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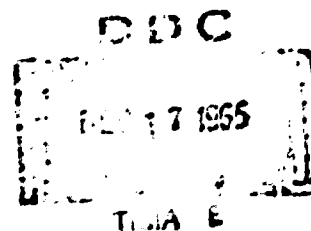
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# SENSITIVITY ANALYSIS OF
# CIVIL DEFENSE SYSTEMS AND COMPONENTS

## FINAL REPORT

## R-OU-157

### INTRODUCTION AND SUMMARY

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Introduction and Summary to Sensitivity Analysis
of Civil Defense Systems and Components


by

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Floyd M. Guess,
H. Rodney Sink,
and
K. E. Willis

October 1, 1965

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Introduction and Summary to Sensitivity Analysis
of Civil Defense Systems and Components

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FOREWORD

This is the Summary Volume for three separately bound volumes reporting research completed under the general terms of the Office of Civil Defense Subtask Number 4113E, "Sensitivity Analysis of Civil Defense Systems and Components." Volume I by Floyd Guess reports on A Cost/Effectiveness Computer Procedure for Optimum Allocation of Fallout Shelter System Funds Under Uniform or Variable Risk Assumptions, Volume II by Rodney Sink reports on A Sensitivity Analysis of Selected Parameters Based on 8 SMSA's. Volume III by John Neblett and K.E.Willis reports on A Generalized Sensitivity Analysis of CD Systems.

The research of the authors was very ably supported by Herbert Hill, Helen Anderson, and Mary Woodside. Philip McMullan and Robert Brooks are acknowledged for their valuable assistance in the preparation of the final report.

# ABSTRACT

This document summarizes a three part study concerning sensitivity analysis of CD systems and components in a fallout environment. In the first, a cost/effectiveness computer program is developed for optimum allocation of fallout shelter system development funds under uniform or variable risk assumptions. This program, intended for use in OCD planning studies, is programmed for the CDC 3600. It is applied in example studies using data on OCD Region 6. The second part of the study is a sensitivity analysis of selected parameters based on 8 SMSA's. It employs the transportation algorithm in a study of movement of people to fallout shelters. The results show how estimated casualties vary as movement-to-shelter patterns vary from restriction to a standard location up to free movement within the SMSA. They also indicate that detailed planning for shelter utilization can be very effective in reducing expected fallout casualties when the number of shelter spaces exceeds the population of an SMSA. In the third part of the study, a generalized sensitivity analysis is made of the parameters used in fallout vulnerability analysis models which determine total dose and equivalent residual dose. The results show that fallout casualties are very sensitive to estimates of initial intensity, protection factor, and fallout decay rate; and the equivalent residual dose during stay in the initial shelter is insensitive to the recovery fraction and rate of recovery parameters of the equivalent residual dose equation.

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## of Civil Defense Systems and Components

### I. INTRODUCTION

#### A. Shelter Systems Analysis

The general subject of shelter systems analysis is outlined in this section in order to place in context the sensitivity analysis reported in the following sections.

The existing Civil Defense system consists principally of fallout shelters, their support system, and operational plans for their use. Information from the National Fallout Shelter Survey (NFSS) gives the numbers and locations of spaces that could be used and their respective protection factors. Information also exists as to supplies and equipment contained in these shelters. Operational plans of varying degrees of completeness also exist throughout the country for the use of shelters in an emergency--that is, for population assignment to these spaces and shelter management policies.

The evaluation, or vulnerability analysis, of the shelter system requires estimation of both the effectiveness of the system as it now exists in alleviating the effects of nuclear attack and the effectiveness of alternative systems.

In order to perform an analysis of the effectiveness of an existing or proposed shelter system, it is necessary to consider three problem areas. First, some assumptions must be made about the radiation--its initial intensity, the time it will arrive, the time span during which it will continue to fall, and the rate of decay of radioactivity. Second, the shelter posture must be defined, principally in terms of the protective characteristics of the shelter and the time required to reach shelter. Third, some assumptions must be made about the physiological effects resulting from the assumed levels of radioactivity.

Systems analysis also requires that measures of effectiveness be established so that the effect of alternatives can be compared. Some common measures of effectiveness are probability of fatality, probability of non-fatal casualty, or required stay in shelter to meet some specified criterion--such as equivalent residual

dose (ERD) returning to an allowable level.

The results of systems analysis are used to evaluate the current civil defense system, to evaluate alternative systems, and hence, to insure that the limited funds for system improvement yield the greatest gains possible.

Assumptions about thermonuclear war environments obviously are questionable because of the lack of observational experience. Uncertainty also results from lack of reliable data for some necessary inputs to the analysis, such as the dose-response curve for fallout casualties. To evaluate the magnitude of the uncertainty in results and conclusions, one must test the effects of uncertainties in these input variables. When these effects are evaluated, the degree of confidence which can be placed in the results of systems analysis will be better known; further, research can be directed in some cases towards reducing the uncertainty of the inputs to which evaluations are most sensitive. A collateral benefit for systems analysis is simplification of the treatment of variables to which the outputs are insensitive. In some cases, the less sensitive variables may be eliminated.

The sensitivity analysis carried out during the past year is described next.

B.  Objectives of the Study

The contract language is quoted below:

> "Using the tools developed under OCD Projects 4631A and 4521A (formerly 4104A and 4104B respectively), perform for selected local areas detailed sensitivity analyses of the variable elements of shelter systems evaluation (such as relative location of people and shelter, warnings and reaction time, movement to shelter, shelter stay time, food and water supplies, mass decontamination and evacuation) over the range of feasible fallout environments. Emphasis would be placed on incorporating the cost-effectiveness findings of concurrent research on shelter and support systems.
>
> "Use the results of such analysis to (1) assist in the design and performance of total CD system and (2) assist, as specifically authorized by separate letter instruction, in the formulation of computer programs and systems evaluations using the NREC and OCD damage assessment system for the 1103A or CDC 3600 computer."

The description of the approach and research findings is presented in three volumes of this report, as follows:

| Volume No. | Title |
|---|---|
| I | A Cost/Effectiveness Computer Procedure for Optimum Allocation of Fallout Shelter System Funds Under Uniform or Variable Risk Assumptions |
| II | A Sensitivity Analysis of Selected Parameters Based on 8 SMSA's |
| III | A Generalized Sensitivity Analysis of CD Systems |

The summary below follows the same sequence. Sensitivity analysis of various components of CD systems is the subject of Volumes II and III, while cost and effectiveness analysis is the subject of Volume I. The marginal expenditure procedure described in Volume I provides for optimal allocation of funds to shelter improvement options, subject as always to certain policy decisions.

All elements of the research were directed to the "fallout only" attack environment. Recommendations are offered for future research to incorporate prompt weapon effects; a small effort also will be necessary to improve the models and methods employed.

The next three sections summarize the research approach, relevant findings, conclusions, and recommendations for each of the three principal tasks and chapters.

## II. SUMMARY

A. **A Cost/Effectiveness Computer Procedure for Optimum Allocation of Fallout Shelter System Funds Under Uniform or Variable Risk Assumptions**

1. **Approach to the Research**

The dynamics of civil defense planning and systems evaluation require a procedure that will readily yield approximate answers to such questions as:

a. How many lives could be saved with an expenditure of $1 billion, $5 billion, $15 billion, or any other arbitrary budget level?

b. How should such budgets be expended--within regions, states, metropolitan areas, counties, and smaller locations--for each assumed budget level?

c. How and where would the expenditure pattern vary if one assumed that all parts of the United States were subject to a uniform hazard level--or to variable hazard levels?

d.   What is the dollar-costing relationship between attack hazard, casualties, and standards of acceptable shelter?

Our approach has been to develop and demonstrate a computerized procedure that will answer these and related questions under the following constraints:

a.   Use available data, such as the NFSS and National Location Code, wherever feasible.

b.   Use existing computers, programs, and planning techniques as used by OCD, such as RISK or NAHICUS, wherever feasible.

c.   Provide means for readily accepting new or improved data, and for using interim estimates where critical data deficiencies exist.

d.   Concentrate initially on cost and effectiveness of a fallout shelter system, but include provision for extending the system to blast and other prompt effects considerations.

e.   Provide means for accepting data on all civil defense subsystems of measurable significance.

At this point in the research, it is prudent to say only that we present a rational, well-defined methodology for engaging in "risk-oriented programming"; it is not part of this research task to examine the advisability of risk-oriented courses of action. Should "risk-oriented programming" be decided upon, the tool developed in Volume I is ready for application. Further analysis can offer guidance in making the decision of whether or not to adopt "risk".

In order to apply the risk-oriented budget allocation procedure, the following input data are required (note that this demonstration is limited to the fallout-only case):

a.   The present shelter posture and methods for estimating casualties (or other measure of effectiveness) must be specified. This requires a population data base (here taken as residential), a means of assigning them to shelter (of a specified protection factor), and a casualty criterion.

b.   An estimate is required of the probable attack environment defined by areas of such a size that they experience essentially a homogeneous environment. For fallout only, such areas may be quite large. A further constraint on the size of the area within which one matches shelter and population is that the two are close enough together that

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shelters may be assumed occupied on arrival of fallout. The accumulation unit used here for shelter and population is the county. For illustrating the method, NREC RISK-type attack environments are assumed at two levels: 50% (expected value) and 95% (only 1 in 20 chances of being exceeded).

c.  Further, a specified set of alternatives for spending for shelter improvement and a means for computing the contribution of each alternative to the measure of effectiveness are required. The alternatives chosen in this analysis are based on NFSS Phase 2 estimates of improvable shelter (improvable by shielding or ventilation) and PF Category 1 shelter from NFSS Phase 1 data. When existing and improvable NFSS shelters are exhausted, new shelter spaces--for not over 10% of the population--are considered to be available at $25 per space. For costing complete shelter coverage, an additional alternative of unlimited new construction at $50 per space is also examined. With these input data, the appropriate measure of effectiveness (survivors added, for example) may be calculated for combinations of spending alternatives. If one chooses a measure of effectiveness having a continuum of values (such as probability of fatality, from which survivors added are derived), the optimum fund allocation problem is one of classical linear programming. This may be solved by well-known methods, but a program of realistic size can be very time consuming even when a large-scale computer is used. On the other hand, as done here, if one chooses an objective function which takes on two discrete values, such as "ERD greater than 200r is ineffective", the optimal allocation problem reduces to one of ordering the shelter improvement alternatives in the decreasing order of cost/effectiveness. Then one simply chooses the shelter improvement alternative of highest cost/effectiveness, then the one with the next highest, and so on, until either the budget or the spending alternatives are exhausted.

d.  A finite or infinite budget must be specified. Depending upon the budget and the particular improvement alternatives specified, one may "buy" all the available alternatives; more commonly in practice, the budget is the constraint and not all alternatives will be "bought".

## 2. Demonstration of the Model

To demonstrate the model, an analysis is made of OCD Region 6. The total population of these 8 states (619 counties) is 14,000,000. In all, 14 cost studies are run, using selected combinations of the following parameter values:

a. The budget level (unlimited, $20 million, and $10 million);

b. The risk level (50%, or "expected value" of attack environment; and 95%, a very "safe" planning criterion);

c. The Maximum ERD defining an acceptable shelter Protection Factor-fallout level combination (100r, threshold of perceptible physiological effects; and 200r, threshold of casualties);

d. Residential basements excluded, or included;

e. Residential basements and Category 1 NFSS shelters excluded;

f. Shelter overcrowding by 25%;

g. Ventilation costs reduced to $3 per space; and

h. PF's of shelter multiplied by approximately 2 (reflecting approximations of the order of magnitude of the conservative bias used in the Phase 1 NFSS calculations when compared to the more nearly correct calculations using the current Engineering Manual data).

The program is designed to make provision for prompt weapons effects, but they are temporarily excluded from the analysis. Their later inclusion is discussed in Volume I.

## 3. Conclusions

a. The demonstration applied to Region 6 shows the practicality of carrying out large-scale marginal cost/effectiveness analyses.

b. There is a great need for reliable input data--particularly the unit cost and available numbers of new shelters.

c. The model and case studies described give much guidance about shelter development planning. However, the existing procedure still leaves scope for the decision maker. His willingness to apply this procedure is contingent on the sensitivity of allocation decisions to judgment factors such as listed below. Model case studies can give valuable insights concerning these questions.

(1) Should "risk-oriented" programs be developed?

(2) What will be the severity of the impact of future changes in expected attack environments?

(3) What compromise plan would be acceptable for an area in which the optimum improvement programs are very different for day and night population?

4. Recommendations

a. It is recommended that the marginal cost/effectiveness model be extended to incorporate prompt weapons effects, and that alternative measures of effectiveness be explored.

b. It is recommended that numerous systematic case studies be performed to test the impact of possible wrong decisions (due primarily to the inherent uncertainty of forecasting the future).

B. A Sensitivity Analysis of Selected Parameters Based on 8 SMSA's

1. Approach to the Research

The overall objective of this phase is the assessment of casualties in 8 representative cities over a range of fallout environments and shelter utilization patterns. The cities are selected on the basis of "judgment sampling" after making a two-way classification according to population density (residents per square mile) and shelter coverage of the residential population. The population density ranges from 1320 for Mobile, Alabama to 12,950 for Charleston, South Carolina. Shelter coverage (Category 1 or better, based on Phase 1 NFSS) ranges from 20% for Orlando, Florida to 160% for Richmond, Virginia. Residential population ranges from 74,000 for Pittsfield, Massachusetts to 408,000 for Richmond, Virginia. The remaining three cities are Tucson, Arizona; Macon, Georgia; and Waterloo, Iowa. The fallout environments used range from a reference intensity of 600 r/hr with time of arrival of 7 hours to a reference intensity of 30,000 r/hr with time of arrival of 1 hour. The former approximates the median environment based on an assessment of probable fallout environments; e.g., about half are more intense. The latter reference intensity is rarely exceeded (less than one percent are more intense).

Shelter assignments are made using several methods, including the well-known transportation algorithm which minimizes the expected casualties while

allowing for movement in fallout. The cost matrix for the transportation algorithm, when computed (using an RTI computer program), shows the Maximum ERD acquired for each pairing of population in a standard location (SL) and each shelter (taking account for its protection factor). Distances traveled are rectangular distances between centers of SL's. Speed is always a constant, conservative 2 mph. The fraction of casualties then is computed using a "go/no-go" definition of a casualty (ERD $\geq$ 200r).

Since a shelter assignment plan based on the transportation algorithm is mathematically the best possible for a given fallout environment, and instantaneously takes account of the particular environment encountered, it may be regarded as unrealistic. (This is not to say that a more workable decision rule for shelter assignment would not lead to a similar assignment and equivalent movement pattern.) Accordingly, for all cities, alternative shelter assignments are made, introducing more realistic movement restrictions:

    a.   Movement restricted to own standard location.

    b.   Movement restricted to within 2 miles of own standard location.

    c.   Movement unrestricted within the Standard Metropolitan Statistical Area (SMSA).

In each of these three cases, shelters are assigned using a "hand" map technique. Dose due to movement in fallout is not computed, as the circumstances are assumed to be equivalent to a long tactical warning or to strategic warning which would allow movement to shelter before arrival of fallout.

Trade-offs between movement in fallout and primary shelter PF are examined in a general manner because of their importance in the transportation algorithm solution.

2. **Results**

    a.  **General**

        Each city is examined "microscopically": Radial frequency distributions of distances from city centers of both population and shelter are plotted; histograms of shelter spaces by PF category, and numbers and costs of improvable spaces are analyzed. Improvable space numbers and costs average about 17 percent of the population and $7 per space.

        It was hoped that the effects both of protection factor (PF) and juxtaposition of people and shelter and the latter's effect on shelter

utilization could be examined. However, shelter PF's are comparable in most cities (21%-31% of total shelter space was 100 PF or better for six of the eight cities; the other two were 40% and 48%). The effects of different patterns of shelter utilization are discussed below.

b. Discussion

For reasons cited below, the conclusions drawn from this analysis relate to shelter utilization rather than to the more fundamental variables of knowledge, time, and distance which determine utilization. These variables are defined as follows:

(1) Knowledge by the population of what shelter they should use (shelter assignment plan, discipline, crowd control, etc.).

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

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

In a complete analysis, relations among these three variables must be derived (for obviously they are not independent), and these in turn must be related to the shelter utilization pattern.

In the analyses reported here, knowledge, time, and distance to the shelter are introduced by varying "movement restrictions" as follows:

(1) Movement Restricted to Own Standard Location. Knowledge very great, and time and distance allowance great enough, to allow best shelter utilization within one's own standard location (SL) (Movement Restriction 1).

(2) Movement Restricted to 2 Miles from Own Standard Location. Knowledge very great, and time and distance allowance great enough to allow best utilization of any shelter within one's own standard location (SL), or an SL not more than two miles away (rectangular distance) (Movement Restriction 2).

(3) Movement Unrestricted Within SMSA. Knowledge very great, and time allowance great enough to allow best shelter utilization at long distances anywhere in the SMSA (Movement Restriction 3).

(4) Optimum Shelter Utilization (Transportation Algorithm). Knowledge exact, to allow optimal shelter utilization (minimum

casualties) anywhere within the SMSA, including a prior calculation of dose received during transit in fallout and in the primary shelter, all before or during fallout arrival; speed is restricted to 2 mph. (Movement Restriction 4).

An optimum mathematical solution presented in Movement Restriction 4 is not practically realizable, as it assumes "perfect" prior knowledge of the attack environment and "perfect" population response. However, a similar shelter utilization pattern could be generated by other assumptions that are operationally more realistic; for example, this can be seen for unrestricted movement (Restriction 3) in Table I, Summary of Casualty Estimates (% of Population) for Reference Intensity of 2000 r/hr and Time of Arrival of 1.5 Hours. Casualties differ between Restrictions 3 and 4 in only two of the eight SMSA's. Unrestricted movement and a mathematically optimum solution offer a benchmark of ideality against which to measure other shelter utilization patterns.

TABLE I

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

| SMSA | Shelter/Population Ratio Categories 1 and Better | Restriction 1 Movement Restricted To Own SL; Movement Completed Before Fallout | Restriction 3 Movement Unrestricted Within SMSA; Movement Completed Before Fallout | Restriction 4 Constant Movement Speed of 2 mph Restriction; Movement Permitted in Fallout (Transportation Algorithm) |
|---|---|---|---|---|
| Orlando | .20 | 94 | 78 | 78 |
| Tucson | .24 | 89 | 74 | 74 |
| Charleston | .33 | 83 | 70 | 70 |
| Mobile | .48 | 78 | 54 | 54 |
| Macon | .50 | 77 | 46 | 46 |
| Pittsfield | .65 | 64 | 43 | 43 |
| Waterloo | 1.10 | 83 | 0 | 25 |
| Richmond | 1.60 | 66 | 0 | 36 |

c.  Major Conclusions

Efficient shelter utilization appears to be a critical problem when the shelter spaces exceed population; inefficient utilization can lead to a large number of avoidable casualties. This is concluded from the observation of the rapid increase in casualties for a specified attack

environment as one restricts movement progressively from the SMSA down to the SL in which the shelteree finds himself at the time of warning. For the most shelter-abundant cities (Waterloo and Richmond in Table I), the percentage of casualties under a 2000 r/hr fallout environment is progressively reduced. The percentages reduce progressively from a two-city average of 75% to 30% for decreasing movement constraints, and to 0% for unrestricted movement within the SMSA.

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

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

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

d. Secondary Conclusions

(1) Movement in fallout to a better shelter theoretically is warranted in many circumstances. The quantitative trade-offs between protection factor of the shelter and movement time in fallout are shown in Figure 31 of Volume II. The feasibility of applying this principle in the transattack environment is questionable, however. It is a special case of remedial movement, but with a very short decision time and a changing environment.

(2) Neither city size nor population density (one of the city-selection criteria), which might be supposed to have an effect on juxtaposition of people and shelter, could be shown to be significant in this analysis. This is concluded from examining the difference in

casualties in each attack environment, between Movement Restriction 4, (movement in fallout, but limited movement speed), and Restriction 3 (complete freedom) as a function of city size and population density. Small effects which likely exist either are swamped by the more critical shelter/population ratio, or are undistinguishable from the "noise" of variable PF distributions in cities otherwise similar (size and population density). The casualties differ between Restrictions 3 and 4 only for Waterloo (low density, small size) and Richmond (high density, large size) at the intermediate attack environments.

e.   Recommendations

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

## C.   A Generalized Sensitivity Analysis of CD Systems

### 1.   Approach to the Research

#### a.   Introduction

This subtask employs specific models which estimate the total dose, Maximum ERD, or probability of casualty or fatality for an individual exposed to a particular radiological environment. The total dose model is analytical and the ERD model is computerized. These models are used to examine the sensitivity of the dose (or probability of casualty) to variations in the input parameters used to define the radiological environment. The specific parameters used are those in Table II, Input Parameters for Generalized Sensitivity Analysis.

Sensitivity indices are calculated for each parameter. The sensitivity index is defined as the fractional change in dose, probability of casualty or fatality divided by the corresponding fractional change in the input variable. Hence, the relative ranking of these indices serves to identify the input parameters which influence the system performance most significantly.

b. ERD Model

In the computerized ERD model, a range of variations significant for each input parameter is estimated. For each input parameter at least three values are chosen to cover the range; these are listed in Table II. Maximum ERD is calculated for each combination of input parameters. These thousands of data points then are used to obtain an analytical function for Maximum ERD which is equivalent to the computer model. The analytical function allowed the direct calculation of sensitivity indices.

A similar analysis is made using as the measure of effectiveness the length of stay in primary shelter required to allow ERD to fall to 80r or 50r.

## TABLE II

### Input Parameters for Generalized Sensitivity Analysis

| Parameter | Symbol | Input Values |
|---|---|---|
| Reference Intensity (r/hr) | $I_o$ | 300, 1500, 2700, 3900 |
| Time of Arrival of Fallout (hrs) | $T_A$ | 1, 4, 7 |
| Time Outside in Fallout Before 1st. Shelter (hrs) | $T_2$ | 0.0, 0.3, 0.6 |
| Radiation Decay Exponent (dimensionless) | Z | 1.0, 1.2, 1.4 |
| ERD Recovery Fraction (dimensionless) | F | 0.85, 0.90, 0.95 |
| ERD Recovery Rate (fraction/day) | B | 0.020, 0.025, 0.030 |
| Duration of Fallout Buildup[*] (dimensionless) | E | 1.13, 3.64, 6.15 |
| Protection Factor (dimensionless) | PF | 2, 10, 40, 100, 500 |

[*] E is a factor such that $E \cdot T_A$ = duration of fallout deposition.

c. Total Dose Model

When total dose is used as the measure of effectiveness instead of ERD, it is convenient and more economical to use non-computer analytical techniques. With a non-computer analytical model, sensitivity indices are calculated for all the parameters listed in Table II, except ERD Recovery Fraction (F) and ERD Recovery Rate (B). When these indices are evaluated at the "mean values" of the input parameters, they are found to agree closely with the ERD model. This non-computer analytical model is used to plot the sensitivity indices as functions of several of the input variables. These plots are used to examine sensitivity indices for input parameters at values other than "mean values."

2. Results

a. Introduction

The general definition of sensitivity stated above is applied to civil defense systems analysis by relating a range of input parameters to a range of uncertainty for physical constants (such as decay exponent, bodily repair, as reflected in the two ERD parameters, F and B, etc.) or to uncertainty in the attack environment (reference intensity, time of arrival, etc.). When this is done, we can conclude that particular care must be exercised in CD systems evaluations relating to these sensitive parameters, or that for parameters to which probability of casualty or time required in primary shelter are sensitive, further research may be required to narrow the range of uncertainty. When it is found that the output is insensitive, perhaps we can drop any variation in the parameter in our shelter system evaluation, or, at least, we can be secure in the knowledge that no seriously incorrect results can arise from this quarter.

b. Casualty Computation Sensitivity Indices

Table III, Relative Importance of Parameters in the Fallout Shelter Sensitivity Analysis, summarizes the primary conclusions of these sensitivity analyses which were concerned with fallout casualty computations. The table shows (for each input parameter examined) the sensitivity index obtained using both the computerized ERD model and the total dose model. These sensitivity indices indicate the relative importance of the parameters as they appear in the equations used to compute fallout casualties. However, this expression of the mathematical sensitivity of the parameters must be further examined with respect to the estimated accuracy or

"uncertainty" of the parameter. For example, the Radiation Decay Exponent has a sensitivity index of -4.22, which indicates that a +10% change in this exponent (e.g., a change in the radiation decay rate from $t^{-1.2}$ to about $t^{-1.3}$) will produce a -42.2% change in Maximum ERD and a similar change in computed fallout casualties for the appropriate ERD ranges. However, examinations reported in Volume III indicate that errors of this magnitude in predicting the decay exponent are less likely to occur than error of 10% in predicting other parameters (e.g., reference intensity). To account for such differences in probable errors inherent in estimating the parameter values, the column labeled "Uncertainty" in Table III is employed. The listed values of uncertainty are multiplied by the sensitivity indices to obtain a revised ranking of the parameters, labeled "Approximate Relative Importance."

TABLE III

Relative Importance of Parameters in the Fallout
Shelter Systems Analysis

| Parameter | Sensitivity Index | | Uncer- tainty | Approximate Relative Importance |
|---|---|---|---|---|
| | ERD Model | Total Dose Model | | |
| Radiation Decay Exponent | -4.22 | -4.36 | 25% | 1.07 |
| Reference Intensity | +1.02 | +1.00 | 75 | 0.76 |
| Protection Factor | -0.96 | -0.99 | 80 | 0.78 |
| Time of Arrival of Fallout | -0.50 | -0.50 | 75 | 0.38 |
| Duration of Fallout Buildup | -0.18 | -0.25 | 70 | 0.15 |
| ERD Recovery Rate | -0.14 | -- | 70 | 0.10 |
| Time Outside in Fallout | +0.05 | +0.02 | 100 | 0.04 |
| ERD Recovery Fraction | -0.30 | -- | 10 | 0.03 |

It should be noted that the range of uncertainty is difficult to establish for some of the parameters. It often depends upon the context of the systems evaluation. However, Table III shows that only minor re-ranking of the parameters occurs when sensitivity indices are multiplied by the range of uncertainty. That is, the differences among the various "uncertainty" estimates are considerably smaller, generally, than the differences among the mathematical sensitivity indices.

These sensitivities are evaluated at the mean values of the parameters. Some of them change significantly for different values of the input

parameters. Details of variations are contained in Volume III. The most significant are summarized below.

c. Sensitivity Indices for Time Required in Primary Shelter

For time required in primary shelter to achieve bodily repair such that ERD is 50r-80r, the rankings remain the same. However, because of differences in formulation (no time outside in fallout) only reference intensity ($I_o$), protection factor (PF), and radiation decay exponent (Z) can be compared.

3. Conclusions

a. Casualty calculations are quite sensitive to errors in the field decay exponent. This sensitivity remains high and essentially constant throughout the range examined.

b. Sensitivity to variations in fallout reference intensity and protection factor are high over the whole range of parameter values. Hence, precise knowledge of the fallout shelter posture and the fallout reference intensity is much more essential to accurate vulnerability analysis than the remaining parameters in most cases of interest.

c. Sensitivity to time of arrival of fallout can be quite high in some radiological environments.

d. Sensitivity of casualty computations to the remaining parameters is low in most cases of interest.

e. Expansion of the sensitivity analysis to include parameters other than fallout, which define the total casualties from a given attack on the United States, is necessary before further conclusions concerning a national vulnerability analysis can be drawn.

4. Recommendations

a. Vulnerability analyses should employ the best available information on protection factors, and research and/or surveys to improve protection factor data should be encouraged.

b. Because of the sensitivity of systems analysis results to the field decay exponent, continuing analysis of the validity of the $t^{-1.2}$ decay law should be made.

c.   Additional study is required to establish the sensitivity of fatalities, casualties, and dose to duration of shelter stay.

d.   Sensitivity analysis should be extended to include the parameters defining the effects of blast and alternative measures of effectiveness (casualties by type, dose distribution of survivors, etc.).

e.   Sensitivity analysis should be applied to identifying the important cost/effectiveness parameters used in the budget allocation model (see Volume I).