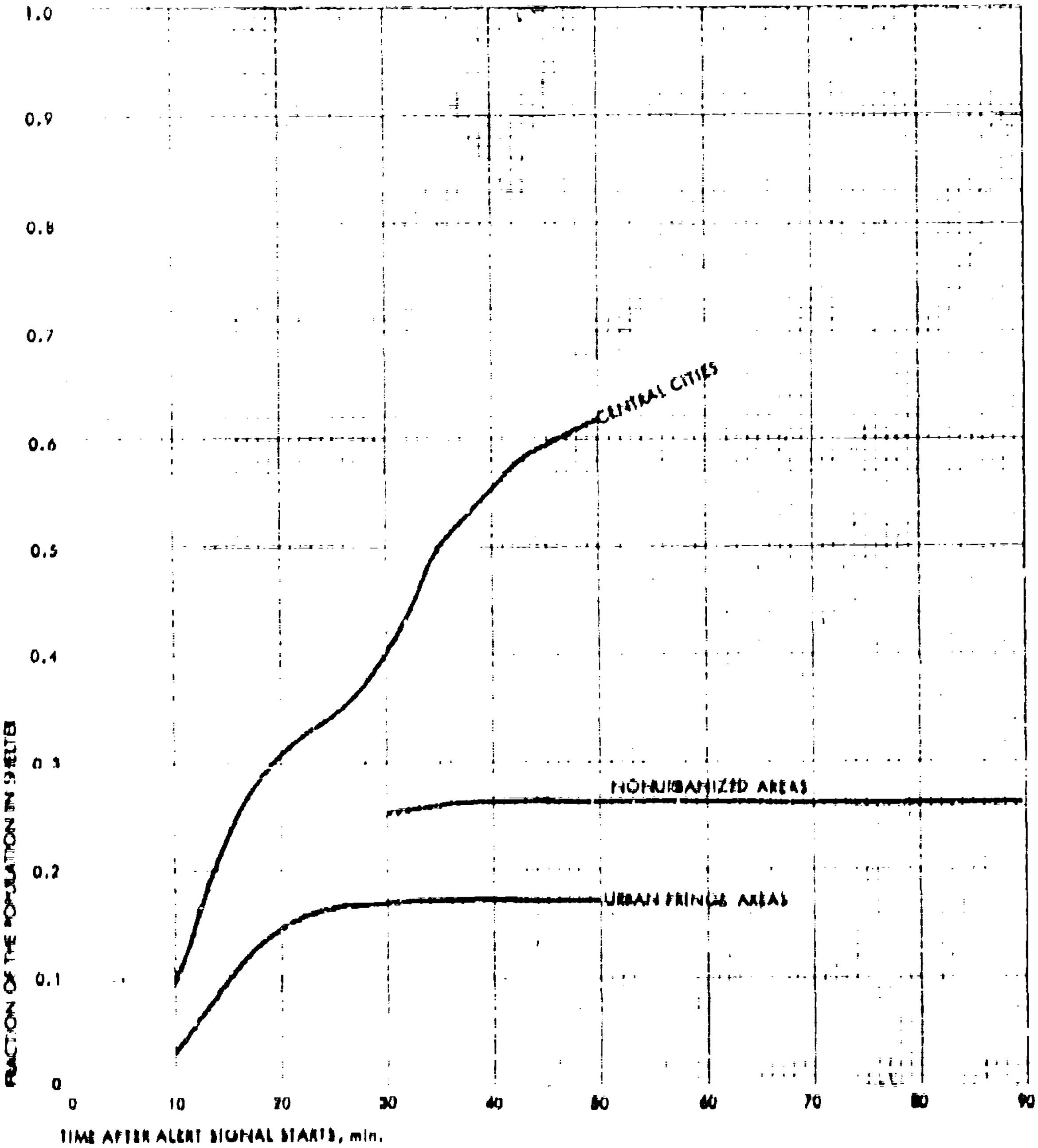

Figure 3

FRACTION IN SHELTER vs TIME

EXISTING SHELTER, SIREN ALERTING

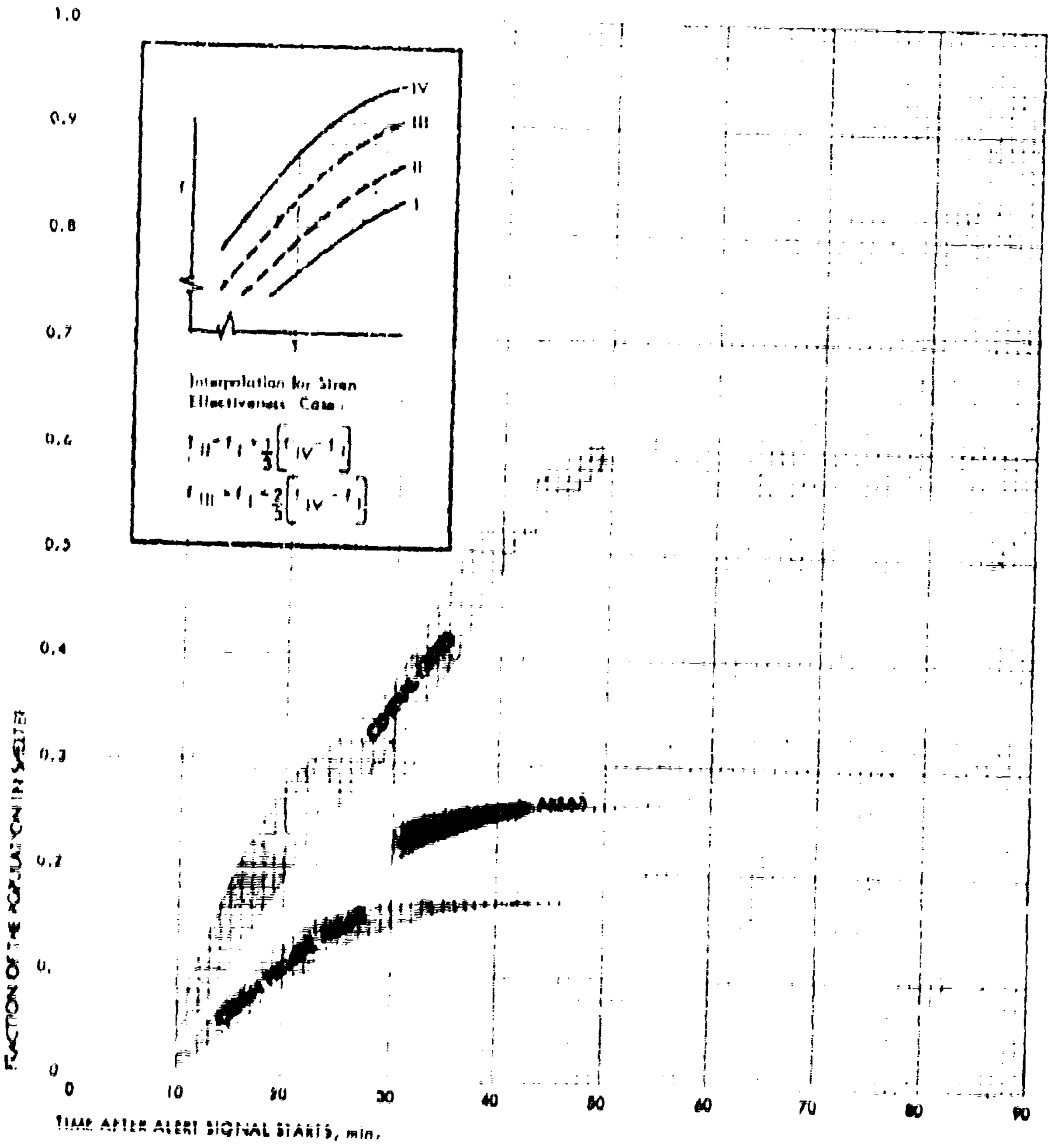

Figure 4

FRACTION IN SHELTER vs TIME

EXISTING SHELTER, NO ALERTING

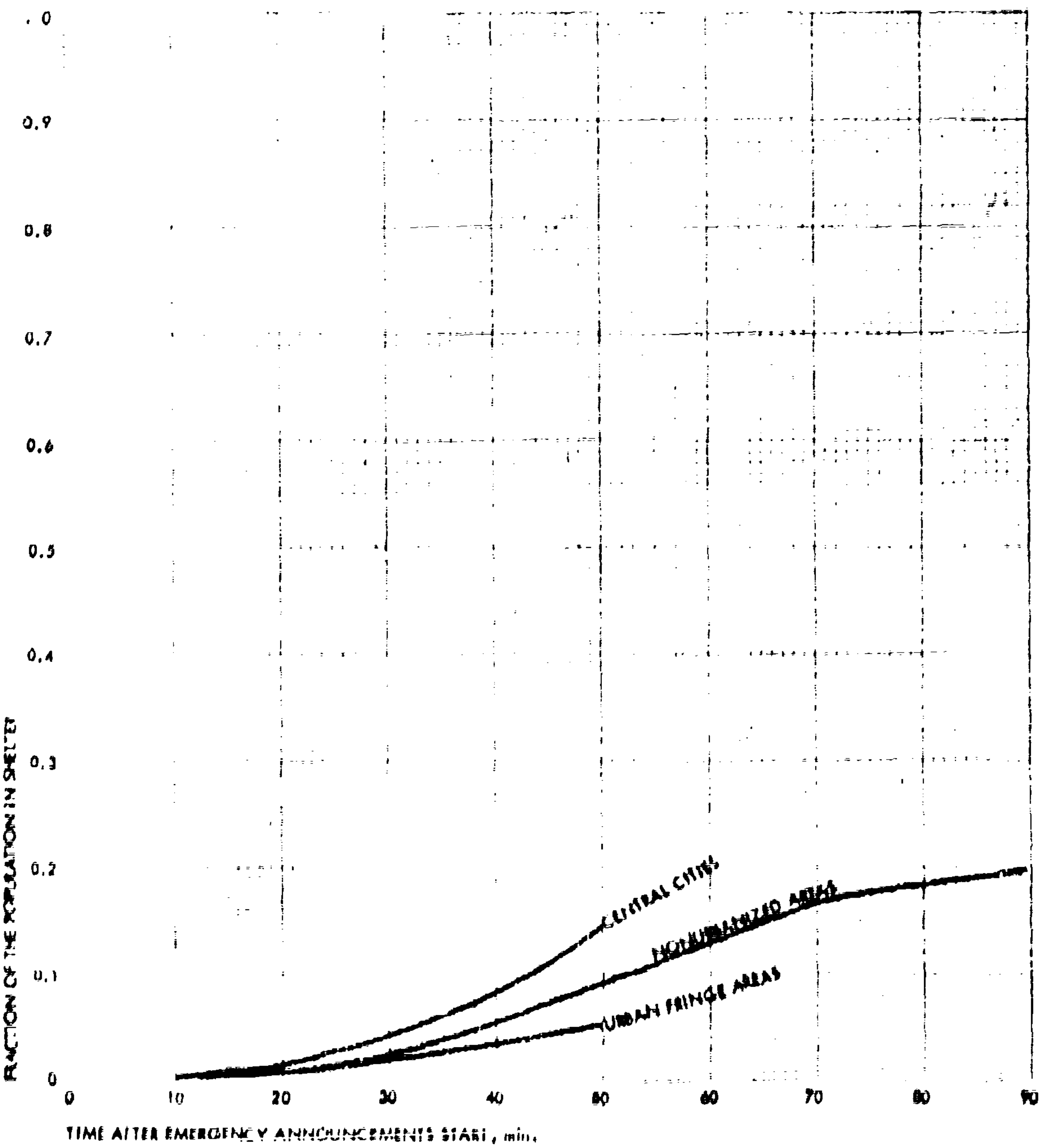

Figure 5

FRACTION IN SHELTER vs TIME

1970 SHELTER, RADIO WARNING

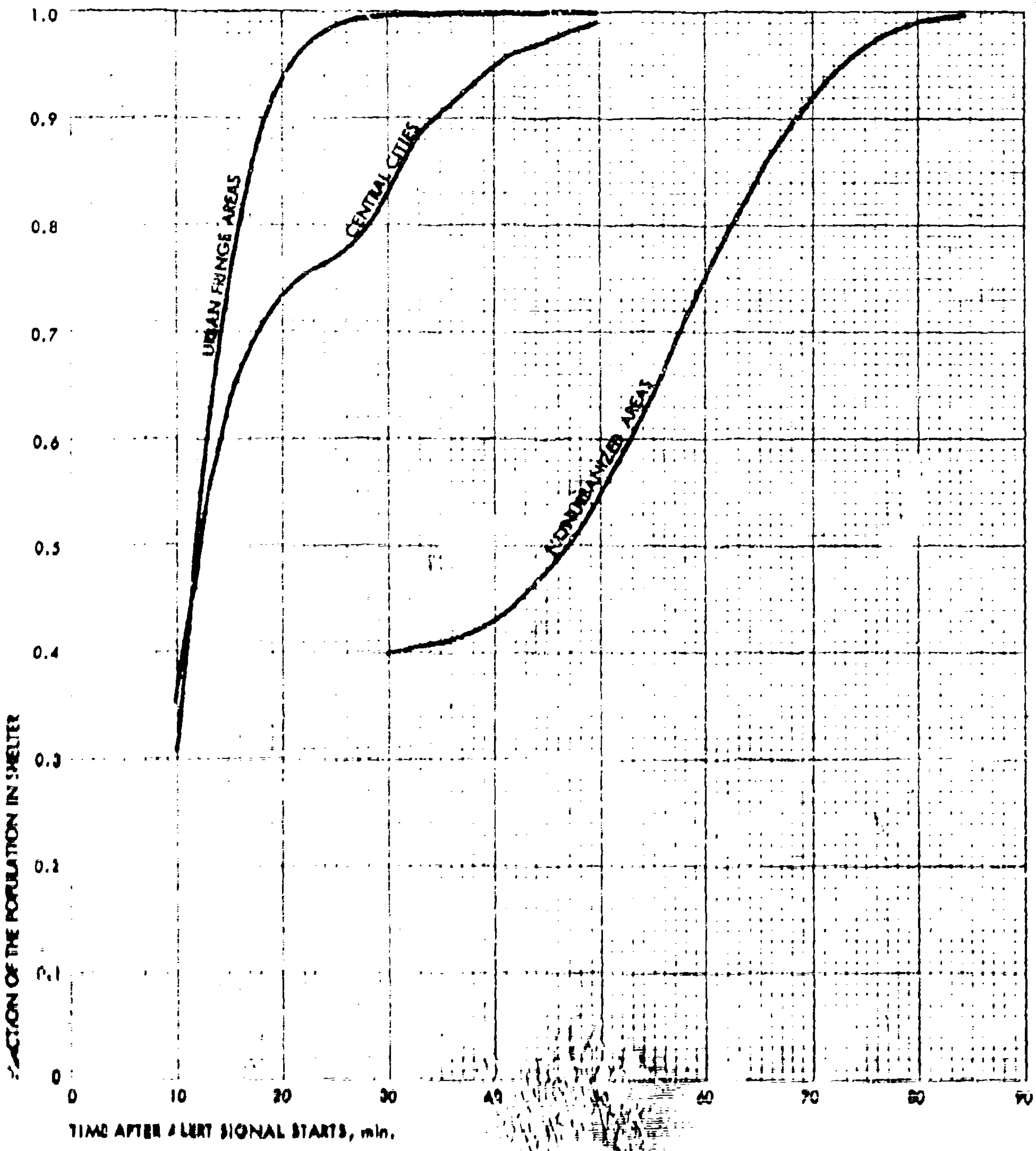

Figure 6

FRACTION IN SHELTER vs TIME

1970 SHELTER, INDOOR ALERTING

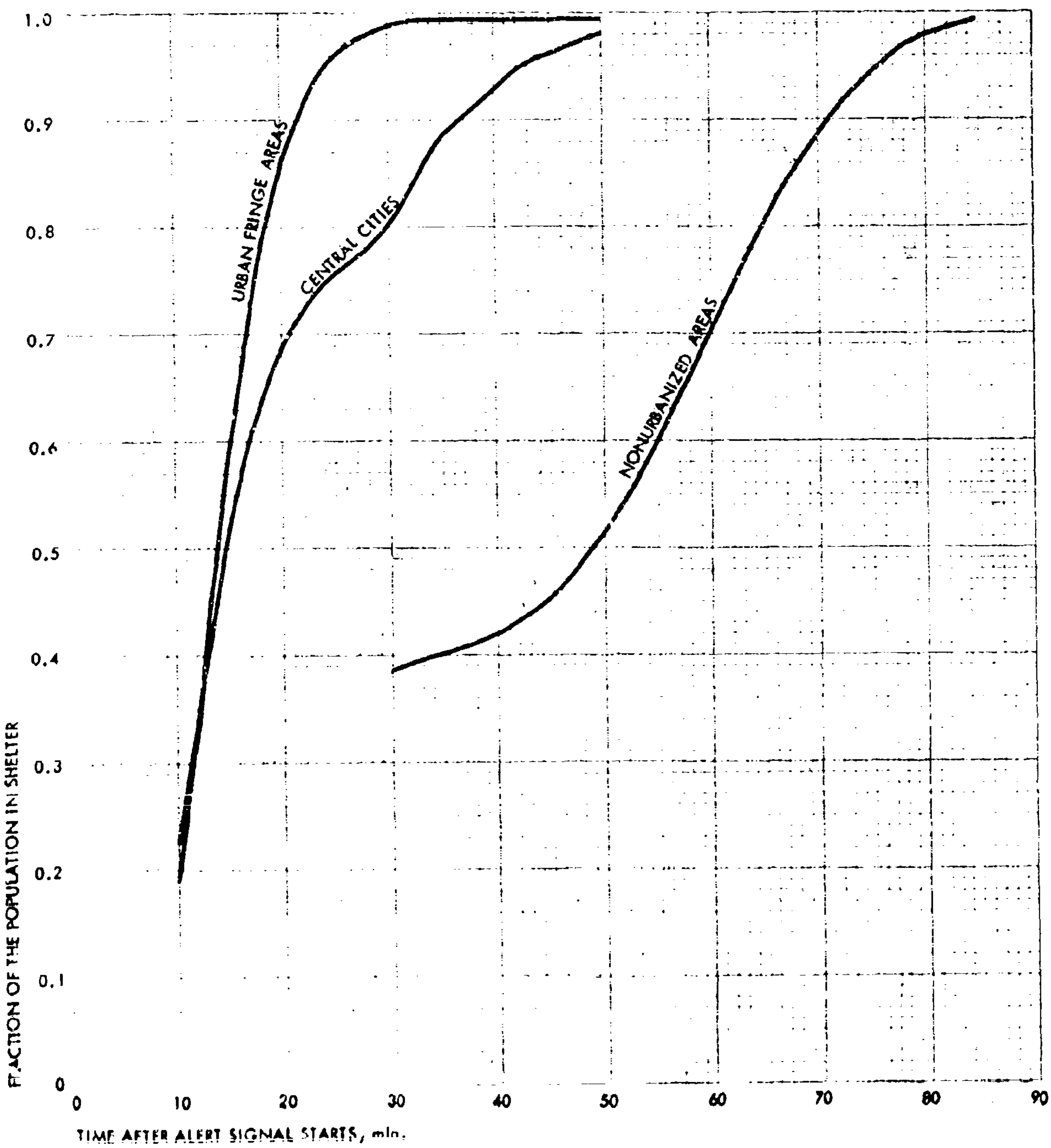

Figure 7

FRACTION IN SHELTER vs TIME

1970 SHELTER, SIREN ALERTING

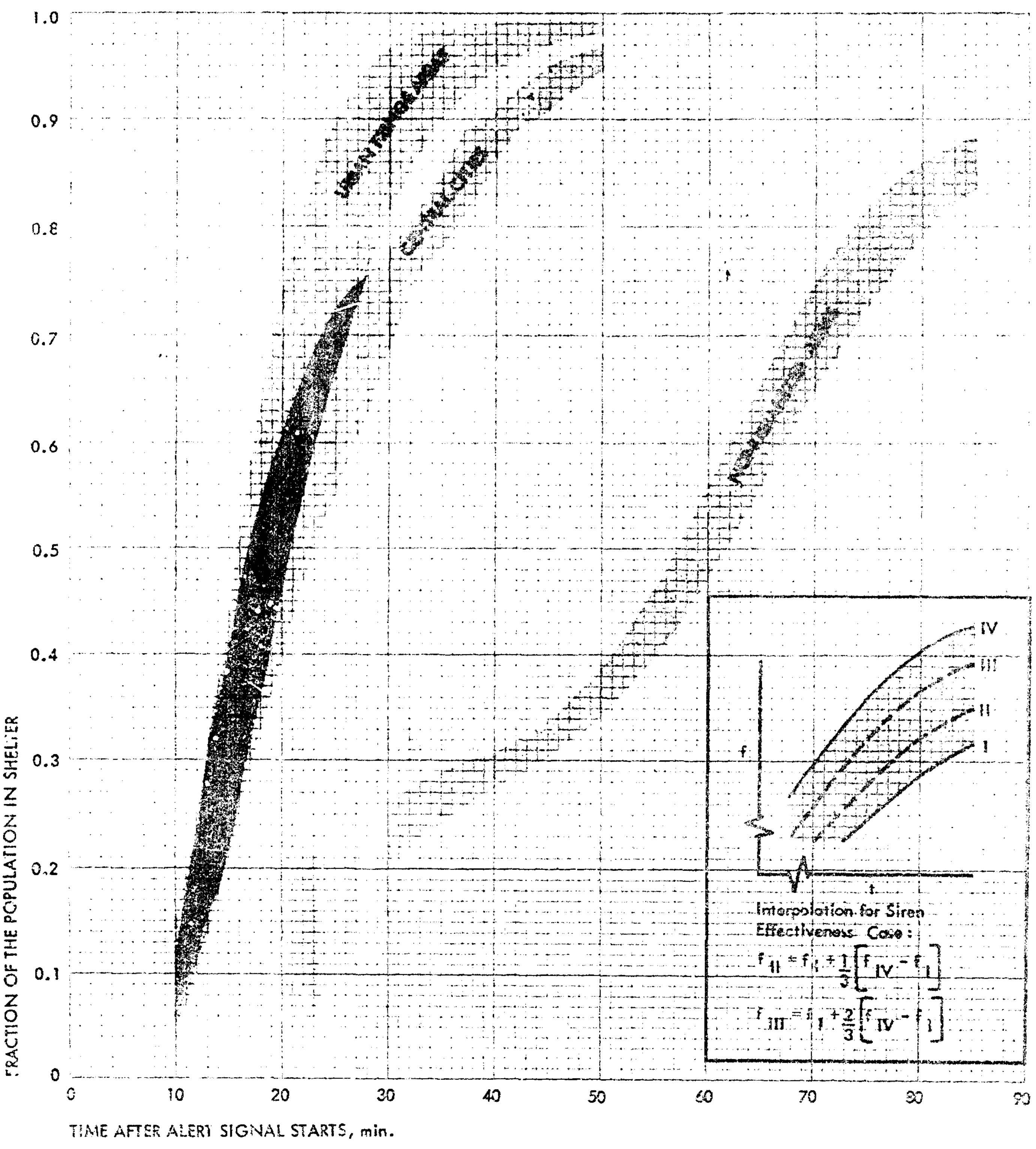

Figure 8

FRACTION IN SHELTER vs TIME

1970 SHELTER, NO ALERTING

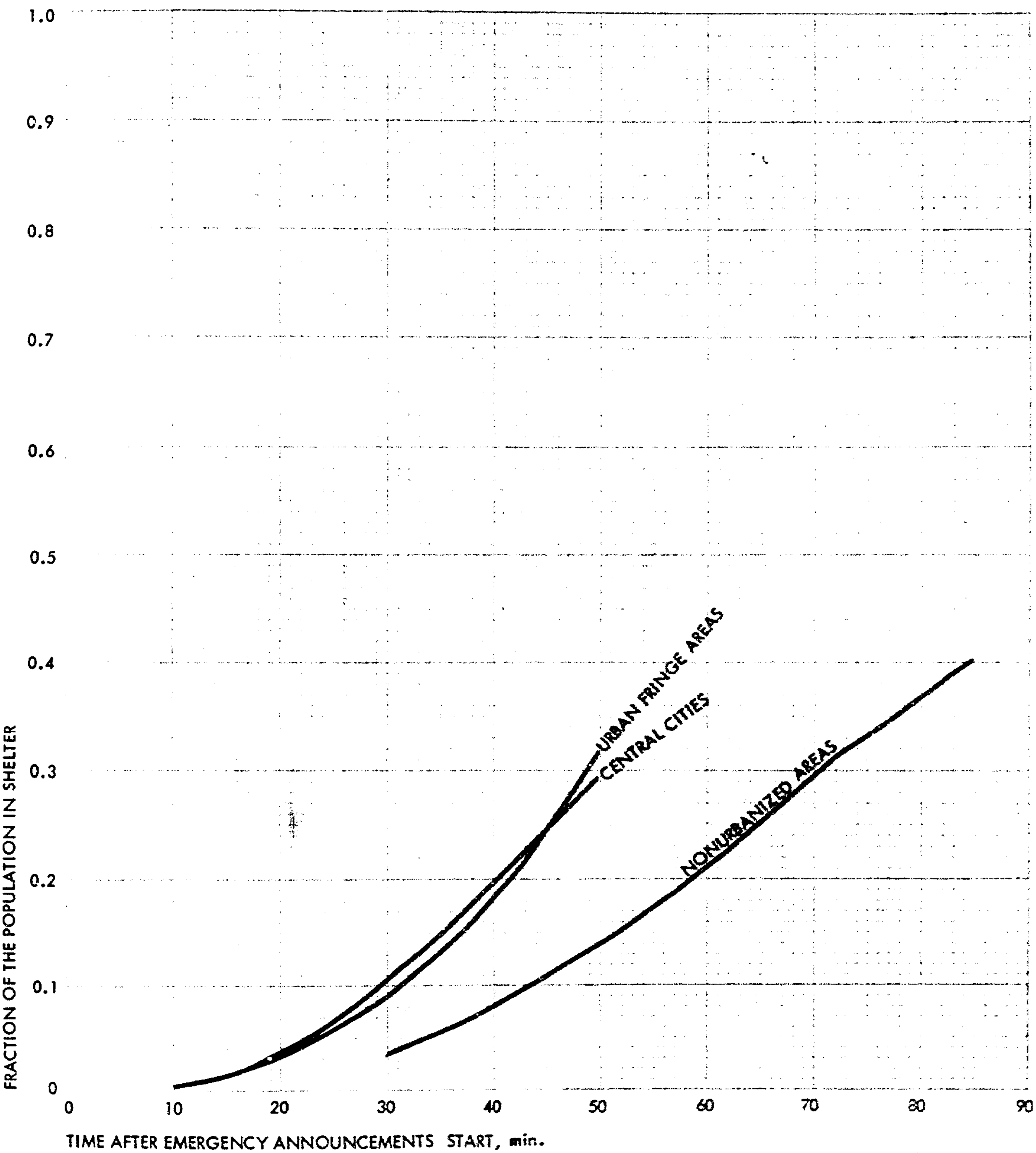

FIGURE 9

WORKSHEET FOR EVALUATING WARNING SYSTEM EFFECTIVENESS

PART I. WARNING SYSTEM ENVIRONMENT

A. Time era ______________________

B. Fallout arrival time computations

1. Time from detection of attack to impact of weapons ______ min.
2. Time from detection of attack to initiation of warning signal (decision to warn time) ______ min.
3. Remaining time from decision to impact (line 1 minus line 2) ______ min.

	COLUMN a CENTRAL CITY AREAS	COLUMN b URBAN FRINGE AREAS	COLUMN c NONURBANIZED AREAS
4. Time from impact to fallout arrival	30.0 min.	30.0 min.	60.0 min.
5. Time from decision to fallout arrival (line 3 plus line 4)	______ min.	______ min.	______ min.

PART II. WARNING SYSTEM EVALUATION SUMMARY

(See following sheets for detailed evaluation of warning system modes. Listed below is a summary of the evaluation.)

WARNING SYSTEM MODE	FRACTION OF POPULATION IN SHELTER WHO WERE WARNED BY EACH MODE
A. Radio Warning	______
B. Indoor Alerting	______
C. Siren Alerting	______
D. No alerting	______
E. Total population in shelter resulting from this warning system configuration (sum of fractions from lines A, B, C, and D above)	______

FIGURE 9 *(Continued)*

PART III. DETAIL OF WARNING SYSTEM EVALUATION

A. Radio Warning Mode

	COLUMN *a* CENTRAL CITY AREAS	COLUMN *b* URBAN FRINGE AREAS	COLUMN *c* NONURBANIZED AREAS
1. Time from decision to fallout arrival (from Part IB, line 5)	____ min.	____ min.	____ min.
2. System response time (time from decision to warn to beginning of alert signal)	____ min.	____ min.	____ min.
3. Time remaining to reach shelter (line 1 less line 2)	____ min.	____ min.	____ min.
4. Fraction of radio warned population in shelter before fallout arrival. (Use radio warning chart for appropriate time era. Enter chart with time from 3 above read fraction from chart)	____	____	____
5. Radio warning coverage (fraction of populations covered by signal and receiver distribution, multiplied by reliability, by area)	____	____	____
6. Fraction of area populations in shelter as a result of the stimulus from radio warning (line 5 times line 4)	____	____	____
7. Fraction of U.S. population residing in each area			
Existing	0.323	0.212	0.465
1970	0.333	0.324	0.343
Other	____	____	____
(Cross out inapplicable line)			
8. Fraction of U.S. population in shelter in each area as a result of radio warning stimulus (line 7 times line 6)	____	____	____
9. Fraction of U.S. population in shelter due to radio warning (sum of line 8, columns *a*, *b*, and *c*)		____	

B. Indoor Alerting Mode

	COLUMN *a* CENTRAL CITY AREAS	COLUMN *b* URBAN FRINGE AREAS	COLUMN *c* NONURBANIZED AREAS
1. Time from decision to fallout arrival (from Part IB, line 5)	____ min.	____ min.	____ min.
2. System response time (time from decision to warn to beginning of alert signal)	____ min.	____ min.	____ min.
3. Time remaining to reach shelter (line 1 less line 2)	____ min.	____ min.	____ min.
4. Fraction of indoor-alerted populations in shelter before fallout arrival. (Use indoor alerting chart for appropriate time era. Enter chart with time from 3 above, read fraction from chart.)	____	____	____
5. Indoor alerting coverage (fraction of populations covered by signal and receiver distribution, multiplied by reliability by area)	____	____	____
6. Fraction of area populations in shelter as a result of the stimulus from indoor alerting (line 5 times line 4)	____	____	____
7. Fraction of U.S. population residing in each area			
Existing	0.323	0.212	0.465
1970	0.333	0.324	0.343
Other	____	____	____
(Cross out inapplicable line)			
8. Fraction of U.S. population in shelter in each area as a result of indoor alerting stimulus (line 7 times line 6)	____	____	____
9. Fraction of U.S. population in shelter due to indoor alerting (sum of line 8, columns *a*, *b*, and *c*)		____	

FIGURE 9 *(Concluded)*

C. Siren Alerting Mode

	COLUMN a CENTRAL CITY AREAS	COLUMN b URBAN FRINGE AREAS	COLUMN c NONURBANIZED AREAS
1. Time from decision to fallout arrival (from Part 1B, line 5)	____ min.	____ min.	____ min.
2. System response time (time from decision to warn to beginning of alert signal)	____ min.	____ min.	____ min.
3. Time remaining to reach shelter (line 1 less line 2)	____ min.	____ min	____ min.
4. Siren Effectiveness Group (see chart below)			

		Radio Support for Sirens Existing	Close
Public Readiness	LO	I	II
	HI	III	IV

	COLUMN a	COLUMN b	COLUMN c
5. Fraction of siren-alerted populations in shelter before fallout arrival (select siren alerting chart for proper time era, enter chart with time from 3, above, determine fraction corresponding to siren effectiveness group)	____	____	____
6. Indoor siren coverage (fraction of population that can hear sirens indoors, by area)	____	____	____
7. Fraction of area populations in shelter as a result of the stimulus from siren alerting (line 6 times line 5)	____	____	____
8. Fraction of U.S. population residing in each area			
Existing	0.323	0.212	0.465
1970	0.333	0.324	0.343
Other	____	____	____
(Cross out inapplicable line)			
9. Fraction of U.S. population in shelter in each area as a result of siren alerting stimulus (line 8 times line 7)	____	____	____
10. Fraction of U.S. population in shelter due to siren alerting (sum of line 9, columns *a*, *b*, and *c*)		____	

D. No Alerting Mode

	COLUMN a CENTRAL CITY AREAS	COLUMN b URBAN FRINGE AREAS	COLUMN c NONURBANIZED AREAS
1. Time from decision to fallout arrival (from Part 1B, line 5)	____ min.	____ min.	____ min.
2 System response time (time from decision to warn to beginning of emergency announcements)	____ min.	____ min.	____ min.
3. Time remaining to reach shelter (line 1 less line 2)	____ min.	____ min.	____ min.
4. Fraction of population warned by the No Alerting Mode in shelter before fallout arrival time. (Use charts for no alerting mode in appropriate time era. Enter chart with time from 3, above, read fraction from curves)	____	____	____
5. Fraction of populations not covered by other warning modes, by area	____	____	____
6. Fraction of area populations in shelter who did not receive alerting stimulus (line 5 times line 4)	____	____	____
7. Fraction of U.S. population residing in each area			
Existing	0.323	0.212	0.465
1970	0.333	0.324	0.343
Other	____	____	____
(Cross out inapplicable line)			
8. Fraction of U.S. population in shelter in each area as a result of stimulus (line 7 times line 6)	____	____	____
9. Fraction of U.S. population in shelter who have been warned by the No Alerting Mode (sum of line 8, columns *a*, *b*, and *c*)		____	

Instructions for Using the Worksheet

To compute the effectiveness of a warning system, the following eight steps must be taken:

1. Identify the environment in which the postulated warning system must operate (Part I of the form). The first part of the environment analysis is a statement of the time era, whether 1965 or 1970. The population and the shelter configuration are determined by this time era. The second part of the environment analysis is an estimate of the time from attack detection to impact and an estimate of the time that will be required to reach a decision to warn the population after attack detection.

   The final part of the environment analysis is the computation of the time from the decision to warn to the arrival of fallout. This is the time available for the warning system components to operate and for the population to recognize signals, prepare to move, and move into shelter. The time is the time from decision to impact plus the time from impact to fallout arrival, less the decision to warn time; it is computed in Part I of the worksheet and then enterdd on line 1 of Part III.

2. Estimate the response time, i.e., the time between completion of the decision to warn and the start of the alert signal for each warning system mode under analysis. Enter on line 2, Part III.

3. Compute the time between start of alert signal and fallout arrival, indicated as "Time Remaining to Reach Shelter" in line 3, Part III of the form. This is the time available for the population to recognize the signal, prepare to move, and move to shelter.

4. For the siren alerting, a determination of one of four siren effectiveness cases is to be made on the basis of population readiness and radio support for the siren system. Select the "LO" population readiness for conditions of surprise attack or for an attack that follows a very rapid buildup of tensions, on the order of less than two days. For longer crisis buildups or for a period of time following a concerted campaign to make the public aware of the sirens, use the "HI" public readiness. Similarly, for systems where the radio broadcast may not come on for as much as ten minutes after the siren start, use the "existing" category of radio support; for systems that tie in

the radios where emergency broadcasts commence within two minutes of the alert signal, use the "close" category. The siren response category will usually be the same for all three types of areas.

5. Determine the fraction of the population of each type of area in shelter who were alerted by each mode. Select the chart for the shelter and population condition under which the evaluation is being made and for the warning mode being evaluated. Read the fraction from the curve for each area at the time between alert signal start and fallout arrival. Record this fraction in the proper column of the worksheet.

   When reading the fraction in shelter for siren alerting, interpolate between the edges of the gray bands according to the effectiveness case, as shown by the diagram and formulas on the siren alerting charts.

6. Determine the warning coverage in each of the census areas for each of the warning modes. The coverages of all the modes of a warning system in each area type should total unity, i.e., no one person will be covered by more than one mode. If modes overlap, give preference to the faster one. Assign all population not covered by other modes to the no alerting mode. Enter these coverage data in the appropriate line and column of the worksheet.

7. Determine the fraction of the total population in shelter as a result of the stimulus from each of the types of alerting and warning devices by following the instructions on the worksheet.

8. Enter the resulting fraction of the total population in shelter as a result of the stimulus from each of the types of alerting and warning devices on the summary section of the worksheet (Part II) and add the fractions together to obtain the fraction of the total population in shelter as a result of the warning system configuration under evaluation. This is the numerical measure of effectiveness that can be used to evaluate prospective systems.

Evaluation of a Hypothetical Warning System: An Example

To illustrate the computation process just described, consider the following problem statement:

Determine the effectiveness, in terms of fraction of the population in shelter before fallout arrival, of a warning system consisting of outdoor sirens in all incorporated and unincorporated places with populations over 2,500, where the sirens are centrally controlled from OCD warning center via a nationwide radio command network. The system is to be evaluated as part of the civil defense program that might exist during the 1970 decade, following the implementation of a nationwide shelter development program.

The performance of the siren-actuating system is such that in metropolitan (urbanized) areas, the activating signal reaches the siren 0.4 minute after the signal is sent out from the warning center, and, in nonurbanized areas, because of security devices in the system, the signal will not reach sirens until 0.7 minute after the signal is sent out. All sirens will require 1.0 minute to come up to speed and reach full sound power output.

Local broadcasting stations will be tied into the radio warning circuits so that they begin broadcasting emergency messages 2 minutes after the signal is sent out from the national warning center.

For the purposes of the evaluation, assume that an attack is detected following a very brief crisis period. Detection is assumed to occur 15 minutes prior to impact of the weapons, and, because of the crisis, the decision to warn the population occurs in negligible time.

Step 1

Enter 1970 in Part IA. Enter the data from the last paragraph of the problem statement in Part IB of the worksheet, and compute the time from decision to warn to fallout arrival. Part I of the worksheet should now look like this:

WORKSHEET FOR EVALUATING WARNING SYSTEM EFFECTIVENESS

PART I. WARNING SYSTEM ENVIRONMENT

A. Time era 1970

B. Fallout arrival time computations

1. Time from detection of attack to impact of weapons 15.0 min.
2. Time from detection of attack to initiation of warning signal (decision to warn time) 0.0 min.
3. Remaining time from decision to impact (line 1 minus line 2) 15.0 min.

	COLUMN a CENTRAL CITY AREAS	COLUMN b URBAN FRINGE AREAS	COLUMN c NONURBANIZED AREAS
4. Time from impact to fallout arrival	30.0 min.	30.0 min.	60.0 min.
5. Time from decision to fallout arrival (line 3 plus line 4)	45.0 min.	45.0 min.	75.0 min.

Step 2

Use Part IIIC of the worksheet to compute the effectiveness of the siren mode. Line 1 is the same as line 5 of Part IB. On line 2 is shown the system response time of 1.4 minutes for central cities and their urban fringes, obtained by adding the 0.4 minute for the signal to reach the siren from the warning center and the 1.0 minute for the siren engine to reach its operating speed. Likewise, the response time in nonurbanized areas is 1.7 minutes.

Step 3

Line 3, the time from alert signal start to fallout arrival, is now computed by subtracting line 2 from line 1. Part IIIC should now look like this:

C. Siren Alerting Mode

	COLUMN a CENTRAL CITY AREAS	COLUMN b URBAN FRINGE AREAS	COLUMN c NONURBANIZED AREAS
1. Time from decision to fallout arrival (from Part IB, line 5)	48.0 min.	48.0 min.	26.0 min.
2. System response time (time from decision to warn to beginning of alert signal)	6.4 min.	6.4 min.	6.2 min.
3. Time remaining to reach shelter (line 1 less line 2)	41.6 min.	41.6 min.	21.3 min.

Step 4

Line 4 should next be completed to show that the siren effectiveness case is II, selected from the table with LO public readiness (due to the rapid crisis buildup) but close radio support (radio broadcasts tied into siren activation system) as follows:

4. Siren Effectiveness Group (see chart below)

		Radio Support for Sirens: Existing	Close
Public	LO	I	II
Readiness	HI	III	IV

Step 5

Now, from the chart for 1970 shelter posture and siren alerting, determine in the following manner the fraction of the siren-alerted population in shelter before fallout arrives:

For central cities, the range of fraction in shelter at 43.6 minutes is 0.900 to 0.944. The inset figure on the chart shows that effectiveness group II is found by adding 1/3 of the height of the range to the lower edge. Since the height of the range is 0.044, the fraction in shelter for a group II effectiveness is 0.900 + 0.15, or 0.915. Enter this value in column a, line 5, as shown below. Using the same procedure, determine the fraction of the urban fringe and nonurbanized area populations in shelter. Enter these values on line 5, columns a, b, and c, as follows:

5. Fraction of siren-alerted populations in shelter before fallout arrival (select siren alerting chart for proper time eta, enter chart with time from 3, above, determine fraction corresponding to siren effectiveness group)	0.915	0.772	0.735

Step 6

From the problem statement that outdoor siren coverage exists in all places with a population greater than 2,500 persons, estimate the indoor siren coverage for the areas in the following manner.

Central Cities. From the census* definition of a central city as a place having a population of 50,000 or more, all central cities fall into the category of places having a population over 2,500 persons. Outdoor coverage is therefore 100% in central cities. Indoor coverage is arbitrarily estimated at 50% of the outdoor coverage. Resulting indoor coverage is then 50%.

Urban Fringe Areas. In 1960, about 75% of the residents of urban fringe areas lived outside places having a population of 2,500 or more.*

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* U.S. Bureau of the Census, U.S. Census of Population: 1960, Vol. I, Characteristics of the Population. Part I, U.S. Summary, U.S. Government Printing Office, Washington, D.C., 1964.

While a considerable increase in the population of these urban fringe areas is projected for 1970 (see Section AIII of this report), the best estimate of the distribution of persons living in places of over 2,500 population and those living outside such places is the same proportion that exists today. The outdoor coverage in these urban fringe areas in 1970 is therefore projected at 75%, and the indoor coverage is then 37.5%, using the arbitrary ratio of 1:0.5 between outdoor and indoor coverage.

<u>Nonurbanized Areas</u>. In Section AIII, the urban population residing in nonurbanized areas has been projected as being 40% of the total population of the nonurbanized areas. Since these urban places are defined as having 2,500 or more residents, the outdoor siren coverage in these areas is 100%, according to the problem statement. The indoor siren coverage for nonurbanized areas in 1970 would then be 20%, again using the arbitrary ratio of outdoor to indoor coverage.

These coverage estimates are entered on line 6 as shown:

6. Indoor siren coverage (fraction of population that can hear sirens indoors, by area)	0.500	0.375	.200

<u>Step 7</u>

The computations necessary to convert these fractions of both population and coverage by area, into fractions of the total population are shown on lines 7, 8, and 9. Note that on line 8, both the existing and other lines are crossed out, leaving the distribution for the 1970 population remaining. These computations are shown below.

7. Fraction of area populations in shelter as a result of the stimulus from siren alerting (line 6 times line 5)	0.457	0.366	0.147
8. Fraction of U.S. population residing in each area			
Existing	[redacted]	[redacted]	[redacted]
1970	0.333	0.324	0.343
Other	[redacted]	[redacted]	[redacted]
(Cross out inapplicable line)			
9. Fraction of U.S. population in shelter in each area as a result of siren alerting stimulus (line 8 times line 7)	0.152	0.119	0.050

Step 8, Preliminary

The addition of columns a, b, and c on line 9 will result in the fraction of the total population in shelter as a result of warning from the siren alerting mode. The result is entered on line 10 as shown below, and on the summary, Part II of the worksheet.

10. Fraction of U.S. population in shelter due to siren alerting (sum of line 9, columns *a*, *b*, and *c*) **0.321**

Before step 8 is completed, the fraction in shelter who were warned by the no alerting mode must be determined. The no alerting mode must be included in the system to bring the total coverage for all modes up to 100%.

Reiteration of Steps 2-7 for Persons Warned by the No Alerting Mode

Again following the instructions and the worksheet, the fraction of the population in shelter who were warned by the no alerting mode is computed, as illustrated by the sample worksheet below.

D. No Alerting Mode

	COLUMN *a* CENTRAL CITY AREAS	COLUMN *b* URBAN FRINGE AREAS	COLUMN *c* NONURBANIZED AREAS
1. Time from decision to fallout arrival (from Part IB, line 5)	45.0 min.	45.0 min.	75.0 min.
2. System response time (time from decision to warn to beginning of emergency announcements)	2.0 min.	2.0 min.	2.0 min.
3. Time remaining to reach shelter (line 1 less line 2)	43.0 min.	43.0 min.	73.0 min.
4. Fraction of population warned by the No Alerting Mode, in shelter before fallout arrival time. (Use charts for no alerting mode in appropriate time era. Enter chart with time from 3, above, read fraction from curves)	0.228	0.219	0.320
5. Fraction of populations not covered by other warning modes, by area	0.500	0.625	[illegible]
6. Fraction of area populations in shelter who did not receive alerting stimulus (line 5 times line 4)	0.114	0.137	0.256
7. Fraction of U.S. population residing in each area			
Existing	[illegible]	[illegible]	[illegible]
1970	0.333	0.324	0.3[illegible]
Other	[illegible]	[illegible]	[illegible]
(Cross out inapplicable line)			
8. Fraction of U.S. population in shelter in each area as a result of stimulus (line 7 times line 6)	0.038	0.044	[illegible]
9. Fraction of U.S. population in shelter who have been warned by the No Alerting Mode (sum of line 8, columns *a*, *b*, and *c*)		0.170	

Step 8

The results of the computations of fraction of the population in shelter as a result of the siren alerting and no alerting modes may now be entered on lines C and D of Part II of the worksheet. The sum of these two fractions is the total fraction of the population in shelter for the warning system described, and is the numerical value of effectiveness that was specified in the problem. Part II of the worksheet is shown below.

PART II. WARNING SYSTEM EVALUATION SUMMARY

(See following sheets for detailed evaluation of warning system modes. Listed below is a summary of the evaluation.)

WARNING SYSTEM MODE	FRACTION OF POPULATION IN SHELTER WHO WERE WARNED BY EACH MODE
A. Radio Warning	
B. Indoor Alerting	
C. Siren Alerting	0.321
D. No alerting	0.170
E. Total population in shelter resulting from this warning system configuration (sum of fractions from lines A, B, C, and D above)	0.491

III APPLICATIONS OF THE EFFECTIVENESS MEASURE

Computations of warning system effectiveness such as those made in Section II are made as part of an analysis that will lead to a particular decision related to warning systems. The present section shows how the numerical expression for effectiveness can be used in two cost-effectiveness analyses of warning systems. The first of the two examples is an application of cost-effectiveness analysis to a system design decision; the second, an application to show the contribution of radio warning to civil defense programs.

The two applications are preceded by a general description of cost-effectiveness analysis.

The examples presented herein are designed only to show how to make the analysis with the aid of the numerical measure of effectiveness, rather than to prepare an analysis upon which conclusions should be based. Definitive analysis cannot be made without having reasonably firm costs available for warning and shelter.

Applicable Theory of Cost-Effectiveness

In the use of cost-effectiveness analysis to reach a decision on an investment, two persons are involved: an analyst and a decision-maker. The task of the analyst is to present to the decision-maker data on relevant alternative courses of action in such a way that the decision-maker's function is expedited. The analyst must therefore use some technique for eliminating alternatives that are not relevant and find a way of presenting the remaining choices in a meaningful fashion.

A schedule of the cost and effectiveness of the various alternatives provides the analyst with the tool he needs to eliminate nonrelevant alternatives and to present the data to the decision-maker in a meaningful way. Fox* describes the schedule and its preparation in the following way:

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* Peter D. Fox, "A Theory of Cost-Effectiveness for Military Systems Analysis," Operations Research, Vol. XIII, No. 1 (January-February 1965).

The analyst estimates the cost that would be incurred and the effectiveness which would result if each of the alternatives were acquired. . . . The analyst may normally discard an alternative that both costs more and is less effective than another alternative. On the other hand, if one alternative costs more but is more effective than another, the analyst should present both alternatives to the decision-maker to determine whether the additional effectiveness is worth the additional costs involved. Thus, a series of effectiveness levels may be available at different costs, and the maximum effectiveness or minimum cost alternatives each represent only the end-points of a range of possible solutions.

The task of the analyst, then, is to determine which systems need not be considered by the decision-maker because there are one or more alternatives that either cost no more and are more effective, or cost less and are at least as effective. The systems that are not eliminated from consideration form the schedule of efficient alternatives. This schedule may consist of a series of specific alternatives or of a continuous curve. . . .

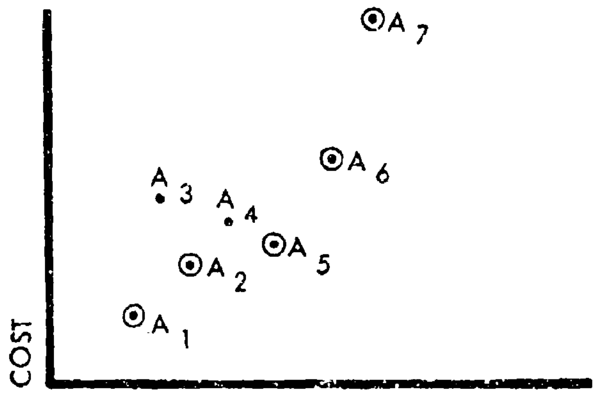
Figure [10] illustrates the formulation of a schedule for the specific alternatives case. The analyst has estimated the cost of each of seven alternatives, A_1 through A_7; he has also estimated the effectiveness of each system relative to the mission that the system is designed to perform. He now seeks to derive the schedule, assuming that the only information he has concerning the preference of the decision-maker is that, for systems with equal costs, the most effective system is desired, and, for equally effective systems, the lowest cost one is desired.

Fox further states:

Systems are compared pairwise to derive the schedule. Alternative A_3 need not be considered further since Alternative A_2 both costs less and is more effective. Thus, A_2 is said to dominate A_3, i.e., it is superior to A_3 based on the two criteria that are assumed to be relevant. It can be noted that A_3 is also dominated by A_4 and A_5. Similarly, A_4 need not be considered further since system A_5 is clearly superior. If, after eliminating A_3 and A_4, the remaining combinations of pairs are examined, the analyst will be unable to find two alternatives, say A_i and A_j, such that A_i is both more effective and costs less than A_j. The remaining five, then, are

Figure 10

COST AND EFFECTIVENESS ALTERNATIVES--
SPECIFIC ALTERNATIVES CASE



Source: Fox, Peter D., " A Theory of Cost-Effectiveness," previously cited.

members of the schedule of efficient alternatives that should be presented to the decision-maker. These are represented by dots surrounded by circles in Figure [10]. A do-nothing alternative, represented by the origin, might be viewed as a sixth member of the schedule.

Application of Cost-Effectiveness Analysis to a Radio Warning System Design Decision

Consider this hypothetical decision that arises during the design of a radio warning system: use of an improved component in the system design will improve system response time for all of the radio-controlled modes in a warning system by 10 seconds--should the component be used?

To prepare a cost-effectiveness schedule for the two alternatives (use the component, or do not use it), it will first be necessary to construct a set of conditions under which the evaluation is to take place. With these conditions, the effectiveness of systems both with and without the faster component will be computed. Finally, a schedule will be prepared from the computed effectiveness and the assumed costs.

To compute the effectiveness (fraction in shelter) for each of the two systems, assume the following conditions:

1. 1970 shelter and population prevail.

2. The United States has the capability to detect attack 15 minutes prior to impact.

3. The decision to warn can be made in negligible time.

4. Radio warning coverage may vary from zero to 100% depending upon receiver distribution.

5. Response time for the radio warning mode is 43 seconds in urbanized and 33 seconds in nonurbanized areas. This can be improved to 33 and 23 seconds, respectively, with the improved component.

6. Sirens are activated as part of the radio warning system. Siren mode response time is 1 minute, 33 seconds, for central city and urban-fringe areas; 1 minute, 50 seconds, for nonurbanized areas. Use of the improved component will improve each of these times by 10 seconds.

7. Siren effectiveness will be evaluated for the case of close radio support and LO population readiness (effectiveness Case II).

8. Outdoor siren coverage is assumed to be 100% for central cities, 88% for urban-fringe areas, and 28% for nonurbanized areas. Indoor coverage (to be used in this analysis) is assumed to be 50% of the outdoor coverage.

9. Emergency radio announcements over commercial broadcast stations will be activated as a part of the radio warning systems. Emergency announcements will start 1 minute 30 seconds after decision to warn. With the improved component, announcements will begin 1 minute 20 seconds after decision.

To determine the increase in effectiveness due to the 10-second improvement in speed of response, four effectiveness computations need to be made to cover the range of radio warning modes:

1. 0% radio warning receiver coverage, slow response;
2. 100% radio warning receiver coverage, slow response;
3. 0% radio warning receiver coverage, fast response; and
4. 100% radio warning receiver coverage, fast response.

Effectiveness at intermediate values of receiver coverage will be directly proportional to the receiver coverage in the interval between zero and 100% coverage.

The four computations of effectiveness to be made differ slightly from the example given in Section II because of the need to preserve the accuracy of reading the charts. Rather than trying to read the time values (which are only 10 seconds apart) from the charts, use the following interpolation technique to compute the radio warning effectiveness for central cities for the slow response and the fast response system:

1. The time available to reach shelter (time from decision to warn to time of fallout arrival less system response time) is between 44 and 45 minutes. The fraction in shelter at 44 minutes after the alert signal sounds for radio warning, 1970 shelter posture, in central cities is 0.968. At 45 minutes this same fraction is 0.972.

2. The fraction of the population in shelter at 44 minutes 17 seconds is 17/60 of the difference, 0.004, between the fraction in shelter at 44 minutes and the fraction in shelter at 45 minutes, plus the fraction in shelter at 44 minutes. The resulting fraction in shelter at 44 minutes 17 seconds is: 0.968 + 17/60 (0.004) = 0.969.

3. Similarly, the fraction in shelter at 44 minutes 27 seconds is: 0.963 + 27/60 (0.013) = 0.970.

This same technique is used to compute the fraction in shelter for radio warning, 100% receiver coverage, for urban-fringe and nonurbanized areas, followed by the computation on the worksheet for lines 6-9.

Likewise, the zero percent radio warning receiver coverage effectiveness values are found by using the interpolation from technique above, to find the contribution to the fraction in shelter by the siren alerting and no alerting modes.

The cost-effectiveness schedule can now be prepared if the receiver cost is estimated at $15 and the estimate of 65 million receivers to achieve 100% receiver distribution is made. The receiver cost and the cost of faster response are the only costs being considered here.

The cost-effectiveness schedule for the four system configurations is shown in Table 2.

Table 2

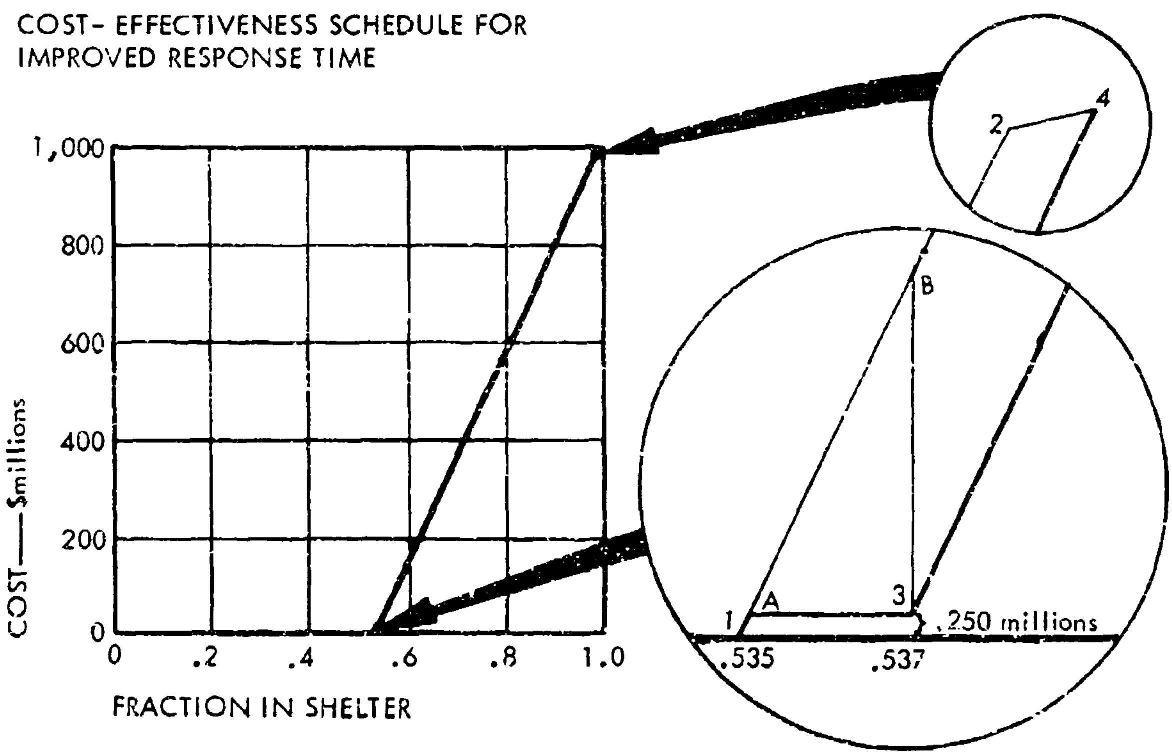
COST-EFFECTIVENESS SCHEDULE FOR
IMPROVED RESPONSE TIME

Configuration	Fraction in Shelter	Cost (millions of dollars)
1. 0% receiver coverage, slow response	0.535	$ 0.000
2. 100% receiver coverage, slow response	0.977	975.000
3. 0% receiver coverage, fast response	0.537	0.250
4. 100% receiver coverage, fast response	0.978	975.250

The schedule is plotted in Figure 11.

Figure 11

COST- EFFECTIVENESS SCHEDULE FOR
IMPROVED RESPONSE TIME



In Figure 11 the lower enlarged portion shows the cost plotted against effectiveness for configurations 1 (slow response, zero coverage) and 3 (fast response, zero coverage), identified by the circled numbers. Both points 1 and 3 must be presented to the decision-maker, since point 3 has higher effectiveness than point 1, but also has a higher cost. The decision to approve configuration 3 would imply a willingness to spend $0.250 million in order to obtain an added fraction in shelter of .003, which the analyst could express as a ratio of dollars per added person sheltered if such information is useful to the decision-maker.

The heavy line between configurations 3 and 4 indicates that the 3-4 configurations dominate the 1-2 configurations at all points; i.e., they obtain greater effectiveness for the same or lower cost. This dominance may be seen clearly in the lower enlarged portion, where point 3 dominates all points from A to B inclusive on the 1-2 configuration line, indicating that spending $0.250 million on configuration 3 is preferable to spending even greater amounts on added receiver coverage for configuration 1. Below point A, the heavy line follows the slow response configuration line, indicating that if less than $0.250 million is available, system effectiveness could best be increased by adding receiver coverage to configuration 1.

Application of Cost-Effectiveness Analysis to Determine the Contribution of Radio Warning to Civil Defense Programs

In the following example a cost-effectiveness schedule is prepared for four hypothetical civil defense programs. In these programs only the warning and shelter portions will be considered. The four programs are: existing shelter and warning capability, existing shelter capability plus radio warning, shelter development (1970 shelter) plus existing warning capability, and shelter development plus radio warning. For each of the programs that include radio warning, the cost and effectiveness are computed over a range of receiver distribution coverage from zero to 100 percent.

In the analysis of each of the systems that follows, the detection capability is assumed to be 15 minutes from detection to impact, and the decision to warn will require negligible time. In all cases, the attack is a surprise, or it comes after a very rapid crisis buildup, which leaves the population unprepared to respond to warning. Also, in the following analyses, the total cost of programs includes capital outlays for equipment, plus estimated operating and maintenance costs for 10 years.

The four systems are described in the following paragraphs.

Program I, Existing Shelter, Existing Warning System

In this program the number of shelter spaces grows at about the same rate as does the population, and distribution of the population growth is such that the coverage from existing sirens remains about the same in terms of percentages of population who can be alerted by sirens. These assumptions allow the use of the charts for the existing shelter posture to be used over the 10-year period.

For the existing siren system, assume that the outdoor siren coverages are 50 percent of central city residents, 20 percent of urban fringe area residents, and 10 percent of nonurbanized area residents. Indoor coverages will be one-half of these figures. Response time for the sirens in central cities will be 30 minutes, in urban fringe areas 40 minutes, and in nonurbanized areas 50 minutes. Each of these times includes 1.0 minute for the siren motor to come up to speed and begin delivering full output.

Emergency radio broadcasts will begin five minutes after the decision to warn.

Cost of this existing system is estimated at $30 million. This includes operating costs of $2.5 million per year and warning maintenance costs and cost of finding new shelter to total $5 million over the five years.

Program II, Existing Shelter, Radio Warning

This second program includes the same shelter posture as the first, but also includes a radio warning system. To allow for uncertainties in receiver distribution, a range of coverage from zero to 100 percent for the radio warning mode is analyzed. Response time for the radio warning mode is 0.7 minute in central city and urban fringe areas, 0.5 minute in nonurbanized areas.

Sirens and emergency announcements over commercial radio are controlled by the radio warning system. Since coverage is the same as in the first program, response time for sirens is 1.5 minutes for central city and urban fringe areas, 1.8 minutes for nonurbanized areas. Emergency announcements begin over broadcast stations in 1.5 minutes.

Cost of this system is estimated to be $35 million plus $15 per receiver up to 65 million receivers. Of the $35 million, $30 million will be required for control and broadcast transmitters, receiving equipment, and the operation and maintenance of this equipment and transmitters. Five million dollars will again be required for additional shelter survey and siren maintenance.

Program III, Improved Shelter, Existing Warning

This program includes shelter development to bring the shelter system up to the 1970 shelter posture shown, but does not include improvement of the warning system. Siren coverage remains about the same as at present.

Siren coverage and response time are as estimated in Program I. Emergency broadcast response time is also the same as in Program I.

Program cost is estimated at $1.001 billion. Of this cost, $1 billion will be required to survey and develop the additional shelter spaces, and $1 million for siren maintenance and operation over the 10-year period.

Program IV, Improved Shelter, Radio Warning

The fourth program includes both the shelter development of the third program and the radio warning system described in Program II. System performance for these parts is the same as in the earlier program.

Program cost is estimated at $1.031 billion, plus receiver cost of $15 each. This cost is made up of $1 billion for shelter development, $30 million for radio warning transmitters, receiving equipment, and operation, and $1 million for siren maintenance and operation.

Cost-Effectiveness Schedule

The effectiveness of each of the programs is computed from the description given. A tabulation of the cost and effectiveness of the four programs is shown in Table 3.

Table 3

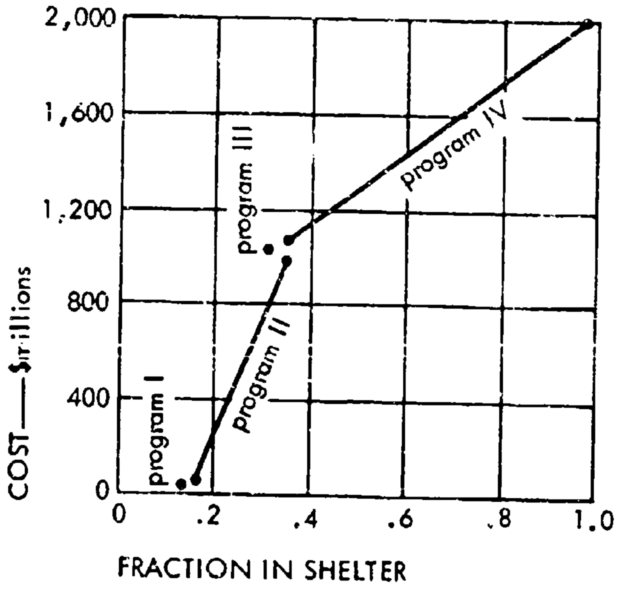
COST-EFFECTIVENESS SCHEDULE FOR
CIVIL DEFENSE PROGRAMS

		Fraction in Shelter	Cost (millions of dollars)
I	Existing Shelter, Existing Warning	0.149	$ 30
II	Existing Shelter, Radio Warning,		
	0% coverage	0.161	35
	100% coverage	0.354	1,010
III	Improved Shelter, Existing Warning	0.316	1,026
IV	Improved Shelter, Radio Warning,		
	0% coverage	0.349	1,031
	100% coverage	0.977	2,006

The cost and effectiveness are plotted in Figure 12.

Figure 12

COST-EFFECTIVENESS SCHEDULE FOR
CIVIL DEFENSE PROGRAMS



Analysis of Figure 12 shows only a few dominant points. For Program II costs somewhat higher than $800 million, Program II dominates Program III, since each level of expenditure on Program II over this level will provide more effectiveness at less cost than would Program III. Likewise, the extreme high range of expenditure on Program II dominates the extreme lower end of the range of receiver distribution in Program IV. Neither of these extreme ranges is likely to be obtained in practice, however.

After elimination of these dominated points, the remainder of Figure 12 shows that increased effectiveness can be obtained at increased levels of cost. The selection of a level of cost and effectiveness are now the responsibility of the decision-maker.

Figure 12 illustrates an interesting interrelationship between the effectiveness of warning and the effectiveness of shelters. The increase in effectiveness from the additional shelter spaces together with radio warning is greater than the increase in effectiveness from adding shelters alone plus the increase in effectiveness from adding radio warning alone. That is, the effectiveness of Program I is .149 of the population in shelter. Adding additional shelters to Program I (resulting in Program III with an effectiveness of 0.316) results in an added effectiveness of 0.167 of the population in shelter. The increased gained in fraction in shelter by the addition of radio warning with 100% receiver coverage to Program I (resulting in Program II with 100% coverage, with an effectiveness of 0.354) is 0.205. The sum of these two increases, taken separately, is 0.354. Taken together, the added number of shelters and radio warning with 100% coverage (resulting in Program IV with 100% receiver coverage, with an effectiveness of 0.977) gives an increase of 0.828 of the population in shelter, almost three times the increase in the sum of effectiveness of the two programs taken separately. The interrelationship thus illustrated strongly suggests that a combination of partial receiver coverage and partial accomplishment of the shelter development might result in a greater effectiveness at any level of cost than the sequential accomplishment of the two programs.

The same conclusion could be reached by observing that the lesser slope of the Program IV line (compared with the Program II line) indicates a much greater effectiveness per dollar expended for increased radio warning coverage when the increased coverage is accompanied by the shelter development of Program IV.

Appendix

DEVELOPMENT OF THE MODEL USED TO DESCRIBE THE MOVEMENT TO SHELTER PROCESS

AI INTRODUCTION

The curves of fraction of the population vs time after alert signal sounds (Figures 1-8) are the basis of the computation of the effectiveness of radio warning as described in this report. These curves have been generated by a model of the movement to shelter process. This model is a simplified and idealized description of the times people take to do the things they must do before they arrive at their assigned fallout shelter.

These things that people must do before they reach shelter are divided into three groups: alert verification, movement preparation, and movement. Alert verification is the process of hearing the warning signals, understanding them, and deciding to act upon them. Movement preparation is the process of getting ready to move to shelter. Movement to shelter is the process of traversing the distance between the pre-warning location and shelter.

The times required to accomplish these actions will not be the same for everyone; indeed, the time to accomplish an action might not be the same for the same person on two separate trials. Because of this variability, the times required for a group of persons to complete an action must be described by a formula, curve, or table, which describes the fraction of the number in the group who are expected to complete the action within a given interval, or by a given time. Such a formula, curve, or table describing the times associated with a fraction of the population completing a process is called a distribution function, or a distribution.

The time to complete the three actions and thus reach shelter is the sum of the times required for the three actions if an individual is being considered. Again, however, the function of the sum of these three distributions for a group of persons is itself a distribution.

Operations Research, Inc.* (ORI) developed a model that uses these times to find the number of persons in shelter at a given time after the

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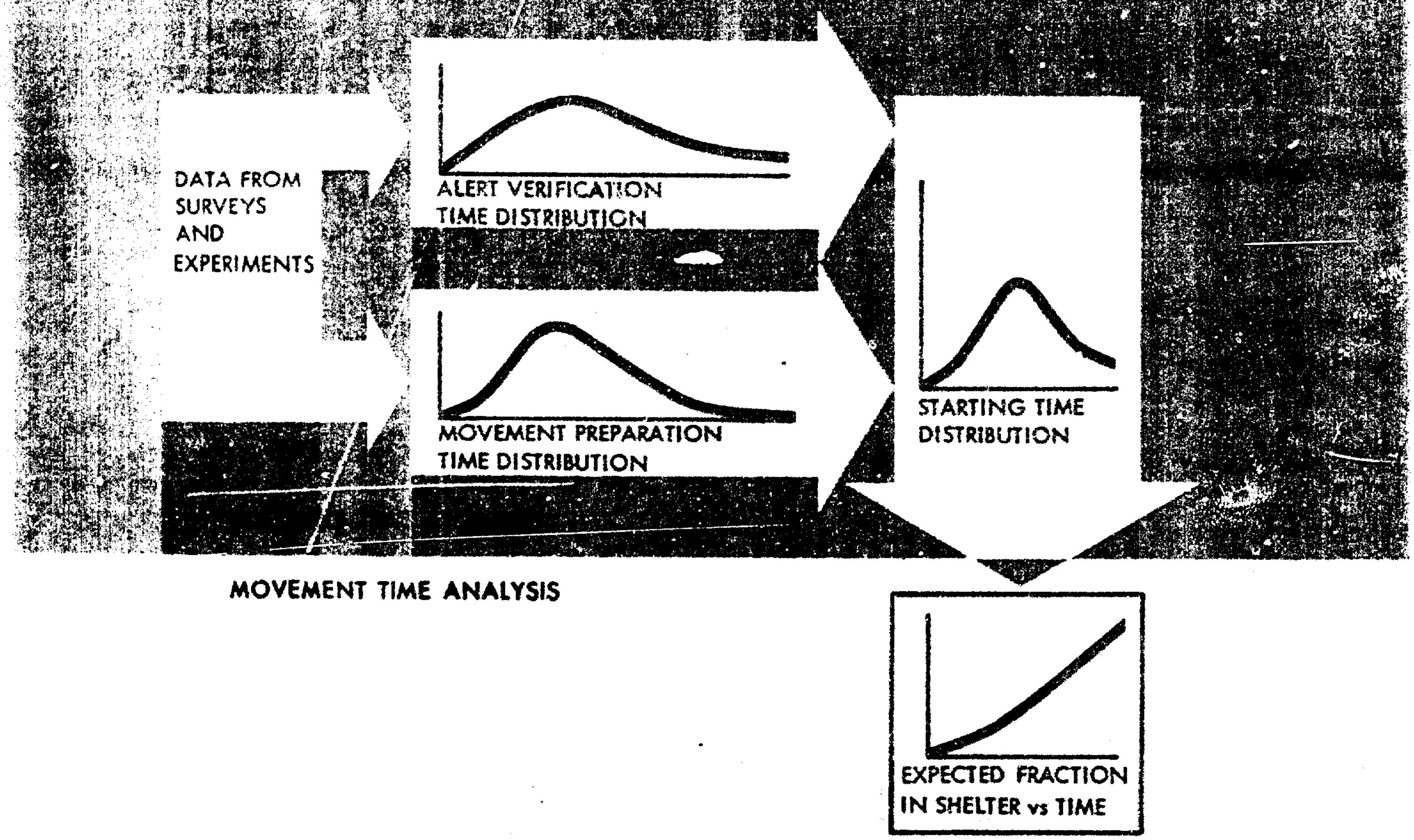
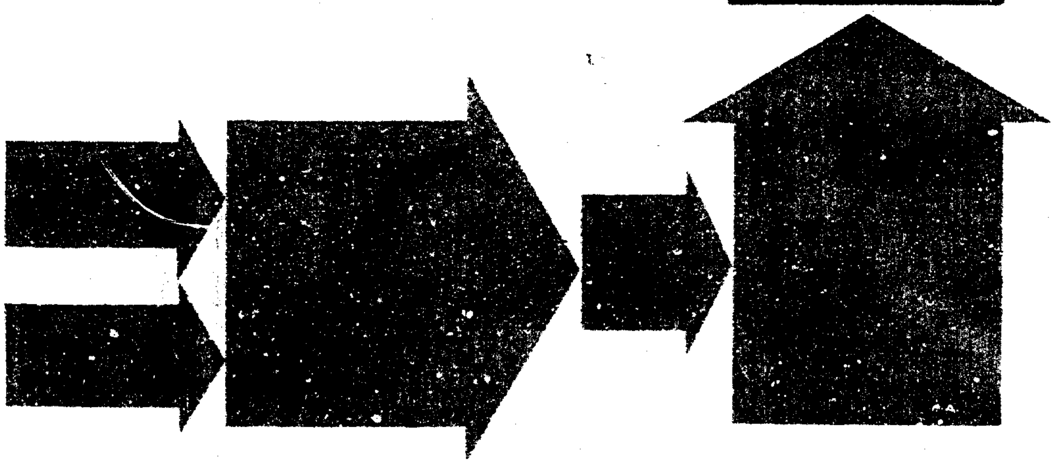
* W. A. Hamberg, A. M. Faloe, and H. Watkins, "A Study of Tactical Movement Concepts in Civil Defense Planning," Operations Research, Inc. Technical Report No. 210, August 1963.

alert signal sounds. In the study reported here, ORI's model has been adapted to fit the data and computational scheme required for use on a nationwide basis. A schematic diagram of the model is shown by Figure 13. This diagram shows how available experimental data have been used to produce estimates of the distributions of alert verification times and movement preparation times. The distributions of alert verification time and movement preparation time are combined into a distribution of starting times. Census data and fallout shelter data, used with assumptions about the speed of travel, result in a distribution of movement times. The resulting distributions of starting times and movement times are finally combined into a distribution of times to reach shelter after the alert signal starts, which, when plotted, result in a curve showing the fraction of the population in shelter as a function of the time after the alert signal sounds.

The analysis used to arrive at the distributions is presented in Sections AII and AIII. Section AII describes the analysis of the alert verification time distribution, movement time distribution, and the resulting starting time distribution. Section AIII describes the analysis of movement times and discusses the combination of movement time and starting time distributions into the final distribution of time required to reach shelter.



MOVEMENT TIME ANALYSIS



AII STARTING TIME ANALYSIS

The analysis of starting time distributions includes an analysis of alert verification time distribution and of movement preparation time distribution, and an analysis of how the two distributions are combined.

Alert Verification Time

Alert verification time begins when the alert signal first begins to sound, and ends when the individual decides to take action and begins to prepare to seek protection from the event warned against. The individual may perform a number of subordinate processes during the alert verification time. They are:

1. Hear signal
2. Recognize signal
3. Seek confirmation of signal meaning and validity
4. Find confirmation of signal meaning and validity
5. Relate signal meaning to self
6. Decide to act

To illustrate these sub-processes that take place during the alert verification time, consider a person who is asleep as the telephone begins to ring. Some time after the ringing starts, he will become aroused enough to be consciously aware of the ringing (hear signal). Shortly thereafter he will recognize the sound as that of the telephone (recognize signal) He may wait for another ring to assure himself that the ringing is not the result of a dialing error on the part of the caller (confirmation of validity) and that someone really wants to talk to him (relate meaning to self), after which he decides he must get out of bed and answer (decision to act). Finally he takes this action. In this illustration, the repeated sounding of the telephone serves as a confirmation to the listener. In the civil defense warning modes, a separate voice confirmation is used. The processes are otherwise identical.

As part of a study to determine the time required to leave home for a fallout shelter in response to a warning, ORI conducted an experiment to determine the response of a sleeping population to an early-morning telephone call.* ORI called approximately 100 persons in Atlanta, Georgia, between 12:00 midnight and 5:00 a.m. and measured the time between the first ring of the telephone and the time that the respondent spoke the first word. The results of this experiment are shown in Figures 14 and 15.

Unfortunately, it is not as easy to obtain data on the response of people to civil defense alerting devices as on their response to the telephone ring. Not only is the response to the civil defense alert more complex and hence more difficult to measure, but the measurement of the response is more difficult because there is no two-way communication with the person when he responds, as there is in the case of the telephone. Then, too, there are constraints that would make the sounding of an alerting device unfeasible or inadvisable for such a test.

Since there is difficulty in measuring alert verification time for an individual, the following approach is used to construct the alert verification time distribution. First, data collected in the telephone experiment are used to define the form of a probability distribution assumed to represent the response time for any alert signal. This formula, which describes the distribution, contains a constant α, which determines the spread of the distribution of alert verification times. Each warning mode is then analyzed to determine the appropriate value of α.

Determination of the Form of Alert Verification Time Distributions

The histogram of measured responses to the telephone call shown by Figure 14 shows a rate of responses that increases rather rapidly with time, then falls off more gradually. This rapid rise and more gradual fall can be described by a relationship of the form: $f(t) = \alpha^2 te^{-\alpha t}$; where f(t) is a probability density distributing function,† or more simply,

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* T. L. Newberry, J. C. Edenfield, and D. T. Kelley, "Experimental Measurement of the Time Required for an At-Home Sleeping Population to Prepare for Movement to a Civil Defense Fallout Shelter," Operations Research, Inc., Draft Report No. TM-151-62.

† The probability density distributing function may be interpreted in the following way: If one selects a small interval about a given value of v, say v_1, and samples individuals at random from the population, the frequency with which the so-sampled time values fall in the interval is given approximately by $f(v_1)$ times the width of the interval (the accuracy of the approximation is improved either by making the interval smaller or the sample larger, or both).

Figure 14

FREQUENCY DISTRIBUTIONS OF RESPONSES TO TELEPHONE RING

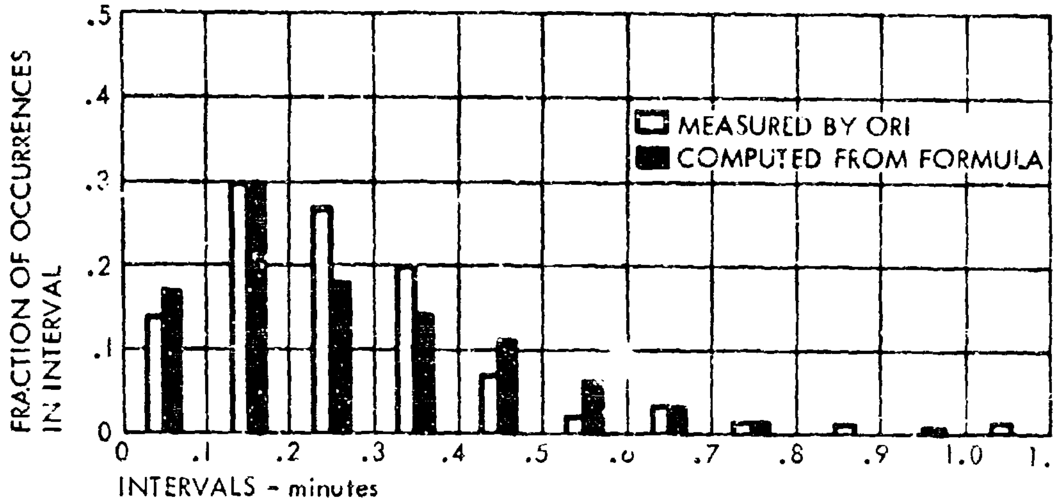
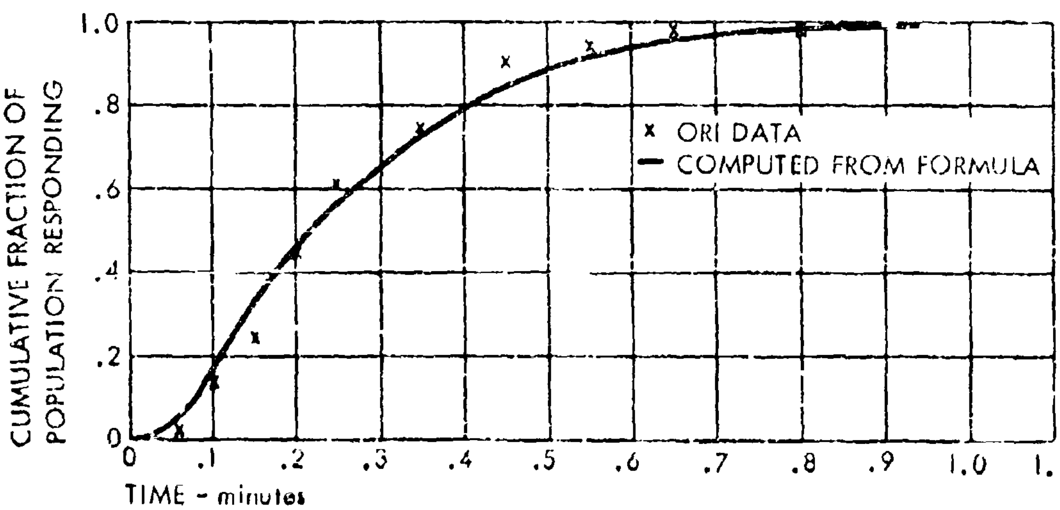


Figure 15

CUMULATIVE DISTRIBUTIONS OF RESPONSES TO TELEPHONE RING



the distribution of alert verification times; t is the time since the alert signal has sounded; and α is a constant that determines the shape of the distribution. The mean time for this distribution is $2/\alpha$, and the maximum value of the function occurs at $t=1/\alpha$.

Using the mean values of the ORI telephone data to determine the mean value for the formula for distribution of alert verification time, a distribution for response to a telephone ring is computed. A comparison of the resulting frequency distributions and cumulative distributions with the ORI telephone data is shown by Figures 14 and 15. These figures show a good fit between the data and the assumed formula.

Alert Verification Time Distribution for Radio Warning

The radio warning mode consists of an alert signal delivered to the population by indoor radio warning receivers, followed by a warning message automatically delivered by the same receiver.

The alert verification time for radio warning was determined by assuming that the peak of the distribution (i.e., the maximum number of responses in a unit time) will occur at the end of the first repetition of the cycle of alert signals and confirming messages.

From the curve for responses to the telephone call, it appears that about 90% of the population would respond to a signal in 0.5 minute. It is assumed for the purposes of this report that this is the optimum time for sounding the alert signal. It is further assumed that an effective warning message can be delivered in one-half minute, based upon the prevalence of spot radio and TV announcements that are expected to convey a message in this period of time.

The warning message will thus be complete one minute after the alert signal starts. The value of α, which places the peak number of persons responding at 1.0 minute, is $\alpha = 1.0$. This value of α (1.0) is the one that has been used to construct the curves of fraction of the population in shelter vs time after alert signal sounds for radio warning.

Alert Verification Time Distribution for Indoor Alerting

The indoor alerting mode consists of an alert signal delivered to the public by an indoor signaling device such as a NEAR receiver or an alert-only radio receiver and a confirming message delivered over commercial radio and television stations.

The alert verification time distribution for indoor alerting is derived from the alert verification time distribution for radio warning. The indoor alerting mode differs from the radio warning mode in that the individual who hears the alerting signal from the indoor alerting device must seek confirmation from another source (home radio or TV), whereas in radio warning, voice confirmation is automatically provided. It is reasonable to assume that the peak number of responses per unit time will still fall immediately after the completion of the confirming voice message. The voice message in the indoor alerting mode cannot, however, be received until the individual goes to his radio or TV and activates it. The time to activate the confirming source must therefore be added to the time for the alert signal and voice message found for radio warning to determine the time to the end of the voice message.

The time required to find and activate the confirming source will not be the same for everyone. Another distribution will thus be required to describe it completely. Unfortunately, no data are available to aid in describing such a distribution. It does seem reasonable, however, to estimate that about one minute would be required to turn on a radio, wait for warnings, and find a station. It has therefore been estimated that the effect of adding the distribution of times to activate the household radio after the alerting signal has been heard would be the same as the effect of adding one minute to the time of the peak response in the distributing function of alert verification times for radio warning.

The value of α, which makes the alert verification time distributing function peak at two minutes, is 0.5. This is the value used to determine the fraction of the population in shelter as a result of having been warned by the indoor alerting mode.

Alert Verification Time Distributions for Siren Alerting

The siren alerting mode consists of an alerting signal delivered by an outdoor siren, and a confirming message delivered over commercial radio and television stations.

Whereas a single distribution could be developed for the alert verification times for radio warning and for indoor alerting, a range of distributions must be presented for the siren alerting mode because of the range of radio support that may accompany the sirens and the less distinctive sound of sirens as compared to the indoor alarm devices just discussed.

In the development of the parameter, α, for the alert verification time of the indoor alerting mode, it was anticipated that the emergency radio broadcast would be on the air by the time people responded to the alerting signal and turned on their radios, since an advanced system such as indoor alerting would require simultaneous radio broadcasting to justify the relatively high cost of such a system. On the other hand, the outdoor sirens might operate in a condition such as prevails today, where the radio emergency announcements would not be made for several minutes after the sirens had begun their alert signals.

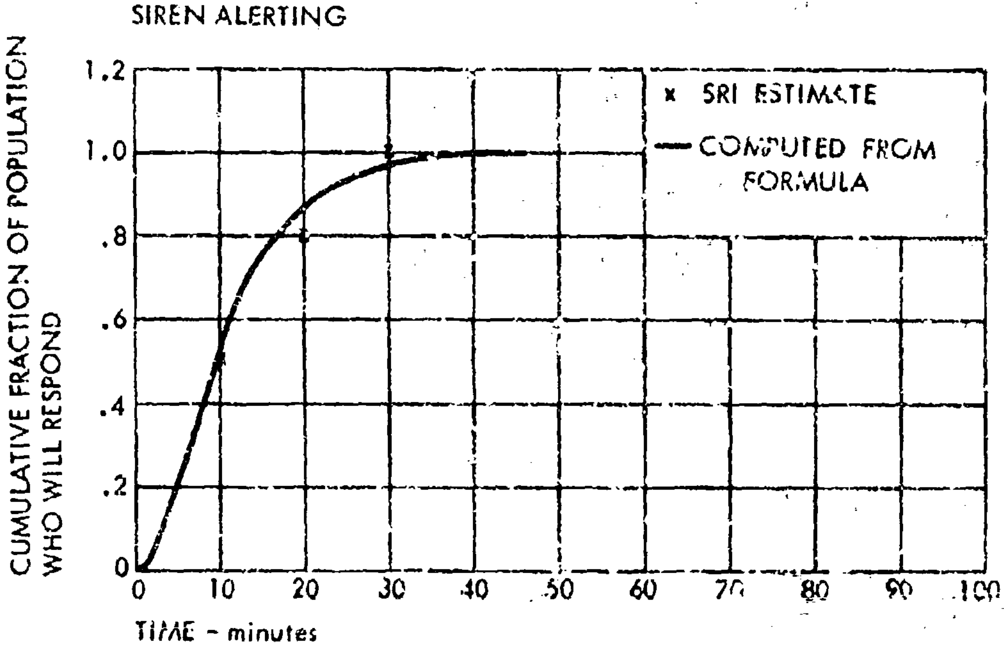
The fact that siren alerting signals are similar to siren signals heard routinely by the public from ambulances, fire trucks, and police vehicles also dictates that a range of alert verification time distributions be considered. The differences between civil defense sirens and those on emergency vehicles are duration, movement, pitch, and, in some cases, coding. To distinguish between these features of the two signals will require a period of time and concentration on the sounds. The casual listener will not give the concentration required unless he is intimately familiar with the signal and pitch differences of the two types of emergency signals, but he may offer this attention if the siren signal persists for an extended period of time. The population may offer the required attention to the civil defense siren signals more quickly under two conditions: (1) in a period of crisis during which the threat of attack becomes more immediate and civil defense instructions are given extraordinary heed, or (2) when a concerted effort is made to make the population aware of the civil defense siren sounds through a massive promotional program. Even in the crisis period, however, time is required to learn to listen to the signals, with the result that an attack after a crisis of only a day or two, or a surprise attack, might find the public unprepared for the siren signal. Under these conditions the alert verification process would be speeded up, in the sense that a greater fraction of the population might be alerted within a given time, or a given fraction of the population would complete the verification process faster under the crisis or training condition.

Since a single distribution cannot be constructed for the range of conditions under which the siren mode might be used to warn the population, a range of values of α is determined, and guidelines are formulated for selecting values of fraction of the population in shelter within that range.

The conditions for siren mode warning where radio support is slow and where the public is unprepared for warning represents the slow limit of the distribution. In a false air raid alert in Chicago in 1959,* sirens were sounded at night under conditions where radio broadcasts were not made and where the population was not prepared for warning. Using as a basis the study of the responses of the people to this false alert, SRI has prepared estimates of the number of persons who came to recognize the siren signal within various times after the alert began.† The estimates are plotted as x's on Figure 16, while the solid line on the figure shows the values obtained from the alert verification time distributing function with a value of α that makes the mean value of the function represented by the curve the same as the mean value of the estimated points. The value of α used is 0.17, resulting in a modal value of 1/.17 or about six minutes. Figure 16 shows a good correspondence between the previous estimates and the distributing function selected,

Figure 16

ALERT VERIFICATION TIME DISTRIBUTIONS -- SIREN ALERTING



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* Elihu Katz, Joy in Mudville, National Opinion Research Center, University of Chicago, June 1960.

† Robert A. Harker, Richard L. Goen, and Kendall D. Moll, A Method for Evaluating Local Civil Defense Effectiveness, Stanford Research Institute, A draft report prepared for the Institute for Defense Analysis, October 1964.

A population that is ready to react to the sirens and is in a warning environment where emergency announcements over radio and TV are broadcast at the same time as the siren signals will have an alert verification time distribution approaching that for the indoor alerting mode. However, it is believed that the siren alerting mode cannot equal the speed of indoor alerting because the lack of distinctiveness in the siren signal will always result in listeners requiring more time to recognize it. A value of 0.33 was therefore chosen as the value for the fast response to sirens, resulting in a modal value of 1/.33 or three minutes.

Between the limits of the two cases just described--sirens unsupported by radio broadcast warning an unprepared population and sirens supported by radio broadcasts warning a prepared population--two intermediate cases are of interest. These cases are those of sirens supported by radio broadcasts warning an unprepared population and sirens unsupported by radio broadcasts warning a prepared population. The two limits and the two intermediate cases are assigned siren effectiveness case numbers according to Table 4.

Table 4

SIREN EFFECTIVENESS CASES

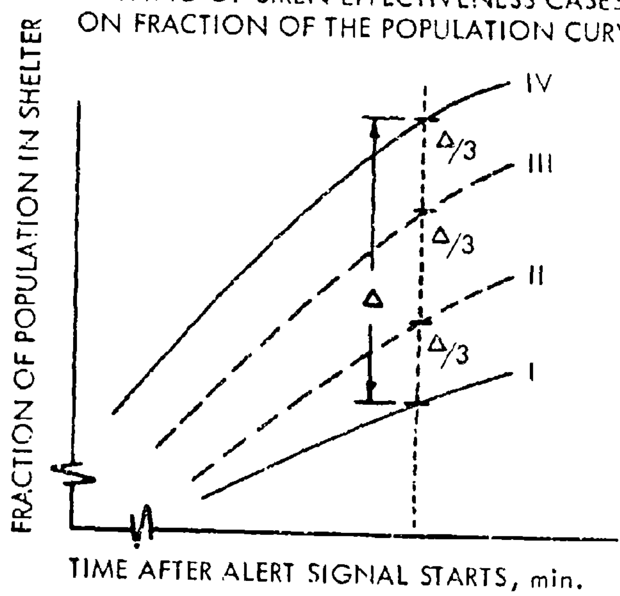
Population Readiness	Radio Support for Sirens: Existing	Radio Support for Sirens: Close
LO	I	II
HI	III	IV

In Table 4, population preparedness is identified by LO readiness, the state that exists today, and HI, which would result from an extended crisis or from an extraordinary effort to increase public readiness through public information. Radio broadcast support is indicated by Existing, the case that exists today, where several minutes would elapse between the siren signal start and the start of emergency announcements, and Close, where the start of emergency announcements on radio would closely follow the start of the siren signals.

The alert verification time distributions for cases I and IV are the limiting cases. Since the spread between the limits is not great (see Figures 3 and 7), the interval between the two limits of *performance* has been divided into three equal parts in such a way that the intervals between the four cases are equal. The upper limit of the curve is then the fraction of population in shelter for Case IV siren effectiveness for the particular time after the alert signal sounds; interpolating one-third down into the region gives the fraction for Case III; one-third of the region measured from the lower limit gives the fraction for Case II; and the lower edge of the region is the fraction for Case I. Figure 17 illustrates the spacing of the siren effectiveness cases in the area shown by the curve.

Figure 17

SPACING OF SIREN EFFECTIVENESS CASES ON FRACTION OF THE POPULATION CURVES



Formulas for the necessary interpolations of Cases II and III are given, for convenience, on Figures 3 and 7.

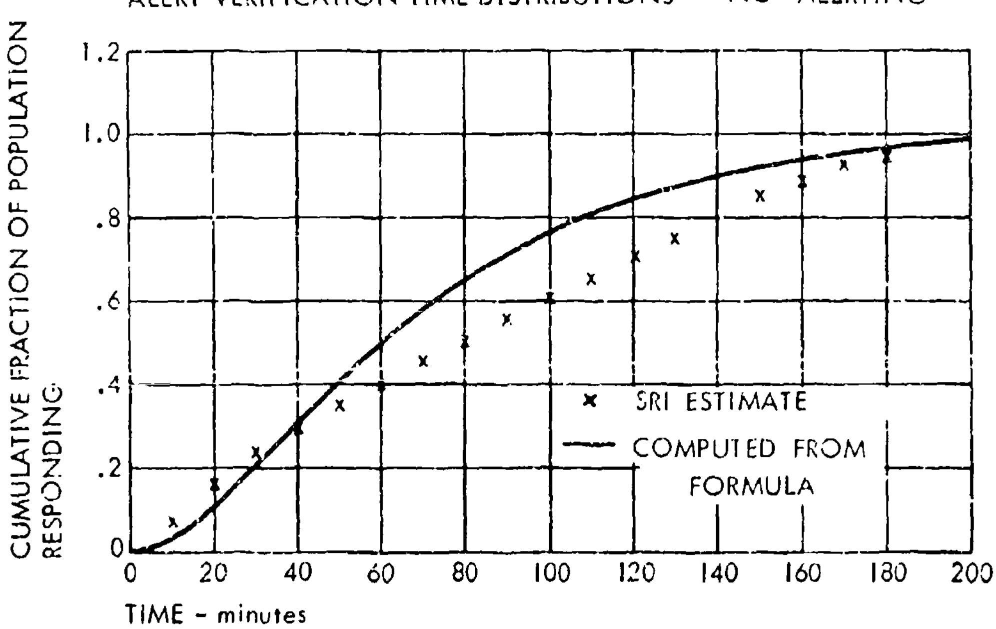
Alert Verification Time Distribution for No Alerting

The no alerting mode of warning consists of warning without the use of an alerting signal. Persons warned by this mode may hear emergency broadcasts over radio or TV if they have their radio and TV sets on and are listening. Persons may also be warned, without using alerting devices, through community actions of spreading the warning by word of mouth. Contacts by telephone are not considered because the telephone system may be overloaded or subjected to restriction by the telephone company during the emergency period.

SRI has prepared an estimate of the fraction of the population warned for a nighttime condition without using alerting devices.* These estimates are based on an earlier SRI analysis of the response of the residents of several California communities to nighttime flood warnings. The estimates are shown by x's on Figure 18. Also shown on Figure 18 is a solid line computed from the alert verification time distributing formula with a value of α obtained by matching the mean value of the formula with that of the points in the estimate. The resulting value of α is 0.0275. This is the value of alpha used in the alert verification time distributing formula that was used to prepare the curves for fraction of the population in shelter as a function of time after emergency broadcast starts for the no alert warning mode.

Figure 18

ALERT VERIFICATION TIME DISTRIBUTIONS -- NO ALERTING



* Harker, Goen, and Moll, previously cited.

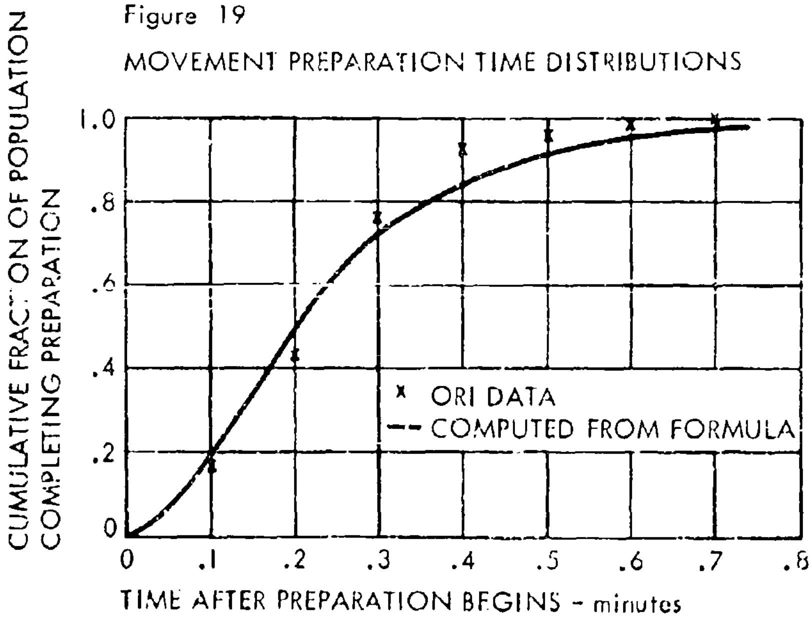
Movement Preparation Time

Once the individual has decided that action is required, preparations must be made before he can begin the movement toward shelter. The time consumed in making these preparations is called movement preparation time. Movement preparation time begins when the individual verifies the alert and decides to act, and ends when he begins movement toward shelter. These preparations include the shutdown of utilities, the collection of clothing and personal effects that will be needed in the shelter, and securing the home.

ORI performed an experiment to determine the preparation time for a nighttime population.* The results are shown in Figure 19. While ORI gave certain caveats about using these data for a nationwide preparation time, the set of modifying circumstances is close enough to this situation for their data to be usable here. The experimental probability distribution indicated by the experiment has, therefore, been approximated by a formula similar to that used for the alert verification time: $f(t) = \beta^2 te^{-\beta t}$; where f(t) is probability density distribution function for preparation times; t is the time since preparations began; and β is a constant that determines the shape of the curve. The assumed distribution with this formula is also plotted on Figure 19. The value of β, computed from the mean of the sample data, is 0.41. Again, Figure 19 shows good agreement between the sample data and the assumed formula.

Figure 19

MOVEMENT PREPARATION TIME DISTRIBUTIONS



* Experimental Measurement, previously cited.

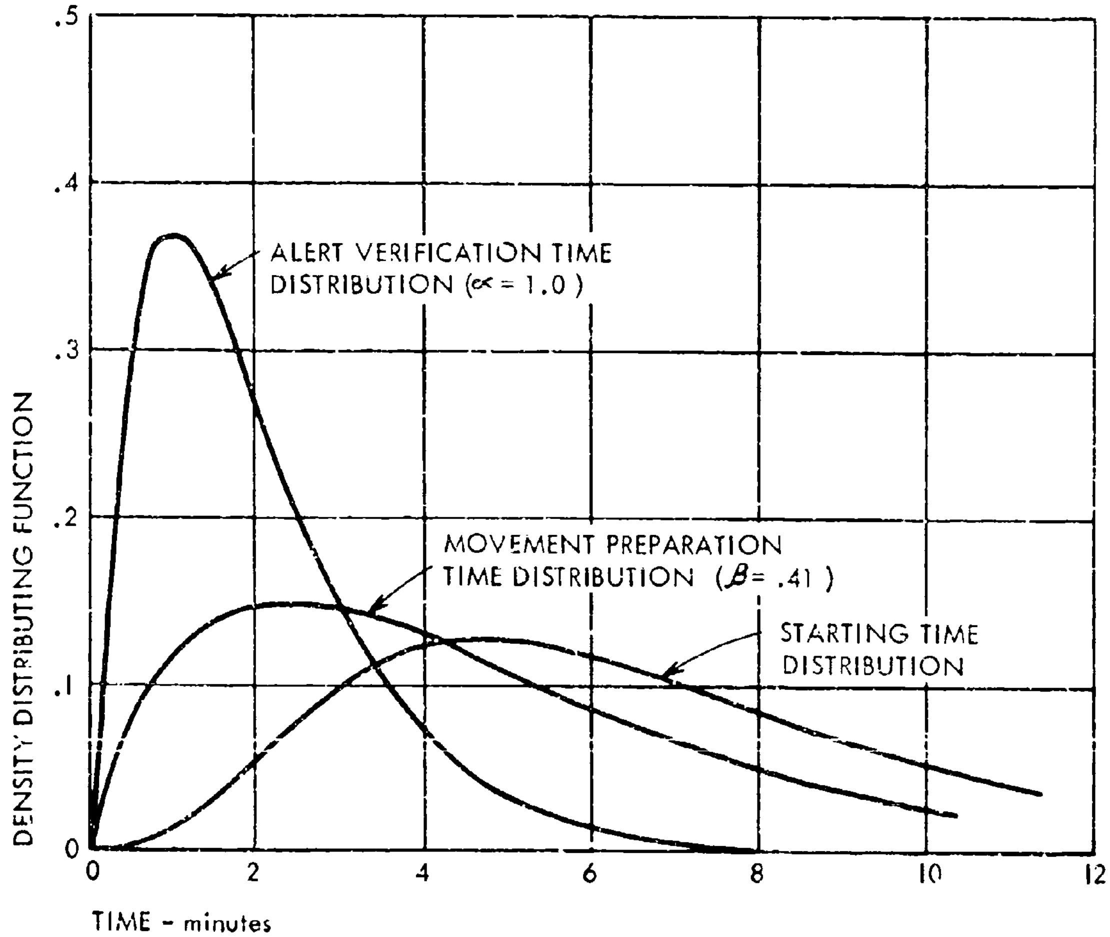
Computing Starting Time Distributions

Once the probability that an individual will complete the alert verification process and the movement preparation in a given time has been determined, the next step is to compute the probability that he will be ready to leave for the shelter at a given time after the alert signal begins. Since the individual is now being considered, the two times cannot be simply added together, because there is no discrete time assigned to either event. Rather, a distributing function must be constructed for the sum of the two times, alert verification and movement preparation, using the distributing functions for the two times. The value of the distributing function for the sum of the two times, at any time, T is the sum of the products of the two distributing functions evaluated for all possible combinations of the two times, which add up to T. This is simply a statement that the fraction of the population that requires, say, 10 minutes to complete both verification and preparation is the sum of the following fractions of the population: the fraction that would complete verification in 5 minutes and preparation in 5 minutes, the fraction that would complete verification in 4 minutes and preparation in 6 minutes, the fraction that would complete verification in 6 minutes and preparation in 4 minutes, and so on for all combinations of time that total 10 minutes. This process is repeated for all values of T.

Figure 20 illustrates the shape of a starting time distribution. Also shown on Figure 20 is the movement preparation time distribution and alert verification time distribution from which it is obtained.

Figure 20

DISTRIBUTION OF STARTING TIMES WITH RADIO WARNING



TIME - minutes

AIII MOVEMENT TIME ANALYSIS

The manner in which the movement time distributions for the existing and 1970 shelter postures were developed, is described in this section. Also discussed is the method by which the starting time distribution was combined with the movement time distribution to yield the number expected in shelter as a function of time after the alert signal starts.

Movement time is the time elapsing between the instant an individual completes his preparations to move to shelter and starts moving toward shelter and the instant at which he arrives at the shelter. The movement time for an individual is determined solely by the distance he must travel between his location at the time of the emergency and his assigned shelter, and the average speed he is likely to attain in traversing this distance.

To simplify the problem of deriving the distributing functions for movement time, the location of the population at the time the warning is delivered will be specified as the resident population. This population distribution would be approximated if an attack occurred during the nighttime hours. This approximation is sufficiently accurate, since this method has been designed for evaluation of systems involving radio warning, which employs an indoor device most applicable to these periods when most of the population is at home.

The number and location of the population, as well as the number and locations of the shelters for the public, will change with time. To provide a range of these variables over which to analyze warning systems, two sets of movement time distributions have been derived: one for the 1960 resident population and the number and location of fallout shelter spaces in existence on January 1, 1965; and the second for the estimated 1970 resident population and the estimated number and location of shelter spaces that would result from the implementation of a nationwide shelter development program These two sets of conditions of people and shelters are called the existing shelter posture and the 1970 shelter posture, respectively.

Because population density and availability of shelter are different in large cities, in suburbs of large cities, and in rural areas (including small towns), warning system performance may not be the same in each of these areas. Also, the arrival time of the fallout from a nuclear attack is assumed to be longer in nonmetropolitan areas than in metropolitan areas. To allow for these differences, three movement time distributions have been prepared and kept separated for each shelter posture. The three distributions are for central cities of urbanized areas, urban fringe areas, and nonurbanized areas.

The census defines an urbanized area as one which

> . . . contains at least one city of 50,000 inhabitants or more in 1960, as well as the surrounding closely settled incorporated places and unincorporated areas that meet the criteria listed below. An urbanized area may be thought of as divided into the central city, or cities, and the remainder of the area, or the urban fringe . . . .
>
> In addition to its central city or cities, an urbanized area contains the following types of contiguous areas, which together constitute its urban fringe:
>
> 1. Incorporated places with 2,500 inhabitants or more.
> 2. Incorporated places with less than 2,500 inhabitants, provided each has a closely settled area of 100 housing units or more.
> 3. Towns in the New England States, townships in New Jersey and Pennsylvania, and counties elsewhere which are classified as urban.
> 4. Enumeration districts (ED's) in incorporated territory with a population density of 1,000 or more per square mile. (The areas of large nonresidential tracts devoted to such urban land uses as railroad yards, factories, and cemeteries were excluded in computing the population density of an ED.)
> 5. Other ED's, provided that they served one of the following purposes:
>   a. To eliminate enclaves.
>   b. To close indentions in the urbanized areas of one mile or less across the open end.
>   c. To link outlying ED's of qualifying density that were no more than 1-1/2 miles from the main body of the urbanized area.*

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* Characteristics of the Population, previously cited.

Movement Time Distributions for Existing Shelter Posture

The shelter spaces that have been identified by the National Fallout Shelter Survey are predominantly located in the downtown areas of central cities, where the core areas of multistory office buildings offer a considerable amount of space with an adequate protection from fallout radiation. Smaller amounts of space are located in areas outside the downtown area. Shelters outside the downtown area usually serve only a limited number of persons in the immediate vicinity of the shelter, requiring most of the residents of urbanized areas to seek shelter in the downtown area of the central city or to improvise their own protection. For the purposes of this discussion, the shelters located away from the downtown areas are called neighborhood shelters, and those located in the downtown area are called downtown shelters.

The approach taken to find the movement time distributions for the central cities, urban fringe areas, and nonurbanized areas for the existing shelter posture has been to derive one form of distribution for movement to neighborhood shelters and another for movement to downtown shelters. These basic movement time distributions contain parameters for time to complete the move, for population involved, and for population density distribution. Each area--central cities, urban fringe, and nonurbanized--is analyzed to determine the parameters to use and the allocation of the area population between neighborhood shelters and downtown shelters, and for those who will not be able to find shelter.

Although many communities seek to provide shelter for all of their residents, using overcrowding or shelters of lower protection factor where there are not enough bona fide spaces for the residents, such interim solutions are not considered here. Only the number of spaces identified in the survey is considered.

Basic Movement Time Distributions

Distribution of Movement Times to a Neighborhood Shelter. The service area for a shelter (or shelter complex) is the area containing the residents assigned to that shelter for which the area is defined. The shelter service area provides the shelter planner with a convenient method of assigning persons to shelter, since the identification of the service area on a map is an explicit instruction of where to go for shelter.

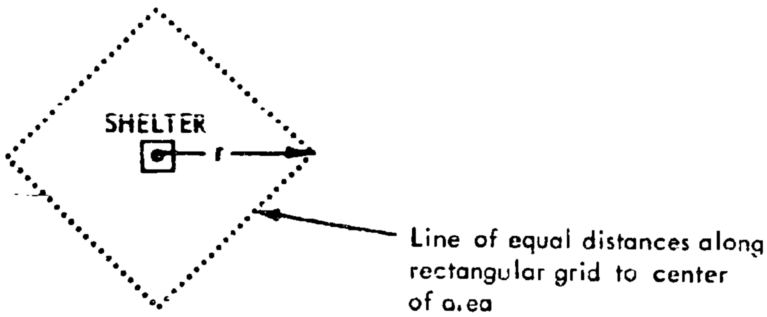
Neighborhood shelter service areas will usually be a square area with the shelter, or shelter complex, in the center of the square. This follows because the planner must usually limit himself to assigning all the residents of whole blocks within the service area, and because he hopes to fill the shelter as quickly as possible. The restriction to whole blocks, made because of ease of describing the area and avoidance of discrimination between next-door neighbors on the basis of estimated data, means that the shelter service area must be rectangular. The attempt to fill the shelter as quickly as possible results in taking blocks equidistant from the shelter, and hence the square shape.

For the purpose of this analysis it is assumed that the shelter service area has a uniform resident population density. The assumption of equal population density is justified by the earlier premise that the area served by the neighborhood shelters is small. Further, all persons moving to the shelter must follow the streets; that is, must take a path consisting of segments parallel to the sides of the area--shortcuts are not allowed.

The restriction of travel to a rectangular grid system of streets results in a locus of equal distance to the shelter, which is square, rotated at a 45° angle to the street axis, as shown in Figure 21.

Figure 21

ILLUSTRATION OF SHELTER SERVICE AREA
AND LINE OF EQUAL DISTANCES
TO CENTER OF AREA



BOUNDARY OF SERVICE AREA

Consider such a square, constructed to represent the locus of all points a distance, r, from the center of the area. The number of persons who are located a distance r or less from the shelter is the area of the square times the population density for the area. The cumulative distribution of the population with distance can therefore be described by describing the area of the square of constant distance that is also inside the service area, as a function of r and multiplying the resulting expression by the constant density.

For neighborhood shelters it will be assumed that the service areas are small enough that if all the population were to walk to the shelter, they would reach it within the required time. The speed of walking is not the same for everyone, which means that a precise description of the walking speed could be made only by a distribution of speeds for the population. However, the variability of walking speed is considered small enough that a good representation of the distribution can be made by using a single average speed. Use of a single, rather than distributed, walking speed also greatly simplifies the computation of movement time and fraction of the population in shelter.

Using the average walking speed, the cumulative distribution of distance can be converted to a distribution of movement time by dividing the distance scale by the movement speed. The final formula for cumulative movement time distribution is derived by expressing the movement time as a fraction of the maximum movement time in the area, i.e., the time required for the person farthest from the shelter to move to the shelter. The population in the final formula, is expressed as a fraction of the total number of residents of the area. Explicit requirements for the velocity term and the value of the population density are thus eliminated. The formula for cumulative distribution that results is:

$$F_{pn}(t_m) = \frac{1}{2}\frac{t_m^2}{T^2} \quad : \quad 0 < t_m < T/2 \ .$$

$$F_{pn}(t_m) = 1 - \frac{(T - t_m)^2}{2} \quad : \quad T/2 < t_m < T \ ;$$

$$F_{pn}(t_m) = 1 \quad : \quad T < t_m .$$

where:

$F_{pn}(t_m)$ is the fraction of the population served by the neighborhood shelter who will require a time, t_m, or less to move to the shelter.

t_m is the movement to shelter time, usually in minutes.

T is the movement time required by the person in the area who is farthest from the shelter.

Distribution of Movement Times to Downtown Shelters. Because the number of shelter spaces in the downtown sections of urbanized areas is relatively large, the area served by these downtown shelters, taken as a group or cluster, is large. Because of this relatively large area the assumption of constant population density over the shelter service area does not apply. The population density of metropolitan areas is, on the average, however, fairly predictable in terms of distance from the center of the area. With the density known as a function of distance from the center of the metropolitan area, the distribution of the population with distance from the center can also be found.

Weiss* describes the work of Clark in the late 1940s and early 1950s, which shows the exponential trend of decreasing population density with increasing distance from the center of the area. From Clark's distribution of population density, Weiss develops a formula for the number of persons who live a given distance, or less, from the center of an urban area, as follows:

$$P(r) = P_m \left[1 - e^{-br}(1 + br) \right]$$

where:

$P(r)$ is the number of persons who live on, or within, a circle of radius r, whose center is in the center of the urbanized area.

P_m is the total population of the urbanized area,

r is the distance from the center of the urbanized area, and

b is a constant for each urbanized area which describes the rate at which the population density falls off with distance from the center of the area.

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* Herbert K. Weiss, "The Distribution of Urban Population and an Application to a Servicing Problem," Operations Research, The Journal of the Operations Research Society of America, Vol. 9, No. 6, November-December 1961, pp. 860-74.

Weiss also develops a method for estimating b, based upon the population of the urbanized area, as follows:

$$b = \left[\frac{10^5}{P_m} \right]^{\frac{1}{3}} ,$$

where:

b and P_m are as defined above.

This expression was derived by fitting a straight line to a set of b-values plotted against population. The variance of points from this line is considerable. This means that the value of b thus obtained may be in error for a particular city. Fortunately, however, the mean value for several cities combined is satisfactory from such an estimate; hence the use of this expression for the nationwide distribution of persons is also satisfactory.

The distribution of movement times to downtown shelters may be derived from Weiss's formulas by again assuming that an average speed can be used to approximate the distribution of movement speeds, and by making an assumption about the distribution of the neighborhood shelters. While some estimates of the distribution of shelter spaces have been made,* the estimates offer no way of predicting the distribution of the spaces for any given city. For this reason, the distribution of those sheltered in neighborhood shelters will be assumed to be proportional to the population. With this assumption, the movement time distribution for movement to downtown shelters is:

$$F_{pd}(t_m) = 1 - e^{-\frac{\pi}{4} b v t_m} \left(1 + \frac{\pi}{4} b v t_m\right);$$

where:

$F_{pd}(t_m)$ is the fraction of the population of a metropolitan area that can reach downtown shelter in a time, t_m, or less;

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* John Crain and Charles D. Bigelow, Civil Defense Rescue Requirements Following a Nuclear Attack, Stanford Research Institute, February 1965, pp. 17-19.

t_m is the movement time,

b is a constant that describes how urban population density falls off with distance from the center of the area,

v is the average movement speed with which persons in the area can move to the shelter.

The speed, v, used in this expression, must be reduced by a factor of $\pi/4$, because the distance from the center of the urbanized area is measured radially in the Clark distribution, but the people can travel only along the streets. The factor $\pi/4$ is the average radial speed of persons traveling with a speed of one unit along rectangular street pattern.

Model Urbanized Areas Used to Construct Distributions of Movement Times in Central Cities and Urban Fringe Areas

Because of large differences in the number of shelters available to the populations of the different urbanized areas, and, to a lesser extent, because of differences in size of standard locations, population densities, and so on, individual analysis of each of the 212 urbanized areas would be desirable. Such an analysis, however, would be excessively time-consuming for purposes of this study. As a compromise in the detail of analysis, 28 model urbanized areas have been constructed to represent the 212 areas in the 48 states under consideration. A description of how these 28 models have been constructed follows.

Model areas one through twenty-four correspond to the urbanized areas associated with the 24 SMSAs whose population exceeded one million in 1960. The numbering of the model areas corresponds to the ranking by number of inhabitants of the 24 SMSAs in 1960. Each of these first 24 model areas corresponds in every way to the corresponding urbanized area, that is, by land area, number of inhabitants, number of shelter spaces, number of standard locations. The combined population of these 24 SMSAs is about half the total population of SMSAs, but these areas contain about two-thirds of the existing shelter spaces.

The twenty-fifth model is a composite of the urbanized areas corresponding to the next 13 largest SMSAs, ranked according to their 1960 populations. The characteristics of this composite area are such that the total population represented by the model is the sum of the populations of the 13 cities (slightly over 10 million); and the land area, number of standard locations, etc., is likewise the sum of these quantities for all the 13 areas.

The twenty-sixth model is a composite of the urbanized areas associated with the next 18 largest SMSAs. The twenty-seventh is a composite of the next 29, and the twenty-eighth is a composite of the remaining 128.

Movement Time Distribution for Residents of Central Cities

The following approach has been used to analyze the movement time distribution for central cities. The central city of each of the 28 model urbanized areas is divided into two parts, a downtown and the remainder of the central city. Representative movement time distributions to neighborhood shelter were constructed for each area subdivision of each of the 28 model cities. Each of these distributions is weighted by the population sheltered in each of the subdivisions of each city. These weighted distributions are combined by adding the weighted values of all the distributions at each value of movement time. After deducting the number sheltered in neighborhood shelters, a movement time distribution for downtown shelters is constructed for each of the 28 model central cities, each resulting distribution is again weighted by the number of persons represented by the model, and the distribution is truncated if the number of shelters is less than the central city population. The resulting weighted distributions are added at each value of movement time. The two weighted movement time distributions, one for neighborhood shelter, one for downtown shelter, are then added at each value of movement time and divided by the total population of central cities to produce the resulting movement time distribution for all central cities.

For purposes of this study, downtown is used in two senses in this analysis: first, when used to describe the process of moving to shelter in the downtown area, downtown is a non-specific term for the center of town. When used to describe part of the city, however, a specific part of the city is defined. The part of the city that is defined as the downtown is that which lies inside a circle whose radius is equal to one-fourth that of a circle equivalent in size to the urbanized area. The center of the downtown circle lies in the center of the central city.* Downtown areas have been identified for the 100 largest urbanized areas. This definition is arbitrary in the sense that there is no essential characteristic of the area, such as presence of commercial or large multi-story residential buildings, or other land use, which defines the area.

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* David W. Goodrich, Utilization of Existing Shelter in Metropolitan Areas, Stanford Research Institute Report No. RM-OAP-12, Menlo Park, California, February 1965, p. 11.

It may also be seen that the downtown and the central city may not even be coterminous, because the central city's boundaries are legally established, and irregularities of the central city boundary, or a small central city in a large urbanized area, sometimes result in parts of the downtown area lying in the urban fringe. The number of persons living in such areas is small, however; so the effect of the anomaly on the movement time distribution is small. For purposes of this analysis, it will therefore be assumed that the downtown lies entirely within the central city.

The standard location areas (SL) have been identified by the Census Bureau* to facilitate damage assessment computations. The standard locations consist of census tracts in areas that have been tracted, and wards, minor civil divisions, census county division, small towns, and enumeration districts in areas that have not been tracted. Population, as well as number of shelter spaces and other resources have been tabulated by SL for use in computer-based damage assessment programs. For this purpose, each standard location area is numbered and its center located by geographic coordinates.

SRI has compiled a listing of the fraction of populations of component parts of standard metropolitan statistical areas (SMSAs) who can be sheltered in their own SL.† This tabulation is used as the basis of determining the number who will be sheltered in neighborhood shelters for the urbanized areas under consideration in this report. The data are used in the following way.

1. For each of the 28 model cities, the downtown area is computed according to the definition of downtown as one-sixteenth of the area of the urbanized area represented by the model. The areas of the urbanized areas are tabulated in census data.‡

2. The number of standard locations in the downtown area of each model city is determined from data prepared in conjunction with the referenced tabulation.† The average SL size for the downtown area of each of the 28 model cities is then computed from the number of SLs and their area.

3. The assumption is made that each SL had one, and only one, shelter or cluster of shelters. The average service area for neighborhood shelters in the downtown area of each of the 28 model

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* National Location Code, Bureau of the Census, 1962.

† Goodrich, previously cited.

‡ Characteristics of the Population, previously cited.

cities is determined by multiplying the average SL size by the fraction of the population of the model city's population who could be sheltered in their own SL, from the tabulation.

4. The time for the furthermost person in the service area to reach shelter, T in the movement time distribution formula, is found by regarding the average drainage area as a square, making the maximum distance to the center equal to the square root of the area, and considering that the persons in downtown areas can walk at three miles per hour.

5. The weighted distribution is found by multiplying the distribution constructed from the T for each downtown area by the number of persons who can be sheltered in their own SL for that area, from the tabulation.*

The process used to determine the weighted distributions of movement times to neighborhood shelters in the remainder of central cities is the same as that used in finding the distribution for the downtown areas. The area of the remainder of the central city is found by subtracting the downtown area from the central city area, also tabulated by the census.† The number of standard locations and the number of persons who can find shelter in their own standard locations are determined from the SRI tabulation.*

The distribution of movement times to downtown shelters for residents of central cities is found by the following process:

1. The value of the exponent b, which describes the drop-off of population density with distance from the city center, is computed from Weiss's formula, using the population of the model urbanized area for models 1-24, and the average population for models 25-28.

2. For each urbanized area represented by the models of urbanized areas, the resident population of the area is reduced by the number of persons who can find shelter in neighborhood shelters for that area. This population is used to weight the distribution obtained for each of the 28 model urbanized areas.

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* Goodrich, previously cited.

† <u>Characteristics of the Population</u>, previously cited.

3. The weighted distribution of movement times to downtown shelters, using the value of population and b just computed, is compared with the number of shelters available in the downtown area. This number of available shelters is determined by subtracting the number of persons in each, sheltered in their own SL, in each metropolitan area corresponding to each of the model areas, from the number of shelters in that metropolitan area. The distribution is truncated if the number of shelters is less than the population of the central city moving to shelter in the downtown area.

4. In each of the model urbanized areas it is assumed that persons can walk at three miles per hour in downtown areas, and that they can ride in automobiles at 20 miles per hour in the remainder of the central cities when moving to downtown shelters. It is further assumed that, whether by plan or not, an effective cordon would exist around the downtown area that would require parking cars used to transport persons from the remainder of the central city. Persons who had used automobiles to ride to the edge of the downtown area would walk from there to the shelter.

   Because the effect upon the result is small and because the computations are greatly simplified, the movement velocity is taken as three mph for everyone if the radius of the downtown is greater than one and one-half miles, corresponding to a travel time of 30 minutes. This simplification is made under the assumption that the fraction of the population in shelter is evaluated at about 30-45 minutes after the alert signal starts, or about 30 minutes of movement time. The number of persons outside the downtown area who can get to the downtown shelters is small for this period of time. In those model urbanized areas where the radius of the downtown area is less than one and one-half miles, the riding velocity of 20 miles per hour is used throughout the trip, but a time delay is introduced to adjust for the walking trip to the shelter. Again, this is a good approximation for the range of movement time under consideration.

   Finally, a weighted movement time distribution for central cities under the existing shelter posture is formed by adding the weighted distributions for movement to both neighborhood and downtown shelter, in both the downtown area and in the rest of the central city. The movement time distribution for central cities is found by dividing the resulting weighted distribution by the total population of all the central cities.

Movement Time Distribution for Residents of Urban Fringe Areas

The weighted movement time distribution for movement to neighborhood shelters in urban fringe areas is computed in exactly the same manner as that for movement to neighborhood shelters in central cities. However, the SRI tabulation* used as a data base for both areas is made for SMSAs, with no distinction between the urban fringe of the urbanized area and the part of the SMSA that does not include the urban fringe. Some modifications in the SRI tabulations have therefore been necessary because the SMSA includes the entire county associated with the central city of the metropolitan area, while the urban fringe area has been identified on the basis of whether the character of the area is, in fact, urban.

This difference between the part of the SMSA outside the central city and the part of the urbanized area outside the central city is dramatized by the following comparison of census data for the two areas:

	Population	Land Area (sq mi)
Urbanized Areas	37,873,355	14,707
SMSAs	54,880,844	299,895

The large discrepancy in the land areas and the much smaller relative difference in population indicate that the population density in the urban fringe areas is much greater than the average for SMSAs outside the central cities. Data developed for the SMSA has therefore been converted to urban fringe data by representing the urban fringe as a part of the SMSA wholly contained within the SMSA. The number of SLs and the number of persons sheltered within their own SL (which had been tabulated for the SMSA) are allocated to urban fringe and nonurbanized areas according to the ratio of the population of the urban fringe portion to that of the non city portion of the SMSA in which it is contained. With the number of urban fringe SLs, their area, and the number of persons who could be sheltered in their own SL thus determined, the weighted distribution of movement times to neighborhood shelters in urban fringe areas is found.

The distribution of movement times to downtown shelters for urban fringe area residents is constructed by continuing the distribution of

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* Goodrich, previously cited.

the movement of central city residents if the shelter capacity does not terminate the distribution. That is, the distribution of movement times to downtown shelters for residents of central cities becomes the distribution of movement times to downtown shelters for urban fringe areas when the residents of the central city have all reached shelter.

Movement Time Distribution for Residents of Nonurbanized Areas

Of about 123 million shelter spaces that had been identified by the National Fallout Shelter Survey by January 1965, almost 22 million are located outside urbanized areas. To describe distributions for movement time to these shelters, it is assumed that all of these spaces are located in urban places as defined by the census. In gereral, an urban place is an incorporated or unincorporated community with a population in excess of 2,500 persons. The shelter spaces in these urban places outside urbanized areas are also considered as being divided into downtown and neighborhood shelters.

The movement time distribution for the neighborhood shelters is derived from a model city with a population and population density equivalent to the average of the 4,000 communities falling into the category of urban places outside urbanized areas. Using the techniques for estimating the movement time distribution for neighborhood shelters in urbanized areas, the average service area is computed. The population of these communities is determined from census data, and the land area computed from population density figures. The number of persons sheltered in their own standard locations in these communities is estimated at 11.5 million for areas outside SMSAs, based upon some intermediate computations prepared in conjunction with a study of nationwide expedient shelter,* plus another 2.5 million persons who are located in SMSAs but outside urbanized areas. The latter group was left over when the population in shelters was allocated in the determination of those sheltered in their own SL in urban fringe areas.

The remainder of the 22 million spaces outside urbanized areas are assigned distribution times based upon a distribution for movement to downtown shelter, using a value of b corresponding to a place with a population of about 7,000, the average size of places in this discussion.

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* Ernest C. Harvey, Preliminary Evaluation of a Nationwide Expedient Shelter Program, Stanford Research Institute, Draft Interim Report, December 1964.

Again, the movement time is truncated when the number of shelter spaces is equal to the weighted movement time distribution. Movement speed is assumed to be 40 mph in nonurbanized areas, and a short time delay is introduced to account for parking and terminal congestion.

Finally, the weighted movement time distribution for nonurbanized areas is computed by adding the weighted values of the distributions for neighborhood and downtown shelter for each value of movement time, then dividing the resulting weighted distribution by the number of persons residing in nonurbanized areas.

Movement Time Distributions for 1970 Shelter Posture

By 1970, according to Census Bureau projections,* the population of the United States will be about 210 million. Of these 210 million, it is estimated by SRI that about 70 million will live in the central cities of urbanized areas, about 68 million in urban fringe areas, and about 72 million in nonurbanized areas. This projection of the components of the national population has been made by extrapolating the trend from the 1950 to 1960 censuses to a 1970 distribution. This rough projection may somewhat overstate the growth of the central city areas, which individually have shown a slowing trend of growth. However, annexation and definition of new areas as urbanized areas will contribute to the projected increase.

A goal of civil defense is to provide fallout shelter for the entire population. It has been estimated† that 240 million shelter spaces will be required to shelter this 1970 population of 210 million persons in both the daytime and nighttime population distributions. These 240 million spaces will be so distributed that residents of urbanized areas will be able to travel to shelter in less than 45 minutes and residents of nonurbanized areas will be able to travel to shelter in less than 75 minutes.

The description of a projected set of distributions for the movement of the 1970 population to the shelters, so located as to meet the goals of the fallout shelter program, is given below.

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* Jacob S. Siegel, Meyer Zittner, and Donald S. Akers, "Projections of the Population of the United States by Age and Sex: 1964 to 1985," Current Population Reports, Population Estimates, Series P-25, No. 286, July 1964.

† Fallout Shelter Effectiveness, The U.S. Civil Defense Program, Department of Defense, Office of Civil Defense, July 1963.

Movement Time Distribution for Residents of Central Cities

From the movement time distributions developed for the existing shelter posture, 36.8 million persons already have movement times less than 45 minutes. Assuming that these same shelter spaces will still be used in 1970, an additional 33.2 million spaces need to be added to the shelter inventory in central cities to shelter the projected resident population. Movement times to these additional shelters will have the same distribution as the movement time to neighborhood shelters in the existing shelter posture. Use of this same distribution assures that the movement times will be within the goal of being accessible within 45 minutes, and will also allow for the fact that the sizes of shelters and shelter complexes will be about the same in 1970 as today.

Movement Time Distribution for Residents of Urban Fringe Areas

In the existing shelter posture, about 6.5 million persons in urban fringe areas are able to reach shelter with movement times less than 45 minutes. All but a hundred thousand of these are sheltered in neighborhood shelters. Although some of these 6.5 million spaces will be lost to central city areas by annexation and redefinition, others will be gained from annexations and redefinition of nonurbanized areas into urbanized areas. The net result will be about the same number of usable spaces in the urban fringe areas. An additional 61.5 million spaces must therefore be provided to shelter the 1970 urban fringe area population. Again, the distribution of movement times to these additional spaces will be the same as that to the existing neighborhood shelter spaces in these urban fringe areas.

Movement Time Distribution for Residents of Nonurbanized Areas

In the existing shelter posture, about 22 million shelter spaces are available for the residents of nonurbanized areas. These are all assumed to be located in urban places in the nonurbanized areas. Some of these shelter spaces will be transferred to central city and urban fringe areas through annexation and redefinition of areas, but it is assumed that new shelters will have the same characteristics as those transferred. The 1970 population of these urban places in nonurbanized areas is projected at 29 million using the same rough projection technique as was used to find the distribution of the population between urbanized and nonurbanized areas. The distribution of movement times to the additional shelters required to complete the sheltering of these 29 million persons will be the same as that to the existing shelters in these urban places in nonurbanized areas.

The remaining 43 million persons in the 1970 nonurbanized population will live in rural areas. These areas will have much lower population densities and longer travel times than the urban places. This lower density and longer travel time require that a new distribution of movement time be constructed for residents of rural areas. To construct this movement time distribution, it has been assumed that shelter service areas have been laid out in such a way that the maximum travel time to the shelter is no greater than 75 minutes. In allowing for this 75-minute travel time, it is assumed that automobiles will be used to travel to the shelter. It will not be possible to drive to the door of the shelter because of the large number of automobiles that will be used, the limited number of access roads, and limited parking facilities. The line of parked cars and parking delays will be such that the last 30 minutes of the journey to shelter will be covered by walking at three miles per hour. It has also been assumed that the population density of the service areas thus defined is constant, although not the same for all service areas.

The final distribution of movement times for residents of nonurbanized areas in 1970 is obtained by weighting the distribution of movement times derived for the residents of urban places in these nonurbanized areas by the projected populations of these areas and adding the weighted distribution to a distribution for rural residents similarly weighted by the rural population, and dividing the sum by the total projected population for nonurbanized areas.

Distribution of Time Required to Reach Shelter after Alert Signal Sounds

Finally, the movement time distributions developed above, and the starting time distributions developed in AII are combined to form a distribution of the times required to reach shelter. This distribution of times to reach shelter is the fraction of the population in shelter as a function of the time after alert signal sounds. The process of combining the starting time and the movement time distributions is exactly the same as that used to combine the alert verification time distributions and the movement preparation time distributions to obtain the starting time distributions. The combination of starting times and movement times has been carried out for each of the four starting time distributions associated with the four warning modes, and for the two movement time distributions associated with the two shelter postures considered. The result of these combinations is the eight curves shown in Figures 1-8.

Figure 1

FRACTION IN SHELTER vs TIME

EXISTING SHELTER, RADIO WARNING

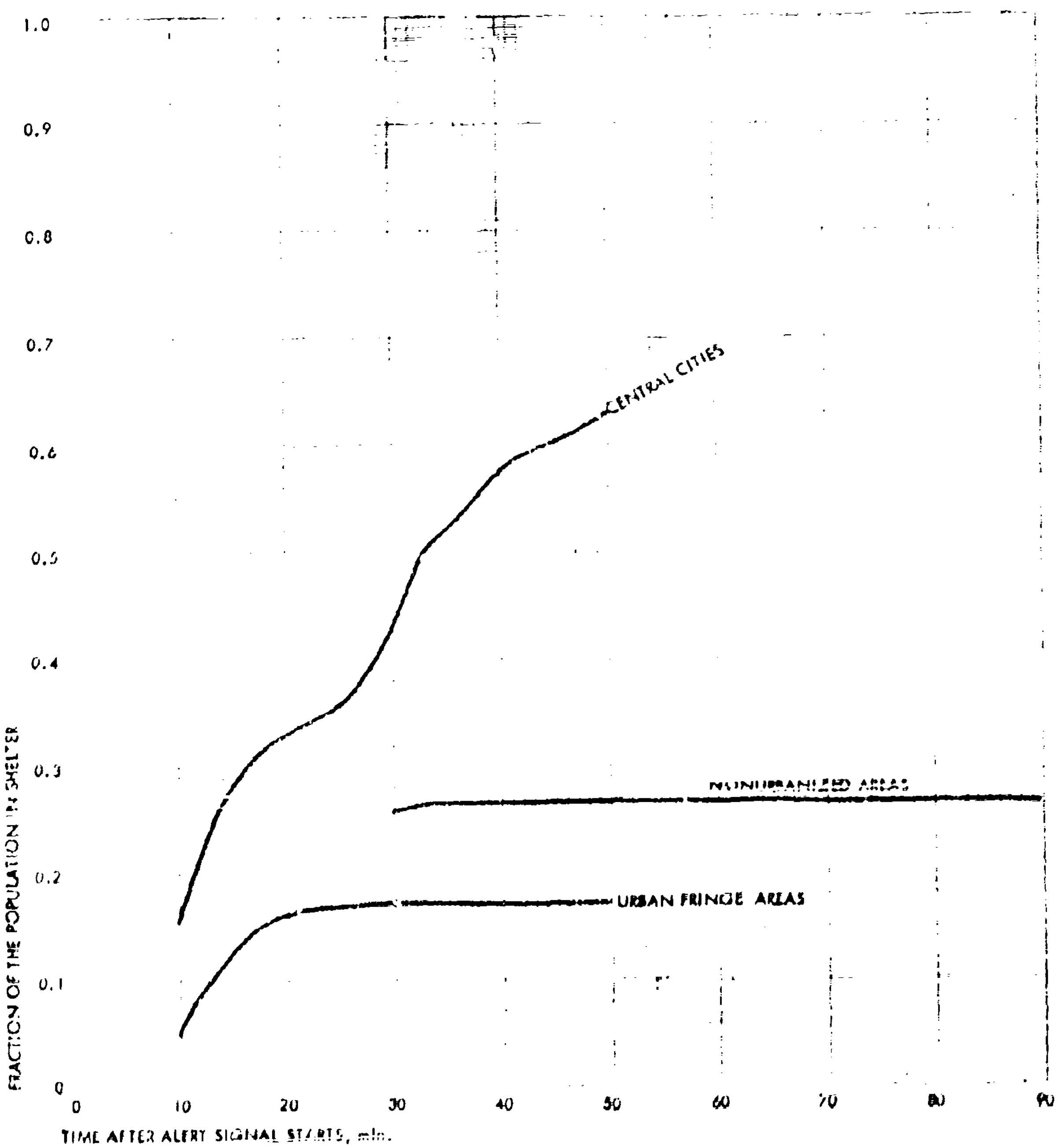

Figure 2

FRACTION IN SHELTER vs TIME

EXISTING SHELTER, INDOOR ALERTING

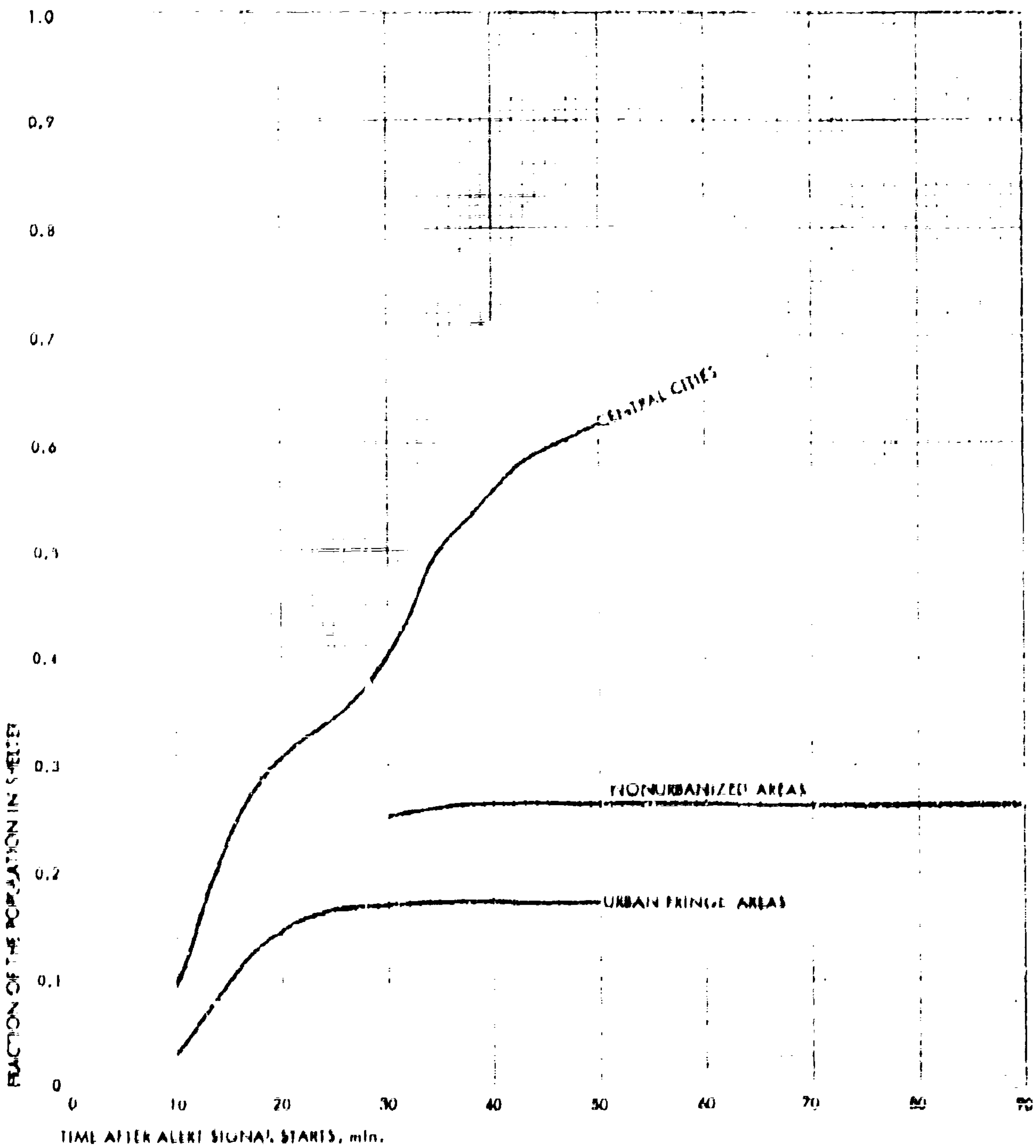

Figure 3

FRACTION IN SHELTER vs TIME

EXISTING SHELTER, SIREN ALERTING

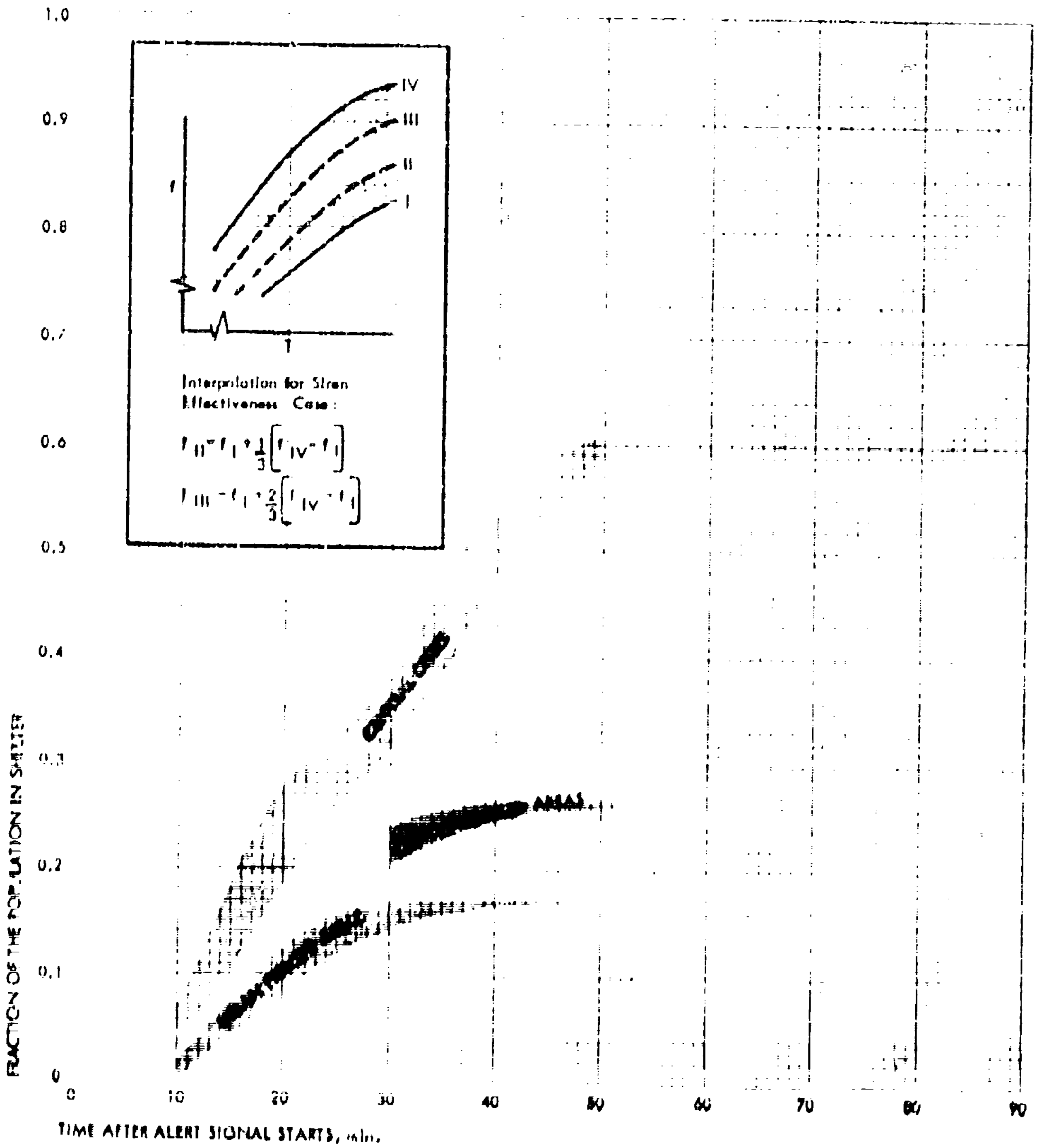

Figure 4

FRACTION IN SHELTER vs TIME

EXISTING SHELTER, NO ALERTING

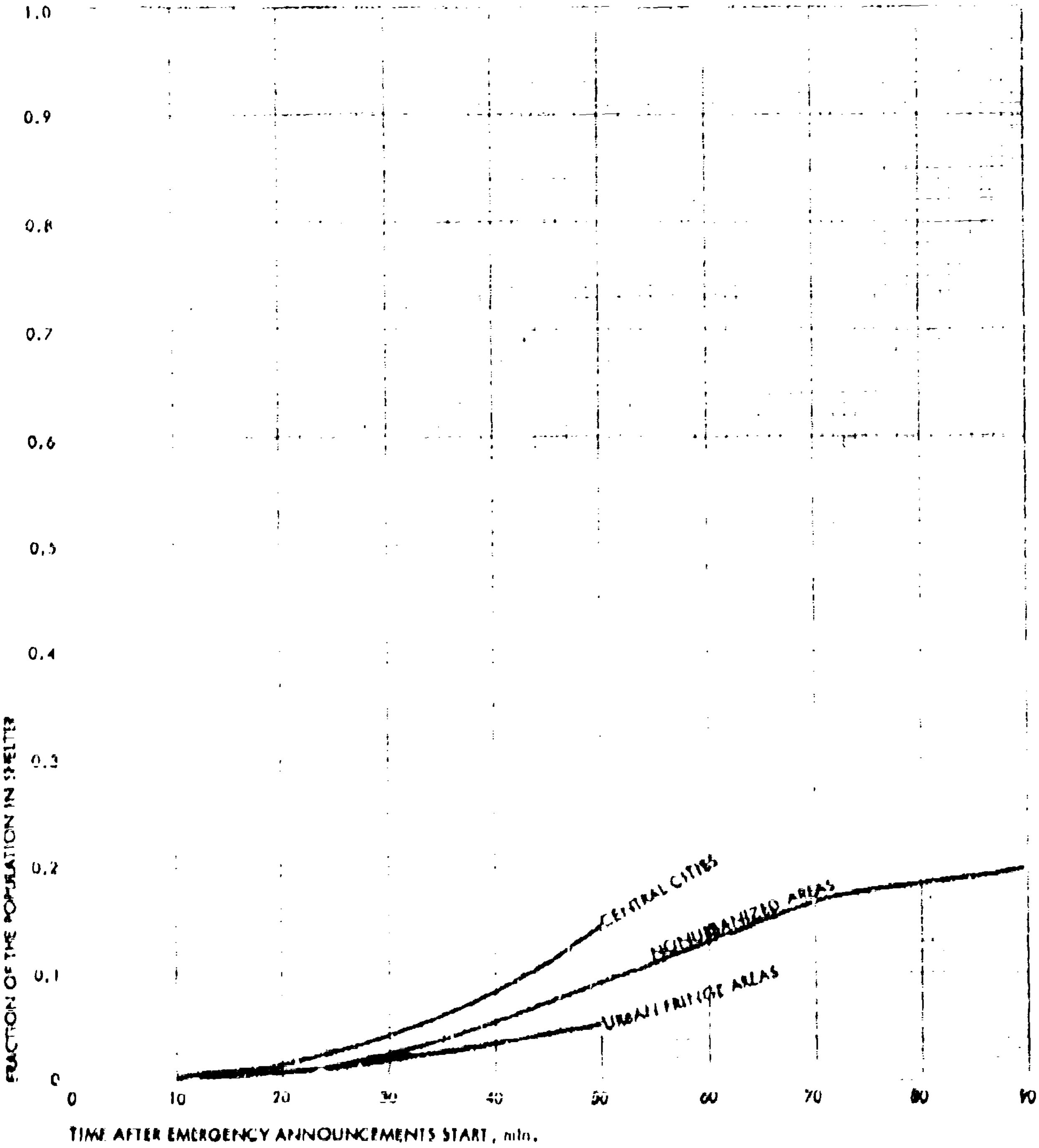

Figure 5

FRACTION IN SHELTER vs TIME

1970 SHELTER, RADIO WARNING

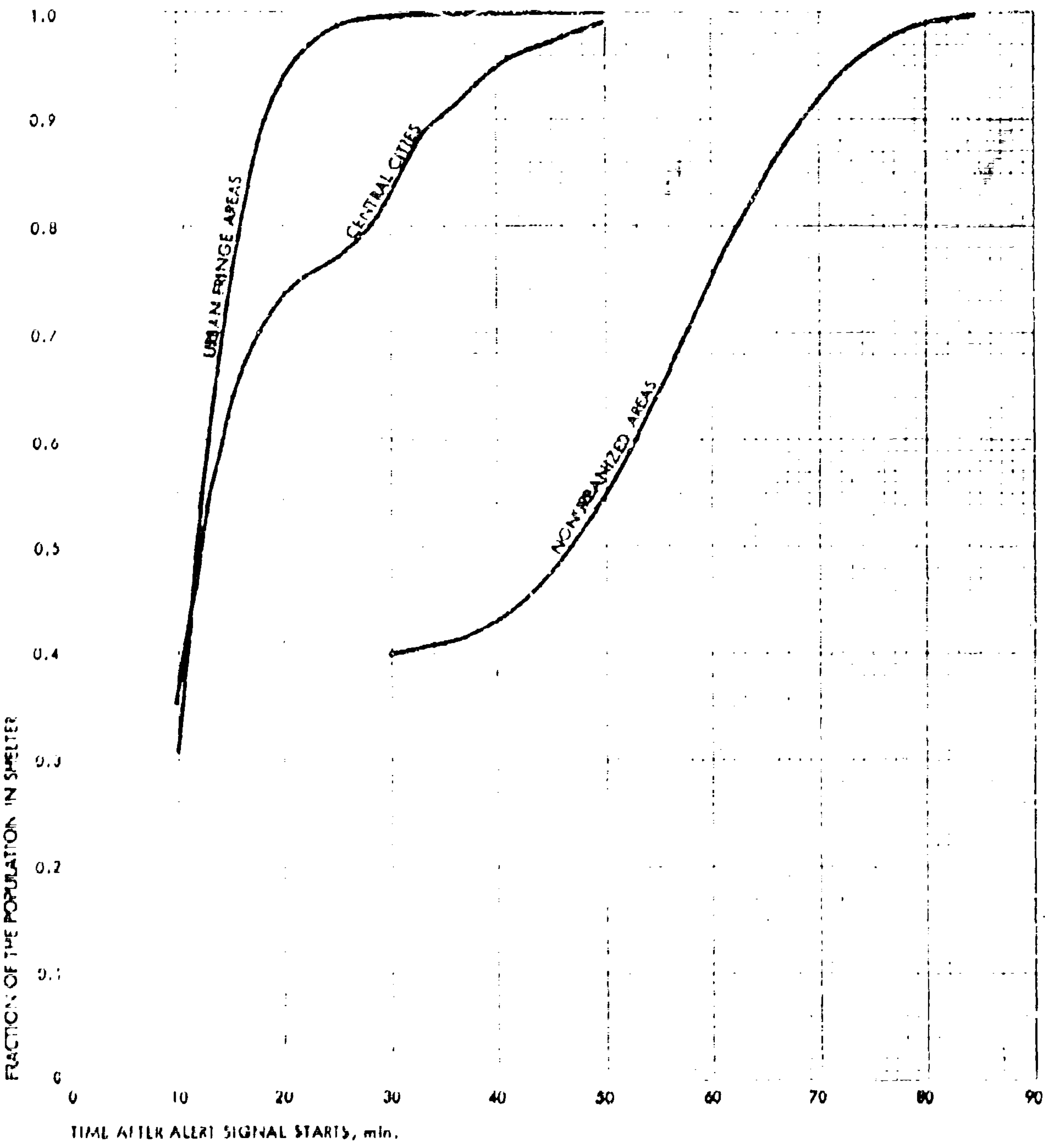

Figure 6

FRACTION IN SHELTER vs TIME

1970 SHELTER, INDOOR ALERTING

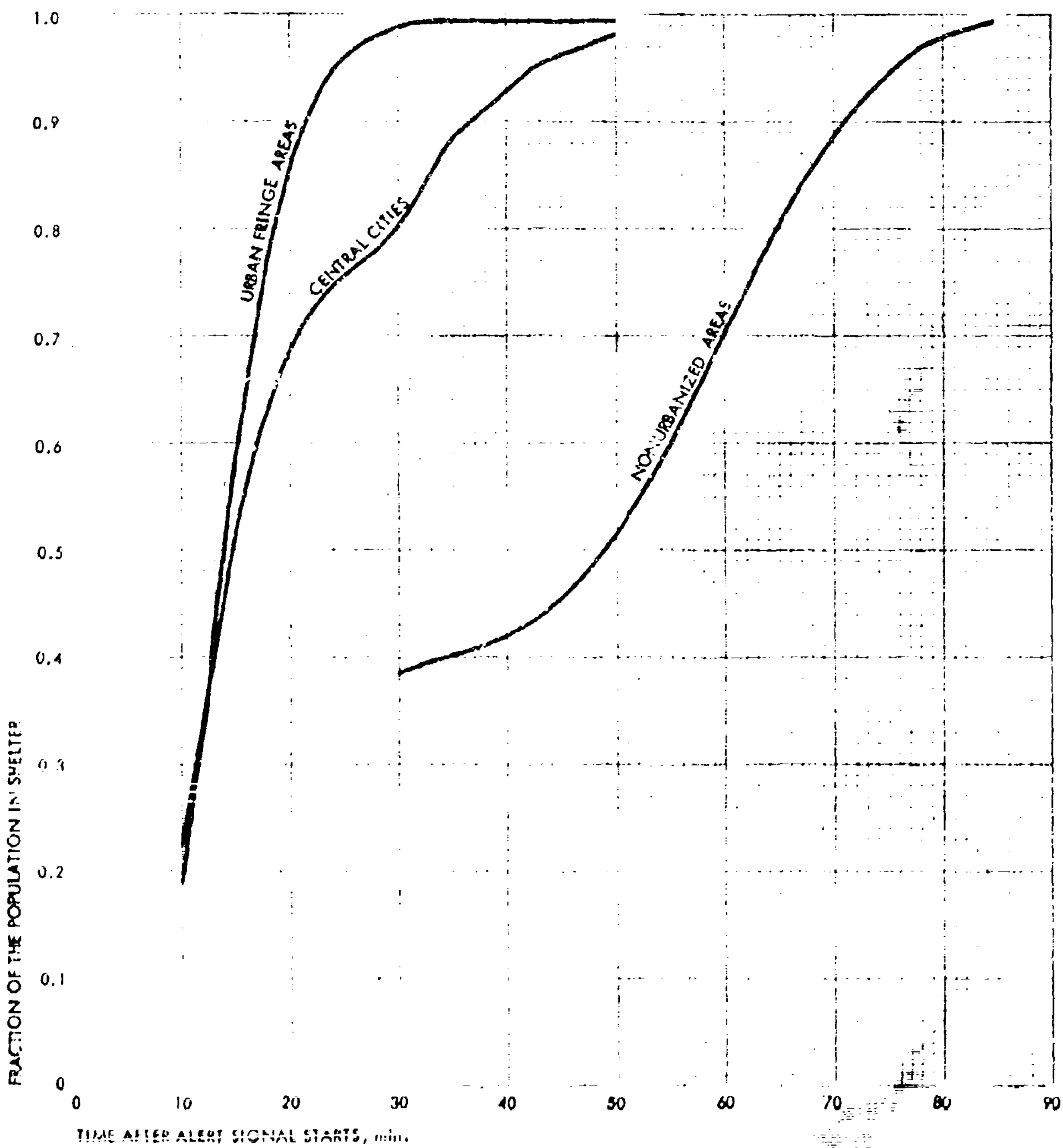

Figure 7

FRACTION IN SHELTER vs TIME

1970 SHELTER, SIREN ALERTING

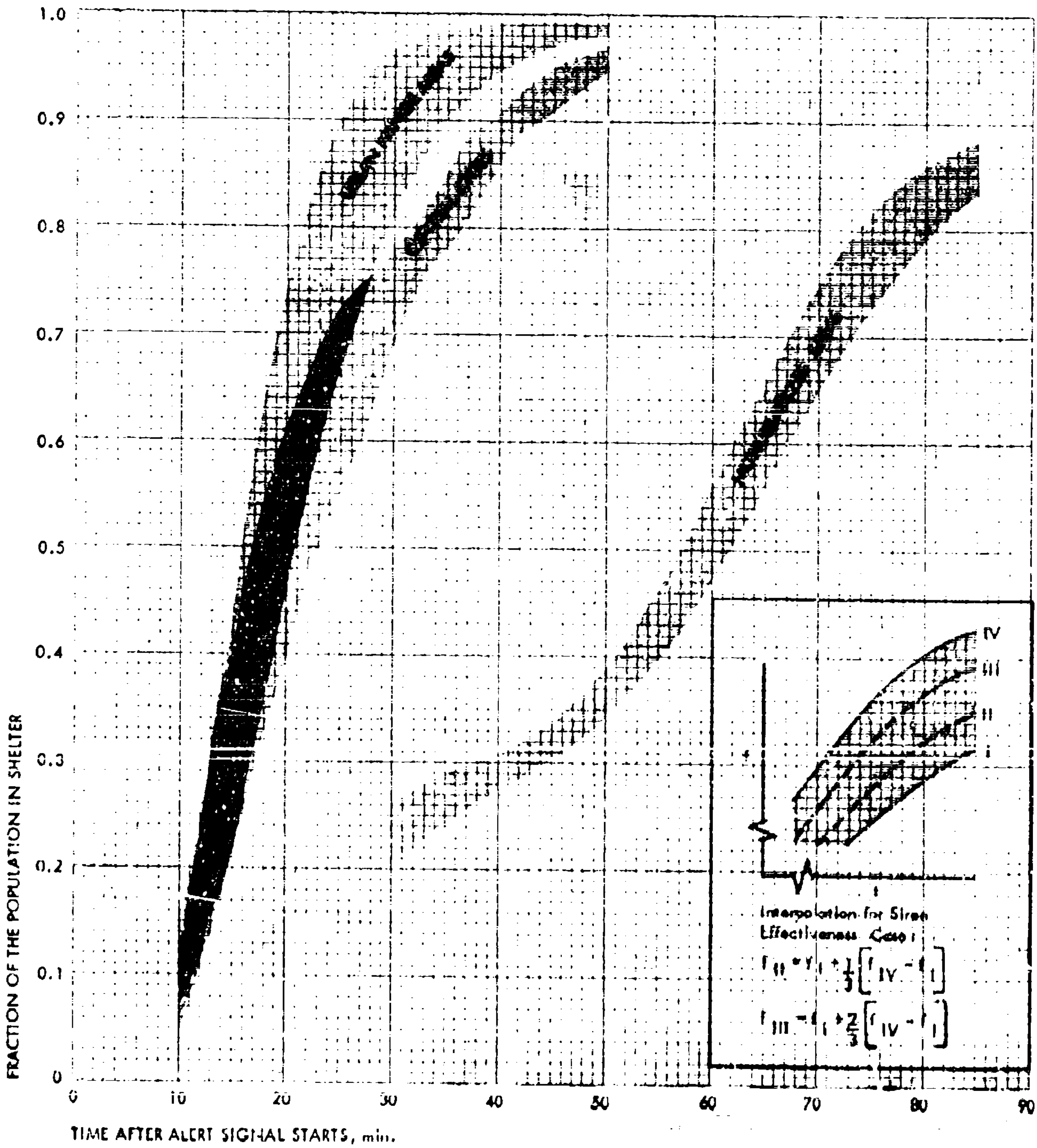

Figure 8

FRACTION IN SHELTER vs TIME

1970 SHELTER, NO ALERTING

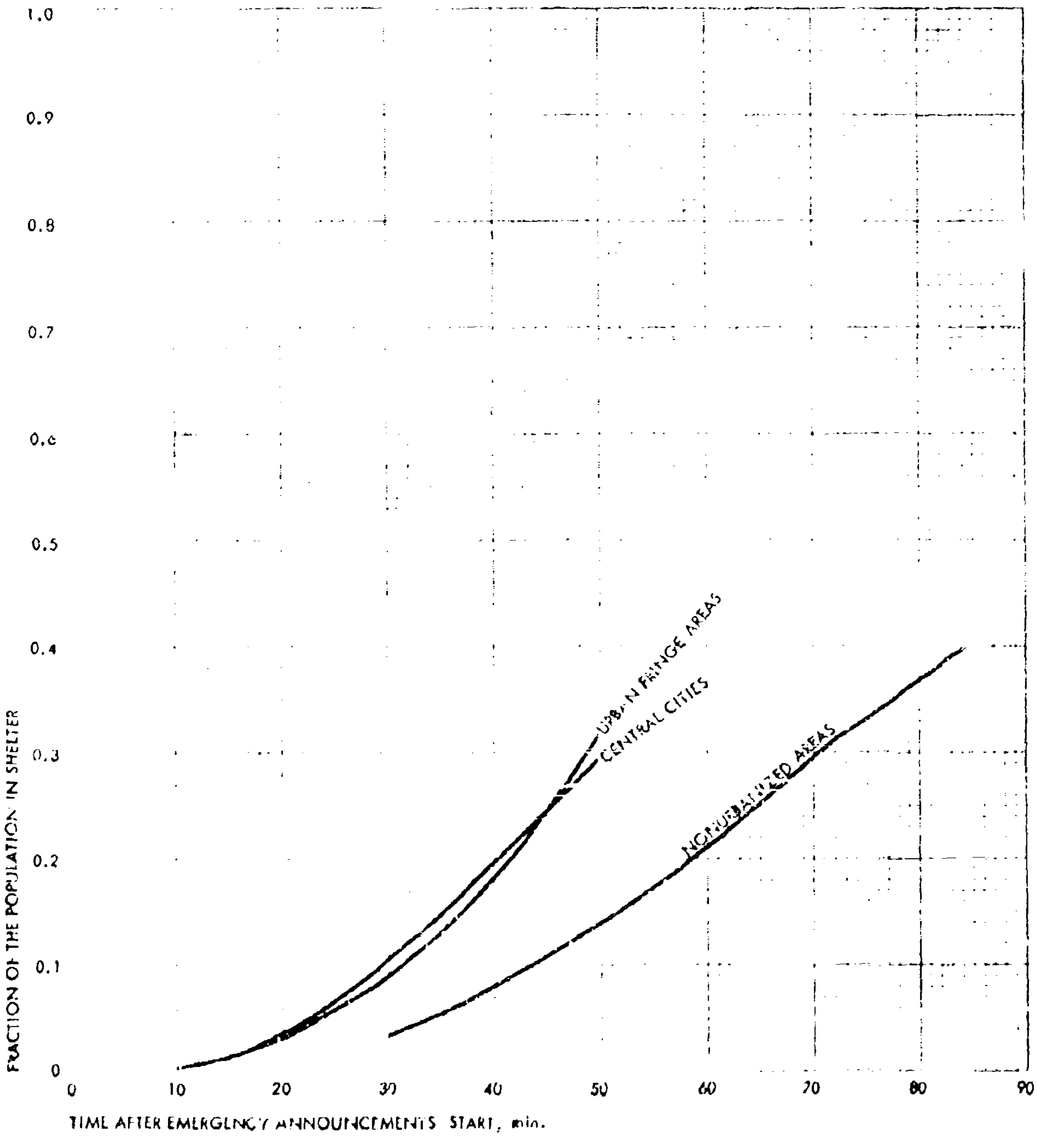

Figure 8

FRACTION IN SHELTER vs TIME

1970 SHELTER, NO ALERTING

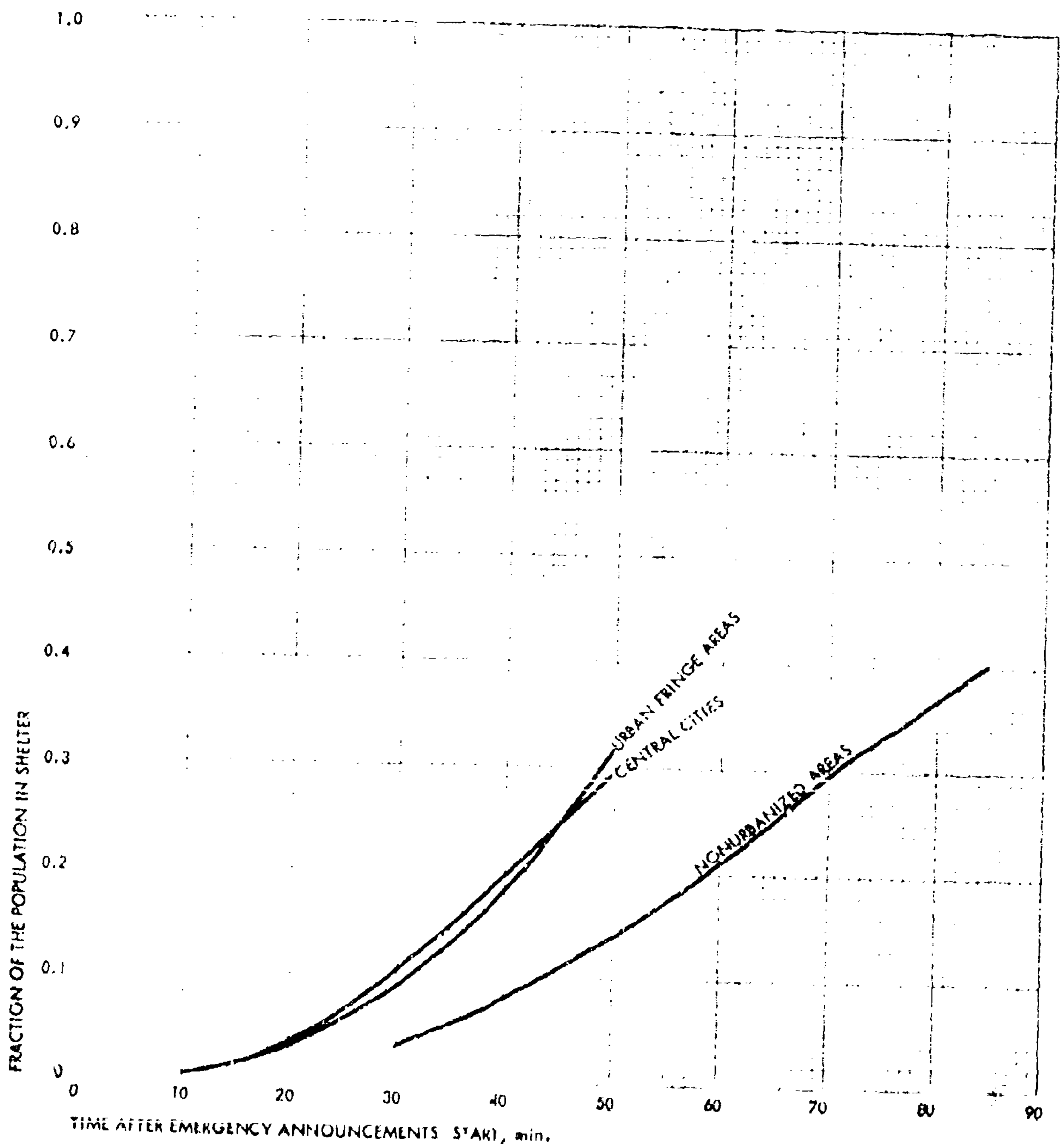

FIGURE 9

WORKSHEET FOR EVALUATING WARNING SYSTEM EFFECTIVENESS

PART I. WARNING SYSTEM ENVIRONMENT

A. Time era ______________________________

B. Fallout arrival time computations

1. Time from detection of attack to impact of weapons ______ min.
2. Time from detection of attack to initiation of warning signal (decision to warn time) ______ min.
3. Remaining time from decision to impact (line 1 minus line 2) ______ min.

	COLUMN a CENTRAL CITY AREAS	COLUMN b URBAN FRINGE AREAS	COLUMN c NONURBANIZED AREAS
4. Time from impact to fallout arrival	30.0 min.	30.0 min.	60.0 min.
5. Time from decision to fallout arrival (line 3 plus line 4)	______ min.	______ min.	______ min.

PART II. WARNING SYSTEM EVALUATION SUMMARY

(See following sheets for detailed evaluation of warning system modes. Listed below is a summary of the evaluation.)

WARNING SYSTEM MODE	FRACTION OF POPULATION IN SHELTER WHO WERE WARNED BY EACH MODE
A. Radio Warning	______
B. Indoor Alerting	______
C. Siren Alerting	______
D. No alerting	______
E. Total population in shelter resulting from this warning system configuration (sum of fractions from lines A, B, C, and D above)	______

FIGURE 9 (Continued)

PART III. DETAIL OF WARNING SYSTEM EVALUATION

A. Radio Warning Mode

	COLUMN a CENTRAL CITY AREAS	COLUMN b URBAN FRINGE AREAS	COLUMN c NONURBANIZED AREAS
1. Time from decision to fallout arrival (from Part IB, line 5)	______ min.	______ min.	______ min.
2. System response time (time from decision to warn to beginning of alert signal)	______ min.	______ min.	______ min.
3. Time remaining to reach shelter (line 1 less line 2)	______ min.	______ min.	______ min.
4. Fraction of radio warned population in shelter before fallout arrival. (Use radio warning chart for appropriate time era. Enter chart with time from 3 above, read fraction from chart)	______	______	______
5. Radio warning coverage (fraction of populations covered by signal and receiver distribution, multiplied by reliability, by area)	______	______	______
6. Fraction of area populations in shelter as a result of the stimulus from radio warning (line 5 times line 4)	______	______	______
7. Fraction of U.S. population residing in each area			
Existing	0.323	0.212	0.465
1970	0.333	0.324	0.343
Other	______	______	______
(Cross out inapplicable line)			
8. Fraction of U.S. population in shelter in each area as a result of radio warning stimulus (line 7 times line 6)	______	______	______
9. Fraction of U.S. population in shelter due to radio warning (sum of line 8, columns a, b, and c)		______	

B. Indoor Alerting Mode

	COLUMN a CENTRAL CITY AREAS	COLUMN b URBAN FRINGE AREAS	COLUMN c NONURBANIZED AREAS
1. Time from decision to fallout arrival (from Part IB, line 5)	______ min.	______ min.	______ min.
2. System response time (time from decision to warn to beginning of alert signal)	______ min.	______ min.	______ min.
3. Time remaining to reach shelter (line 1 less line 2)	______ min.	______ min.	______ min.
4. Fraction of indoor-alerted populations in shelter before fallout arrival. (Use indoor alerting chart for appropriate time era. Enter chart with time from 3 above, read fraction from chart.)	______	______	______
5. Indoor alerting coverage (fraction of populations covered by signal and receiver distribution, multiplied by reliability by area)	______	______	______
6. Fraction of area populations in shelter as a result of the stimulus from indoor alerting (line 5 times line 4)	______	______	______
7. Fraction of U.S. population residing in each area			
Existing	0.323	0.212	0.465
1970	0.333	0.324	0.343
Other	______	______	______
(Cross out inapplicable line)			
8. Fraction of U.S. population in shelter in each area as a result of indoor alerting stimulus (line 7 times line 6)	______	______	______
9. Fraction of U.S. population in shelter due to indoor alerting (sum of line 8, columns a, b, and c)		______	

FIG'RE 9 *(Concluded)*

C. Siren Alerting Mode

	COLUMN *a* CENTRAL CITY AREAS	COLUMN *b* URBAN FRINGE AREAS	COLUMN *c* NONURBANIZED AREAS
1. Time from decision to fallout arrival (from Part IB, line 5)	____ min.	____ min.	____ min.
2. System response time (time from decision to warn to beginning of alert signal)	____ min.	____ min.	____ min.
3. Time remaining to reach shelter (line 1 less line 2)	____ min.	____ min.	____ min.

4. Siren Effectiveness Group (see chart below)

		Radio Support for Sirens: Existing	Radio Support for Sirens: Close
Public Readiness	LO	I	II
	HI	III	IV

	COLUMN *a*	COLUMN *b*	COLUMN *c*
5. Fraction of siren-alerted populations in shelter before fallout arrival (select siren alerting chart for proper time era, enter chart with time from 3, above, determine fraction corresponding to siren effectiveness group)	____	____	____
6. Indoor siren coverage (fraction of population that can hear sirens indoors, by area)	____	____	____
7. Fraction of area populations in shelter as a result of the stimulus from siren alerting (line 6 times line 5)	____	____	____
8. Fraction of U.S. population residing in each area			
Existing	0.323	0.212	0.465
1970	0.333	0.324	0.343
Other	____	____	____
(Cross out inapplicable line)			
9. Fraction of U.S. population in shelter in each area as a result of siren alerting stimulus (line 8 times line 7)	____	____	____
10. Fraction of U.S. population in shelter due to siren alerting (sum of line 9, columns *a*, *b*, and *c*)		____	

D. No Alerting Mode

	COLUMN *a* CENTRAL CITY AREAS	COLUMN *b* URBAN FRINGE AREAS	COLUMN *c* NONURBANIZED AREAS
1. Time from decision to fallout arrival (from Part IB, line 5)	____ min.	____ min.	____ min.
2 System response time (time from decision to warn to beginning of emergency announcements)	____ min.	____ min.	____ min.
3. Time remaining to reach shelter (line 1 less line 2)	____ min.	____ min.	____ min.
4. Fraction of population warned by the No Alerting Mode, in shelter before fallout arrival time. (Use charts for no alerting mode in appropriate time era. Enter chart with time from 3, above, read fraction from curves)	____	____	____
5. Fraction of populations not covered by other warning modes, by area	____	____	____
6. Fraction of area populations in shelter who did not receive alerting stimulus (line 5 times line 4)	____	____	____
7. Fraction of U.S. population residing in each area			
Existing	0.323	0.212	0.465
1970	0.333	0.324	0.343
Other	____	____	____
(Cross out inapplicable line)			
8. Fraction of U.S. population in shelter in each area as a result of stimulus (line 7 times line 6)	____	____	____
9. Fraction of U.S. population in shelter who have been warned by the No Alerting Mode (sum of line 8, columns *a*, *b*, and *c*)		____	

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13 ABSTRACT

This report contains charts, worksheets, and instructions which permit a user to compute the fraction of the national population which will be able to reach fallout shelters within specified times. The computation of fraction of population in shelter may be performed for warning systems made up of combinations of radio warning, indoor alerting, siren alerting, and no-alerting modes. Fraction in shelter may be determined for the posture of existing shelter spaces as well as for a full fallout shelter posture.

Examples of the computation are presented, as well as examples of application of fraction in shelter as a measure of effectiveness.

An appendix describes the mathematical basis of the computation and the sources of data which went into the preparation of the charts.

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