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FINAL REPORT: VOLUME I

R-OU-82/83

Improvement of Protection Data Base for Damage Assessment and Data Base on Shelter Needs

Philip McMullan, John Neblett, Joseph Battle,
Herbert Campbell, Quentin Ludgin, Philip McGill,
Rodney Sink and Arnold Weiss

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OCD Sub-tasks 4613A & 4521A
RTI Project OU-82/83

by

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Improvement of Protection Data Base for Damage Assessment and Data Base on Shelter Needs

SUMMARY

I. Introduction

This is a summary of the final report on OCD sub-task 4613A, Improvement of Protection Data Base for Damage Assessment, and sub-task 4521A, Data Base on Shelter Needs (Reference a). The Office of Civil Defense statement of objectives is presented in Annex A and abstracts of tasks reported in Volumes II and III are presented in Annex B.

The two principal tasks were:

1. The incorporation of NFSS fallout protection data into the Jumbo III damage assessment system (Reference b), and
2. The development of a computer procedure to be used in the micro-analysis of civil defense systems and the evaluation of system improvements for a fallout only environment.

These two tasks will be summarized separately.

II. Incorporation of National Fallout Shelter Survey Data Into Jumbo III

A. Scope of Task

This task was completed as a part of the requirement to "formulate the procedures and analytical steps necessary to initiate full incorporation of the National Fallout Shelter Survey into damage assessment routines." The OCD objective calls for emphasis upon procedures for incorporation of NFSS data into existing National Resource Evaluation Center (NREC) systems such as Jumbo III, a complex system in which assessments are made on an individual point or standard location basis; Streak IV, in which a rougher, but high speed assessment of casualties and damage is made; and Risk II, which provides probabilistic estimates of the vulnerability of individual resource points (Reference c).

B. Results

A procedure was designed, data were obtained from the National Bureau of Standards, and a computer routine was prepared to incorporate NFSS fallout shelter data into the Jumbo III system. A test of the program was made in that system using nation-wide attack environment data from the training exercise called SPADEFORK. The program was then employed by the National Resource Evaluation Center in performing one of the analyses of project SPAN (an evaluation by OCD of shelter systems under a range of probable attack conditions).

C. Conclusions

Conclusions were drawn from the test of the procedure using the exercise SPADEFORK attack pattern and thus are not necessarily applicable to other attack patterns:

1. Effective use of available fallout shelter, as identified by the NFSS, will produce fallout casualty estimates substantially lower than those derived from data heretofore available on existing shelter. (Fallout fatalities were reduced from 15 million to 5 million in the SPADEFORK analysis).
2. Survivor and casualty estimates are extremely sensitive to the combined warning time and movement to shelter assumptions. (In SPADEFORK, the calculated fallout fatalities assuming movement restricted to a standard location were 9 million, versus 5 million if movement to best fallout shelter in the county were assumed).
3. When using levels of fallout protection available in NFSS shelter, casualty estimation procedures should include dose received after

leaving the initial shelter. Procedures which do not include radiation dose accumulated after emerging from shelter may produce misleading survivor estimates, as peak dose frequently occurs after shelter emergence.

4. In terms of reducing fallout fatalities, the selective marking and stocking of Category 1 shelter, the lowest class in the NFSS and one which was excluded from Phase 2 of the NFSS, may offer substantial benefit at a low cost per survivor added.1/

III. Development of the "Mainline" Computer Program

A. Scope

Other activities described in Volume I of the final report were those required to "devise means for relating probable postattack measures of conditions to: (1) costs of improved protection, (2) effectiveness of various types of expenditures in reducing expected casualties, and (3) alternative effectiveness of higher or lower levels of protection."

The task was limited to fallout conditions only, and "survivors added" was required by the contract language as the measure of effectiveness for fallout protection countermeasures. It was necessary to develop a fallout fatality computation procedure which was sensitive to local variations in shelter and population location and to numerous other parameters which must be considered in comparing alternative countermeasures.

1/ Conclusions 1 and 4 may be strengthened by findings in a related RTI study (Reference h). This study has shown that there is a definite conservative bias in protection factors (PF's) as computed by the National Bureau of Standards (NBS). True protection factors in Categories 2, 3, and 4 (PF's of 40-150) are shown to average twice the NBS value.

B. Results

1. General

A computer program called the "Mainline Program" has been developed for use in the evaluations called for above. The program essentially models the movement of people to existing or proposed shelter in a city and computes the resulting fatalities. It is designed to be used in repeated case studies over a range of possible attack conditions.

2. The Allocation Model

An allocation procedure, based upon the Transportation Algorithm (Reference d), has been developed for use in allocating people to shelter. The procedure is sensitive to local variations in degree of risk, location of people, location of shelter, protection factor of shelter, and speed of movement to shelter. In its present form, the model allocates the population of a city to shelter in a manner which produces a minimum number of fatalities for given warning (and movement) times and fallout environments. Constraints will be placed upon the model to make it more nearly simulate realistic movement patterns. Inputs to the model are initial location of people by standard location (SL), location of shelter by SL, and the probability of fatality for movement from each SL to each shelter in the area under study.

3. The Equivalent Residual Dose Model

A computer program has been devised for computing peak equivalent residual dose (peak ERD) and, from it, the probability of fatality required by the allocation procedure (Reference d). The inputs required are listed below:

Time of arrival of fallout
Fallout reference intensity
Protection factor for each shelter period
Length of stay in each shelter period
Distance to shelter and speed of movement
Warning/reaction time
Radioactive decay constant of fallout
Repair rate (of fallout damage to the body)
Irreparable fraction of radiation dose
Dose response curve.

4. An Application of the ERD Computer Program

Although the principal effort was expended in preparing a procedure for the required evaluations, a part of the Mainline Program was used to assist in a then current OCD evaluation. For that special OCD study, the part of the Mainline Program which computes the equivalent residual dose was used in the incorporation of NFSS data into the Jumbo III system. It was found that in the SPAN evaluation statement of conditions, the peak ERD generally occurred after exit from shelter. Since the Population III Program (the casualty program in Jumbo III) is designed to compute only the peak ERD of the initial shelter period, a modification was required. The Mainline ERD procedure was used to compute the later period peak ERD. These results were used in modifying the Population III program for the SPAN evaluation.

IV. Future Research

The report contains no "Recommendation" section because the principal recommendations for future research which follow from this work have already been recognized by the Office of Civil Defense and are the subject of an RTI follow-on contract. Activities included under the follow-on contract by specific instruction include:

A. Use repeated case studies, performed for a group of representative cities, to develop "Rules of Thumb" or broadly applicable results which may be used by OCD in national planning or by planners of local civil defense systems.

B. Evaluate the sensitivity of fatalities and casualties to changes in the parameters included in the Mainline model.

C. Evaluate the cost effectiveness of measures to increase survival (e.g., stocking, marking, ventilating, or increasing protection factors of shelter; and increasing warning and training of the population).

Annex A

OCD Description of Projects

Sub-task- 4521A - Improvement of Protection Data Base for Damage Assessment

Formulate the procedure and analytical steps necessary to initiate full incorporation of results of the National Fallout Shelter Survey into damage assessment routines, with emphasis on the RISK, JUMBO, and STREAK programs. Devise means for relating probable post-attack measures of conditions to: (1) costs of improving protection, (2) effectiveness of various types of expenditures in reducing expected casualties, and (3) alternative effectiveness of higher or lower levels of protection.

Sub-task- 4613A - Data Base on Shelter Needs

Devise a means for extracting from the National Fallout Shelter Survey results current data on location, capacity and protective characteristics of marked shelters by standard location for use in determination of need for additional shelter space in incentive and other programs.

Annex B

SUMMARIES OF VOLUMES II AND III OF THE FINAL REPORT

I. Introduction

The following paragraphs describe other tasks performed under the contract but not summarized in the body of this summary. These additional tasks are reported in Volumes II and III (Reference a).

II. Bureau of the Census Residential Basement Data

The purpose of this study was to investigate the availability of the Bureau of the Census residential basement data and its compatibility with the Phase 1 findings of the National Fallout Shelter Survey.

After considering the nature of the data itself and pointing out some cautions in its use, the conclusion is reached that the census data could be combined and used with the NFSS in fallout casualty computation programs.

A brief section on some possible additional uses of the information in CD studies follows the main sections; two annexes are included which provide population, shelter space, and basement figures for 180 tracted metropolitan areas.

III. Electric Power Availability in the Postattack Period

This sub-task was performed jointly for the Directorate of Research and the Shelter Survey Division. Its objective was to design a form for a mail questionnaire to identify the blast and fallout resistance in electric power generating stations and substations. It was demonstrated that reliable estimates of fallout protection and systems vulnerability data to the required significant detail could not be collected using such a questionnaire. As a pilot study, an analysis of the vulnerability of power generating stations and transmission systems to nuclear attack was made for the Duke Power Company system.

IV. A Model of Population Distribution in Shelter

This sub-task extended work previously performed by Mr. Jack Rogers in which a relatively simple mathematical model was used to indicate the distribution of people in shelter throughout a city (Reference f). The Rogers model was completed prior to the NFSS, using shelter data obtained in preliminary studies of selected state capitals. The RTI sub-task re-evaluated and modified the original model to accord to the NFSS data. The model was not further developed for systems evaluation because it models a static situation rather than the dynamic movement to shelter later found to be more relevant.

V. Summaries of Attack Environment Data

This sub-task was performed at the request of the project monitor to assist an OCD in-house project whose objective was to design procedures for national CD systems evaluations. The sub-task suggested a procedure by which large area statistical summaries of attack environment data may be obtained from the Jumbo III system by using a three dimension sort summary routine.

VI. Distribution of Shelter Characteristics

This sub-task was performed in an attempt to reduce the NFSS data to a more compact and useful form. As an example, the model is used in determing optimal allocations of funds to ventilate below ground shelter spaces to increase their capacity.

VII. Sensitivity of Fatality Computations to Variations in Shelter Physical Vulnerability

Volume III of the final report was presented in a separate volume because of its CONFIDENTIAL security classification. The purpose of the research reported was to examine the sensitivity of direct weapons effects (essentially blast and prompt radiation) fatality computations to the changes in structure protection indicated by the physical vulnerability (PV) data from the National Fallout Shelter Survey (NFSS). This examination was made as a preliminary to incorporation of PV data into existing damage assessment and vulnerability analysis routines such as those in the National Resource Evaluation Center's (NREC) Jumbo III system.

An analysis of three typical cities shows that when available NFSS shelters are utilized rather than residential dwellings alone, predicted fatalities decrease by at most 10 percent of the city's population. This analysis holds the population distribution and weapon characteristics invariant while changing only the structural protection afforded shelterees. For probable national attack patterns it is unlikely that the reduction would approach or exceed this percentage, except for a few selected city-attack combinations. To reflect this increase in protection, it is recommended that minor modifications be made in existing damage assessment routines for national assessments. Extensive modifications required to employ PV data from the NFSS in detail (e.g., standard location by standard location) are not recommended.

An analytical procedure using the Weiss population distribution model and an analytic fatality-distance curve is also derived and its application to one city is illustrated.

SUMMARY REFERENCES

a. Philip McMullan et al.. Improvement of Protection Data Base for Damage Assessment and Data Base on Shelter Needs. Volumes I and II (UNCLASSIFIED) and Volume III (CONFIDENTIAL), (Final Report on OCD Tasks 4613A and 4521A). Durham: Research Triangle Institute, Operations Research Division, 13 January 1964. (Volume III, 20 January 1964.)

b. Victor Lewicke and Irving E. Gaskill. NREC Damage Assessment Computation Program, Jumbo III. (Revised) NREC Technical Report No. 2. Washington: National Resource Evaluation Center, August, 1961.

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d. J. B. Dennis. A High Speed Technique for the Transportation Problem. ACM Journal, Volume 5, April, 1958, pp. 132-153.

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h. E. L. Hill, W. K. Grogan, R. O. Lyday and H. G. Norment. Analysis of Survey Data. Final Report R-OU-81, Office of Civil Defense Project 1115A. Durham, N. C.: Research Triangle Institute, Operations Research Division, January, 1963, (Parts I and II).

PREFACE

This is Volume I of three separately bound volumes which report the research completed under the general terms of the combined Office of Civil Defense Sub-tasks No. 4613A, "Improvement of Protection Data Base for Damage Assessment," and No. 4521A, "Data Base on Shelter Needs." This volume describes the two most extensive investigations completed in meeting the objectives of these sub-tasks. Volume II describes five related studies, all previously reported to the Office of Civil Defense in research memoranda. Volume III contains the CONFIDENTIAL portion of this final report. The abstract for each of the volumes is presented on the following pages.

The authors are pleased to acknowledge the cooperation of Dr. Joseph Coker, National Resource Evaluation Center; the valuable assistance given by Mr. John Spencer, and the staff of the Mathematics and Computation Laboratory, National Resource Evaluation Center; and the judicious direction of Messrs. John Deveney and Robert Whitney, Systems Evaluation Division, the Office of Civil Defense.

ABSTRACT FOR VOLUME I

This is Volume I of three separately bound volumes reporting the procedures devised for using the National Fallout Shelter Survey (NFSS) data in damage assessment systems and civil defense systems evaluation. A procedure for using NFSS data in existing damage assessment systems is devised, programmed for the UNIVAC 1105, and tested in the Jumbo III system of the National Resource Evaluation Center. Tests results,using a single attack pattern and Phase 1 NFSS data, show significant fallout casualty reductions over previous estimates. Category 1 shelter (PF 20-39) contributes substantially to this reduction. The results also show fallout casualties to be quite sensitive to the movement-to-shelter assumption. Casualty results from a test assuming county-wide population mobility are significantly less than those obtained when movement is limited to within a standard location. A "Transportation Problem" formulation is used to simulate the movement of people to shelter within a city. The solution to the problem when so formulated allocates people to shelter in a manner to maximize survivors (or other objective functions). Tests over a range of fallout environments using this information show that the minimum fatality allocation to shelter is particularly sensitive to fallout "build-up," movement through fallout, and shelter PF's. An equivalent residual dose (ERD) model which computes ERD in a time-varying radiation environment is programmed for the IBM 1620 and 7072. It has been found that the peak ERD after emergence may exceed the peak ERD in the initial shelter. The shelter allocation model and the peak ERD model form the basis for the "Mainline Computer Program," a procedure for computing the survivors added by alternative CD system improvements. This program is currently being developed into a working tool for CD systems evaluation.

ABSTRACT FOR VOLUME II*

This volume contains five studies concerned with obtaining, compiling, or analyzing fallout shelter protection data. These studies cover the following subjects: (1) a review of the residential basement data which were obtained from the 1960 U. S. Census of Housing; (2) an examination of electric power availability in the postattack period, with emphasis upon fallout protection in power plants; (3) the preparation of a procedure for extracting summary distributions of overpressure, reference intensity, and fallout arrival time and relating these to numbers of people exposed; these data are to be extracted from the Attack Environment III output tapes of the Jumbo III damage assessment system (4) the re-evaluation, with National Fallout Shelter Survey data, of an analytical model for predicting fallout protection for people as a function of their distance from the center of a city; and (5) a statistical analysis of NFSS data from Houston, Texas; and Durham, North Carolina, performed to determine distribution functions expressing their shelter characteristics. These analytical representations of NFSS data are applied, in an illustrative example, to optimal allocation of improvement dollars to ventilating below ground shelters to increase their capacity.

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* Philip McMullan, et al. Improvement of Protection Data Base for Damage Assessment and Data Base on Shelter Needs. Volume II (Final Report on OCD Sub-tasks 4613A and 4521A). Durham: Research Triangle Institute, Operations Research Division, January 13, 1964.

ABSTRACT FOR VOLUME III*

Volume III is presented in a separate volume because of its CONFIDENTIAL security classification. The purpose of the research reported here is to examine the sensitivity of direct weapons effects fatality computations to the changes in structure protection indicated by the Physical Vulnerability (PV) data from the National Fallout Shelter Survey (NFSS). This examination is made as a preliminary to utilizing the PV data for existing damage assessment and vulnerability analysis routines such as those in the National Resource Evaluation Center's (NREC) Jumbo III system.

An analysis of three typical cities shows that when available NFSS shelters are utilized rather than residential dwellings alone, predicted fatalities decrease by at most 10 percent of the city's population. This analysis holds the population distribution and weapon characteristics invariant while changing only the structural protection afforded shelterees. For probable national attack patterns it is unlikely that the reduction would approach or exceed this percentage except for a few selected city-attack combinations. To reflect this increase in protection, it is recommended that minor modifications be made in existing damage assessment routines for national assessments. Extensive modifications required to employ PV data from the NFSS in detail (*e.g.*, standard location by standard location) are not recommended.

An analytical procedure using the Weiss population distribution model and an analytic fatality-distance curve is also derived and its application to one city is illustrated.

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* Philip McMullan, et al. Improvement of Protection Data Base for Damage Assessment and Data Base on Shelter Needs. Volume III (CONFIDENTIAL) (Final Report on OCD Sub-tasks 4613A and 4521A) Durham: Research Triangle Institute, Operations Research Division, January 20, 1964.

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Chapter 1

Introduction and Summary

I. INTRODUCTION

The purpose of Federal civil defense (CD) programs is to increase the probability of survival of the civil population and speed the recovery of the nation from the effects of enemy attack. The core of the present Federal civil defense program is the National Fallout Shelter Survey (NFSS), in which existing buildings, mines, tunnels, and other enclosures were examined for their fallout shelter potential. Those facilities which met minimum standards of protection, capacity, liveability, and certain other constraints are being marked and stocked with food and water and other necessities. The initial survey was complete in 1962, and over 100 million shelter spaces meeting minimum standards have been identified (Reference a).[1] These form a base from which to build a complete CD system for protection of the nation's population in the event of nuclear attack. The survey will be continued and this initial shelter base will be increased by locating additional existing spaces and by encouragement of shelter provision in new construction. (A more complete NFSS description may be found in Appendix A.)

In addition to immediate preparedness benefits attainable by using existing shelter resources, the survey also provides an important new data base to the Office of Civil Defense (OCD) for the evaluation of present and future CD systems, for CD planning, for damage assessment, and for vulnerability analysis. The present report, prepared under Contract Number OCD-OS-62-144 for the OCD Research Directorate, describes the procedures and analytical steps devised by

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[1] References cited may be found at the end of each chapter and appendix.

the Research Triangle Institute, Operations Research Division, for making full use of the new data base in the above activities.

II. OCD PROJECT DESCRIPTION AND DISCUSSION

Contract Number OCD-OS-62-144 is a package contract consisting of four separately identified tasks. This is a final report on two of the four: Improvement of Protection Data Base, task 4613A and Data Base on Shelter Needs, task 4521A.[2] These two closely related tasks have been performed and are reported as a single project. The combined OCD statement of task objectives follows:

1. "Formulate the procedures and analytical steps necessary to initiate full incorporation of the National Fallout Shelter Survey into damage assessment routines, with emphasis on the Risk, Jumbo, and Streak programs.

2. "Devise means for relating probable postattack measures of [fallout] conditions to:

   (a) Costs of improved protection
   (b) Effectiveness of various types of expenditures in reducing expected casualties
   (c) Alternative effectiveness of higher or lower levels of protection.

3. "Devise a means for extracting from the National Fallout Shelter Survey results current data on location, capacity and protective characteristics of marked shelters by standard location for use in determination of need for additional shelter space in incentive and other programs."

These objectives are all concerned with the use of the new data base provided by the NFSS.

Objective 1 recognizes the value of NFSS data in damage assessment and vulnerability analysis. If properly employed, these data could permit greatly improved casualty estimation. They provide an estimate of the number of spaces and of the level of protection in potential shelter which is far more detailed than any estimates previously used.

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[2] New numbers were assigned to these tasks by OCD toward the end of Fiscal Year 1963. 4104A became 4613A and 4104B became 4521A.

Objective 2 recognizes that the NFSS results are a valuable new data base with which extensive CD systems can be evaluated when procedures are available. Analyses must be made to determine how best to use presently available shelter and how to increase economically the effectiveness of the shelter program. New procedures for such analyses must be devised to take advantage of the new data base.

Objective 3 recognizes that a simple listing of aggregated data from the survey matched with population summaries will not determine need for additional shelter spaces, nor will such a listing tell how best to improve sheltering capability. A quick comparison of the U. S. population of 186 million with the 203 million spaces found in the survey (Reference b) might indicate an excess of 17 million spaces.[3] However, the distance between population and shelter is a critical factor. For example, over 60 million spaces in the New York City area are available to a population of about 11 million. The apparent excess would be of little value in the nation's shelter plans. This extreme example illustrates the need for analysis and adjustment of the data base to meet the requirements of specific evaluations.

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[3] This example refers to all spaces identified in Phase 1 of the survey (Reference a and Appendix A). A June 1963 estimate by OCD shows that about 100 million of the 203 million identified spaces fall in the lowest protection category (Category 1) and are not presently considered useable. About 30 million of the remainder will not be used (Reference b).

III. EVALUATION PROCEDURES

A. Introduction

The evaluation of CD systems may be performed in many ways depending upon the scope of the inquiry, the timeliness requirements, and the availability of adequate procedures. Three classes of evaluation procedure were considered in this project. They are: (1) vulnerability analysis using existing large-scale computer damage-assessment systems; (2) micro-analysis; and (3) national systems analysis. The distinctions are made because each has its place in CD systems analysis, but they differ in procedure design requirements as well as in area of application.

B. Existing Damage Assessment System Analysis

The damage assessment systems of the National Resource Evaluation Center (NREC) and other government entities have often served OCD and its predecessors in preattack planning and population vulnerability studies. Objective 1, which calls for the incorporation of NFSS data into existing damage assessment systems, recognizes a continued role for such systems in preattack planning as well as in postattack damage assessment. National results are summed up in NREC systems from the results of assessments at individual resource points or small area resource aggregations. National population survival or vulnerability can be assessed in this way with results at intermediate levels of summary, such as county, state, and OCD region, obtained in the process.

The NREC computer systems do not necessarily represent an ideal tool for OCD systems evaluation because of a lack of flexibility, insufficient availability of computer time, and high cost. NREC systems were designed to serve a variety of needs. Cost may become a limiting factor if the systems are used in sensitivity analysis of all the significant factors in casualty estimation or in examinations of all feasible system improvements. Other procedures are more appropriate for such evaluations.

C. National Systems Analysis

The term "National Systems Analysis" is used here for convenience to distinguish between a broad approach to analysis and the detailed approach in which individual or small group hazards and protection are examined. In such broad procedures the actions of an individual, such as his reaction to warning or movement to shelter, and the specific postattack fallout environment at a point are submerged in averages or distributions representative of a large geographic area. An example of such an analysis can be found in Shelter (Reference c).

The analysis in Shelter makes use of distributions of people in shelter within groups of OCD regions. New National Systems Analysis procedures using NFSS data might employ different groupings, but they would continue to use large-area distributions of people in shelter and of the attack environment to which the population is subjected.

National and regional analysis of CD systems is by its very nature limited to evaluations for large-scale planning. Such procedures can produce valid results at national and regional levels despite uncertainties in weapon location and lack of detail in the elements of the analysis.

D. Micro-Analysis of CD Systems

The term "Micro-Analysis of CD Systems" is used in this report to describe detailed operational studies on a limited geographic scale. (Existing NREC models resemble both micro-analysis and national systems analysis but do not eliminate the need for either of these techniques.)

Micro-analysis offers the opportunity to examine thoroughly NFSS data at the lowest feasible level of summary. Parametric studies at this level can serve in sensitivity analysis of the variables which must be considered in casualty estimation. The results of such studies can improve the validity of more general systems analysis procedures and of large-scale computer damage assessment and vulnerability analysis procedures. They do this by demonstrating the range within which casualty estimation is sensitive or insensitive to the variables. For example, a parametric study may demonstrate that casualty estimates do not vary significantly with changes in warning time between four and twenty-four hours, or that casualty estimates vary significantly with a 5 percent increase in building protection factor estimates. Such findings can improve the soundness of the assumptions which must be employed in broader evaluation.

Through the use of a representative sample of cities or areas, micro-analysis may also be used in performing national analysis. In such a procedure, evaluation for a class of cities is extrapolated from a detailed analysis of a single city representative of the class. For example, analyses to determine standards for the location of new fallout shelter facilities or evaluations of the cost effectiveness of proposed improvement plans may be performed efficiently using such sample procedures.

IV. SUMMARY OF THIS STUDY

A. Introduction

This study has been equally concerned with procedures for population vulnerability analysis and with procedures for micro-analysis of CD systems. Also, a beginning step was made which will assist in design of procedures for national systems analysis. In each area the new NFSS data base prominently influenced the procedures for the evaluation of CD systems. The improvement in fallout casualty estimation procedures is a common thread in each area.

Casualty or survivor estimation procedures received emphasis because "survivors added" or "reduction in casualties" was the measure of the effectiveness of a CD system improvement specifically called for in the OCD statement of objectives. The cost per survivor added is to be compared in choosing between alternative improvement measures. (Although it is recognized that some features of CD systems cannot be evaluated adequately using this measure of effectiveness, it is appropriate for the investigation of this project.) Casualty estimation procedures used at civil defense agencies and NREC prior to the NFSS need revision, if they are to take full advantage of the new data base. The changes proposed vary with the need for sensitivity in the procedure. Proposed changes will be discussed throughout this report.

During the performance of the contract, the analysts were often called upon to undertake short-term sub-tasks of immediate interest to OCD. In several instances the sub-tasks did not directly involve the procedure under development to satisfy the major objectives. Such sub-tasks have been reported previously in research memoranda. These and several other previous reports are compiled in Volume II.

Analyses performed during this study were of value to OCD in current evaluations, but the major emphasis was on procedures design. Parametric studies and sensitivity analyses were performed primarily to test assumptions and procedures. When findings from such analyses were judged to be of current interest to OCD, they are discussed at appropriate places in the report.

The following sections provide a summary discussion of the sub-tasks which are described elsewhere in this report.

B. Incorporation of NFSS Data into Existing Damage Assessment Systems

This sub-task, reported in Chapter 2, involved the design of procedures to initiate full incorporation of fallout protection data from the National Fallout Shelter Survey into damage assessment systems, with emphasis upon Risk, Jumbo, and Streak.[4] This sub-task has been completed. Tentative procedures which extract the new data base from the first phase NFSS results and employ them in the Jumbo system have been tested against a simulated nation-wide attack. The computer program and the extracted data used in the test have also been used by OCD in a comprehensive planning exercise called SPAN.

Tentative conclusions drawn from the test results and related analyses are listed below. The conclusions are tentative because of known limitations of both the procedures and the data, and because only one attack pattern was employed in the test.

1. Effective use of shelter identified in the survey will produce fallout casualty estimates lower than those derived from data heretofore available on existing shelter.

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[4] Risk, Jumbo, and Streak are code names for National Resource Evaluation Center computer damage assessment systems. These systems are also used in vulnerability analysis. They are explained in Chapter 2.

2. Survivor and casualty estimates are extremely sensitive to warning time and movement-to-shelter assumptions used in allocating people to shelter.

3. With the higher levels of fallout protection generally available in NFSS shelter, casualty estimation procedures should compute the dose received after leaving the initial fallout shelter. Procedures which do not examine the peak radiation dose accumulated after emerging from shelter may produce misleading survivor estimates, as peak dose will frequently occur after shelter emergence.

4. In terms of reducing fallout fatalities, the selective marking and stocking of Category 1 (PF of 20 to 39) shelter, the lowest class in the NFSS and one which was excluded from the second phase of the survey, may offer substantial benefit at a low cost per survivor added.

C. Examination of the PV Code from the NFSS

In addition to fallout protection data, the NFSS also contains a two-digit PV code. This code indicates the structural characteristics of NFSS facilities. An examination of these data and of their place in population vulnerability analysis is presented in Chapter 2. (The classified part of this examination is presented in Volume III).

D. Micro-Analysis of CD Systems

Chapter 3 contains the background investigation leading to the design of a procedure to evaluate CD strategies against probable postattack measures of conditions. This procedure is called the "Mainline" Program. It is basically a procedure to be used in estimating fallout casualties in a micro-analysis. Its components are models which can represent a broad range of fallout environments and alternative CD strategies, but with primary attention given to the shelter system.

The Mainline is designed for use in analysis of the sensitivity of fallout casualties to such variables as warning/reaction time, walking speed and distance to shelter, dose during fallout build-up, prime shelter protection factor, time in shelter, and dose after leaving shelter. The strategies to be evaluated in terms of cost per survivor added may include:

Increased protection factors in existing shelters

Improved ventilation (hence added capacity)

Improved warning systems

Construction of new shelter and optimum location strategy

Extra food for longer stay in prime shelter

Decontamination procedure

Public education and training for improved shelter utilization.

Such strategies can be examined against a range of fallout environments for a representative group of cities and the results presented to the decision maker as a function of the environment. In most cases selection between alternatives for a given city will then depend upon an estimate of the probable fallout environment. Nation-wide results can be obtained by extrapolation from evaluations in representative cities.

The Mainline has been programmed in FORTRAN language and has been tested. . The tests were designed primarily for the evaluation of the procedure. However, one component of the program produced a set of revised protection factors which permitted existing Jumbo III casualty estimation procedures to include dose build-up after leaving shelter. This permitted the use of NFSS data in the SPAN exercise.

A tentative conclusion drawn from a test of the shelter allocation procedure may have operational significance.[5] A preliminary sensitivity analysis shows that operational shelter planning based upon the most pessimistic estimate of fallout intensity may be less satisfactory than planning for moderate intensity and experiencing high intensity. This results from the complex interaction between dose accumulated while moving through fallout and that accumulated after reaching shelter. More thorough examinations must be made to determine the limits and significance of this finding. This conclusion would support the need for more precise estimates of the probable range of the fallout environment for a city and the careful dissemination of specific planning assumptions to local planners.

E. Extraction of Data from the NFSS

Objective 3 calls for means for extracting data from the NFSS by standard location for use in various evaluation procedures. The major elements of this task were accomplished prior to and in the early phases of this contract by the design of the survey specifications, particularly the requirement for NFSS area designators to utilize the national location code. RTI staff participated in this work, the main elements of which were performed by OCD staff. Because of the inherent flexibility of the NFSS, it has developed that no specific subtask has been necessary, as the extraction of data can be tailored to suit each procedure in which such data are used. Specific mention of ways to extract data and examples of data extractions from the NFSS are in Appendix E, Volume II,

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5/ See Chapter 3, Section III.

in which statistical distribution functions are fitted to the data, and in:

1. Chapter 2, in which data extracted for use in the Jumbo III system are discussed.
2. Chapter 3, in which data from the NFSS are used in the evaluation procedures discussed.
3. Appendix C, which contains a list showing the estimated unsheltered population by political subdivision (nation, region, and state) for several different shelter utilization assumptions.
4. A random sample of about 1500 facilities has been extracted from Phase 1 data tapes for use in categorizing shelter spaces and facilities (Reference d). One of the uses, categorizing facilities by PV code, is discussed in Chapter 2.

F. Basement Shelter

The facilities identified by the NFSS do not constitute all of the places in which persons may be located in the event of an attack. All such places cannot by conveniently identified, but the residential basement data from the 1960 U. S. Census provide an important addition.

Basement data from the 1960 U. S. Census have been examined and included in the procedures of Chapter 2. A report of this examination was previously submitted to OCD as a research memorandum (Reference e). This research memorandum is included in Volume II of this final report.

G. Other Investigations

Volume II includes reports of several sub-tasks performed under the contract which are not directly connected with the two principal investigations, and the report of the basement investigation. These sub-tasks were performed either in response to special requests from OCD or were investigations related to the principal investigations. All were previously reported in research memoranda.

1. Electric Power Availability in the Postattack Period

This sub-task was performed in cooperation with the Directorate of Research and at the request of the Shelter Survey Division, Office of Civil Defense. Its objective was to design a form for a mail questionnaire to be used to estimate the blast and fallout resistance of electric power generating stations and substations. It was demonstrated that reliable estimates of fallout protection and systems vulnerability data could not be collected using such a survey. A preliminary evaluation of the vulnerability of the Duke Power Company generating stations and transmission systems to nuclear attack was also made.[6/]

2. A Model of Population Distribution in Shelter

This sub-task builds upon work previously performed by Mr. Jack Rogers in which a relatively simple mathematical model was used to describe the distribution of people in shelter throughout a city (Reference f). The Rogers model was completed prior to the NFSS, using shelter data obtained in preliminary studies of selected state capitals. The RTI sub-task re-evaluated and modified the original model to conform to the NFSS data. The model was not further developed for systems evaluation because it models a static situation rather than dynamic movement to shelter later found to be important.

6/ A vulnerability analysis of present and future electric power systems has been made at RTI under separate contract with the Federal Power Commission (Reference g).

3. Summaries of Attack Environment Data

This sub-task was performed at the request of the project monitor to assist an OCD in-house project whose objective is to design procedures for national CD systems evaluations. The sub-task suggested a procedure by which large area statistical summaries of attack environment data may be obtained from the Jumbo system by using a three-dimension sort summary routine..

4. Distribution of Shelter Characteristics

This sub-task was performed in an attempt to reduce the NFSS data to a more compact and useful form. A demonstration is given of how a simplified analytical expression of the NFSS data may be used in determining the number and size of shelters to be ventilated for a given shelter improvement budget.

5. Other Tasks

Two other tasks were performed under the contract. The first suggested a method for predicting the rate of licensing fallout shelter facilities. The second produced a list of facilities to be used in analysis of CW-BW protection in facilities of the NFSS. The reports of these tasks will not be presented in Volume II. Loan copies can be made available if desired.

V. LIMITATIONS

The analyses performed and procedures designed in the study were primarily directed to consideration of the fallout threat to the population. It is recognized that such analyses are incomplete and that procedures designed without concurrent consideration of direct effects hazards will likely require later revisions to insure compatibility. For example, procedures to incorporate fallout protection data into existing damage assessment systems (Chapter 2) do not account for degradation of fallout protection caused by blast damage. Future analyses may show that this step is necessary in order to obtain valid casualty estimates.

Limitations have also been noted in the data base. Omissions of potential shelter spaces in the NFSS are discussed in Appendix A ("A Description of the National Fallout Shelter Survey"). Even more important in casualty computations is the conservative bias in PF as computed by NBS (true PF's in Categories 2, 3, and 4 are on the average about twice the NBS value). Other input errors leading to incorrect PF's also occur in the NFSS. These NFSS data limitations are described in detail in another RTI study (Reference 1).

A major uncertainty concerning all conclusions discussed in this report stems from a lack of data pertaining to probable actions of the population in the event of a nuclear attack. This factor causes difficulty in determining the extent to which available shelters will be employed. As often as possible the designed procedures have been made flexible so that new information from in-progress and future case studies and surveys can be incorporated.

VI. RESULTS AND EXTENSIONS OF THIS STUDY

A. Discussion

The broad objectives of this project have led to investigations touching upon the many facets of CD systems, but each investigation was related to the full use of the data from the National Fallout Shelter Survey in systems evaluation. Each investigation, and particularly the design of procedures for incorporating NFSS data into NREC damage assessment routines, pointed to the need for sensitivity analyses of the variables in casualty estimations and the need for a detailed model for the parametric evaluation of alternative civil defense strategies. The Mainline Program described in this report provides such a model for a fallout environment.

B. Major Products of the Study

Procedures for the incorporation of NFSS fallout protection data into damage assessment routines have been produced, and the RTI computer program for incorporation into the Jumbo system has been furnished to the National Resource Evaluation Center. A procedure for the micro-analysis of alternative civil defense strategies has been programmed for the IBM 7072 and is adaptable to medium or large computers with FORTRAN compilers. These programs are major products of this study.

C. Extensions

Continuing analyses will be made of the sensitivity of survival estimation to variations in the elements of CD systems evaluation over a range of possible postattack environments under a follow-on contract (Reference h). The need for such continued analysis is demonstrated in this report under those sub-tasks which examine the relative location of people and shelter, shelter stay time, and the effectiveness of higher and lower protection factors. Variables which were of little importance when the house or residential basement was the principal shelter for the population now take on great importance. All such variables will be identified and examined for sensitivity in CD systems analysis.

Existing and planned damage assessment models, vulnerability analysis models, and micro-analysis procedures will need reexamination as each sensitivity analysis is reported. Several changes to Jumbo procedures have been made as a result of analyses in this study, but more comprehensive changes may be desirable after sensitivity analyses are complete. The follow-on contract referenced above will permit such changes to be made as their need becomes justified.

This report contains no "Recommendations" section because the principal recommendations for future research which follow from the work reported here have already been recognized by the Office of Civil Defense and are the subject of an RTI follow-on contract (Reference h).

VII. CHAPTER 1 REFERENCES

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i. E. L. Hill, W. K. Grogan, R. O. Lyday, and H. G. Norment. Analysis of Survey Data. Final Report R-OU-81, Office of Civil Defense Project 1115A. Durham, N. C.: Research Triangle Institute, Operations Research Division, January, 1964. (Parts I and II).

Chapter 2

Incorporation of National Fallout Shelter Survey Data Into Damage Assessment Routines

For the reader not familiar with the procedures, terms, and data forms of the Survey, it is suggested that Appendix A be read before continuing.

I. INTRODUCTION

As explained in Appendix A, the National Fallout Shelter Survey provides a new and improved data base for studies of the location, number, and protective characteristics of fallout shelter facilities in the United States. Such data are of great interest to the Systems Analysis Division, OCD Research Directorate; the National Resource Evaluation Center (NREC); the Defense Communications Agency; the Defense Intelligence Agency; and other government groups which perform evaluations of potential nuclear attack damage to the resources of the United States. People are the most important resource in all such studies, and an improved estimation of potential casualties is paramount. The use of the new NFSS data base would be an important element in improving such casualty estimation.

One of the objectives of Contract Number OCD-OS-63-144 is to: "Formulate the procedures and analytical steps necessary to initiate full incorporation of results of the National Fallout Shelter Survey into damage assessment routines, with emphasis on the (NREC) Risk, Jumbo, and Streak Programs." This chapter contains a discussion of the steps taken by RTI in satisfying this objective and a description of the results obtained from a completed and tested computer program which is currently in use at NREC.

In addition to completing the program, the action taken to satisfy the above objective included: (1) the performance of parametric analyses to determine the sensitivity of casualty assessment routines to the various elements of the new data base; (2) the examination of tentative procedures for incorporating the data on fallout protection into damage assessment routines by physically completing such incorporation into the Jumbo III system; and (3) formulation of improved procedures based upon (1) and (2). The following discussion of these three steps will show that significant changes must be made in casualty assessment procedures in order to take full advantage of the new data made available by the NFSS. The changes of greatest significance concern assumptions about utilization of existing shelter space, movement to shelter, and time of stay in the prime shelter.

Both in the NFSS and in this study, emphasis has been placed upon fallout protection. However, the NFSS also contains some information on physical vulnerability of surveyed structures to the direct effects of nuclear weapons. This chapter also reports an examination of these physical vulnerability data, and a further examination is reported in Volume III of this final report.

II. BACKGROUND

A. The Risk, Jumbo, and Streak Systems

Risk, Jumbo and Streak are three computer systems used by NREC for vulnerability analysis and damage assessment.[6] The following brief descriptions are quoted from the NREC Analytical Program Compendium (Reference 1, pp. 5, 14, 25).

1. "Risk II provides the combined probabilities of nuclear attack experience in terms of blast overpressure, fallout arrival time, radiation dose rate and total radiation dose, or in terms of damage, casualties or denial for weapons and resource points of interest anywhere in the world.

2. "Jumbo III provides a detailed damage and casualty assessment on an individual point basis, with national summaries and partial sums based on a flexible classification breakdown. The program has the capability to evaluate damage and casualties for bases and resource coverage around the world.

3. "Streak IV provides a high-speed estimate of blast and fallout casualties, or a high-speed estimate of damage and denial to facilities for a given set of ground zeros."

The three descriptions are given because these are the damage assessment routines to which attention is called in the contract objective. When viewed from the standpoint of incorporation of NFSS data, the following features are

6/ NREC is administratively under the Office of Emergency Planning and has among its tasks responsibility to assist the Office of Civil Defense in performing both postattack damage assessments and vulnerability analyses for preattack evaluations.

significant. Jumbo III is larger, more comprehensive, and more time-consuming than Streak IV. Streak IV is designed to perform a rapid assessment, and much of its speed is obtained by using reduced record size and normalized data. However, it is basically similar to Jumbo III in the procedures used to compute fallout casualties. Risk II involves repeated runs of Streak IV using Monte Carlo techniques by which random selections from distribution of winds and attack parameters are used to obtain probabilistic results. It follows that the determination of a proper procedure for incorporating NFSS data into Jumbo III will solve most of the incorporation problems for Streak IV and Risk II as well. Such procedures will also have application to other damage assessment routines not discussed here - including the Ready I system for the CDC 3600 computer, now under development jointly by OCD and NREC. As a result, emphasis has been placed upon the development of procedures for Jumbo III.

B. Jumbo III Fallout Protection Data Base

The discussion in this section is presented so that the form, content, and use of the old data base in Jumbo III can be understood. This will help in understanding new procedures which have been designed in this task and will assist in the interpretation of some of the SPADEFORK test results presented later in this chapter. The existing procedure in Jumbo III should also be understood because it is still appropriate for some national evaluations.

Casualty estimation for a population group requires three major data elements. These are the attack environment or effects of a nuclear attack (blast, heat, and radiation), the unprotected vulnerability of population to these effects, and the amount of protection available to reduce population vulnerability. The data from the NFSS provide information about the amount of protection.

Fallout protection for a population group is estimated in Jumbo III on the basis of factors shown in Table I. The basic assumption behind this table is that the amount of basement shelter can be correlated with the severity of winter; i.e., northern belt states have an abundance of basements, middle belt states have a smaller number, and southern belt states have few. A sample of metropolitan and non-metropolitan places in each belt was taken from an SRI study to determine the percentage of the population within each belt which could be sheltered in basements (Reference j, p. 121). Table I shows a PV code for both metropolitan and non-metropolitan areas within each belt.[7] Residential basements are considered to have an exposure rate of 0.10; that is, they will provide a tenfold reduction from outside radiation levels, or a protection factor (PF) of 10. Percentiles under the other exposures rates (reduction factors) are the results of judgement extrapolations from the basement sample. An exposure rate of 0.01, or PF of 100, may represent a basement in a large structure; 0.50 represents protection in houses without basements; 0.70, partial outside protection by natural terrain features; and 1.00, exposure to outside fallout radiation with no protection.

Every city or other population group in the United States is assigned to one of six PV codes. In a Jumbo population casualty assessment, every population group is distributed among the five exposure rates by keying to the PV code. For example, the population of Seattle and the population of New York, both being metropolitan areas in the northern belt, would receive the same percentage distribution among the exposure rates.

7/ PV stands for physical vulnerability. In Table I PV relates to fallout radiation. The term is also used to relate the vulnerability of people or facilities to blast or thermal effect of nuclear weapons.

TABLE I

Jumbo III Shelter Percentiles

(Percent distribution of population among various shelter classes)

PV Code	Area	Exposure Rate 0.01	0.10	0.50	0.70	1.00
70	Severe Winter, Metro. Area	10	75	8	5	2
71	Severe Winter, Non-Metro. Area	10	70	8	10	2
72	Moderate Winter, Metro. Area	8	50	35	5	2
73	Moderate Winter, Non-Metro. Area	8	40	40	10	2
74	Light Winter, Metro. Area	3	30	60	5	2
75	Light Winter, Non-Metro, Area	3	5	80	10	2

Source: Victor Lewicke and Irving Gaskill, NREC DAMAGE ASSESSMENT COMPUTATION PROGRAM, JUMBO III, NREC Technical Report No. 2, Revised edition. August 1961, National Resource Evaluation Center, Washington, D. C. pp. 36, 37.

The procedure described above for estimating the fallout protection for a population group was adequate in light of the limited accuracy of the available radiation protection data base and because the basic shelter was considered to be a residential basement rather than a community shelter. However, more suitable procedures with which to employ the new NFSS data base have been devised and are presented in Section III.

C. Direct Effects Data Base

Population III, the program in the Jumbo III system which contains casualty computation procedures, has a single set of casualty curves (Probability of Death or Injury vs. Distance from Ground Zero) for determining direct (primary blast) effects casualties. Each curve is based upon the composite results of conventional and atomic weapon casualty experiences in World War II (Reference k).

The NFSS results provide data which may assist in the assignment of variable amounts of direct effects protection according to the type of building in which population groups are sheltered. These data are examined in this chapter and in Volume III.

III. EVALUATING THE NEW DATA BASE PARAMETRICALLY[8/]

A. Introduction

In evaluating possible procedures for incorporating NFSS data into damage assessment routines, one problem seemed most difficult: selecting the most realistic shelter utilization assumption.

Phase 1 of the NFSS disclosed about 203 million shelter spaces with PF greater than 20 for a national population of about 186 million people. However, the New York metropolitan area alone contains 60 million of these spaces for a residential population of about 11 million. It is not likely that the excess of 49 million spaces could be used in the event of an attack. This example points up the requirement for careful consideration of the manner of using the NFSS data in population vulnerability analysis.

The problem of describing shelter utilization is complex and depends on many parameters (warning time, level of training, movement speed, location of people and shelter, etc.). To aid in understanding the effects of these parameters, a preliminary analysis was made of the variation of fallout casualties with variations in these parameters and resulting variations in shelter utilization.

B. The Method

Using fallout shelter data for Durham, N. C., and the procedures for casualty computation in Jumbo III, a parametric analycis was performed for four distributions of people in shelter over a range of fallout intensities. A

8/ The investigation described in this section was originally reported to OCD in a research memorandum by Herbert Campbell (Reference 1).

constant 1-hour time of arrival and an unlimited stay in shelter were the simplifying criteria used. The four methods compared are:

1. NREC Table - In this method, the people of Durham were given the amount of protection indicated by Table I for a light winter metropolitan area. This is the level of protection which would be assigned to Durham by Jumbo III.

2. Tract or Standard Location - In this method the actual number of spaces found by the NFSS in a census tract (standard location) were made available only to a number of shelterees equal to the residential population of the census tract.

3. NFSS Table - In this method the assigned level of protection was selected from Table II, which is similar to that in Jumbo III (Table I), but prepared from NFSS Phase 1 data. In using it, Durham is assigned a shelter distribution for a light winter metropolitan area (PV Code 74).

4. Whole City - This method assumes that any person in Durham may move to any available NFSS shelter in Durham, and it further assumes a knowledge of and preference for the highest PF shelter available.

Method 2 (Tract or Standard Location) represents a pessimistic shelter utilization plan in that it limits the movement of people to shelter within a small geographic area. Method 4 (Whole City) represents an optimistic shelter utilization plan in that travel over a much larger area may be involved for a portion of the population. (Additional discussion about the movement of people to shelter may be found in Chapter 3, Section III). The problem is to determine

TABLE II

Revised Jumbo III Shelter Percentiles

(Percentage distribution of population among various shelter classes)

PV Code	Area	Exposure Rate 0.01	0.018	0.037	0.275	0.50
70	Severe Winter, Metro. Area	21	25	31	23	-
71	Severe Winter, Non-Metro. Area	6	7	12	75	-
72	Moderate Winter, Metro. Area	30	34	19	16	1
73	Moderate Winter, Non-Metro. Area	3	5	9	53	30
74	Light Winter, Metro. Area	12	25	29	34	-
75	Light Winter, Non-Metro. Area	1	2	7	59	31

Source: Philip McMullan, PRELIMINARY REPORT ON POPULATION DISTRIBUTION IN SHELTERS, Research Memorandum RM-82-1, Operations Research Division, Research Triangle Institute, Durham, North Carolina, May, 1962.

the sensitivity of casualty assessment procedures within these extremes of shelter utilization assumptions.

C. The Results

The results are summarized in Figure 1. This graph shows the percentage of expected casualties for each method as a function of the reference dose rate (50 R/HR to 10,000 R/HR). In all other methods of representing fallout protection, the percentage of expected casualties is lower than that for the NREC table. This is to be expected, since all other methods include NFSS shelter with high PF in far greater numbers than that included in the NREC table. However, the tract-by-tract method shows only slight differences until about 700 R/HR initial intensity. It should be noted that in the census-tract method, people without NFSS shelter were assigned to residential basements or houses as was done in the NREC table. As a result of the movement limitations implied by the census-tract method, much of the available NFSS shelter remains unused, and basement shelter becomes a dominant factor.

The whole-city method curve is significantly lower than the census-tract method curve throughout the range of intensities. In this method, the entire population of the city was placed in shelter with PF values greater than 40. Since the NFSS table was designed using a whole-city shelter utilization assumption, this method is comparable to the whole-city method. It shows that Durham has better shelter than the average for light-winter metropolitan areas.

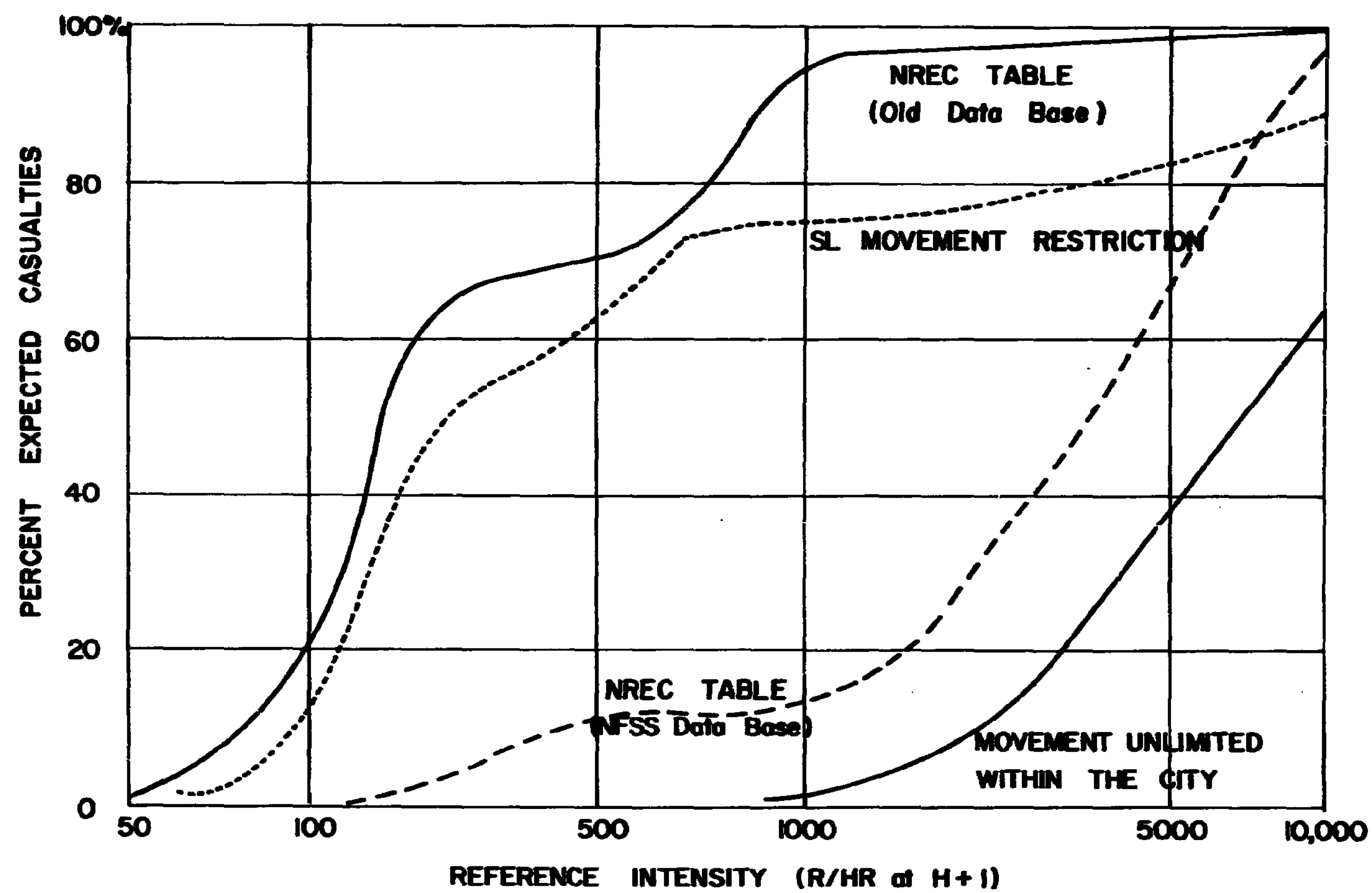
D. Significance of the Analysis for this Study

This brief study verified the expected high sensitivity of casualty computations to the shelter utilization assumption. This is very noticeable at the

FIGURE 1

Expected Casualties as a Function of the Intensity at H + 1

Durham Case Study



1000 R/HR H + 1 level. Here the limitation of movement within a standard location shows expected casualties of nearly 80 percent; while at the same intensity level, the expected casualties for the whole-city method, which permits movement to shelter anywhere in the city, were about 1 percent. This difference is too significant to ignore in designing procedures for incorporating NFSS data into existing damage assessment routines.

What is a reasonable assumption as to proper representation of people in shelters? The only answer to the question is that the assumption depends upon many other questions and particularly: How well is the population trained, and how much time will people have to move to shelter? These questions will be discussed further in Chapter 3, where an investigation of movement to shelter will be reported as part of another sub-task. In order to consider other problems relevant to incorporating the new data base into existing damage assessment systems, the following tentative assumptions were made:

1. Matching shelter with people on a standard location basis provides an estimate of disorderly shelter utilization and represents the pessimistic case.
2. Matching shelter with people on a county basis provides an estimate of well planned and executed shelter utilization and represents the optimistic case.

Analysis shows that much of the population is near shelter centers within any county. Counties with widely scattered population are unlikely to have sufficient shelter for the distant population, and this tendency minimizes the number of exceptional cases involving hours of travel. Investigations reported in Chapter 3 disclose that the population of Durham can walk (at 5 miles per hour) to shelter and be entirely sheltered within 31 minutes (excluding reaction time) after movement begins. An Operations Research Incorporated analysis using the same speed shows that much of Milwaukee can be sheltered within 60 minutes (including reaction time) with orderly and planned movment (Reference m). Also, an assignment plan prepared by the Stanford Research Institute for Lincoln, Nebraska, using a slower speed of 3 miles per hour had 75 percent of available spaces occupied within 60 minutes (Reference n). Movement times within this range should be available for any city or region subjected only to fallout. The practical consideration that standard location and county levels are convenient levels of summary for the NFSS data, together with the movement findings, led to the use of both in incorporating NFSS data into the Jumbo III system.

IV. EVALUATING THE NEW DATA BASE IN THE JUMBO III SYSTEM[9]

A procedure for incorporating NFSS fallout data into existing damage assessment routines with minimum reprogramming, but full use of the new data base, was developed and tested in the Jumbo III system using Phase 1 data. The procedure required that data be extracted from Phase 1 magnetic tapes at the National Bureau of Standards (these tapes are described in Appendix B), be converted from IBM to UNIVAC format, and be incorporated into Jumbo III. A computer program prepared as part of this sub-task matches the shelter data with population data by standard location or county, produces percentage distributions of people in shelter, and merges these distributions into an existing Jumbo III record. Population III, the Jumbo III casualty routine, was revised by NREC to receive the new data base. In all other respects the Jumbo III system is unchanged. The procedure is outlined in the flow chart in Figure 2. This flow chart shows the point at which the incorporation program interrupts the Jumbo III system. A description of the computer techniques may be found in Appendix B.

The new data tapes,[10] the RTI program, and operating instructions are now available at NREC and RTI and have been used by OCD in a planning evaluation called SPAN. The results of SPAN are classified, but a test performed by RTI using an unclassified nation-wide attack called SPADEFORK are described below:

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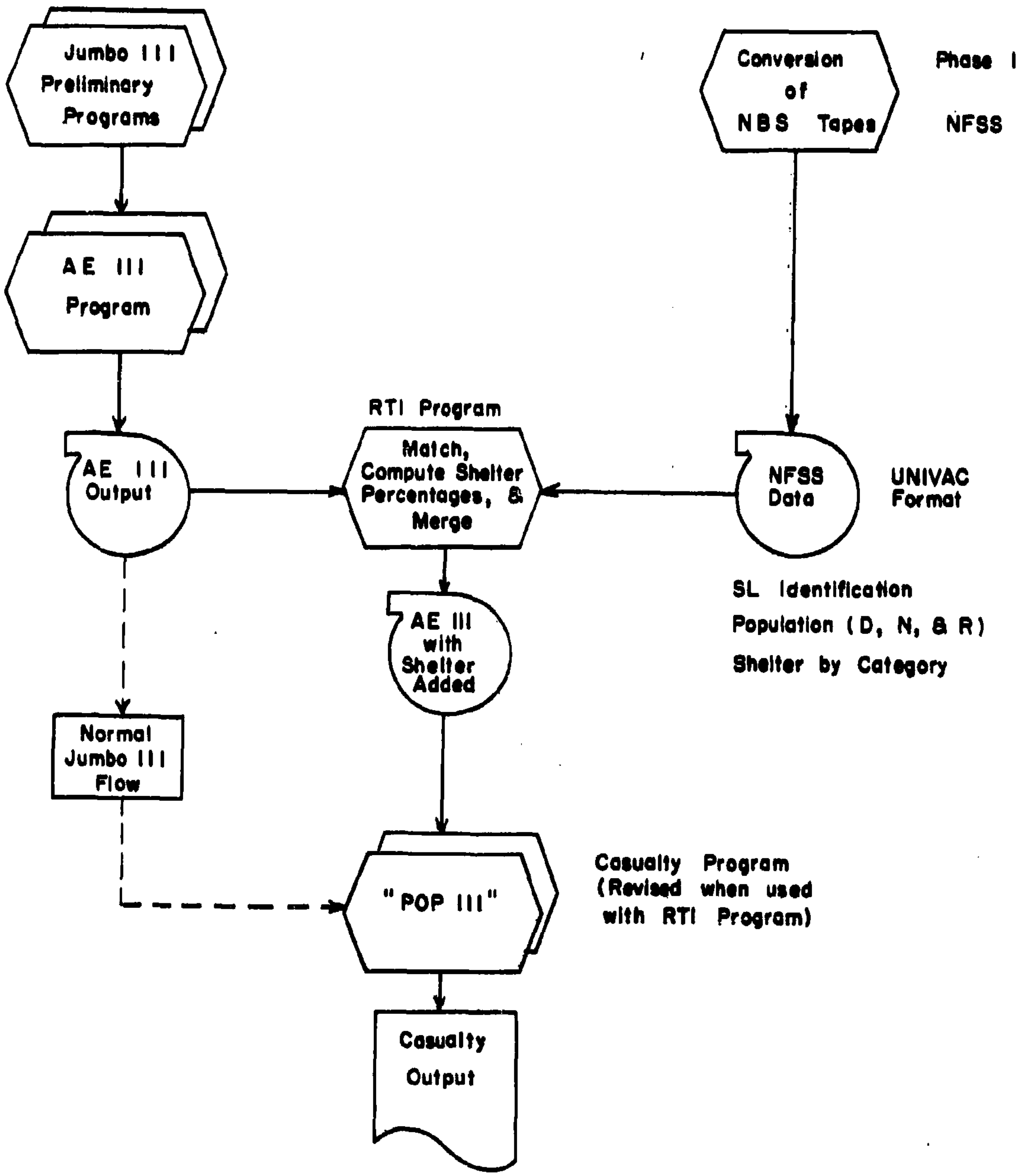
[9] Previously reported in a research memorandum by Quentin Ludgin (Reference o).

[10] Data tapes in IBM format are available at RTI.

FIGURE 2

Generalized Schematic for Incorporating NFSS Data into JUMBO III System.



A. Test Description

1. Attack Data - In Exercise SPADEFORK, an OCD practice alert, a relatively small scale counterforce attack was simulated. This attack was not intended to be representative of intelligence estimates of enemy capability. Of the 355 simulated weapons employed, 186 were air bursts and were assumed to produce no fallout. As a result, the number of fallout casualties was small relative to a large-scale attack regardless of the casualty assessment procedure.

   The Attack Environment III (AE III) program is that component of the Jumbo III system which places weapons effects data into the standard Jumbo III record. The standard record, one record for each standard location when population is the resource being evaluated, normally becomes an input to the Population III program after AE III data are added. This process is interrupted when NFSS data are incorporated into the AE III record by the RTI program, as shown in Figure 2. The AE III output tapes from Exercise SPADEFORK were obtained from NREC and used in the test described here.

2. Shelter Data - Each standard location (SL) record from AE III contained unused data fields. Percentage distributions of people in NFSS and basement and residential shelter are computed in the RTI program and placed in the previously unused data fields. In determining the shelter distribution percentages, persons who could not be sheltered in NFSS shelter were assumed to take shelter in residential basements, when available, or

in homes. The procedure for computing these distributions is shown in Appendix B, Section III.

In performing the test, a nation-wide run was completed using county-wide allocations of people to shelter; then another was completed using the SL movement limitation assumption. As explained previously, these represent the optimistic and pessimistic shelter utilization assumptions. In order that results of these computer runs could be compared with the previous Jumbo III results using the old data base, the original SPADEFORK results were obtained. The three results are compared in the following sections.

B. Test Results[11]

Test results are presented graphically in Figures 3, 4, and 5. In terms of fatalities the old data base SPADEFORK results show 15.0 million killed by fallout; the new data base with SL option shows 8.6 million killed; and the new data base with county option shows 4.9 million killed. Not more than 5 percent of the nation's population is assigned to a PF of 100 by the old data table, and approximately 60 percent of the remainder is assigned to residential basements with a PF of 10, and 35 percent to a space with a PF of 2 or less. In the SL option, about 25 percent of the population is assigned to NFSS shelter with PF's ranging from 20 to 1000, 60 percent to basements, and 15 percent to houses with a PF of 2. In the county option, about 65 percent are assigned to PF's of 20 to 1000, 30 percent to basements, and 5 percent to houses.

The shelter assignments estimated above explain why the SL results show increased survivors over the old data base and why the county option shows an

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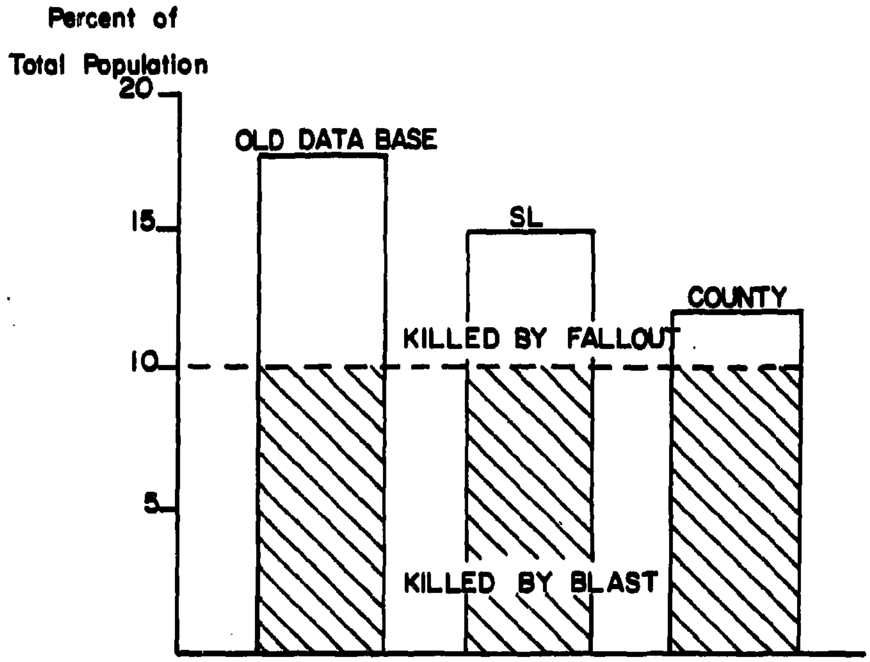
11/ Previously reported in a Research Memorandum by Philip McMullan and Quentin Ludgin (Reference p).

FIGURE 3

Exercise SPADEFORK National Fatalities



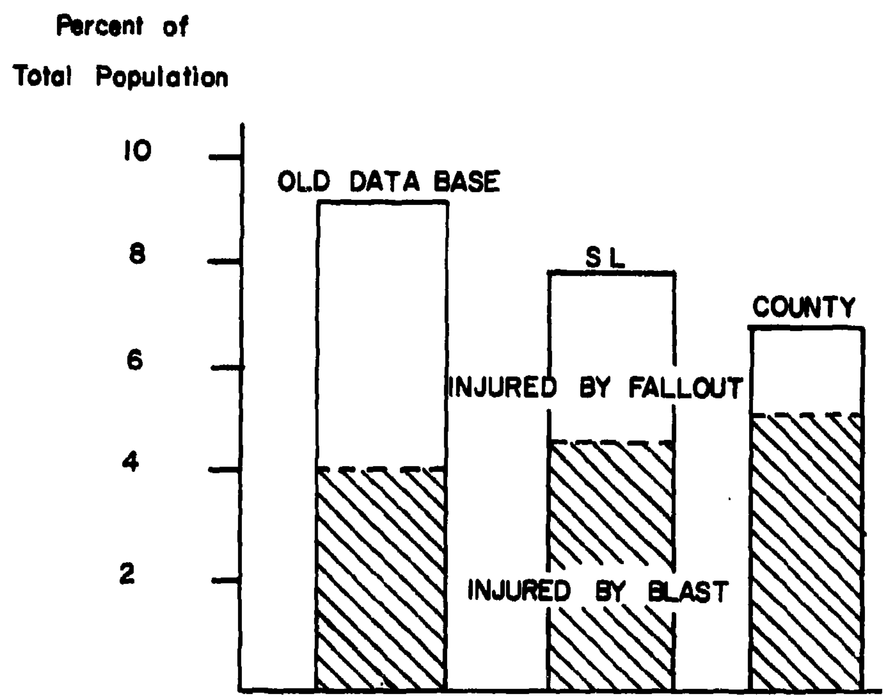
NATIONAL FATALITIES

	Blast Killed	Fallout Killed	Total*
OLD DATA BASE	18,950,000	15,030,000	33,980,000
STANDARD LOCATION MOVEMENT	18,950,000	8,560,000	27,510,000
COUNTY-WIDE MOVEMENT	18,950,000	4,887,000	23,837,000

* Based on Total Population of 185,713,000.

FIGURE 4

Exercise SPADEFORK National Injuries



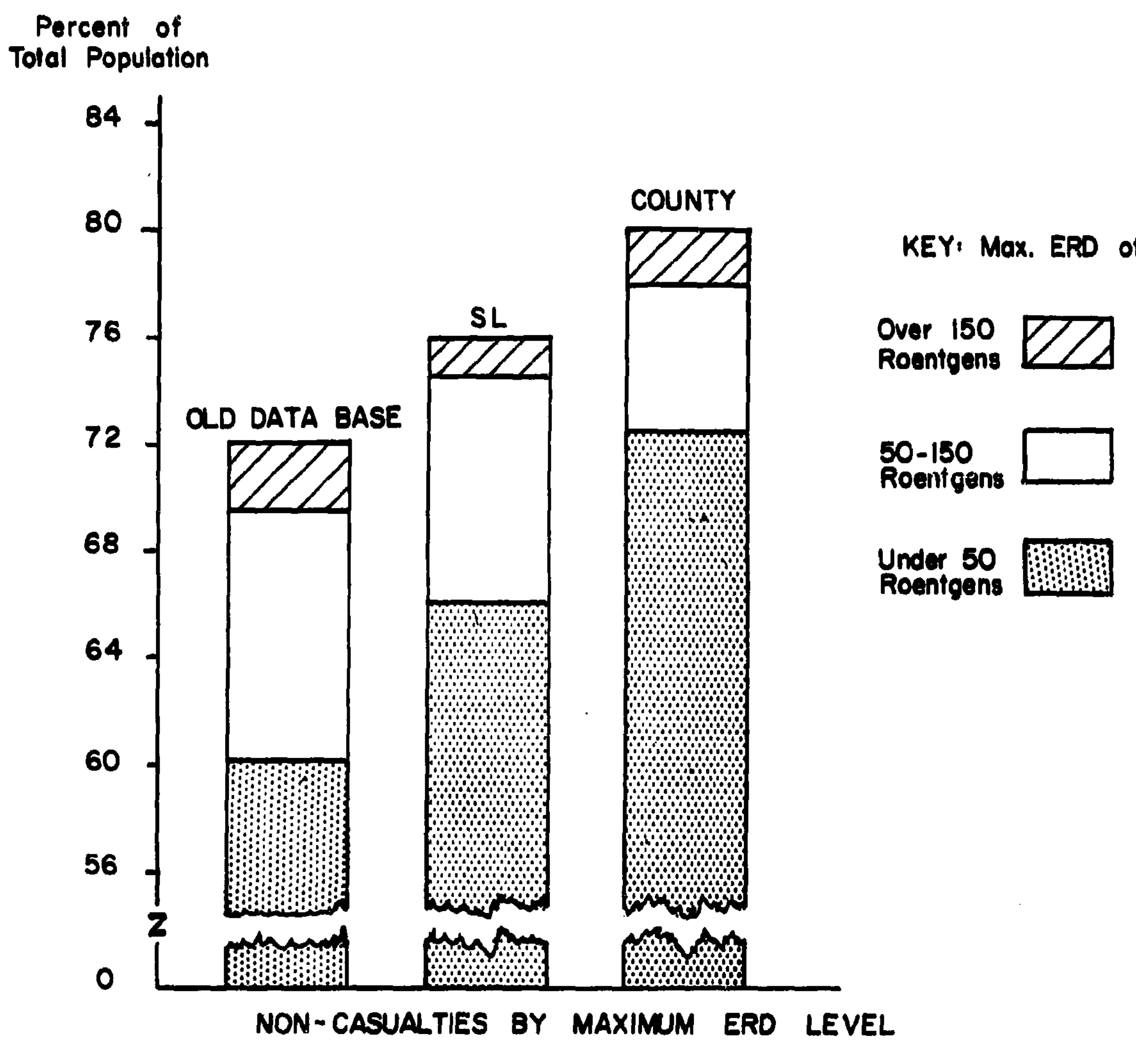
NATIONAL INJURIES

	Blast Injured	Fallout Injured	Total*
OLD DATA BASE	7,500,000	9,500,000	17,000,000
STANDARD LOCATION MOVEMENT	8,200,000	7,000,000	15,200,000
COUNTY-WIDE MOVEMENT	8,800,000	4,400,000	13,200,000

* Based on Total Population of 185,713,000.

FIGURE 5

Exercise SPADEFORK National Non-Casualties



	Under 50 Roentgens	50-150 Roentgens	Over 150 Roentgens	Total*
OLD DATA BASE	112,800,000	17,200,000	4,800,000	134,800,000
STANDARD LOCATION	124,100,000	15,000,000	4,000,000	143,100,000
COUNTY	134,500,000	11,500,000	2,700,000	148,700,000

* Based on Total Population of 185,713,000

increase over the SL option. Similar differences are found for non-fatal fallout injuries and for dose to the non-injured, as is shown in the graphs of Figures 3, 4, and 5.

Figure 3 illustrates the difference in fatalities for the three computer runs. Blast fatalities do not differ because no change was made in the blast fatality computational method. If the attack had been larger in size with many surface bursts upon counterforce targets, the number of fallout fatalities would have been increased, and the probable difference between the methods would have been even more striking. This is due to the fact that as more people are exposed to higher intensities, the value of the basement shelter is diminished.

Figure 4 shows the non-fatal injuries resulting from the three runs. The reductions in fallout-injured resulting from use of NFSS data are consistent with the fatality reductions. It will be noted that the number of surviving blast-injured increases as total injuries decrease. This occurs because the NREC Population III program (both in original and revised form) assumes that some of the blast injured are killed by the additional effects of fallout. With increased fallout protection, more of the Blast-Injured Killed-by-Fallout revert to the Blast-Injured column.

Figure 5 shows the non-casualty survivors and the maximum ERD which they have received. As would be expected after examining Figures 3, 4, and 5, much more of the population falls into the Under 50 Roentgen category when NFSS data is used.

Appendix C contains a regional listing of the results of the test.

C. <u>Revised Procedure, Test, and Results</u>

The test above was performed to insure that the procedure for incorporating NFSS data into Jumbo III was workable for the entire nation. Its results were also useful in re-examining the sensitivity of casualty computation to the method of representing the distribution of people in shelter -- the shelter-utilization assumption. The test data base included the Category 1 shelter from the NFSS with PF range of 20 to 39.

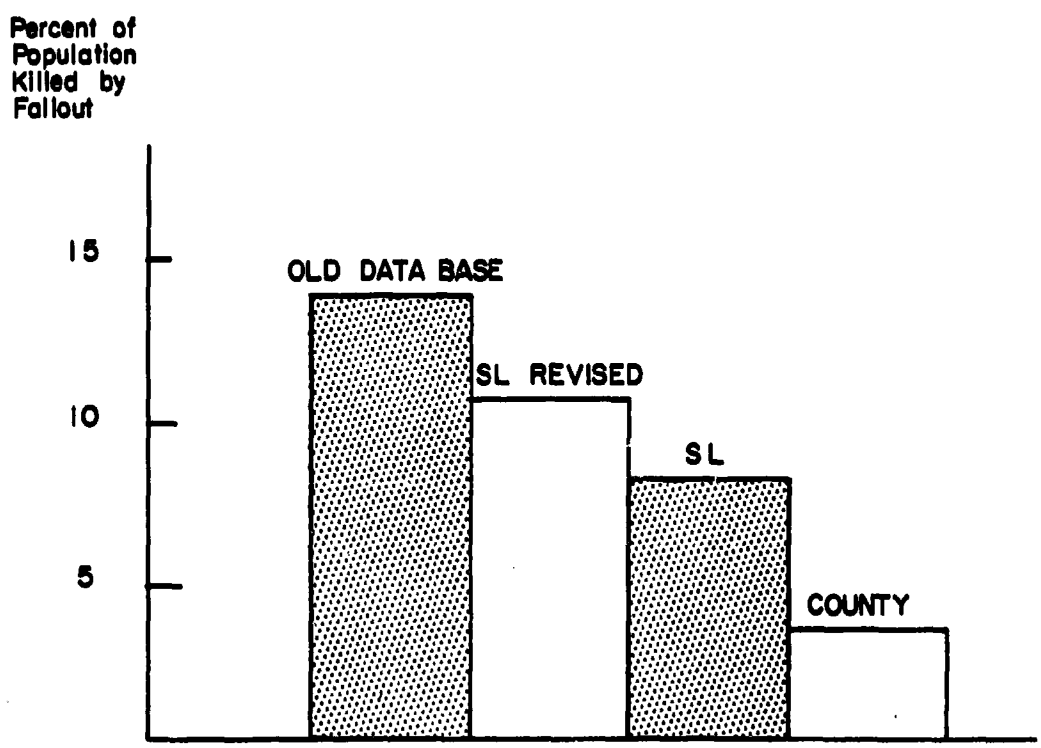
In order to make the available Phase 1 data comparable to the Phase 2 data base, still in preparation (see Appendix A), the RTI program was revised to eliminate Category 1 shelter before computing the shelter percentages. A brief test of this change was made using SPADEFORK AE III tapes for OCD Region 1. The results of the test are illustrated by the bar graph in Figure 6. Fall-out fatality results for the State of Connecticut are presented for the revised program and for the three tests previously discussed. Table III lists state summary casualty results for both Connecticut and New Jersey.

The revision was tested only for the SL option. Figure 6 shows revised SL results together with the results from the original three runs. For Connecticut the estimates of fatalities are about 3 percent higher when Category 1 shelters are not considered. If county results were available, it is expected that they would show an even greater increase. County option permits a much greater use of Category 1 shelter than the SL option, because the latter leaves many lower PF category spaces empty when there are people in neighboring SL's who could fill them.

The above by-product results may not be significant when considered against the many uncertainties of weapon size and location, but they suggest

FIGURE 6

Exercise SPADEFORK Casualties:
State of Connecticut



Key:

OLD DATA BASE - Obtained from previous SPADEFORK results which used old data base.

SL REVISED - SL movement with category I shelter excluded.

SL - Standard Location movement limitation.

COUNTY - County-wide movement limitation.

TABLE III

Exercise SPADEFORK Casualty Summary - Connecticut and New Jersey
(Figures over percentages in thousands)

	Total Population	Fatalities			Injured			Total Casualties	Non-Casualties ERD Received (R)			Total Non-Casualties
		Blast	Fallout	Total	Blast	Fallout	Total		Under 50	50-150	Over 50	
CONNECTICUT												
Jumbo III	2660 100.0 %	240 9.0	389 14.6	629 23.6	123 4.6	268 10.1	391 14.7	1020 38.3	1164 43.8	324 12.2	153 5.7	1640 61.7
SL Revised (Cat. 1 Rem.)	2660 100.0 %	240 9.0	280 10.5	520 19.5	136 5.1	257 9.7	393 14.8	913 34.3	1276 48.0	319 12.0	153 5.8	1748 65.7
Std. Loc.	2660 100.0 %	240 9.0	202 7.6	442 16.6	143 5.1	231 8.7	374 14.1	816 30.7	1348 50.7	359 13.5	139 5.6	1845 69.4
County	2660 100.0 %	240 9.0	71 2.7	311 11.7	169 6.4	128 4.8	297 11.2	608 22.9	1598 60.1	366 13.8	90 3.4	2054 77.2
NEW JERSEY												
Jumbo III	6354 100.0 %	564 8.9	91 1.3	655 10.3	365 5.7	241 3.8	607 9.6	1261 19.9	4389 69.1	562 8.8	138 2.2	5089 80.1
SL Revised (Cat. 1 Rem.)	6354 100.0 %	564 8.9	38 .6	602 9.5	374 5.9	78 1.2	452 7.1	1054 16.6	4831 67.0	408 6.4	66 1.0	5305 83.5
Std. Loc.	6354 100.0 %	564 8.9	18 .3	582 9.2	375 5.9	17 .3	391 6.2	973 15.3	5089 80.1	291 4.6	5 .1	5385 84.7
County	6354 100.0 %	564 8.9	15 .2	579 9.1	375 5.9	13 .2	388 6.1	966 15.2	5252 82.7	135 2.1	5 .1	5392 84.9

a need for a more critical examination of the possible role which Category 1 shelters might play in immediate shelter planning.

D. The SPAN Program

The RTI computer program and the Phase 1 data base, revised to eliminate Category 1, were used in the SPAN program. SPAN is the code name of an OCD study conducted by the Plans and Programs Directorate. In SPAN the Jumbo III system was used to test a range of possible blast and fallout shelter systems against a range of attack conditions. The RTI computer program and data were used to represent the present shelter situation with optimistic shelter utilization, i.e., the county option. The results of the SPAN study are classified.

Phase 1 NFSS data were used to approximate Phase 2 shelter data (not yet available) by eliminating Category 1 shelter. An off-line computer program was used to determine the number of shelter spaces which had been utilized in the SPAN run with the county-wide movement option. Of the 119 million Category 2-8 spaces listed in Phase 1 by the NFSS, 79 million are assigned when using this option. Data from the Bureau of the Census, using the county option and Phase 2 data, indicate that a comparable assignment method would assign 76 million to shelter in Category 2-8 spaces. (Appendix C, Table C-II, shows unsheltered population by state, region, and nation for the county-wide movement option and the SL movement option.)

E. Revised Exposure Rates

In keeping with the existing NREC programs, the original RTI computer program, discussed in Appendix B, used the mid-point values for PF categories as exposure rates. No problems arise when the shelter PF is low; but when the higher PF values of the NFSS are used, a revision must be made. Existing NREC programs do not take into account that a person emerging from a high PF shelter after several weeks may receive a greater dose after exit than was received in shelter. Since SPAN assumed a 14-day stay in the first shelter, it was necessary to account for the later period dose.

A procedure that had been developed as part of another sub-task made it possible for a table of "Revised Protection Factors" to be prepared as a temporary expedient to solve this problem. The major effect is to reduce the previously assumed high effectiveness of the 100 PF and greater shelters. (Maximum ERD is higher than previously computed.)

The procedure used to develop the revised protection factors is explained in Chapter 3 and Appendix D, and the revised values are listed in Table VII in Chapter 3.

V. RECOMMENDED PROCEDURES FOR IMPROVED NFSS FALLOUT DATA INCORPORATION INTO DAMAGE ASSESSMENT ROUTINES

A. Introduction

A general procedure for the incorporation of fallout protection data from the NFSS into damage assessment programs has been developed and demonstrated by application in the Jumbo III system. A similar procedure may be used by Streak and Risk after reducing the number of categories of fallout protection.

The procedure as outlined in this chapter and in Appendix B will accomplish the objective of full incorporation of NFSS data into NREC damage-assessment systems. Further improvements in the procedure will require major changes in the basic casualty model, and continuing sensitivity analyses should lead to recommendations for such changes. Some improvements are possible with the existing procedure and models. They are recommended below:

B. Recommendations

1. Population Data Base

In SPAN and in the SPADEFORK test the population was assumed to be located before movement at their place of residence. The NFSS included an estimate of day population and of night population for each SL. These estimates are included in the record obtained by RTI from NBS and can be used with a small change in the RTI Computer Program. However, their accuracy is questionable, and it is not recommended that they be used in fallout casualty computations until a current Bureau of the Census study of these data is complete.

The use of the county option minimizes the effect on casualty computations of the population base for fallout casualties, since casualty estimates vary only if large numbers move across county lines from their residences to their place of work or cross county lines for other reasons.

However, it is expected that differences between day and night population locations will be significant in computations of direct effects casualties.

2. Shelter Utilization Assumption

Until a better understanding of the effect of population reaction to warning and of movement to shelter can be gathered, it is recommended that the NFSS data be used in procedures similar to the county option. By using a fractional shelter-utilization, this method can be varied to accommodate assumptions of less than optimum shelter utilization. Such percentage reductions can be applied to reduce the number of spaces available in a county. In the present Jumbo III procedure, this reduction could be accomplished in an off-line program as part of the RTI routine. As more realistic data on shelter utilization become available from on-going studies by ORI, SRI, and RTI, it is recommended that the entire procedure be modified accordingly.

3. Shelter Data Base

The tested procedure used Phase 1 data and broad-area average basement data. The format used is equally applicable to Phase 2 NFSS data now being put on tapes at the Bureau of the Census.

Because these data were not completed during the performance of this task, they were not used. It is recommended that when complete they be obtained in proper form for use in the RTI Computer Program for Jumbo III. Such data will be available by SL at the Bureau of the Census and at NREC.

4. <u>Exposure Rate Revision</u>

Table VII, Chapter 3, showing revised protection factors, is a special purpose revision. It is applicable only to the specific conditions of the SPAN study.

The procedure to establish revised exposure rates is explained in Chapter 3, Section IV. It may be used again for other special purpose evaluations, but it is recommended that an improved casualty model such as that described in Chapter 3 be used in population vulnerability analyses.

VI. ANALYSIS OF THE NFSS PHYSICAL VULNERABILITY DATA

A. Introduction

In accordance with specific instructions from the Directorate of Research, Office of Civil Defense, protection from the immediate effects of nuclear weapons has received less attention than fallout protection in this study. Blast and other immediate effects are the subject of numerous other OCD research tasks. However, some attention has been given to the physical vulnerability (PV) data collected in the NFSS because of the contract requirement for full incorporation of the NFSS protection data base into damage assessment routines.

A PV code in the NFSS is a two-digit number which classifies a facility by its structural characteristics. The PV code can be used in estimating the probable damage to the facility from the peak static overpressure and the dynamic over-pressure which may result from a nuclear explosion. If the necessary casualty functions are available, the PV code may also be used in estimating the vulnerability of people in the facility to the immediate effects of nuclear weapons. The casualty function gives the probability that a person in a given type of building will become a casualty as a result of blast or other immediate effects (gamma, neutron, thermal, etc.) which may reach the building. The NFSS PV defines the type of building in which shelter spaces (and possibly people) are located. For a given attack, existing NREC damage assessment routines estimate the casualties and fatalities due to direct weapons effects using one casualty function and one fatality function for all structures.

Casualty and fatality functions are available in NREC computer routines for only one of the 36 PV codes into which NFSS facilities are classified. The Dikewood Corporation has been preparing casualty and fatality functions from such sources as the data accumulated after the atomic attacks of World War II on Japan. Specific procedures for the incorporation of PV data into existing damage assessment routines have been postponed until completion of the Dikewood study (Reference q). However, a general procedure for use of PV data in damage assessment or vulnerability analysis is discussed in this section, and a preliminary examination of the frequency of occurrence of the 36 PV codes in Phase 1 records is presented. (An examination of the data using classified information is presented in Volume III of this report.)

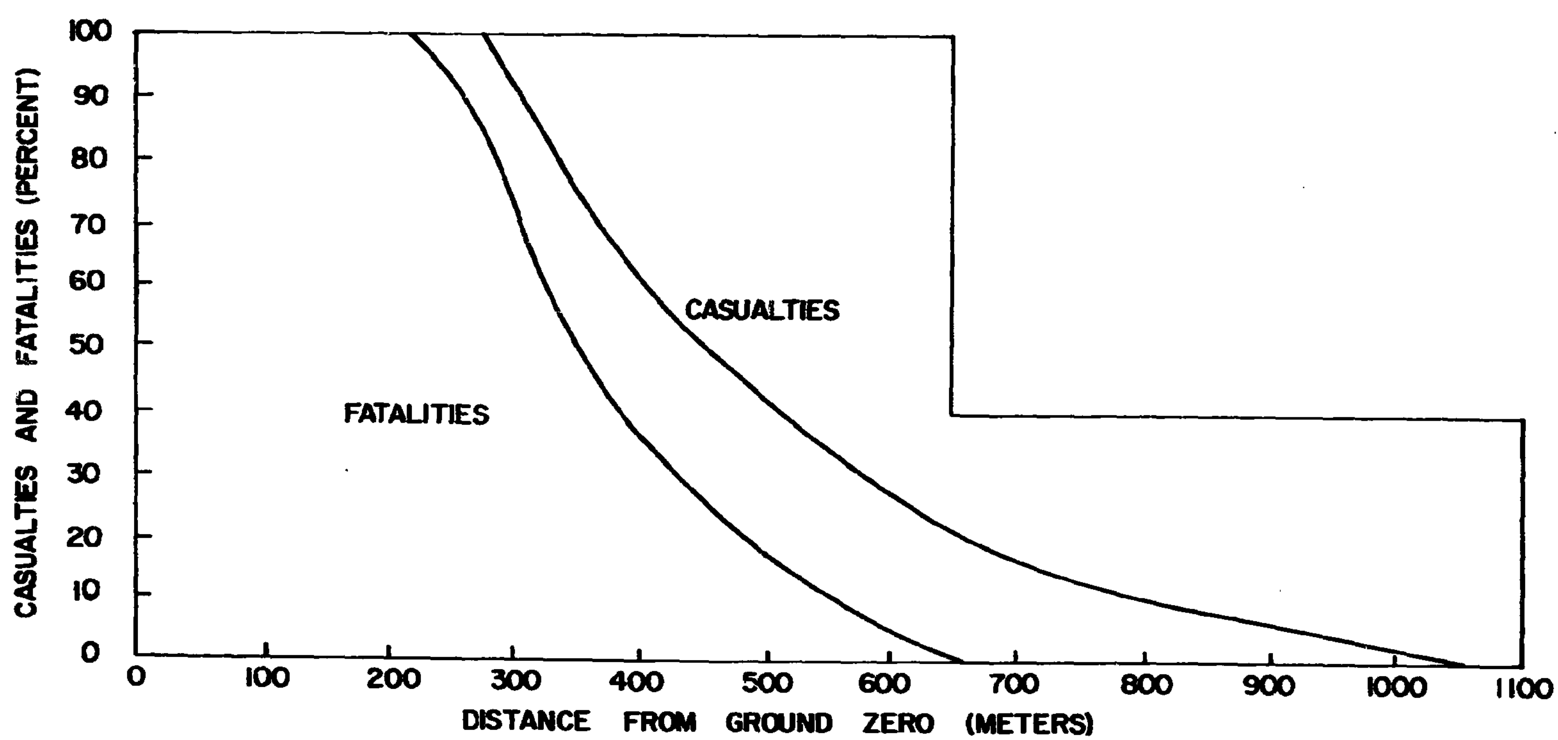
B. A General Procedure for Using PV Codes in Damage Assessment Routines

The following steps demonstrate a possible, but not necessarily optimal, method for using PV data and casualty functions in damage-assessment routines.

1. People are assigned an index of vulnerability to direct effects of nuclear weapons. This index may be an average for the nation, an average for some sectional breakdown, or it may be one which represents the vulnerability of occupants in specific buildings. When appropriate for damage assessment or vulnerability analysis, the PV code in the NFSS may be used in this latter type of assignment.
2. The distance from people to weapon(s) is measured. Direct effects are computed for the specified distance between resource (in this case, people) and ground zero.
3. Probability of fatal or non-fatal injury is obtained from casualty and fatality functions for the specified vulnerability index and weapon parameters. Figure 7 is an example of fatality and casualty functions used by NREC in their damage assessment systems (Reference k). It shows the probability of fatal or non-fatal injury for a 1 KT weapon surface burst as a function of distance from ground zero. Scaling factors are used to project these curves to larger weapon-size

FIGURE 7

Casualties and Fatalities from Direct Effects vs. Ground Range - Surface Burst 1 KT



burst-height combinations which may occur in the assessment. The fatality/injury probabilities for the specified distance from ground zero to people are obtained after scaling.

4. The probabilities thus obtained are applied to determine the number of fatalities and injuries to people at the resource point. Multiplying numbers of people at the resource point by the percent fatalities and percent injured gives the estimates of fatal and non-fatal casualties.

C. Computations of Casualties from Immediate Effects in NREC Programs

The procedure described above is approximately that used by NREC in existing damage assessment routines (Reference k). The casualty and fatality curves (Figure 7) used in the above description are representative of those used in such routines. These functions alone are used to represent the vulnerability of any person in the United States. No distinction is made between people in reinforced concrete buildings and those in residential dwellings.

Step 1 in the procedure described above suggests that vulnerability indices can be assigned to people according to the structural characteristics of the building in which they are located. This can be done in NREC routines only after the PV of the building, the number of occupants, and the appropriate casualty functions (or some acceptable groupings or approximations of these factors) are made available to the routines.

D. PV Codes, Descriptions, and Frequencies

1. Description of Data

As a preliminary to the design of procedures for PV data incorporation, an examination has been made of PV data from Phase 1 of the NFSS. Table IV lists the 33 PV codes, the type of facility, and the estimated psi overpressure range. (Reference r, from which this information was obtained, did not explain the meaning of the "overpressure range," but it is assumed to refer to overpressures for severe damage to the facility.) The table also contains a frequency of occurrence column. These frequencies were obtained by a random sample of Phase 1 facility records at the National Bureau of Standards (Reference s).

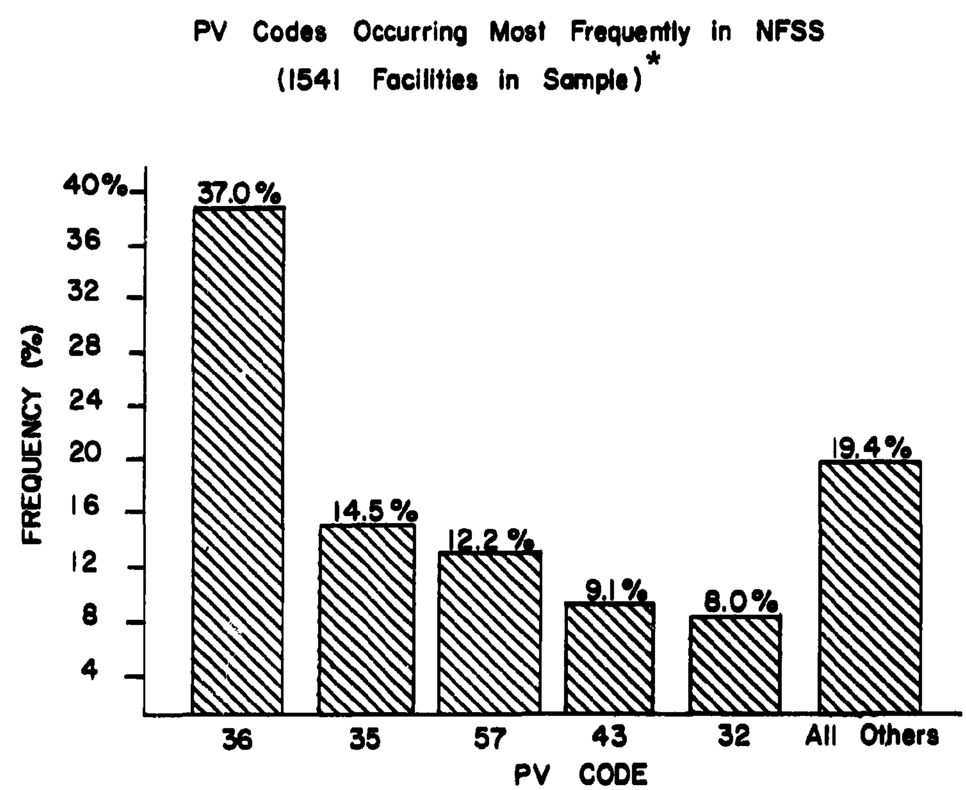
2. Results

The bar graph in Figure 8 shows the frequency with which the five most prevalent facility types occur in the sample of 1541 facilities. These five types account for 80.8 percent of all structures in the sample. There are 33 PV codes which fall into 9 overpressure ranges. Only 19 of the 33 types occur often enough to appear in the sample. Of the five types listed in Figure 8, three are wall-bearing commercial and industrial buildings. These three plus the steel-frame commercial type fall into the 3.1 to 5 psi range (as compared to the 2.1 to 3 psi for a single-story, wall-bearing dwelling), and represent 71.7 percent of the sample.

3. Limitations

Several cautions should be observed in applying these frequency data. The frequency data (Table IV) refer to buildings rather than shelter spaces. Also the psi overpressure ranges are related to facility vulnerability and not necessarily to population vulnerability.

FIGURE 8



PV CODE	TYPE OF FACILITY	PSI OVERPRESSURE
32	Commercial and Industrial - Wall Bearing (1 Story)	3.1 - 5
35	Commercial and Industrial - Wall Bearing (2 Stories)	3.1 - 5
36	Commercial and Industrial - Wall Bearing (3-5 Stories)	3.1 - 5
43	Steel Frame - Commercial	3.1 - 5
57	Reinforced Concrete - Commercial	7.1 - 10

*Phase 1 data.

TABLE IV

Physical Vulnerability Codes

Frequency of Occurrence of Various Types of NFSS Facilities

Type Facility	PV Code	Estimated PSI Overpressure	(Percent) Frequency
Wall-Bearing			
Commercial & industrial (3-5 stories)	36	3.1 - 5	37.0%
Commercial & industrial (2 stories)	35	3.1 - 5	14.5
Commercial & industrial (1 story)	32	3.1 - 5	8.0
Two story dwelling	34	3.1 - 5	3.2
Commercial & industrial (6-8 stories)	37	5.1 - 7	2.7
Multi-story monumental type	38	7.1 - 10	0.7
Single story dwelling	31	2.1 - 3	0.4
Steel Frame			
Multi-story, conventional design, commercial	43	3.1 - 5	9.1
Single story, very light steel frame, commercial or industrial	41	3.1 - 5	1.6
Multi-story, light industrial	44	5.1 - 7	0.9
Single story light steel frame, no cranes or cranes of less than 10 tons, industrial	42	3.1 - 5	0.3
Reinforced Concrete Forms			
Multi-story, conventional commercial	57	7.1 - 10	12.2
Multi-story industrial	58	7.1 - 10	2.1
Single story, very light, industrial or commercial	51	5.1 - 7	1.5
Single story, light frame, industrial	53	5.1 - 7	0.7
Multi-story, earthquake resistant	59	20.1 - 25	0.6
Composite Frame Building			
Single story, no cranes or cranes of less than 10 tons	61	5.1 - 7	0.2

(continued)

TABLE IV (Continued)

Type Facility	PV Code	Estimated PSI Overpressure	(Percent) Frequency
Wood-Framed Building			
Single or multi-story dwelling	21	1.1 - 2	0.8%
Miscellaneous			
Tunnels and earth covered structures	71	Over 25	1.5
Quonset type, single story building	11	1.1 - 2	0
Wood-Framed Building			
Single-story or multi-story commercial or industrial building	22	2.1 - 3	0
Steel-Framed Buildings			
Single-story, industrial with 10-25 ton cranes	45	3.1 - 5	0
30-50 ton cranes	46	5.1 - 7	0
60-100 ton cranes	47	5.1 - 7	
Over 100 ton cranes	48	7.1 - 10	0
Steel-framed multi-story, earthquake resistant	49	15.1 - 20	0
Reinforced Concrete Frame Buildings			
Single-story, light frame, no cranes or cranes of less than 10 tons, industrial	52	5.1 - 7	0
30-50 ton cranes	54	7.1 - 10	0
60-100 ton cranes	55	7.1 - 10	0
Over 100 ton cranes	56	10.1 - 15	0
Multi-story, windowless blast-resistant design	91	20.1 - 25	0
Composite Framed Buildings (Structural Steel & Concrete)			
Single-story 10-50 ton cranes	62	5.1 - 7	0
Mines and Deep Underground Facilities	81	Over 25	0

Weapons effects which inflict minor damage to a facility may cause a high percentage of injuries or fatalities because of broken glass and other flying debris.

E. Summary and Conclusions

Despite the limitations listed above, the results in Figure 8 and Table IV do represent an initial effort toward understanding how the new PV data may influence the estimation of blast fatalities.

It is tentatively concluded that of those facilities which appear frequently in the NFSS, only reinforced concrete buildings offer noticeable improvement in direct effects protection over shelter in dwellings.

It is further concluded that the incorporation of NFSS PV data in the existing routines for computing casualties will probably require not more than four or five casualty and fatality functions.

F. Extensions of the Study

In using the fallout protection data from the NFSS, it was assumed that fallout intensity would be relatively constant throughout a city. With this assumption, it is possible to assume movement of people to shelter through an unchanging fallout environment. It is not reasonable, however, to assume that direct weapons effects are uniform throughout a city. These effects are much more sensitive to distance from ground zero. If the movement to shelter concentrates people nearer ground zero, the result of moving into NFSS shelter may mean an increase in vulnerability. For example, in a national population vulnerability analysis which assumes movement into NFSS shelter before attack, casualties may be higher than those for an analysis which assumes exactly the same weapons and ground zeros, but leaves people in their residences with the protection afforded by such residences. This is an example of but one of many problems which may be encountered in using PV data from the NFSS.

The example above would indicate that an examination should be made of the sensitivity of direct effects casualties to changes in the assumed location of people, to changes in structure protection within the ranges covered by the NFSS, and to changes in weapon location. This should be done using the casualty and fatality functions being prepared by the Dikewood Corporation. The results of such an examination should assist in determining the most appropriate procedures for incorporating NFSS PV data into vulnerability analysis procedures and existing damage assessment routines. A preliminary evaluation of this kind has been made and is presented in Volume III (CONFIDENTIAL) of this final report.

VII. SUMMARY OF MAJOR CONCLUSION AND RECOMMENDATIONS

A. Conclusion

The PF data from the National Fallout Shelter Survey can be used directly and profitably in existing vulnerability analysis/damage assessment programs.[12/] A tested procedure for immediate incorporation has been presented, and an RTI computer program for this purpose can now be used in the Jumbo III system.

B. Recommendations

1. Additional revisions of vulnerability analysis/damage assessment models should be made (see Section V of this chapter). These revisions should also include the findings of the Dikewood (Reference q) and RTI (Chapter 1) follow-on studies in formulating the programming for models to be used in the CDC 3600 computer which is to be obtained by OCD.
2. Phase 2 NFSS data should be obtained from the Bureau of the Census to replace Phase 1 data presently available at NREC. Basement data now used in the RTI program is in regional (by climatic area) form, derived from the 1960 Census of Housing data. These data should be incorporated in standard location form.

12/ This conclusion assumes continued use of detailed procedures to determine casualties by standard location and to summarize these into national totals. No conclusion is drawn as to whether acceptable national totals can be obtained by a simple revision of present NREC tables (e.g., regional distributions of people in shelter as shown in Tables I and II), but it is expected that the table method would be adequate if only national totals are desired.

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Chapter 3

Recommended Procedures Developed for Evaluating Effectiveness of Civil Defense Systems

I. INTRODUCTION

The procedures and results discussed in this chapter are concerned with evaluating the effectiveness of shelter systems. The task described here deals primarily with fallout shelters and their improvement, as described in the National Fallout Shelter Survey (NFSS). However, other features of total CD systems, such as increased warning and variable shelter stay time, are significant as possible trade-offs with improvement in fallout shelters. The contract statement of the objective is as follows:

> "Devise means for relating probable postattack measures of conditions to: (1) costs of improved protection, (2) effectiveness of various types of expenditures in reducing expected casualties, and (3) alternative effectiveness of higher and lower levels of protection."

The procedures developed to satisfy this objective are primarily "Microanalysis" procedures (explained in Chapter 1, Section III). Such procedures operate upon a detailed data base which recognizes local variations in shelter and population rather than upon regional or national aggregate data. This approach was taken because the full evaluation of possible CD strategies requires a detailed procedure which is sensitive to variations in the location of people and shelter, the warning reaction time and movement-to-shelter time, detailed shelter use plans, and other local variables in CD systems. These variables and the possible range of fallout environments present a complex set of situations in which to evaluate the effectiveness in increasing survivors of alternative civil defense expenditures and planning strategies. Analysis in depth is not presently feasible (or necessary) for every place in the entire nation, but micro-analysis using representative cities can produce results which are generally valid for the nation. In this way both the "national" approach and the "local" approach can be kept separate, or can be merged, as appropriate to the interrelationships under investigation.

A procedure for the micro-analysis of CD systems has been developed. It is built upon a computer model called "The Mainline Computer Program." This program performs parametric case studies to determine survivors over a range of possible fallout conditions. All pertinent elements in local CD systems are parameters in the model. Results of case studies performed with the model will be used in sensitivity analyses to determine the relative importance of the variables in order to simplify the analytic tools as much as possible. The procedure then continues into evaluations of alternative strategies and produces results in terms of the value of a course of action as a function of a range of attack conditions or attack assumptions.

II. BACKGROUND

Prior to the National Fallout Shelter Survey, evaluation of CD systems was performed upon a shelter data base of little complexity. Protection in homes and residential basements was almost all that was known to be available. Public fallout or blast shelters were not available in sufficient numbers to be of major concern in evaluations.

The NFSS identified potential shelters in existing facilities and estimated their value for fallout protection. The data also presented new problems in modeling shelter systems. In order to be sheltered in NFSS shelter spaces, people must move. Thus, problems in simulating the movement of people to shelter arise. Many variable factors are immediately introduced in evaluating the existing protection capability even without shelter improvements. Some examples are:

Warning of attack and reaction to warning

Location at time of receipt of warning

Distance from nearest available shelter

Movement desire, capability, and speed

Knowledge of available shelter and amount of pre-planning and training.

Once variables such as these are resolved in acceptable detail, an estimate can be made of the number of people in shelter. This in itself involves interrelationships and attendant problems. When the evaluation proceeds to determine survivors, variables such as those shown below are added:

Dose received in moving through fallout to shelter

Variation in fallout protective value of shelters

Length of stay time in shelters

Variation in radiation exposure after leaving prime shelters.

Countermeasures such as decontamination and evacuation.

The importance of some of these variables will change with the attack conditions. Detailed analysis may also disclose other variables which must be considered.

The discussion above suggests the need for establishing the sensitivity of survivor estimation to changes in the many variables, but first the procedures for such analysis must be placed in the context of CD systems evaluation.

III. THE MAINLINE COMPUTER PROGRAM'S PLACE IN CD SYSTEMS EVALUATION

A. The Output of the Mainline Program

The Mainline Computer Program is the procedure which has been prepared to satisfy the requirements listed in the previous section. Figure 9 illustrates the steps toward strategy decisions contemplated in designing the Mainline Program.

The evaluation of alternative CD strategies must end in a report containing measures of effectiveness of a kind which can be used to trigger or supplement the decision process. With the uncertainty involved in forecasting probable attack conditions, the report will seldom present concise positive statements of the "best" strategy. However, it should contain a ranking of alternative strategies according to decision rules acceptable to the operations manager. Such a report may be prepared when the results of parametric systems analysis are related to an acceptable description of the attack environment. An example of such a report is given in Table V. This table shows a number of competitive feasible strategies (S_1, S_2, ..., S_n) which may include: public buildings incentives programs, new fallout shelter, improvements in existing shelter, comprehensive training programs, or several combinations of the alternatives. The effectiveness of each measure, possibly in terms of cost per survivor added, is shown over a range of possible attack strategies (A_1, A_2, ..., A_m).

Intelligence estimates and external considerations (political, military, etc.) can be used by the decision maker to assign a preference rating to the

FIGURE 9

A Concept of CD Systems Evaluation

(in which basic data is consolidated in steps toward decisions and action)

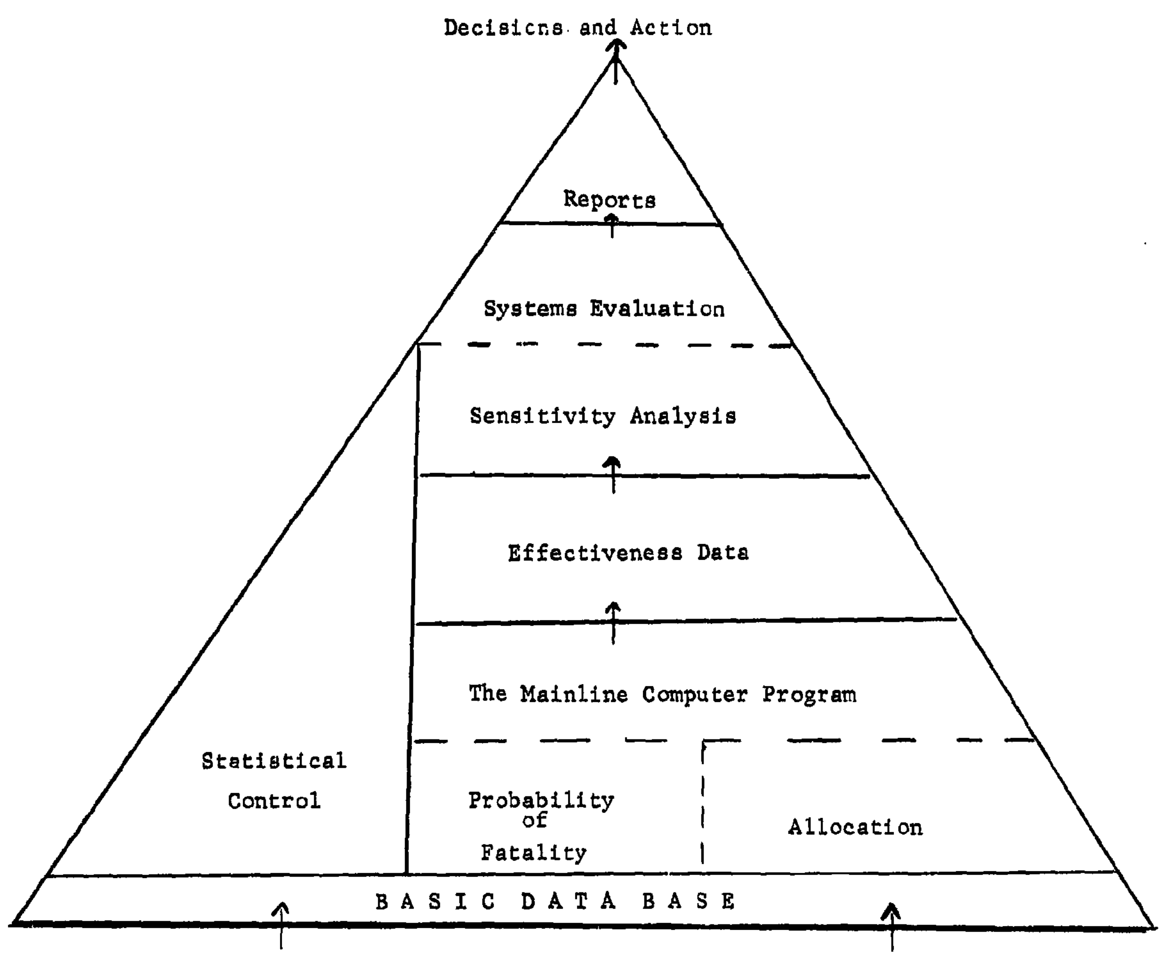


TABLE V

<u>CD Strategy Effectiveness</u>

		Alternative CD Strategies						
		S_1	S_2	S_3	.	.	.	S_n
	A_1	C_{11}	C_{12}	C_{13}	.	.	.	.
Possible	A_2	C_{21}	C_{22}	C_{23}	.	.	.	.
Attack	A_3	C_{31}	C_{32}	C_{33}	.	.	.	.
Options	A_4	C_{41}	C_{42}	C_{43}	.	.	.	.
	.	.	.	.	.	.	.	.
	.	.	.	.	.	.	.	.
	.	.	.	.	.	.	.	.
	A_m							C_{mn}

C_{mn} = Effectiveness (cost per survivor added) of strategy S_n in the event of Attack A_m.

various attack possibilities. Selection must then be made among alternative strategies, possibly with the assistance of Game Theory or other techniques (Reference t). An example of how such techniques may be used in such analyses is presented in Appendix E.

B. Sensitivity Analysis & Systems Evaluation

Systems evaluation procedures must be available to determine feasible strategies and their effectiveness. Sensitivity analysis can be used to select feasible alternative strategies as well as to estimate the importance of parameters in the evaluation models.

Sensitivity analysis helps determine the limits of applicability of a strategy and the degree of variation within the limits. As an example, the improvement of existing NFSS shelter may prove to be of little value except within a limited range of fallout conditions. This may hold despite any change in other CD systems parameters. Such findings would simplify systems evaluation.

Systems evaluation procedures develop the parametric studies of cost effectiveness required for the reports (as shown in Figure 9). Such evaluation over the broad range of possible combined strategies and attack environments which need to be considered are not practical when constructed individually for every place in the nation. For this reason a set of data called the "effectiveness data base" is required. These data can be obtained from case studies performed for representative cities using the Mainline Computer Program and through national systems analysis procedures (Chapter I, Section III). Case studies, when carefully designed, can convert the broad NFSS data base into manageable effectiveness data for systems evaluation.

The Mainline Computer Program is the micro-analysis procedure to be described in this chapter, but its explanation will be preceded by discussions of sub-tasks which led to its development.

IV. A SHELTER ALLOCATION MODEL

A. Introduction

The problem of estimating distributions of people in fallout shelter was discussed in Chapter 2. It was necessary to approximate this distribution in a way which would estimate neither unreasonably extensive nor unreasonably restrictive utilization of available shelter spaces. With adequate warning devices and an educated population, the factor assumed to be limiting in shelter utilization was the time to move to shelter. This, in turn, depends upon such factors as the distance from shelter, the traffic problems, walking or riding, etc. Without the assumption of warning devices and a population trained to move to assigned shelter areas, a multitude of factors enter into the estimation of probable shelter utilization.

For the procedures described in Chapter 2, in which NFSS data were incorporated into existing programs of the Jumbo III system, it was necessary to make assumptions of movement to shelter which could be applied throughout the nation. The result was the use of a "standard location (SL) movement" assumption and of a "county-wide movement" assumption. In the former, movement of people to shelter is restricted to the SL or what is equivalent but more general, any population movement into an SL is equaled by movement out. In the latter, movement of people is restricted to the county, or any movement into the county is equaled by movement out. It is expected that realistic population distributions in shelter will fall between those resulting from use of the two movement assumptions described above. The reasoning used in selecting these two movement assumptions is discussed in Chapter 2, Section III.

Although the use of movement assumptions applicable on a nation-wide basis is required by the components of existing NREC damage assessment routines into which NFSS data have been incorporated, a more detailed model is necessary for the micro-analysis procedures of this chapter. The discussion which follows will explain the detailed model which is proposed for use in micro-analysis.

B. Problem and Approach

In a micro-analysis of CD systems, it is necessary that the procedures be sensitive to those parameters used in modeling alternative strategies or improvement measures. For example, the calculation of survivors added (for a given attack environment) by ventilating existing shelter spaces to increase their capacity must take into account the possibility that persons using the new spaces may accumulate a lethal dose while moving to them. Such a possibility is not accounted for in the general assumptions discussed above. It would be useful to have a model which has, as parameters, all of the factors which determine how people would react, move, and choose a shelter in the event of an attack. However, data are not available and cannot be obtained for completely realistic simulations with such a model. A compromise solution is to design a model which contains those parameters found to be most significant and to perform analyses using upper and lower bounds for the uncertain parameters.

The part of the micro-analysis model discussed in this section is that which describes the movement of people to shelter and obtains resulting allocations of people to shelter. The situation to be modeled is not unlike the standard Transportation Problem (Reference u). Formulating the situation as a Transportation Problem, allocations can be obtained using one of several computers for which library programs are presently available (Reference v). Allocation of people to shelter by such a technique permits the rapid simulation of many alternative situations which must be examined in a micro-analysis of CD systems. The technique also permits the analyst to retrace the movement of people from their starting locations to their shelter. A visual examination of their movement patterns will disclose whether the resulting allocations appear realistic.

C. Discussion of the Transportation Problem

The Transportation Problem is one in which resources at a number of origins must be allocated to demands or requirements at a number of destinations. A cost matrix shows the unit cost of moving from each origin to each destination. The allocation which minimizes total cost is the one to be chosen. Finding this optimal allocation employs solution methods analogous to those used in the more general linear programming problem (Reference u).

Moving groups of people to shelter is an analogous situation to the movement of goods in the usual transportation problem. The origin might be the home, the office, or (more practically) the center of a population group. The destinations are shelters or the centers of shelter clusters. The resources to be moved are people. The objective function to be minimized might be the total (or average) distance traveled, the total (or average) time traveled, total fatalities, or total casualties.

D. Use of the Allocation Model to Examine Time to Move to Shelter

A Transportation Problem formulation was first used in an examination of the time to move to shelter. This was done to assist in understanding the movement time implied by the county-wide movement assumption used in incorporating NFSS data into Jumbo III.

Population and shelter in Durham, North Carolina, were used in a Transportation Problem formulation which had as its objective to minimize the total time for all people to move to shelter. Details of the formulation and procedure are given in Appendix E. The results of the case study were used to prepare Figure 10, which shows the percentage of the total population which has reached shelter as a function of the time after movement begins. The figure shows that 100 percent of the population had reached shelter in about 31 minutes. The results were also used to trace on a map of Durham the movement of groups of people from their homes to their ultimate shelter locations. A visual inspection of the traces on this map disclosed no patterns of movement which seemed unreasonable.

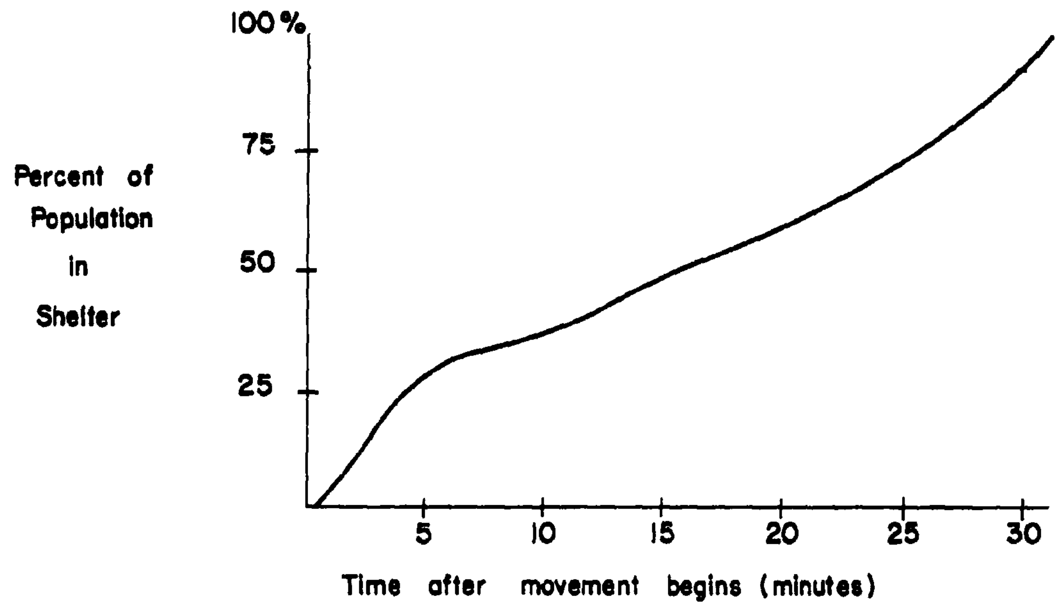
Although the case study results show a very optimistic picture in that immediate reaction to warning, knowledge of where to go, and movement at 5 miles per hour are assumed; it is concluded that with a reasonable amount of advance planning, adequate warning, and training, the City of Durham could be entirely sheltered in less than one hour. This is estimated to be the earliest arrival time for fallout reaching cities not directly affected by blast (Reference w).

E. Other Case Studies Using the Allocation Model

Appendix E describes a number of case studies performed using the Transportation Problem formulation (hereafter referred to generally as the "Allocation Model"). The case study described in Section D used a model which was sufficiently detailed for the required estimate. However, the allocation model as formulated for that study ignored some of the parameters

FIGURE 10

Percent of People in Shelter Over Time For A Durham, N. C. Case Study



Assumptions: Walking Speed - 5 mph
Minimize Time for Total Population to Reach Shelter
Unrestricted Movement Within City

considered important for micro-analysis. A major objection is that it did not distinguish between shelter protection factors in allocating people to shelter. Further, although movement under fallout was not a major concern in the solution discussed above, this factor may be of great importance in determining survivors when travel distances are much greater than those in the Durham case study.

The case studies in Appendix E were designed to determine whether fatality computations are sensitive to the changes in allocation which occur when aspects such as movement under fallout and the shelter protection factor are considered or not. Both movement under fallout and protection factors of shelters must be considered in fatality computations; however, if they can be ignored in modeling the allocation of people to shelter, the allocation model will be simplified. The case studies were also arranged to produce a set of hypothetical results which could be used in planning further development of micro-analysis procedures.

F. Test Results and Limitations

Test results are presented in Appendix E, Table E-I, which shows the number of fatalities resulting for each of 12 formulations of the allocation model using Durham data and an artifically slow movement speed of 1 mile per hour. (The slow speed was used as a computational convenience so that there would be movement under fallout without assuming fallout arrival times under 30 minutes.) Fatalities were computed for each of five sets of fallout environment parameters (time of arrival and H + 1 intensity). These were assumed uniform throughout the city.

As a result of these tests, an allocation model based on the Transportation Problem was tentatively accepted as appropriate for micro-analysis of CD systems. The objective function selected was total fatalities, which are to be minimized; and the element selected for the cost matrix (explained in Appendix E) was probability of fatality. The allocations which result from the model will be an estimate of the best that can be obtained for a given attack environment. In planned extensions of this study, this estimate will be modified by constraints on the model to degrade the resulting shelter allocation to simulate more realistic situations.

Time limitations prevented the examination of a sufficient number of cases to fully evaluate the model, but the test demonstrated a convenient model for quickly obtaining allocations of people to shelter with the apparently significant parameters represented in the allocation. It was intended that other tests be made by applying the model to Milwaukee, Wisconsin, and Lincoln, Nebraska. These allocations would be compared with those obtained by Operations Research, Incorporated, in applying its sheltering procedure to Milwaukee (Reference x), and by Stanford Research Institute in producing a shelter plan for Lincoln, Neb. (Reference y). A brief examination of ORI's procedure suggests that the allocation model generally agrees with the ORI procedure. Both studies cited represent plans which might actually be used by local CD directors and both were prepared from very detailed examinations of the two cities. Comparison should help in validating or modifying the allocation model. Unfortunately, the data for such comparisons were not available during the contract period. It is intended that follow-on research will include such comparisons.

G. Conclusions

Although there may be some modification of the model as further tests are performed, the basic form of the allocation model has been accepted and incorporated into the Mainline micro-analysis procedure for further studies at RTI. A later section will explain the place of this model in the Mainline procedure.

V. EFFECTIVENESS OF SHELTER FALLOUT PROTECTION

A. Introduction

Objective 2 of the project states in part: "Devise means for relating probable postattack measures of (fallout) conditions to . . . alternative effectiveness of higher or lower levels of protection."

This section will introduce a mathematical equivalent residual dose model developed under this sub-task for use in parametric analyses to determine the relative effectiveness of NFSS shelter protection. The model is presented in detail in Appendix D, and several applications are discussed there. This section will be restricted to a general discussion of the model and its use in providing revised PF values for use with Jumbo III in the SPAN evaluations.[13] It will be assumed that readers are familiar with the equivalent residual dose concept. Those who are not, may refer to the brief discussion in Appendix D and to the more complete explanation in "Operations in Fallout" (Reference z).

B. The Model

The mathematical model was prepared for use in sensitivity analysis of one element of total CD systems evaluation: the determination of the peak equivalent residual dose for use in casualty computations. The model is programmed in FORTRAN for the IBM 1620. The form of the output and the parameters are arranged according to the particular sensitivity analysis being performed. Analyses will typically be concerned with the variation of the

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13/ The SPAN program employed the RTI procedure for incorporating NFSS data into Jumbo III. This procedure is discussed in Chapter 2.

time of occurrence and magnitude of the peak ERD with changes in the attack environment and shelter conditions. The parameter of prime concern is the protection factor of the initial shelter within the PF range disclosed in the NFSS.

The model computes ERD day by day, determining independently the reparable and non-reparable portions of the total dose. The mathematical formulation shown in Appendix D includes an expression for both reparable and non-reparable portions for each shelter period. The following variables are employed in expressing changing shelter conditions:

1. Time of arrival of fallout
2. Initial fallout intensity
3. Fallout field decay rate
4. Time of stay in each shelter (or activity) period
5. Protection factor in each period
6. Biological recovery rate.

In the applications which follow, the model used an irreparable portion of 10 percent of total dose and a body recovery of 2.5 percent of the reparable portion per day. The decay rate used was $t^{-1.2}$.

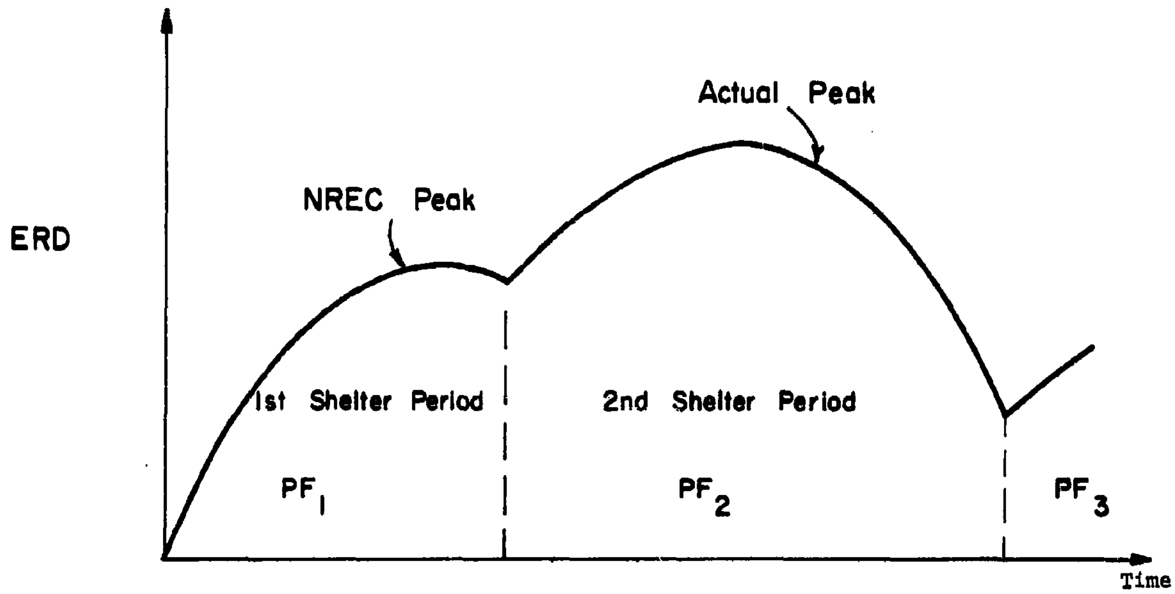
C. Period of Peak ERD

As discussed in Chapter 2, Section VI, the high PF values disclosed in the NFSS may present a situation in which the peak ERD occurs, not during stay in the initial shelter, but during some subsequent period. The model was first used to determine the conditions under which peak ERD occurs later than the initial shelter period.

This question was of particular interest in incorporating NFSS data into Jumbo III. Figure 11 illustrates the problem. It shows the ERD versus time for

FIGURE 11

NREC Peak and "Actual" Peak
Equivalent Residual Dose



two shelter periods. For example, it may be assumed that the PF_1 of the first shelter period is over 100 with about 14 days' stay. The PF_2 of the second period is assumed to be approximately 10 with about a 60-day stay. The Jumbo III method of calculation cannot account for the shifts in occurrence of peak ERD and would compute a low ERD for casualty computations as shown in Figure 11. No difficulty results as long as shelter PF_1 values and other conditions are such that the indicated NREC peak is also the highest ERD value. A test was made with the model described above to determine when NREC procedures were adequate (Appendix D, Section I).

The test was made to determine those combinations of PF_1 and PF_2 which would produce a peak ERD in the second period with a 14-day stay in the prime shelter. A range of time of arrival of fallout from one hour to five hours was used. The results, which are independent of the reference dose rate, are shown in Table VI.

TABLE VI

Limiting Ratio for First Period Peak ERD

		Time of Arrival of Fallout (Hours)				
		1	2	3	4	5
$\frac{PF_1}{PF_2}$	=	5.04	3.74	3.10	2.68	2.39

The results may be interpreted for the second period protection factor (PF_2) of 10 used in the earlier example as follows: If the time of arrival is one hour and PF_2 equals 10, the PF_1 of the first shelter must be equal to or greater than 50.4 in order for the peak ERD to occur in the PF_2 period. As the time of arrival moves to five hours, the PF_1 value required for second period peak ERD to occur drops to 23.9.

Before NFSS data were available, and when a PF_2 of 4 or more was assumed, the NREC method was not a bad approximation, since few people were assumed to be sheltered with PF_1 values over 10. However, much of the shelter disclosed in the NFSS exceeds a protection factor (PF_1) of 40. An alteration must be made in order to obtain valid results using NFSS data in Jumbo III.

The following discussion will disclose how a temporary alteration was made for the SPAN evaluation.

D. Revised PF Values for SPAN

Figure 11 shows an "NREC Peak" and an "Actual Peak." Time did not permit the revision of Jumbo III programs so that the actual peak could be computed within the Jumbo system for the SPAN expression of the shelter situation. A procedure to determine the actual peak from the NREC peak was required.. This was done by the use of a PF', a number or scaling factor to replace the building PF in the NREC program. In this procedure the reduction factors (reciprocal of the PF) of the buildings are replaced in Jumbo III by revised reduction factors (reciprocal of the PF'). The revised reduction factors are multiplied by the NREC peak ERD for unsheltered (PF = 1) population to obtain an estimate of the actual peak ERD (Appendix D, Section VII).

The PF' values for the protection factor categories used in the SPAN program were obtained using the mathematical model programmed for the IBM 1620. The SPAN statement of conditions was:

1. NFSS shelters occupied for 14 days
2. Controlled living for the next 40 days with PF_2 of 12.5
3. For the remainder of the exposure to fallout, a PF_3 of 10 is maintained.

These constraints plus the decay rate, body repair rate, and irreparable fraction mentioned earlier, set most of the parameters for the program. Time of arrival and PF_1 remained variable. Preliminary examination indicated that the third period with $PF_3 = 10$ did not contain the peak ERD for this set of conditions and the NFSS range of PF_1 values.

The temporary procedure permits use of only one time of arrival. As directed by the project monitor, a time of arrival of 2 hours was chosen as appropriate. The PF' was determined by computing the actual peak ERD for each building PF category. When the actual peak occurred in the first shelter period, the building PF was not revised. When it occurred in the second period, the PF' became that number by which NREC peak unsheltered ERD could be divided to obtain the actual peak ERD. The results for NFSS shelter Categories 2 - 8, using the SPAN assumptions, are shown below:

TABLE VII

Revised PF's for SPAN Program*

NFSS PF Category	Assigned PF	Period of Peak	PF'
2	56	2	55.00
3	85	2	72.22
4	125	2	86.55
5	200	2	100.87
6	375	2	114.34
7	750	2	123.00
8	1000	2	125.36

*PF_2 = 12.5

VI. THE MAINLINE COMPUTER PROGRAM

The preceding sections describe two major elements of the Mainline Computer Program. This is the program which has been developed to perform micro-analysis of CD strategies over a range of attack conditions. Its repeated use in case studies will produce the effectiveness data required in deciding between alternative planning or spending strategies.

The program allocates people to shelter and computes survivors for any statement of the fallout environment and the shelter situation. This is its basic function. A sample of cities tentatively selected to be representative of all cities under fallout conditions has been obtained. The Mainline program and the selection of representative cities will be explained in this section.

A. General Explanation of the Mainline Computer Program

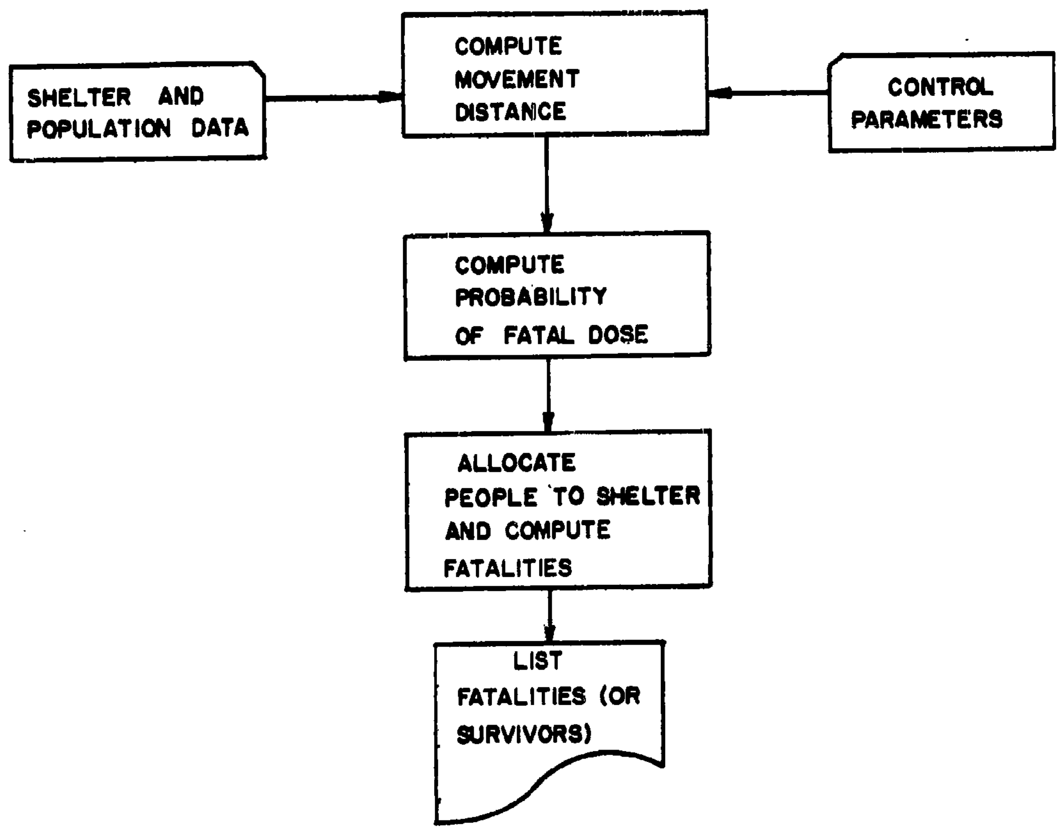
The Mainline Computer Program receives as input the population, shelter, and fallout environment data which describe a case study situation. Population is moved to shelter according to the allocation procedure which minimizes fatalities, as described in Section IV. Survivors are computed using a procedure similar to that described in Section V. The parameters of interest are changed in discrete intervals until a sufficient number of cases have been examined to reveal trends, limits, and variations in survivors. The procedure is repeated for all of the sample cities. This output is then organized into the effectiveness data required for systems evaluation.

B. Components of the Program

The program consists of many interrelated sub-routines and data sets, as illustrated in the flow chart in Figure 12. These components are discussed below:

FIGURE 12

The Mainline Computer Program Generalized Flow Chart



1. <u>Shelter and Population Data</u>

The shelter and population data enter the program through punched cards for each standard location (SL). These cards contain the following information:

a. SL identification

b. SL geographic coordinates

c. Spaces in each PF category (actual or proposed) in each SL

d. Population in each SL

2. <u>Control Parameters</u>

The functions of the program which can vary are controlled by values entered on control parameter cards. At present, the control parameters are:

a. Category protection factor

b. Equivalent or actual protection factor for other than prime shelter

c. Reference intensity

d. Warning time

e. Fallout arrival time and build-up function

f. Decay constant

g. Repair rate (for ERD)

h. Irreparable fraction (for ERD)

i. Dose response curve

j. Length of stay in shelters (up to 4 time periods)

k. Movement speed.

These parameters adjust the model to the particular situation under examination. Some of the parameters (such as dose response curve, repair rate, irreparable fraction, and category protection factor) are expected to be fixed for most of the case studies. However, the program permits them to be varied in response to expected future inputs from other research projects. They will also be varied in sensitivity analysis of the program elements. Other parameters, together with the shelter and population data, are used to describe changing operational situations or the fallout environments.

3. Movement Distances

The coordinates of the SL are used to determine rectangular distances between people and shelter. These distances and the movement speed will determine times to move to shelter. Coordinates are obtained from the National Location Code (a list of SL's and their coordinates prepared by the Bureau of the Census).

4. Probability of Fatality

This sub-routine computes the probability that a person in SL_i moving to a given shelter in SL_j will become a fatality. (Probability of non-fatal injury may also be used when appropriate.) Such probabilities are computed for each combination of SL's with population and SL's with shelter. The procedure takes into account the following factors:

a. Radiation build-up phase
b. Long term exponential decay and radiation field
c. Change in shelter protection with time
d. Equivalent residual dose and dose response curve

e. Biological recovery rate

f. Non-recoverable dose fraction

g. Reference intensity

h. Time of arrival of fallout.

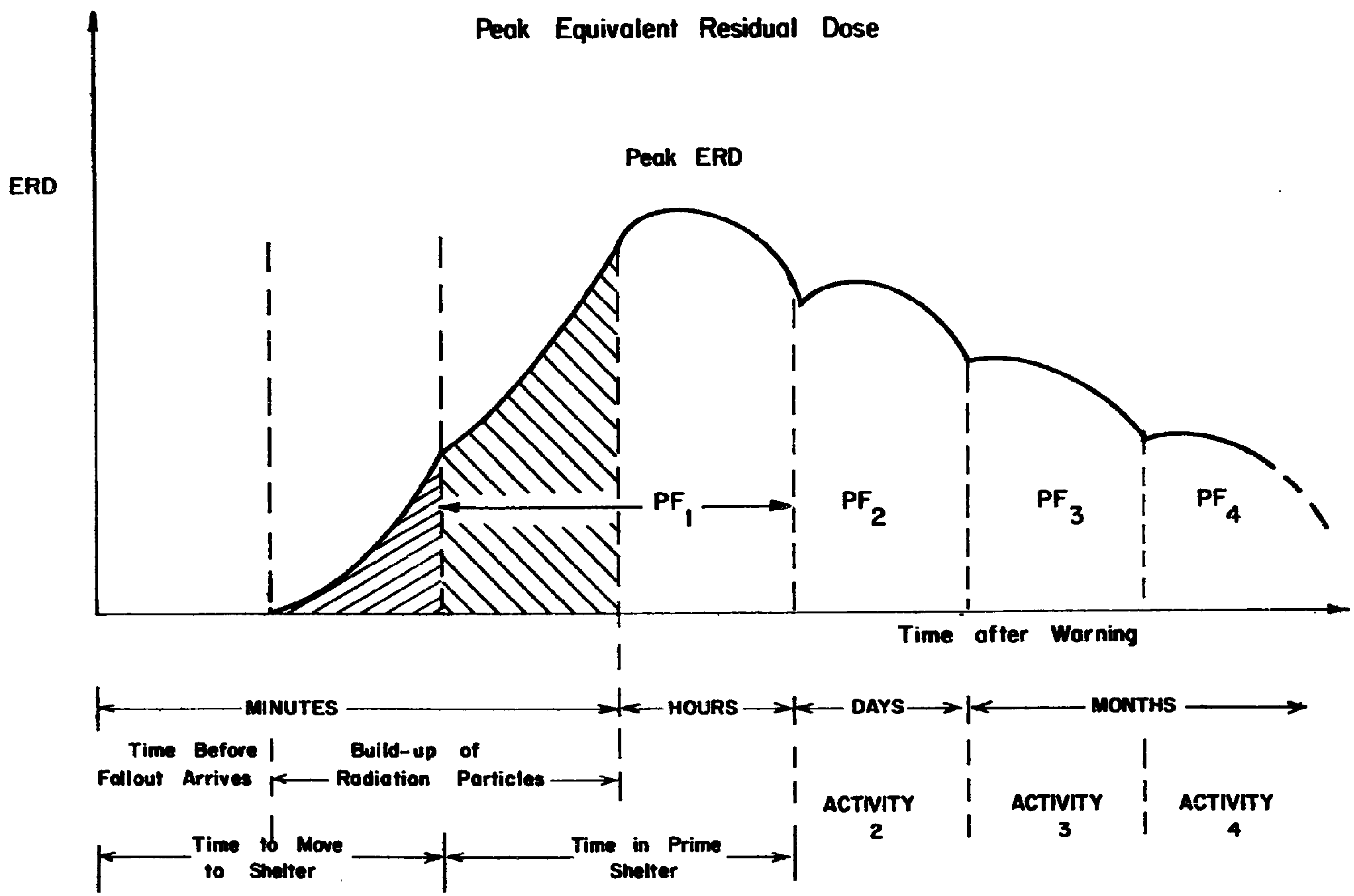
Some of these factors are illustrated in Figure 13, which shows the elements which go into the calculation of the peak ERD. This graph resembles the one in Figure 11 of Section V, in which peak ERD was first discussed. However, several factors which were not included in the earlier discussion have been added.

The importance of dose accumulated during movement through a fallout field was highlighted by the tests performed with the allocation procedure. Use of a long-term decay constant (e.g., $t^{-1.2}$) from the time of arrival throughout the period of significant intensity overestimates the amount of early dose accumulation. This is so because the finite time over which fallout buildsup on the ground is neglected. This is of no great importance in studies in which movement to good shelter is accomplished before fallout arrives; but for early arrival times, where movement under fallout occurs, the rate at which the radiation field builds up to peak intensity may significantly influence allocation to shelter and numbers of fatalities. An estimated build-up function has been hypothesized, and studies to improve this function are continuing.

Because the Mainline probability-of-fatality program also includes four shelter or activity periods, various activities which

FIGURE 13

Graphic Illustration of Factors Influencing Determination of Peak Equivalent Residual Dose



cause a change in the actual or equivalent protection factor (EPF - see Appendix D, Section IX) may be evaluated.

The probability-of-fatality program receives as input the control parameters, shelter data, and the time to move from each population center to each shelter center. For each combination of population center and shelter center, a person is assumed to start at receipt of warning and move to shelter. Time to shelter and time of arrival of fallout determine whether movement through fallout is involved. If so, the build-up model and PF = 1 portions of the program are employed in accumulating dose. The program continues through each activity until a peak ERD is determined. This ERD is then related to the dose response curve to determine a probability of death for the particular movement from the population center to the shelter center. The procedure is continued until all possible SL combinations have been assigned a probability.

5. <u>The Allocation Program</u>

The allocation program will take the probability of death from the preceding program as the cost function and minimize the overall number of fatalities. The primary output from this program is a listing of numbers of survivors, but additional information is also obtained. Patterns of population distribution in shelter and the movement time or fatalities for each SL population group allocation can be printed out.

This part of the Mainline Computer Program is essentially the same as that explained earlier in a test of the Transportation Problem allocation procedure.

C. Sample Selection

A problem associated with the development of CD systems analysis procedures is the handling of the large mass of basic data from the NFSS and census. Micro-analysis procedures employ the data at the smallest practical level of summary and manage it by careful selection of representative case study cities. A preliminary selection of cities is described below. Revised selections may be made after analysis of the case study results.

When selecting a sample from a non-uniform universe, it is usually desirable to randomly select from each of the sets that are stratified by a given characteristic. In sampling the Standard Metropolitan Statistical Areas (SMSA) for processing in a fallout shelter system evaluation procedure, this characteristic is "number of fatalities expected." Of course, it is impossible to calculate this quantity in any simple way. Thus we hypothesize that the population density and the shelter spaces/person ratio will be parameters which correlate best with fatalities. (Other parameters are also important, such as the distribution of shelter protection factors, the population, the shape of the city, etc.) Greater stratification seems undesirable, if only because it is difficult to get a sub-group of cities with common characteristics.

Two stratifications were made using the 176 SMSA's listed in Table F-I of Appendix F. This table shows the spaces/person ratio and the population density for each SMSA. Stratification was first accomplished by plotting the spaces/person ratio versus population density for the 176 SMSA's and observing clusters of data points. Within a cluster, the most centrally located SMSA was chosen as the sample SMSA for the stratum. The 18 SMSA's so selected are listed in Table F-III of Appendix F. Multiple city SMSA's were excluded in selecting the sample SMSA. The SMSA's thus excluded are listed in Table F-V of Appendix F.

The second stratification is based only upon the shelter/person ratio. Division into 15 equal intervals was made and a central point within each interval was chosen. The stratification thus accomplished is shown in Table F-II, and the sample SMSA's are listed in Table F-IV of Appendix F. This stratification is presently judged to be less desirable for the objectives of this sub-task, and the 18 SMSA's of the first stratification will be used in follow-on analyses.

The population information was obtained from the 1960 census (Reference aa). Shelter data were obtained from the National Fallout Shelter Survey Phase 1. The shelter capacities in protection factor Categories 1 through 8 were summarized to obtain the shelter space totals (Reference bb).

VII. CHAPTER SUMMARY

A. Present Status of the Mainline Computer Program

The Mainline Computer Program has been completed and is ready for immediate use. Parts of the program have already assisted a special OCD task, as described at several points in this chapter. Data are available to begin performing case studies to collect the effectiveness data (see Section III) required for systems evaluation and sensitivity analysis. It is expected that improvements will be made in the program as effectiveness data are processed.

An alternative approach to analysis of NFSS data and of improvement programs was investigated and reported in Appendix E, Volume II, "Reduction of Shelter Characteristics." It appeared to be less promising than the Mainline Program.

B. Cost

The Mainline Computer Program recognizes the importance of dollar cost data in systems evaluation, but procedures that have been designed up to the present time have concentrated primarily upon survival calculations. In alternative strategies which require funds, the expenditure of funds results in a system change which can be specified in terms of the input parameters to the Mainline Program. Results of the change in terms of "survivors added", or other effectiveness measures can easily be combined with costs to yield the "cost effectiveness" required in systems evaluation.

Dollar cost data for systems evaluation are available from a number of sources, and development of such data continues. A prime source will be that collected in the NFSS during Phase 2 (Reference cc). These data include the cost of improved ventilation, improved shielding, or electric power generators. They can be used in detail in micro-analysis or as averages, such as the $25-per-person estimate of the cost to improve potential shelter spaces stated in Reference dd, page 95. This same reference also estimates the cost of new shelter to be $40 per person.

Estimates of costs of warning devices, radiological monitoring devices, and blast shelter have also been made (References ee, ff, and dd, respectively). These costs, as well as the cost of improved fallout shelter, may be related to systems improvements and evaluated as a part of the total civil defense system in the Mainline program.

C. Limitations

The Mainline Program is not intended as a completely comprehensive procedure which will serve for all analyses required in the evaluation of civil defense systems. Its most notable limitation is that it is applicable only where protection against fallout alone is being considered. Direct effects must be accounted for outside of the framework of the present program. However, fallout alone will be the major threat to much of the country, and the Mainline Program will permit a detailed micro-analysis in such areas. Major limitation, not of the model but of the data base, are the conservative bias and incompleteness of the NFSS. These limitations are discussed in Chapter 1, Section V and Appendix A.

VIII. CHAPTER 3 REFERENCES

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Appendix A

A Description of the National Fallout Shelter Survey

I. INTRODUCTION

This appendix is included to aid the reader who is not acquainted with the National Fallout Shelter Survey (NFSS). Some concept of the basic elements of the NFSS is required to understand many sections of this report.

The specification of an effective civil defense program has included among its criteria the following points: In order to provide the greatest amount of protection possible against fallout from nuclear explosions, a system of shelters, sufficient in numbers and conveniently located, must be developed; further, this development must take place in a short period of time and at a minimum cost. The solution has been, therefore, to utilize first those existing facilities, buildings, and other structures which could be readily identified, marked, and stocked.

With this objective in mind, and with the sense of urgency precipitated by the Berlin crisis, the Office of Civil Defense undertook the NFSS in late 1961. This has since become the "cornerstone" of our present civil defense preparedness. Not only was this survey made to realize immediate preparedness using existing facilities, but also to serve as a "basic data source for analytical studies and planning future programs" such as shelter incentive programs, war-gaming techniques, damage assessment routines, and vulnerability analyses.

II. SURVEY ORGANIZATION

(References A-a, A-b, & A-c)

In administering the survey, the Office of Civil Defense called on the Bureau of the Census, the National Bureau of Standards, the Army Corps of Engineers, and the Navy Bureau of Yards and Docks for assistance. The latter two groups, in turn, contracted with professional architects and engineers throughout the country to conduct the necessary field work. Prior to the survey itself, special training courses were conducted for architects and engineering (A&E) groups to provide technical background for survey personnel.

The survey was divided into Phases 1 and 2, with more than 600 architectural and engineering firms employed, using over 2000 graduates of shelter analysis courses. The basic function of the first phase was to identify and classify potential shelter as it currently existed. During the course of Phase 2, qualified shelters were marked and stocked, and feasibility and cost estimates for improving others were made.

III. SOME BASIC CONCEPTS AND DEFINITIONS

(References A-a, A-c, & A-d)

While it is beyond the scope of this report to go into a detailed explanation of such topics as radiation effects and measurements, certain basic concepts must be understood. Once this is done, it will then be possible to describe briefly the operations involved in both Phases 1 and 2.

Basically, gamma rays from fallout may penetrate a structure through the roof and ceilings (roof contribution) and through the walls (ground contribution).

When analyzing a structure for potential shelter, the center of the floor three feet above the surface is chosen as a reference point. At this reference point we imagine a "detector" to be located. It is at this detector that the total radiation contribution (expressed as a "reduction factor") is estimated. In estimating contribution, numerous measurements and calculations are made. These include such things as the thickness and composition of walls, ceilings, and roofs; design and area of floors; as well as many other design characteristics.

The total contribution is converted into a "Protection Factor" (PF) which expresses the ratio of the amount of radiation that would be received by a detector in the open to the amount that it would receive with the structure present. For example, if a particular shelter is said to have a PF of 20, the radiation inside the shelter is 20 times less than that in the open.

Protection Factors are grouped into 8 categories in summary reports, as shown in Table A-I.

PF is one of two terms used extensively in the project described in this report, the other term being Physical Vulnerability (PV) which is a numeric code used to describe the type of construction and which is related to the estimated pounds per square inch (psi) of overpressure the structure can withstand.

More exact and detailed explanations may be found in various handbooks, guides, and other OCD publications. References are listed at the end of this appendix.

IV. NFSS - PHASE 1
(References A-a, A-e, A-f, & A-g)

An understanding of Phase 1 may be obtained by considering the various steps taken. A&E firms were given the responsibility of data collection. Included were such tasks as making day and night population estimates to complement census residential figures, identifying facilities which could provide shelter, and collecting information on shielding which would be used by the National Bureau of Standards to calculate Protection Factors. Various survey methods were employed by the A&E teams ranging from Code 1 through Code 7. Code 1, for example, was a search of office records only, while Code 6 included office records and an exterior and interior examination of structures. Examples of data sources employed were: Bureau of the Census publications, Sanborn maps, building codes, tax records, zoning codes, along with private business and association information.

TABLE A-I

Protection Factor Categories

Protection Factor Category	Protection Factor Range
1	20 - 39
2	40 - 69
3	70 - 99
4	100 - 149
5	150 - 249
6	250 - 499
7	500 - 1000
8	over 1000

The A&E firms recorded descriptions, dimensions, measurements, and other structural information for each potential facility on separate FOSDIC (Film Optical Sensing Device for Input to Computers) forms. Over 500,000 FOSDIC forms were processed (Reference A-h). Excluding single-family residences, a facility was eligible to be surveyed if it was thought to have a PF of 20 or better and potential space for 50 or more people.

After the architects and engineers filled in the forms, they were sent to the Bureau of the Census, where they were microfilmed. By means of the FOSDIC process, the microfilmed data were then converted into electronic computer tapes and forwarded to the National Bureau of Standards.

The National Bureau of Standards, using the data on building geometry and shielding, computed PF's and estimated the number of people that could be sheltered. Results were made available on printouts. A Phase 1 printout typically gives such information as standard location and facility numbers, names and addresses of facilities, and for each floor the contribution of walls and ceiling, the PF categories (1 through 8), measurements of area and volume, and the number of people who could be sheltered on each floor. In the event that none of the floors in a given facility contained a PF rating of at least 20, this fact was noted on the printout.

The resulting data from computations by NBS are summarized on various levels: (1) Standard Location, (2) County and County Area, (3) State, (4) Regional, and (5) National.

According to Office of Civil Defense Annual Statistical Report, 1962 (Reference A-g), "During FY 1962, nearly 375,000 existing buildings and other enclosures were examined for shelter potential." Adding the total of all protection factor categories from Category 1 (PF 20-39) through Category 8 (PF over 1,000), Phase 1 identified over 200 million shelter spaces.

Figure A-1 is an example of a specific facility description found in the Phase 1 printout for the Atlanta, Georgia, area. The top line above gives the standard location (SL) number for identification purposes, the field office (Savannah District), and the contract number within the field office. This information is presented once at the beginning of each SL.

FIGURE A-1

An Example of a National Bureau of Standards' Facility Printout

National Fallout Shelter Survey - Phase 1

SL 3324-004 FO-C4 C-03

FAC=00407 PT=01 of 01 REV=0 ST=08 1330 BLDG 1330 W PEACHTREE ST ATLANTA GA USE=51 OWN 4 PV=57 YEAR 1957 SM=6

STORY	A	B	C	D	CL	TOT	PF	FLOOR	S-AREA	CORE	VOLUME	PEOPLE
1	00	00	28	00	00	28	1	17820	8910		80190	891*
2	00	00	38	00	00	39	1	17820	8910		98010	891*
3	00	02	24	02	00	27	1	17820	8910			891*
4	17	09	05	09	00	41	1	17820	8910			891*
5	08	06	04	06	01	26	1	17820	8910			891*
6	06	04	03	05	03	31	2	17820	8910			891*
7	05	03	02	03	12	26	1	17820	8910			891*

The identification line includes such information as: a number designating the facility within the SL, the number of parts to the facility, the number of data revisions, the number of stories in the building, the name and address of the building, a use class code (51 - commercial offices) and an ownership code (private, local, state, Federal Government, or other), a Physical Vulnerability (PV) code which describes the type of construction (57 - multi-story, conventional, commercial), the year of construction, and the method of survey (SM-6-search of office records, and exterior and interior inspection).

Of the 8 floors in this building, 7 were estimated to have a PF of at least 20. For each floor, the effects of radiation on each wall (A, B, C, D), or ground contribution, and the ceiling (CL), or roof contribution, are listed and totaled (TOT). A decimal and a first zero were omitted from the printouts. In this instance the first story had a reduction factor (total contribution) of .028. Since the Protection Factor is simply the reciprocal of the reduction factor, the PF is slightly less than 36 (35.7) and it falls in PF Category 1 (20-39).

The heading FLOOR is the total area in square feet. The S-AREA, or shelter area, is that fraction of the total floor area having a specified PF nearly as great as the center PF (for example, a floor having a center PF in PF Category 5 is assumed to have a PF of 100 in at least 70 percent of the total area). The CORE is that central area, if existing, surrounded on two or more sides by interior partitions and may be considered the desired shelter area if smaller than the S-AREA. In this specific case, no CORE information was reported.

The figure under the heading VOLUME is the floor area multiplied by story height, while PEOPLE (shelter capacity) is the CORE, when given, or S-AREA divided by 10 square feet (assuming ventilation is adequate) for the first and upper stories, or VOLUME divided by 500 cubic feet for basements (assuming inadequate ventilation).

Coincident with the completion of Office of Civil Defense review of the findings of the Phase 1 data, Phase 2 was put into operation.

V. NFSS - PHASE 2

(References A-a, A-c, & A-d)

Since the major function of Phase 1 was to identify and classify potential shelter, structural data collected during the first phase were related to shielding but not to habitability or possible modification. Once shelters were tentatively identified, however, it was then meaningful and economical to perform a more thorough and complete analysis.

During Phase 2, contractors (i.e., designated A&E firms) were required to make detailed building inspections and analyses to review the accuracy of PF calculations of Phase 1, and to determine both the feasibility and the estimated cost of improving the protection factor in shelters falling in Categories 2 and 3 (PF 40 - 99). In many cases shelters originally assigned a low PF rating were, when examined during Phase 2, upgraded one or more categories. Few were downgraded. One of several explanations for this was the influence of a sill height factor. In other cases, if permission was not received to mark the shelter, it was dropped from the list and no longer included in the aggregate. Also, as part of Phase 2, those shelters falling in Category 1 were dropped. This category was included originally as a "safety factor" to reduce the danger of omitting potential shelter which had at least PF of 40. Shelters determined to have a PF of 100 or better were determined eligible for marking and stocking. Local civil defense officials were later authorized to mark, but not stock, PF Categories 2 and 3 shelters when enough PF Category 4 spaces were not available.

As a part of Phase 2 operations, a survey was made of selected special facilities including subways, caves, and mines. Special facilities, like regular structures, were to be marked if they met the established criteria for public fallout shelters.

Some interesting comparisons may be made between summary figures of the two phases. The total number of shelter spaces identified (Categories 2-8) in Phase 2 remains less than in Phase 1 (almost 103.7 million vs. 119 million), but if Categories 4-8 are considered (PF of 100 and better), Phase 2 has a net increase of 16.5 million over Phase 1 (69.8 million vs. 53.3). In addition, there were approximately 60 million spaces which could be improved to the point where they could be added to the existing 4-8 spaces. The addition would come from shielding and ventilation improvements at an average cost of between eleven and twelve dollars per space. As of August, 1963, 45 percent of the 125,445 facilities located have been marked (Reference A-1).

VI. LIMITATIONS

As a data base for vulnerability analysis or similar use, the NFSS has several notable limitations. These concern anticipated bias and omissions.

A. Bias

A primary purpose of the NFSS was to obtain the largest number of shelters in the quickest time at the least cost. This of necessity led to the use of data collection and machine protection factor computational procedures which stressed speed and economy.

The accuracy of the survey data is being examined in another RTI task, (Reference A-j). The final report for this task will show that the calculated PF's reported to date for spaces identified in the survey tend to be conservative, or to understate the actual protection afforded by the structure. The effect of such underestimation on vulnerability analysis and systems evaluations is yet to be determined.

B. Omissions

A completed OCD Contract (Reference A-k) has also disclosed that a number of buildings which should have been included in the survey were overlooked by the various A&E contractors. The number of available spaces will be increased when such omissions are corrected in follow-up investigations which are a part of the permanent OCD program.

Residential basements add another important element to the total shelter data base. Information about the availability of such basements was obtained in the 1960 Census. An examination was made of these data and a procedure for their inclusion in existing damage assessment systems was devised. This feature has been programmed and tested in the Jumbo III system (Chapter 2, Section IV). The examinations, previously reported in a research memorandum, are reproduced in Volume II of this final report.

A data base including facilities identified in the NFSS, residential basements, and homes without basements can now be made available for vulnerability analysis and damage assessment. Not included in the data base are other places in which people may be located at the time of attack. These include buildings or special facilities omitted from the survey by oversight (Reference A-k), structures other than residences with less than the minimum protection factor, and structures with less than the minimum number of spaces. No extensive attempt has been made to identify such places and add them to the basic data during this task performance, because it was assumed that they would not substantially improve the data base. This assumption is based upon the following considerations: (1) although such spaces are numerous, they are not marked and hence will be little utilized; or (2) the PF's are in the range 2 to 20 (generally), hence will not yield casualty estimates much different than estimates from the basement/house assumption. Further investigation of the latter assumption will be made in a follow-on to the sub-tasks reported here.

VII. APPENDIX A REFERENCES

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A-f. National Bureau of Standards. Description of Computer Program for National Fallout Shelter Survey. Washington: Government Printing Office, March 16, 1963.

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A-i. Office of Civil Defense, Department of Defense. Selected Statistics on the Fallout Shelter Program. OCD Statistical Report #7720.9. Washington: Office of Civil Defense, August 7, 1963.

A-j. Research Triangle Institute. Analysis of Survey Data. OCD Task 1115A. (Final Report in Preparation). Durham: Research Triangle Institute, Operations Research Division, January 1964.

A-k. W. K. Grogan and E. L. Hill. Evaluation of the Completeness of Architect-Engineer Coverage of Buildings. (Final Technical Report) Durham: Research Triangle Institute, Operations Research Division, July 31, 1962.

Appendix B

Description of RTI Computer Program: Techniques, Flow Charts & Records

I. INTRODUCTION

This appendix contains a more detailed explanation of the procedures and computer programs used in incorporating NFSS fallout protection data in the Jumbo System, as discussed in Chapter 2.

The inputs to the program are:

Tape A - Attack Environment III output tapes (Chapter 2, Section III-A).

Tape B - NFSS tapes as extracted from NBS (Chapter 2, Section III-A).

The sections which follow will explain how these tapes are processed to produce input tapes to the revised Population III Program (Reference B-a).

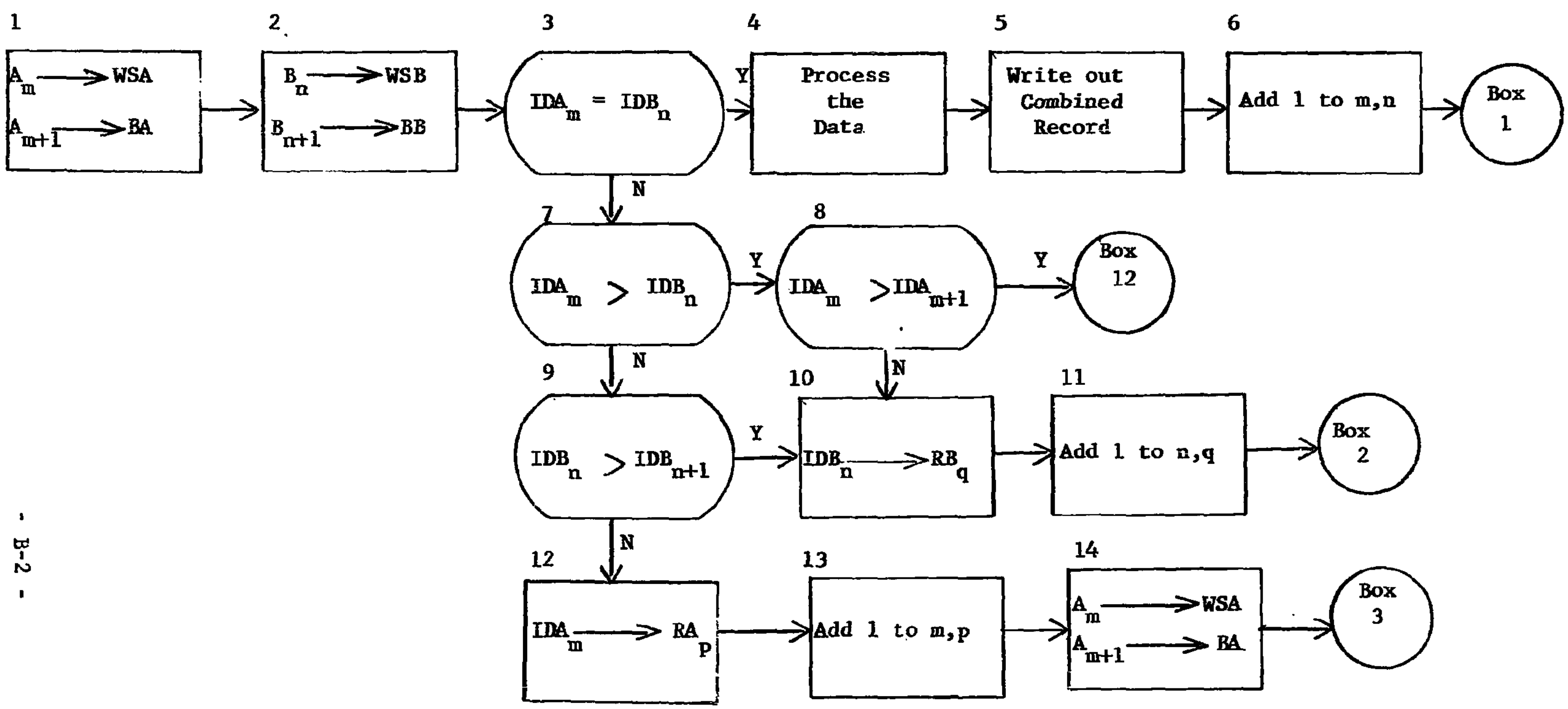
II. MATCHING INPUT IDENTIFICATION CODES

Normally, there is a high correlation between the two input tapes. For every data record on Tape A there should be a corresponding data record on Tape B. The RTI program assumes that in most cases a pair of input records will match on the identification record and, therefore, be sent through the normal processing path. The cases where a discrepancy occurs are few, but unless extensive precautions are used to isolate the error, further processing would either be halted or erroneous results produced. A schematic flow chart of the matching process is shown in Figure B-1 and explained below.

If an error in identification records does occur (either records are out of sequence or illegal character(s) in I.D.), the program must isolate and reject the record. It is useful to keep two input records from each tape in process at all

FIGURE B-1

Schematic Flow Chart of Error Comparison Checks*



Legend:

A_m = The mth record on Tape A.

B_n = The nth record on Tape B.

BA = Buffer storage for a record from Tape A.

BB = Buffer storage for a record from Tape B.

WSA = Work storage area for a record from Tape A.

WSB = Work storage area for a record from Tape B.

IDA_m = Identification data for record A_m.

IDB_n = Identification data for record B_n.

RA_p = Storage area for the pth rejected record from Tape A.

RB_q = Storage area for the qth rejected record from Tape B.

*Note: Initialization and termination designators have not been shown in this simplified diagram. Box shapes are explained in Figure B-2.

times. New records are read into the buffer storage area, BA or BB. They are later transferred into the working storage area, WSA, WSB, at the same time as a new record comes into BA or BB. If the identification code (IDA_m) of the record A_m in WSA matches the identification coding (IDB_n) of record B_n in WSB, then the actual data processing will occur.

However, if IDA_m does not match IDB_n, then the standby records, A_{m+1} and B_{n+1}, which are in the buffer storages BA and BB are useful for the comparison tests which are checks for sequence errors on the input tapes. The program must first determine which record I.D. is higher than the other. Let us assume, for example, that IDA_m (the I.D. data for record A_m, which is in WSA) exceeds IDB_n (the I.D. data for B_n, which is in WSB). The program compares IDA_m with IDA_{m+1} (record A_{m+1} is in the buffer storage BA). If IDA_m is greater than IDA_{m+1}, then the records are not in sequence or IDA_m is in error. In either case, IDA_m is sent to the reject area for Tape A. This I.D. record is later printed out and examined to determine the source of the error.

If IDA_m is not greater than IDA_{m+1}, then Tape A is in order. This means that IDB_n is the mismatched record (since it did not match IDA_m and there is no sequence error on Tape A). In this case, IDB_n is sent to a reject area for Tape B records. Mirror image logic operates if B_n is greater than A_m in the first comparison.

The matching is either a one-stage or a two-stage process, dependent upon the option chosen. The county-wide allocation needs merely to verify a match on the region-state-area-county code (RSAC code). The standard location option requires agreement on the RSAC code and a match on the individual SL code identification. If a record is out of sequence on one tape, it will be rejected. However, since its counterpart on the second tape will be unmatched; it, too, will be rejected in turn. It is important to note that the standard location allocation option will reject a standard location completely if the two input records differ in the identification code. There were cases in Alaska and New England where the National Bureau of Standards and the National Resource Evaluation

Center identified the same standard location in differing ways. Because the program could find no corresponding records for these mis-identified records, they were all deleted as unmatched. The problem of mismatching is less serious and more subtle if the county-wide allocation option is used. Here, all of the Attack Environment III records generated by the Jumbo system are used, but the shelter allocation stored in them may be erroneous.

III. COMPUTING THE SHELTER DISTRIBUTION FACTOR

The computation of the shelter distribution factor is based on the use of National Fallout Shelter Survey data (for either a standard location or a whole county) and the residential population as enumerated in the 1960 Census of Population and Housing. It is assumed that all of the shelter affording the most protection (Category 8) will be filled first. Then spaces in lower shelter categories will fill, until the population has been sheltered or until no more shelter spaces are available.

The computations are made by dividing the number of Category 8 shelters by the total population of the area and rounding the result to the nearest unit (1/64th). This sub-factor is then stored in the correct position in the shelter distribution factor. Similarly, sub-factors are computed for Categories 7, 6, 5, etc., until the whole population has been assigned to shelter or until the shelter spaces have been exhausted. This latter case will be discussed under the next topic.

Let us consider the case where enough shelter is available. If, for example, the sum of the shelter spaces in Categories 4 through 8 was equal to 87.5 percent of the population and Category 3 could hold 15 percent of the population, the program will put only enough persons in Category 3 to shelter the remaining population (and thus leave many spaces unused). To do this, it subtracts the sum of the sub-factors showing the percentage sheltered in higher categories from 100 percent. The remainder is the sub-factor to be assigned to Category 3, the overflow category. The lower categories receive sub-factors of zero.

Due to the method Population III handles these sub-factors in its casualty computations, each sub-factor must be expressed as a multiple of 1/64th and the entire shelter distribution factor must always sum to unity. Thus, in the example cited above, the sum of the sub-factors for Categories 4 through 8 would have 56/64th and the sub-factor for Category 3 would have been 8/64th.

The shelter distribution factor is stored in words 35 and 36 of the Attack Environment III output record for each standard location. It has been computed for either the particular standard location or on the basis of the population and shelter available in the whole county. In the latter case, the same shelter distribution is stored in each standard location record in the county.

IV. LOW PROTECTION SHELTER

If enough shelter with a protection factor of at least 40 (Categories 2 through 8) is not available, the remaining persons must be sheltered in Category 1 shelter spaces, in basements, or in houses. In the original RTI program, Category 1 is treated like any higher category and a sub-factor computed for it. If these spaces were insufficient, the remainder of the population was allocated to either basements or houses. The allocation scheme was keyed to the PV code, so it is a regional-average basement shelter estimate. After analyzing the Census Bureau basement shelter data, some simplified factors were selected. These factors were also partially based on assumptions as to how much better shelters would be available. Thus, if little shelter in basements will be needed and a large amount is normally available, then it was assumed that all those seeking basement shelter will have it.

The Census Bureau has recently computed more precise basement shelter estimates for the six PV code-designated regions. One of the modifications OCD requested in the RTI program for some test runs was the substitution of these six factors for the original basement shelter factors used. This was done, as well as dropping all data for Category 1. The reasons for the change and the test results are covered in the body of this report, (Chapter 2, Section IV). Table B-I on the following page compares the two methods for allocating persons to low-protection shelter spaces.

In the RTI scheme, the sum of the sub-factors representing NFSS shelter (including Category 1) is subtracted from unity, and the difference expressed as a multiple of 1/64th. Dependent upon the PV code (denoting region), this factor is assigned totally to basements, all to houses, or halved and half assigned to each. For odd values, the extra persons are sheltered in basements.

In the OCD modification, the Census Bureau's basement shelter factor is also selected by reference to the PV code. If the factor shows more shelter spaces are available in basements than needed, the sub-factor stored in the shelter distribution factor shows only the spaces used. If not all of the excess population can be sheltered in basements, the sub-factor computed showing the portion which can be sheltered is stored, and another sub-factor is computed showing the portion of the people who are in houses. Thus, the basement sub-factor is always less than or equal to the Census basement shelter factor and the factor for houses is zero or the residual class.

V. SPECIAL SHELTER FACTOR COMPUTATIONS

There is no standard location in America that has a total of over one million shelter spaces in any shelter category within it. There are thirteen counties, however, that have one or more shelter categories that contain over one million spaces. Special provision for handling such categories had to be made in the county-wide shelter computation option. The thirteen counties are shown in Section VIII of this appendix.

TABLE B-I

Allocation of Excess Population to Basements and Houses

Region	Original RTI Allocation Scheme Portion of Excess Population Placed In: Basements	 Houses	Revised OCD Allocation Scheme Portion of Excess Population which is Shelterable in Basements	
Severe Winter Metropolitan Area	All	-	89%	57/64ths
Severe Winter Non-Metropolitan Area	All	-	72%	46/64ths
Moderate Winter Metropolitan Area	All	-	67%	43/64ths
Moderate Winter Non-Metropolitan Area	1/2*	1/2*	35%	22/64ths
Light Winter Metropolitan Area	1/2*	1/2*	14%	9/64ths
Light Winter Non-Metropolitan Area	-	All	8%	5/64ths
Unknown	-	All	8%	5/64ths

* For odd remainders, the extra unit is placed in basements.

Because the NBS record limitations prohibited inclusion of the information, it was necessary to substitute a code for the excessive data. It is, therefore, impossible to compute shelter distribution sub-factors for these categories in the thirteen counties. In six of the affected counties, this is no problem. There are enough shelter spaces available in higher shelter categories to accommodate the whole population. No special provision has been made for handling these six counties.

In the other seven counties, special coding was provided to avoid this problem. Since there are only seven exceptional cases, it was simpler to arrange that the computer perform a table lookup and insert a pre-set constant into the data records rather than make special computations.

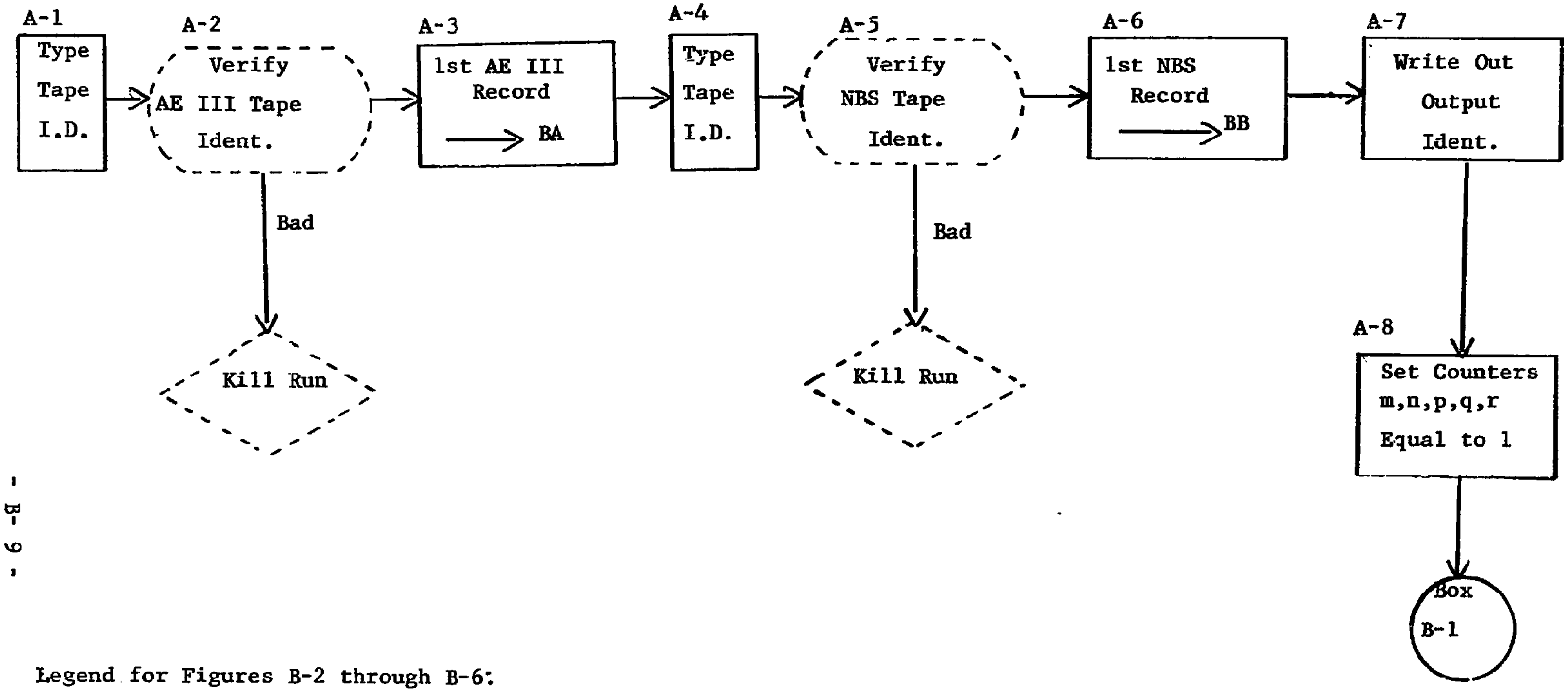
Whenever the program detects the "trigger code" ("xxxxxx"), it must process one of these seven counties. By matching on the RSAC code, the correct shelter factor is determined. The shelter distribution factor for this county is selected from those stored in the computer, then used in all further operations just as if it had been computed by the program.

VI. GENERAL SCHEMATIC FLOW CHART OF THE RTI PROGRAM

The flow charts in Figures B-2 through B-6 illustrate various steps in the RTI program. Figure B-2 describes the verification of the input tapes and Figure B-3 describes parameter insertion. Figure B-4 shows how data are processed in the standard location option. It follows the general processing schematic previously shown in Figure B-1. The comparable procedure for the county option is shown in Figure B-6. Figure B-5 describes the steps taken to prepare records for the computation of the shelter distribution factor using the county allocation option.

FIGURE B-2

<u>Input Verification</u>



Legend for Figures B-2 through B-6:

A_m = The mth record on Tape A.

B_n = The nth record on Tape B.

C_r = The rth county summary record on Tape B.

BA = Buffer storage for a record from Tape A.

BB = Buffer storage for a record from Tape B.

WSA = Work storage area for a record from Tape A.

WSB = Work storage area for a record from Tape B.

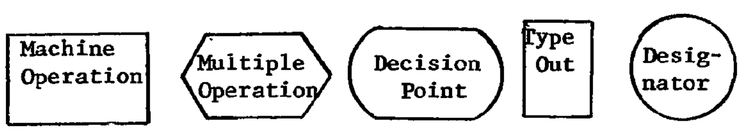
IDA_m = Identification data for record A_m.

IDB_n = Identification data for record B_n.

IDC_r = Identification data for county summary record C_r.

RA_p = Storage area for the pth rejected record from Tape A.

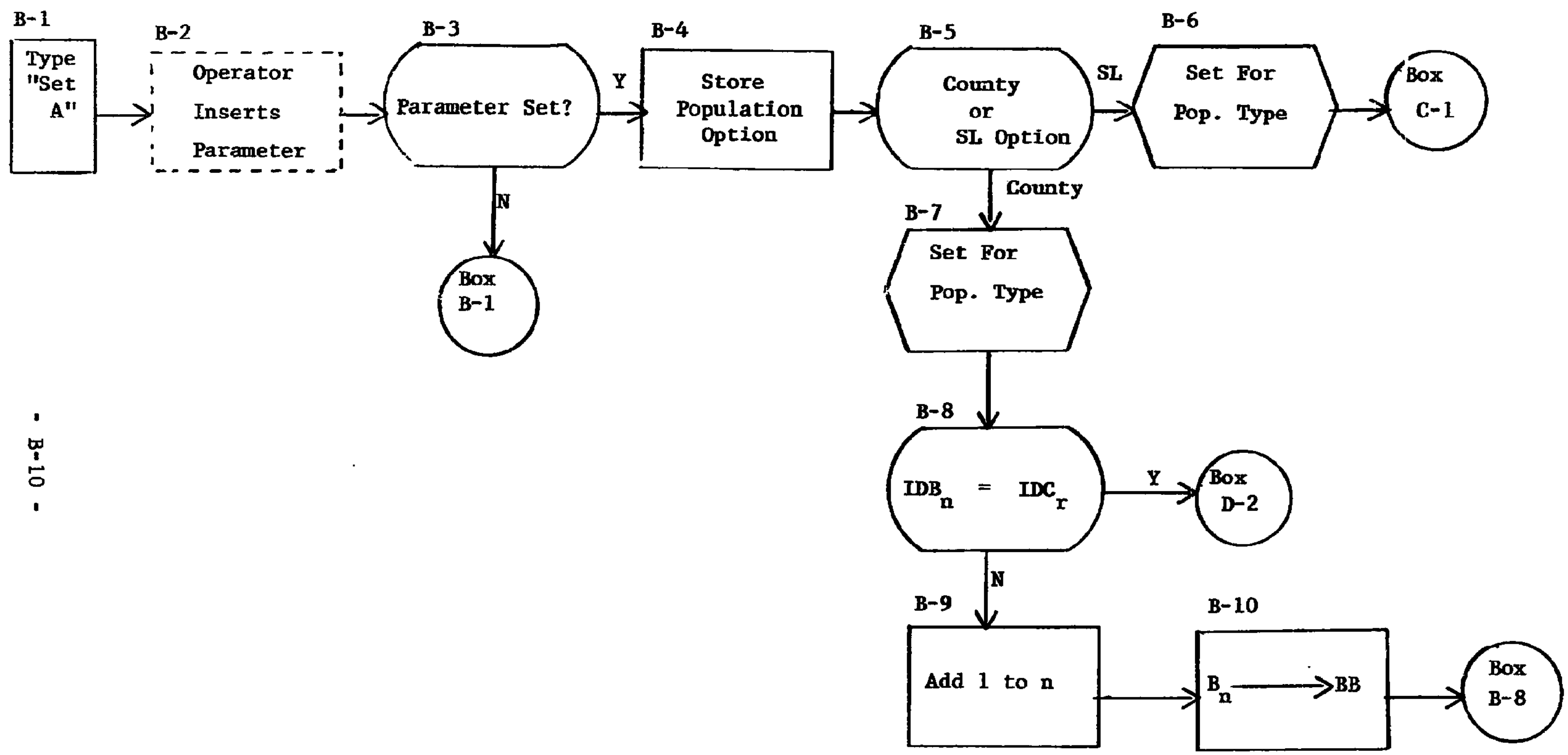
RB_q = Storage area for the qth rejected record from Tape B.



——— = Machine Operations - - - - - - = Manual Intervention

FIGURE B-3

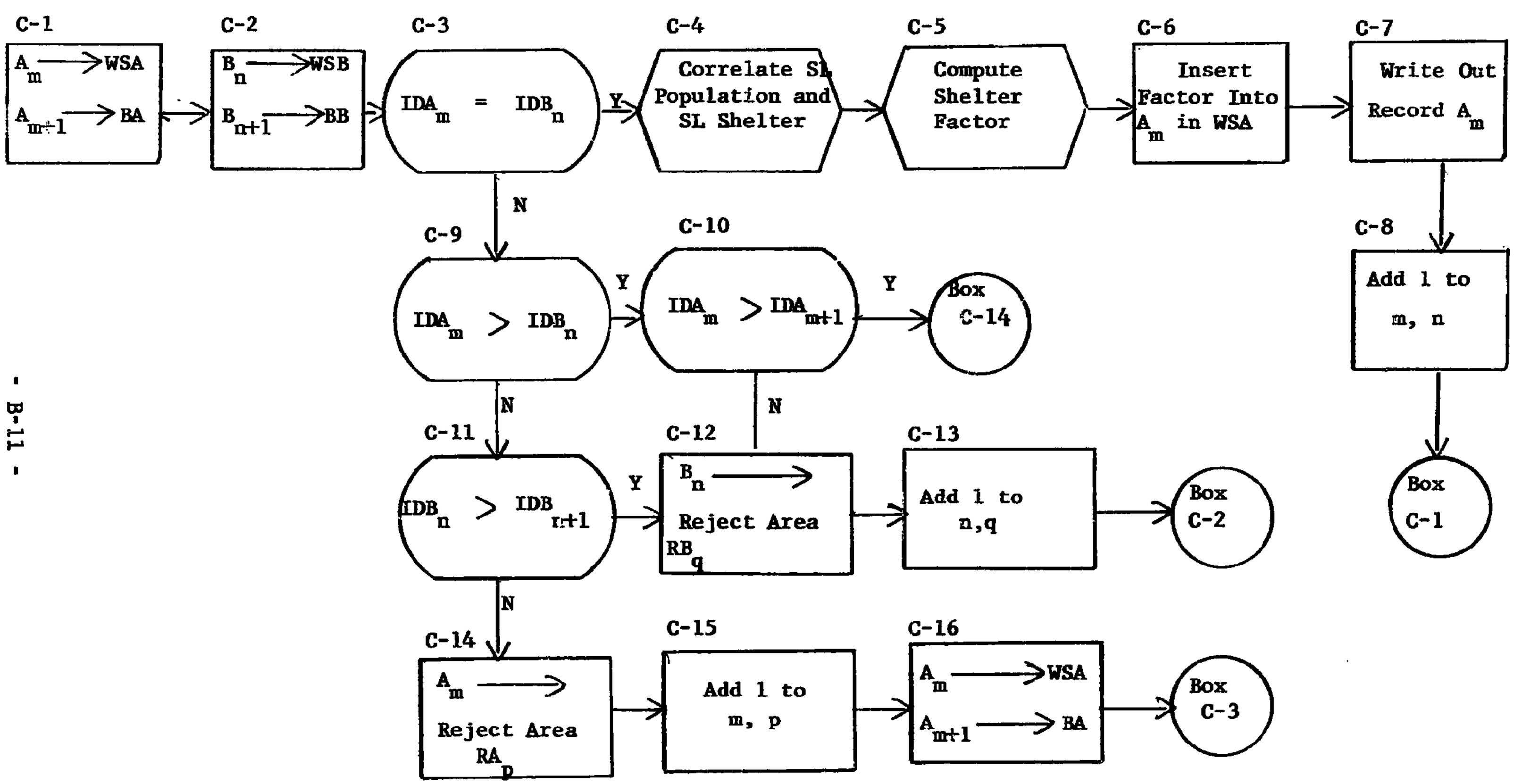
<u>Parameter Insertion*</u>



* Terms defined on Figure B-2.

FIGURE B-4

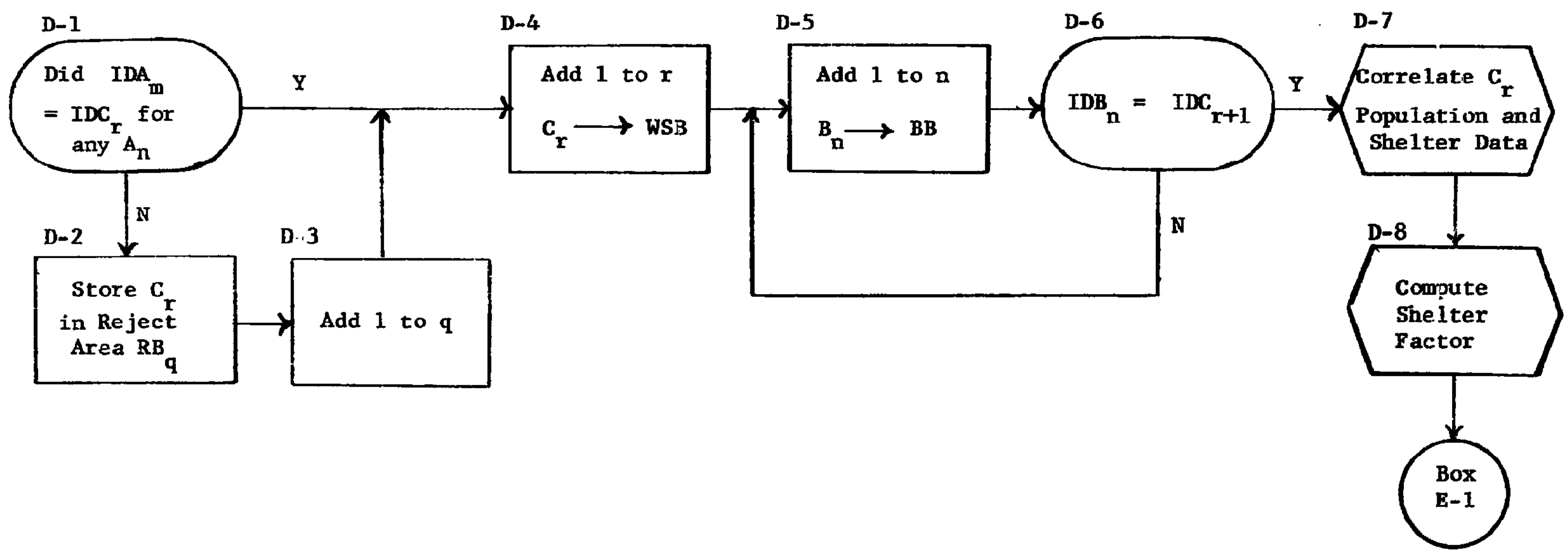
Standard Location Allocation Option - Matching and Processing the Data *



* Terms defined on Figure B-2.

FIGURE B-5

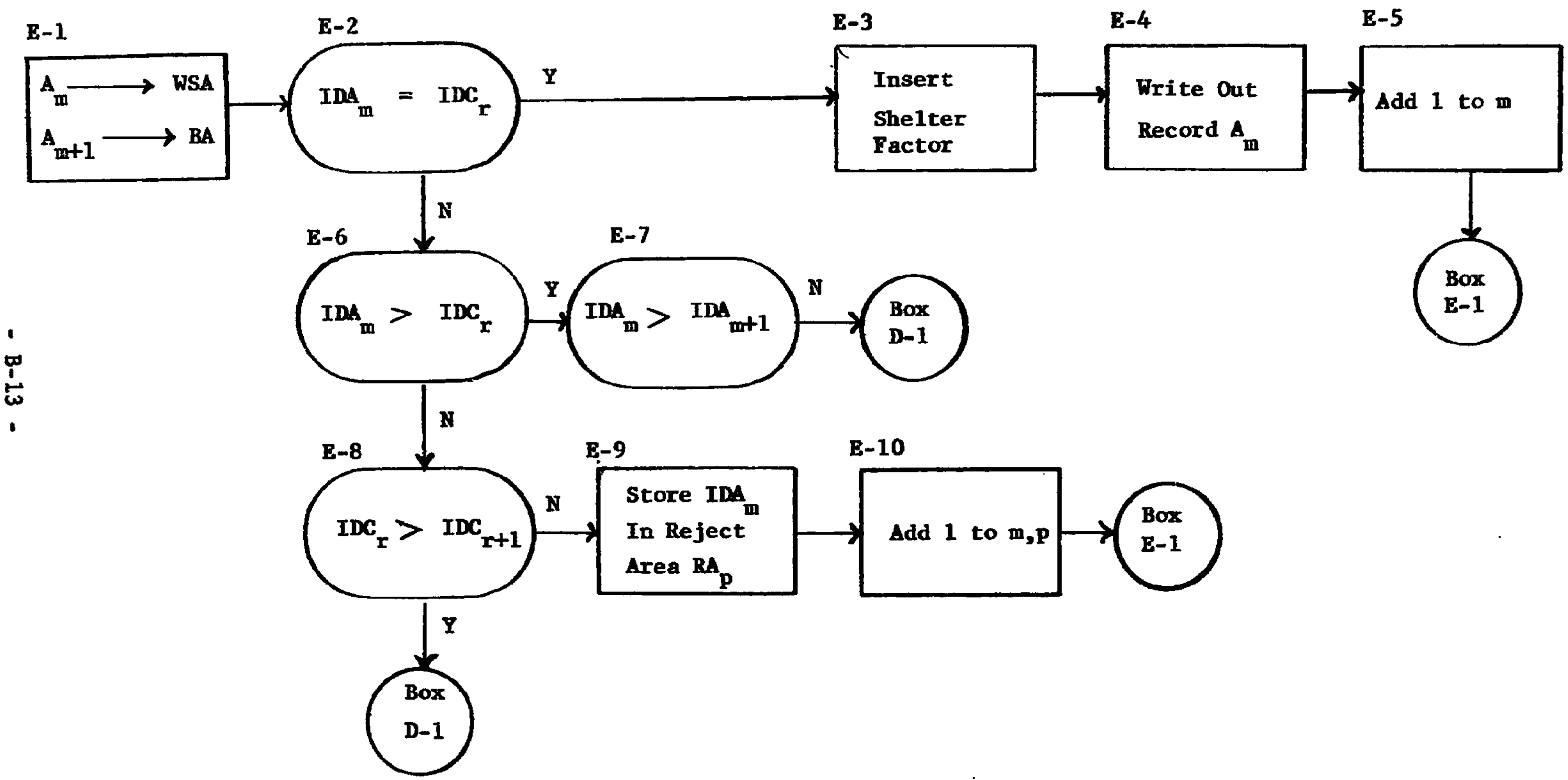
County Allocation Option - Computing New Shelter Distribution Factor *



* Terms defined on Figure B-2.

FIGURE B-6

County Allocation Option - Matching and Processing Data *



* Terms defined in Figure B-2.

VII. FORMAT OF THE NBS SHELTER DATA RECORDS

SL Record	County Record	
RSACLL	RSAC**	RSAC = Region-State-Area-County
LL****	*****R	LLLL = Standard Location Number
RRRRR* 1/	RRRRRR 2/	R's = Residential Population
DDDDD* 1/	*****D	D's = Daytime Population
NNNNN* 1/	DDDDDD 2/	N's = Nighttime Population
******	*****N	
******	NNNNNN 2/	
111111	111111	
222222	222222	
333333	333333	
444444	444444	
555555	555555	
666666	666666	
777777	777777	
888888	888888	

1's through 8's — Potential shelter identified in each category. No SL will have over a million shelter spaces in any one category. If a county has over a million shelter spaces in any category, the symbol "xxxxxx" is substituted for the data. These cases are handled separately.

*'s express blank positions

NOTE: Spaces are substituted for all non-significant zeros.

1/ The population of a standard location is never over 100,000. The sixth digits of these words are spaces. For example:

49,724 = 49724* Since non-significant zeros are dropped; 1418 = *1418*

2/ The population of a county can never exceed seven digits. If the population is over a million, the million's digit is in word one and the others in word two. If under a million, the digits are in word one and word two is blank. For example:

37,625 = *37625 / ******   376,259 = 376259 / ******   and 3,762,594 = *****3 / 762594

VIII. COUNTIES WITH OVER A MILLION SPACES IN ONE OR MORE SHELTER CATEGORIES

There are thirteen counties in the United States that have over a million shelter spaces in one or more shelter categories. As was noted on the previous page, the symbol "xxxxxx" is substituted for the data in the NBS records for these categories in the thirteen counties. The computer processing of these thirteen counties is discussed in Section IV of Appendix C. The seven counties designated by an asterisk are the ones for which special shelter constants had to be stored.

RSAC Code	County	Shelter Categories		
		1	2	Other
1315	Suffolk, Mass.	1,846,306	1,008,823	
1541	Essex, N. J.	1,144,546		
1641	Bronx, N. Y.*	4,599,733	2,031,271	
1642	Kings, N. Y.*	4,357,485	1,539,331	
1644	New York, N. Y.*	10,741,717	8,651,141	3 = 4,431,222
				4 = 2,228,320
				5 = 4,141,886
				6 = 4,028,220
				7 = 1,514,996
				8 = 1,614,723
1645	Queens, N. Y.*	2,737,631		
2241	Washington, D. C.	2,210,294	1,342,768	
2541	Cuyahoga, Ohio	1,109,745		
2675	Philadelphia, Pa.	2,074,734	1,391,029	
4121	Cook, Illinois*	4,042,017	2,861,314	3 = 1,507,551
				5 = 1,710,403
				6 = 1,877,799
				8 = 1,110,206
4333	Wayne, Michigan*	1,753,106		
7231	Los Angeles, Calif.*	1,901,632	1,242,539	
7274	San Francisco, Calif.	1,366,763		

IX. FORMAT OF THE SHELTER DISTRIBUTION FACTOR

A. Purpose - to show the percentile distribution of population in each shelter category, filling the best shelters first. A shelter distribution factor is computed for either each standard location or each whole-county summary.

B. Storage Location - in words 35 and 36 of the Attack Environment III output record. This record is the input to Population III.

C. Bit Pattern - OAA AAA AAB BBB BBB CCC CCC CDD DDD DDE EEE EEE
OFF FFF FFG GGG GGG HHH HHH HJJ JJJ JJK KKK KKK

0 = Zero Bit (Bit Not Used).

A = Portion of the population sheltered in houses (to nearest 1/64th)

B = Portion of the population sheltered in residential basements (to nearest 1/64th)

C = Portion of the population sheltered in Category 1 (to nearest 1/64th)*

D = Portion of the population sheltered in Category 2 (to nearest 1/64th)

E = Portion of the population sheltered in Category 3 (to nearest 1/64th)

F = Portion of the population sheltered in Category 4 (to nearest 1/64th)

G = Portion of the population sheltered in Category 5 (to nearest 1/64th)

H = Portion of the population sheltered in Category 6 (to nearest 1/64th)

J = Portion of the population sheltered in Category 7 (to nearest 1/64th)

K = Portion of the population sheltered in Category 8 (to nearest 1/64th)

* Category 1 is always zero in the OCD modification.

X. INFORMATION CONCERNING THE BASIC SHELTER SURVEY DATA TAPES STORED AT THE NATIONAL BUREAU OF STANDARDS

A. Introduction

As was noted in the body of this report, the National Bureau of Standards computed the original data on shelter characteristics of buildings surveyed in the National Fallout Shelter Survey. It may prove useful to include a brief summary of the nature of the data, the record format, and the tape format.

B. Content of the Two NBS Master Tapes

1. Master Tape 1 consists of nine data reels. These contain all of the edited FOSDIC forms for all of the buildings surveyed in Phase 1 of the National Fallout Shelter Survey. These data were received from the field offices and processed by the Census Bureau. Once the data were collated and edited, they were transcribed onto IBM tapes and sent to NBS for processing and storage.

2. Master Tape 2 consists of four data reels. These tapes contain all of the essential information about shelter spaces in Category 1 or better (i.e., a minimum protection factor of twenty). These are Phase 1 data, the output from the computer program for PF computations.

3. JB Tape and MP Tape - These are intermediate processing tapes, identical in format to the Master Tape 2 except for the title identification. They may have been blanked.

C. Description of Master Tape 2

1. First Record: BCD record of 8 words.

   Word 1 = 00 i 004 (Tape No. = i = 1, 2, 3, ..., n)

   Words 2 - 3 = date tape was written

   Words 4 - 8 = MASTER 2 NAT FALLOUT SURVEY

2. The remaining records of the first file have the following format: All records are binary and contain 2402 words. <u>The first word</u> of each record is a record number. For record 1 it is 000000000001, for record 2 it is 000000000002, etc. <u>The next 2400 words</u> are grouped into units of 8 words representing the

necessary information about a shelter for computing the summaries. All records but the last one on the last tape (00 n 003) have 300 units of shelter information. The last record on the last tape may contain $x(x \leq 300)$ units of shelter data followed by $y(y = 300 - x)$ units of words = 777777777777. The last word of each record is the 1's complement of the logical sum of word 2 through word 2401. Therefore the logical sum of words 1 through 2402 is equal to the record number. The content of each unit is shown in Section IV.

3. The second file on each tape contains only one binary record of 4 words. Word 1 is one greater than the record number of the last record of the first file. Word 2 is the total number of shelter units on this tape.

Word 3 is = 000000000000 for i = 1, 2, ..., n-1

is = 777777777777 for i = n

Word 4 is the logical sum of the first three words of this record.

D. Data Unit Record Format

Word 1	AAA AAA AAA AAA AAA AAA AAA AAA AAA AAA AAA AAA
Word 2	AAA AAA AAA AAA BBB BBB BBB BBB CCC CCC CCC CCC
Word 3	DDD DDD DDD DDD DDD DDD DDD DDD DDD DDD EEE EEE
Word 4	EEE EEE FFF FFF GGG GGG GGG HHH HHH HJJ JJJ JJJ
Word 5	KKK KKK KKK KKK KKK KKK LLL LLL LLL LLL LLL LLL
Word 6	MMM MMM MMM MMM MMM MMM NNN NNN NNN NNN NNN NNN
Word 7	PPP PPP PPP PPP PPP PPP QQQ QQQ QQQ QQQ QQQ QQQ
Word 8	RRR RRR RRR RRR RRR RRR SSS TTT TTT TTT TTT TTT

Field A = Standard Location Code (8 BCD Characters)

Field B = Field Office Code (2 BCD Characters)

Field C = Contract Code (2 BCD Characters)

Field D = Facility Number (5 BCD Characters)

Field E = Building Part Number (2 BCD Characters)

Field F = Revision Number (1 BCD Character)

Field G = Height of Story as a Binary Integer (9 Bits)

Field H = Use Code as a Binary Integer (7 Bits)

Field J = Story as a Binary Integer (8 Bits, the leftmost is the sign bit)

Field K = Total Radiation Contribution from Side A (18 Bits)

Field L = Total Radiation Contribution from Side B (18 Bits)

Field M = Total Radiation Contribution from Side C (18 Bits)

Field N = Total Radiation Contribution from Side D (18 Bits)

Field P = Total Radiation Contribution from the Ceiling (18 Bits)

Field Q = Protection Factor as computed (18 Bits)

Field R = Core Area as a Binary Integer (18 Bits)

Field S = Owner Code as a Binary Integer (3 Bits)

Field T = Total Floor Area Divided by 10 as a Binary Integer (15 Bits)

XI. APPENDIX B REFERENCES

B-a. Victor Lewicke and Irving E. Gaskill. NREC Damage Assessment Computation Program, Jumbo III. (Revised) NREC Technical Report No. 2. Washington: National Resource Evaluation Center, August, 1961.

B-b. Quentin Ludgin. A Program to Integrate National Fallout Shelter Survey Data Into Jumbo III Casualty Computations. Research Memorandum RM-82-7. Durham: Research Triangle Institute, Operations Research Division, May 20, 1963.

Appendix C

SPADEFORK Casualty Summary and Estimate of Unsheltered Population

The tables in this appendix show results of a test of the RTI procedure for incorporating NFSS data into the Jumbo III system. The procedure is discussed in Chapter 2, Section IV of this report.

This appendix includes:

Table C-I - SPADEFORK Casualty Summary by OCD Region and Nation

Table C-II - Estimate of Unsheltered Population by Political Sub-Division

TABLE C-I

SPADEFORK Casualty Summary by OCD Region and Nation

(Figures over percentages in thousands)

		Casualties							Non-Casualties			
		Fatalities			Injured				ERD			
	Total Population	Blast	Fallout	Total	Blast	Fallout	Total	Total Casualties	Under 50	50-150	Over 150	Total Non-Casualties
NATIONAL SUMMARY												
Jumbo III	185,712	18,950	15,030	33,980	7,500	9,500	17,000	50,980	112,800	17,200	4,800	134,800
	100.0%	10.2	8.1	18.3	4.0	5.1	9.2	27.5	60.7	9.3	2.6	73.0
Std. Loc.	185,633	18,950	8,560	27,510	8,200	7,000	15,200	42,710	124,100	15,000	4,000	143,100
	100.0	10.2	4.6	14.8	4.4	3.7	8.2	23.0	67.0	8.1	2.6	77.7
County	185,713	18,950	4,887	23,837	8,800	4,400	13,200	37,037	134,500	11,500	2,700	148,700
	100.0	10.2	2.6	12.8	4.7	2.4	7.1	20.0	72.5	6.2	1.5	80.2
Region 1												
Jumbo III	34,453	5,379	2,332	7,711	2,153	1,690	3,843	11,554	18,653	3,402	817	22,872
	100.0%	15.6	6.8	22.4	6.3	4.9	11.2	33.5	54.2	9.9	2.4	66.4
Std. Loc.	34,406	5,370	1,237	6,607	2,341	862	3,203	9,810	21,489	2,710	420	24,619
	100.0	15.6	3.6	19.2	6.8	2.5	9.3	28.5	62.5	7.9	1.2	71.6
County	34,453	5,379	631	6,010	2,462	559	3,021	9,031	23,089	2,099	261	25,449
	100.0	15.6	1.9	17.4	7.2	1.6	8.8	26.2	67.0	6.1	.8	73.9

TABLE C-I (Continued)

	Total Population	Casualties: Fatalities Blast	Fatalities Fallout	Fatalities Total	Injured Blast	Injured Fallout	Injured Total	Total Casualties	Non-Casualties: ERD Under 50	ERD 50-150	ERD Over 150	Total Non-Casualties
Region 2												
Jumbo III	35,208 100.0%	2,048 5.8	2,931 8.4	4,979 14.1	888 2.5	2,443 6.9	3,331 9.5	8,309 23.6	20,331 57.7	4,944 14.0	1,652 4.7	26,927 76.5
Std. Loc.	35,208 100.0	2,048 5.8	1,261 3.6	3,309 9.4	984 2.8	1,845 5.3	2,829 8.0	6,138 17.4	23,397 66.5	4,220 12.0	1,467 4.2	29,084 82.6
County	35,208 100.0	2,048 5.8	819 2.3	2,867 8.1	1,038 2.9	1,210 3.4	2,248 6.4	5,115 14.5	26,424 75.1	3,002 8.5	686 1.9	30,112 85.5
Region 3												
Jumbo III	25,682 100.0%	1,184 4.6	1,686 6.6	2,870 11.2	637 2.5	830 3.2	1,467 5.7	4,337 16.9	20,053 78.1	1,062 4.1	235 .9	21,351 83.1
Std. Loc.	25,682 100.0	1,184 4.6	1,229 4.8	2,413 9.4	662 2.6	769 3.0	1,431 5.6	3,844 15.0	20,513 79.9	1,104 4.3	226 .9	21,843 85.1
County	25,682 100.0	1,184 4.6	936 3.7	2,120 8.3	672 2.6	515 2.0	1,187 4.6	3,307 12.9	21,189 82.5	981 3.8	209 .8	22,379 87.1

TABLE C-I (Continued)

	Total	Casualties							Non-Casualties			
		Fatalities			Injured			Total	EED			Total
	Population	Blast	Fallout	Total	Blast	Fallout	Total	Casualties	Under 50	50-150	Over 150	Non-Casualties
Region 4												
Jumbo III	30,938 100.0%	3,091 10.0	2,654 8.6	5,745 18.6	1,012 3.3	1,461 4.7	2,473 8.0	8,218 26.6	18,436 59.6	3,309 10.7	979 3.2	22,724 73.5
Std. Loc.	30,938 100.0	3,091 10.0	1,206 3.9	4,297 13.9	1,303 4.2	952 3.1	2,255 7.3	6,552 21.2	21,103 68.2	2,546 8.2	740 2.4	24,389 78.8
County	30,938 100.0	3,091 10.0	273 .9	3,364 10.0	1,494 4.8	454 1.5	1,948 6.3	5,312 17.2	23,419 75.7	1,671 5.4	550 1.8	25,640 82.9
Region 5												
Jumbo III	18,391 100.0%	1,887 10.2	1,982 10.8	3,869 21.0	708 3.9	1,279 7.0	1,986 10.8	5,855 31.8	10,679 58.1	1,358 7.4	503 2.7	12,540 68.2
Std. Loc.	18,391 100.0	1,887 10.2	1,535 8.4	3,422 18.6	738 4.0	1,004 5.5	1,742 9.5	5,164 28.1	11,300 61.5	1,416 7.7	524 2.9	13,240 72.0
County	18,391 100.0	1,887 10.2	1,006 5.5	2,893 15.7	828 4.5	630 3.4	1,458 7.9	4,351 23.7	12,577 68.4	985 5.4	488 2.7	14,050 76.4

TABLE C-I (Continued)

	Total	Casualties							Non-Casualties			
		Fatalities			Injured			Total	ERD			Total
	Population	Blast	Fallout	Total	Blast	Fallout	Total	Casualties	Under 50	50-150	Over 150	Non-Casualties
Region 6												
Jumbo III	14,392	1,736	727	2,463	735	672	1,407	3,870	8,850	1,405	281	10,535
	100.0%	12.0	5.1	17.1	5.1	4.7	9.8	26.9	61.5	9.8	2.0	73.2
Std. Loc.	14,392	1,736	347	2,083	739	459	1,198	3,281	9,691	1,224	214	11,129
	100.0	12.0	2.5	14.5	5.1	3.2	8.3	22.8	37.3	8.5	1.5	77.3
County	14,392	1,736	296	2,032	739	376	1,115	3,147	9,916	1,183	158	11,257
	100.0	12.0	2.1	14.1	5.1	2.6	7.7	21.9	68.9	8.2	1.1	78.2
Region 7												
Jumbo III	20,249	2,570	1,990	4,560	1,134	756	1,890	6,451	12,549	1,040	216	13,804
	100.0%	12.7	9.8	22.5	5.6	3.7	9.3	31.9	62.0	5.1	1.1	68.2
Std. Loc.	20,249	2,570	1,367	3,937	1,196	720	1,916	5,853	12,980	1,176	265	14,421
	100.0	12.7	6.7	19.4	5.9	3.6	9.5	28.9	64.1	5.8	1.3	71.2
County	20,249	2,570	781	3,351	1,311	524	1,835	5,186	13,803	1,027	246	15,076
	100.0	12.7	3.9	16.6	6.5	2.6	9.1	25.6	68.2	5.1	1.2	74.5

TABLE C-I (Continued)

	Total	Casualties							Non-Casualties			
		Fatalities			Injured			Total	ERD			Total
	Population	Blast	Fallout	Total	Blast	Fallout	Total	Casualties	Under 50	50-150	Over 150	Non-Casualties
						Region 8						
Jumbo III	6,399	1,025	761	1,786	186	411	597	2,384	3,220	674	124	4,017
	100.0%	16.1	11.8	27.9	2.9	6.4	9.3	37.3	50.3	10.5	1.9	62.8
Std. Loc.	6,376	1,025	417	1,442	210	390	601	2,042	3,628	594	117	4,339
	100.0	16.1	6.5	22.6	3.3	6.1	9.4	32.0	56.9	9.3	1.8	68.0
County	6,999	1,025	175	1,200	276	154	430	1,630	4,057	601	115	4,773
	100.0	16.1	2.7	18.8	4.3	2.4	6.7	25.5	63.4	9.4	1.8	74.6

TABLE C-II

Estimate of Unsheltered Population by Political Sub-Division*

(All figures are in thousands)

	1960 Census Population	Resident Population on which Tabulation is based	Unsheltered Population			
			SL Level	County Level	State Level	National Level
NATIONAL	181,834	178,799	149,447	103,675	84,651	75,270
		Region 1				
Connecticut	2,535	2,353.7	1,768.3	876.9	361.6	
Maine	969	962.7	828.0	725.5	725.4	
Massachusetts	5,149	5,052.4	3,956.7	2,868.6	1,312.5	
New Hampshire	607	589.0	494.3	433.5	433.5	
New Jersey	6,067	5,970.0	4,525.4	2,950.9	2,816.8	
New York	16,782	16,476.1	10,498.2	4,913.8	0	
Rhode Island	859	857.0	698.1	359.5	359.4	
Vermont	390	381.9	336.8	300.2	291.9	
		Region 2				
Delaware	446	446.2	373.6	244.4	244.4	
District of Columbia	764	762.0	351.1	0	0	
Kentucky	3,038	3,032.8	2,494.9	1,732.1	1,170.1	
Maryland	3,101	3,104.4	2,578.3	1,590.8	1,493.6	
Ohio	9,706	9,627.0	8,109.1	5,430.3	5,430.1	
Pennsylvania	11,319	11,105.4	8,932.4	5,462.8	3,763.2	
Virginia	3,967	3,739.0	3,225.7	2,374.8	1,926.6	
West Virginia	1,806	1,738.7	1,603.2	1,352.9	1,333.1	

* For example, matching people with shelter spaces in Categories 2-8 by standard location leaves 149,447,000 people out of a total of 178,799,000 without shelter.

TABLE C-II (Continued)

	1960 Census Population	Resident Population on which Tabulation is based	Unsheltered Population			
			SL Level	County Level	State Level	National Level
NATIONAL						
Region 3						
Alabama	3,267	3,286.8	2,939.2	2,502.2	2,501.3	
Florida	4,952	4,832.5	4,579.8	4,225.4	4,225.3	
Georgia	3,942	4,011.2	3,728.1	3,146.9	2,960.6	
Mississippi	2,178	2,080.3	2,047.6	1,909.0	1,901.0	
North Carolina	4,556	4,565.0	4,137.7	3,685.1	3,666.3	
South Carolina	2,383	2,152.9	2,158.4	1,856.0	1,855.7	
Tennessee	3,567	3,535.1	3,019.8	2,126.4	1,932.0	
Region 4						
Illinois	10,081	9,648.6	7,871.3	3,491.1	.0	
Indiana	4,662	4,417.5	3,748.4	2,814.0	2,393.9	
Michigan	7,823	7,796.8	6,730.6	4,853.8	4,849.1	
Missouri	4,320	4,305.4	3,423.1	2,090.1	471.2	
Wisconsin	3,952	3,918.0	3,054.9	2,037.7	1,934.0	
Region 5						
Arkansas	1,786	1,780.6	1,612.3	1,338.2	1,020.0	
Louisiana	3,257	3,237.8	3,011.3	2,409.8	2,409.8	
New Mexico	951	935.7	835.9	777.9	772.8	
Oklahoma	2,328	2,312.6	2,040.5	1,487.0	1,388.1	
Texas	9,580	9,483.0	8,656.4	6,558.1	6,526.7	

TABLE C-II (Continued)

	1960 Census Population	Resident Population on which Tabulation is based	Unsheltered Population			
			SL Level	County Level	State Level	National Level
NATIONAL						
Region 6						
Colorado	1,754	1,757.0	1,422.7	983.4	926.4	
Iowa	2,758	2,927.5	2,545.8	2,059.0	1,985.1	
Kansas	2,179	2,135.6	1,835.6	1,327.1	1,036.8	
Minnesota	3,414	3,361.6	2,755.6	1,600.6	1,398.0	
Nebraska	1,411	1,402.8	1,223.0	868.5	717.0	
North Dakota	632	632.2	554.3	523.7	523.7	
South Dakota	681	663.7	564.9	528.4	485.0	
Wyoming	330	327.2	270.6	260.2	260.0	
Region 7						
Arizona	1,302	1,291.1	1,177.8	1,023.7	1,001.4	
California	15,717	15,549.2	13,669.3	9,120.4	7,604.3	
Hawaii	633	632.8	544.7	449.7	449.7	
Nevada	285	355.0	280.7	219.8	198.9	
Utah	390	381.9	336.8	300.2	291.9	
Region 8						
Alaska	226	225.6	171.2	140.9	115.9	
Idaho	667	657.1	578.4	559.9	559.6	
Montana	675	667.2	554.9	531.9	531.9	
Oregon	1,769	1,761.9	1,475.2	842.1	759.7	
Washington	2,853	2,625.6	2,460.9	1,246.9	1,245.1	

Appendix D

A Procedure for Computing Equivalent Residual Dose and Several Applications

I. INTRODUCTION

This appendix will present the mathematical model reported in Chapter 2, Section III of this report. The model generalizes work done by Hawkins (Reference D-a) and is designed to calculate an Equivalent Residual Dose under conditions specified for the sensitivity analysis of shelter protection factors. The mathematical model will be explained and several applications will illustrate its use.

II. ERD CONCEPT

The Equivalent Residual Dose (ERD) concept is based upon the expectation that the body will repair some of the damage inflicted by exposure to gamma radiation. Thus, the total number of roentgens of radiation received in a long exposure to a radiation source is not an adequate indication of probable body radiation damage. The ERD concept attempts to make the severity of the total dose a decreasing function of the length of time over which the dose is received. The concept also encompasses the assumption that a portion of the total dose can be related to non-reparable body damage. Authorities do not completely agree however as to:

1. The rate at which the damage is repaired.
2. The percentage of the damage which is reparable.

3. The time at which the repair begins.

The Equivalent Residual Dose (ERD) by definition is the accumulated dose corrected for such recovery as has occurred by a specific time. To calculate ERD values it is necessary to assume: (a) a radiation exposure rate and (b) values for the debatable inputs (1), (2), and (3) above. Values used in specific applications in this appendix are given in References D-a and D-b.

III. THE MATHEMATICAL MODEL

The mathematical model presented here attempts to capture the dynamic inter-play between the human body and a radiation field. The human body acts as a collector when placed in a radiation field. The radiation collected tends to damage the body and the body attempts to repair the damage. If the radiation is being collected at a sufficiently high rate, the rate at which the damage is done will exceed the rate at which the body can make repairs. The result will be a mounting backlog of damage which will manifest itself in symptoms ranging from blood changes to death.

Researchers generally agree that the backlog of radiation damage at any time after exposure can be classified into the categories: (a) reparable damage and (b) non-reparable damage. The classification of the backlog of radiation damage suggests a similar classification for the radiation absorbed by the body. This classification is shown below:

The recoverable dose at some specific time T after exposure is defined as that portion of the radiation absorbed by the body prior to time T causing reparable damage which has not been repaired by time T.

The non-recoverable dose at some specific time T after exposure is defined as that portion of the radiation which caused non-reparable damage prior to time T.

The equivalent residual dose (ERD) at some specific time T is defined as the sum of the recoverable dose and the non-recoverable dose at time T. The intent of the remainder of this section is to derive a mathematical formula for calculating ERD under the assumption of varying fallout fields over time.

The following is a list of the symbols and assumptions which are incorporated in the mathematical model for ERD.

A. Notation

1. d_n = the recoverable dose at the end of the n^{th} day after exposure begins.
2. d_n^* = the non-recoverable dose at the end of the n^{th} day after exposure begins.
3. E_n = the ERD at the end of the n^{th} day after exposure begins.
4. R = the H + 1 intensity of the radiation field.
5. r_i = the unit-reference unsheltered total dose received on the i^{th} day after arrival of fallout (i.e., the unsheltered dose

received on the i^{th} day if the H + 1 intensity were 1 roentgen per hour).

6. P_i = the protection factor achieved on the i^{th} day.
7. α = the fraction of the daily dose which does reparable damage.
8. ϕ = the fraction of the recoverable dose whose effect the body repairs each day.
9. β = $(1 - \phi)$ = the unrepaired daily fraction.

B. Assumptions

1. The body begins recovery 24 hours after onset of exposure (a computational convenience rather than an assumption derived from References).
2. Recovery is continuous.

We observe the following relationship for the recoverable dose:

$$d_1 = R\left[\alpha\frac{r_1}{P_1}\right]$$

$$d_2 = \beta d_1 + R\left[\alpha\frac{r_2}{P_2}\right] = \alpha\left[\beta\frac{r_1}{P_1} + \frac{r_2}{P_2}\right]R$$

$$d_3 = \beta d_2 + \left[\alpha\frac{r_3}{P_3}\right]R = \alpha\left[\beta^2\frac{r_1}{P_1} + \beta\frac{r_2}{P_2} + \frac{r_3}{P_3}\right]R$$

$$\vdots$$

$$d_n = \alpha\left[\sum_{i=1}^{n} \beta^{n-1}\frac{r_i}{P_i}\right]R \qquad (1)$$

similarly, for the non-recoverable dose:

$$d_n^* = \left[(1 - \alpha) \sum_{i=1}^{n} \frac{r_i}{P_i}\right] R \ . \qquad (2)$$

Therefore, the ERD at the end of the n^{th} day is:

$$E_n = d_n + d_n^* = \left[\alpha \sum_{i=1}^{n} \beta^{n-1} \frac{r_i}{P_i} + (1 - \alpha) \sum_{i=1}^{n} \frac{r_i}{P_i}\right] R \ . \qquad (3)$$

If residence is maintained in the same shelter with protection factor P_1 for each of the n-days then:

$$E_n = \left[\frac{\alpha}{P_1} \sum_{i=1}^{n} \beta^{n-i} r_i + \frac{(1-\alpha)}{P_1} \sum_{i=1}^{n} r_i\right] R \qquad (3')$$

If after n-days in a shelter S_1 with protection factor P_1, it becomes necessary to move to a shelter S_2 with protection factor P_2, then E_m where $m \geq n$ is given by Equation (4):

$$E_m = \left[\beta^{m-n} \frac{\alpha}{P_1} \sum_{i=1}^{n} \beta^{n-i} r_i\right] R + \left[\frac{\alpha}{P_2} \sum_{i=n+1}^{m} \beta^{m-i} r_i\right] R$$

$$+ \left[\frac{1-\alpha}{P_1} \sum_{i=1}^{n} r_i\right] R + \left[\frac{1-\alpha}{P_2} \sum_{i=n+1}^{m} r_i\right] R. \qquad (4)$$

Observe that each term in Formula (4) can be associated with a well defined portion of the ERD as follows:

1. The term, $\left[\beta^{m-n} \frac{\alpha}{P_1} \sum_{i=1}^{n} \beta^{n-i} r_i\right] R$, determines that portion of the recoverable dose collected in the first shelter which has caused damage not repaired by the end of day m.

2. The term, $\left[\frac{\alpha}{P_2} \sum_{i=n+1}^{m} \beta^{m-i} r_i\right] R$, is that portion of the recoverable dose received in the second shelter which has caused damage not repaired by the end of the day m.

3. The terms, $\left[\frac{(1-\alpha)}{P_1} \sum_{i=1}^{n} r_i\right] R$, and, $\left[\frac{(1-\alpha)}{P_2} \sum_{i=n+1}^{m} r_i\right] R$, determine respectively the non-recoverable dose collected in the first and second shelters.

Formula (4) can be generalized to consider residence in a set of consecutive shelters in the following way:

Denote by n_j (where j = 1, 2, 3, ..., k shelter periods) the last day on which residence is maintained in shelter j. Shelter j is assumed to have protection factor P_j. The ERD on day n_k, the last day in the k^{th} shelter, is given by the following formula:

$$E_{n_k} = R\left[\beta^{n_k-n_1} \frac{\alpha}{P_1} \sum_{i=1}^{n_1} \beta^{n_1-i} r_i + \beta^{n_k-n} \frac{\alpha}{P_2} \sum_{i=n_1+1}^{n_2} \beta^{n_2-i} r_i + \dots \frac{\alpha}{P_k} \sum_{i=n_{k-1}+1}^{n_k} r_i\right] + R\left[\frac{(1-\alpha)}{P_1} \sum_{i=1}^{n_1} r_i + \frac{(1-\alpha)}{P_2} \sum_{i=n_1+1}^{n_2} r_i\right.$$

$$+ \dots \frac{(1-\alpha)}{P_k} \sum_{i=n_{k-1}+1}^{n_k} r_i \Bigg]$$

$$= R\alpha \left[\sum_{j=1}^{k} \left(\frac{\beta^{n_k - n_j}}{P_j} \sum_{i=n_{j-1}+1}^{n_j} \beta^{n_j - i} r_i \right) \right]$$

$$+ R\ (1-\alpha) \left[\sum_{j=1}^{k} \left(\frac{1}{P_j} \sum_{i=n_{j-1}+1}^{n_j} r_i \right) \right] . \qquad (5)$$

Observe that if there are two shelter periods ($k = 2$) then Equation (5) becomes

$$E_{n_2} = R \left[\alpha \sum_{j=1}^{2} \left(\frac{\beta^{n_2 - n_j}}{P_j} \sum_{i=n_{j-1}+1}^{n_j} \beta^{n_j - i} r_i \right) + (1 - \alpha) \sum_{j=1}^{2} \left(\frac{1}{P_j} \sum_{i=n_{j-1}+1}^{n_j} r_i \right) \right]$$

$$= R \left[\alpha \frac{\beta^{n_2 - n_1}}{P_1} \sum_{i=1}^{n_1} \beta^{n_1 - i} r_i + \frac{\alpha\beta^{n_2 - n_2}}{P_2} \sum_{i=n_1+1}^{n_2} \beta^{n_2 - i} r_i \right.$$

$$\left. + (1 - \alpha) \frac{1}{P_1} \sum_{i=1}^{n_1} r_i + (1 - \alpha) \frac{1}{P_2} \sum_{i=n_1+1}^{n_2} r_i \right] \qquad (6)$$

which is precisely the same as Equation (4) where $n = n_1$ and $m = n_2$. Thus, we see that Formula (5) generalizes to the consideration of any desired number of shelters and stay times in each.

The mathematical model (5) derived above involves the parameters R, α, β, $(n_1, n_2, \dots, n_k)$, $(P_1, P_2, \dots, P_k)$ and $(r_1, r_2, \dots, r_{nk})$ and affords a workable tool for a parametric analysis of ERD. A complete parametric analysis is beyond the scope of this paper. A more comprehensive treatment is anticipated in future work.

This paper does examine the model for some special choices of the parameters. The choices were made on the basis of what is currently believed to be the most reliable estimates of the parameters and the most advantageous method of operation in a fallout environment. (References D-a and D-b)

IV. SELECTION OF PARAMETERS AND *MODUS OPERANDI*

The values most frequently used for α, the reparable damage fraction, and ϕ, the recovery rate fraction, respectively, are .9 and .025 per day; and β = .975. These values are used in the applications presented below. The applications which follow also are concerned with residence in two shelters. The first shelter S_1 with protection factor P_1 is to be occupied continuously for a 14 day period after which time a second shelter S_2 with protection factor P_2 is entered. We refer to S_1 as the primary or initial shelter and S_2 as the secondary shelter. Hence, with α = .9 and β = .975; length of stay in shelter one = 14 days and k = 2 shelter periods, the model reduces to the following form:

$$E_n = R\left[\frac{.9(.975)^{n-14}}{P_1}\sum_{i=1}^{14}(.975)^{14-i}\ r_i + \frac{.9}{P_2}\sum_{i=15}^{n}(.975)^{n-i}\ r_i + \frac{.1}{P_1}\sum_{i=1}^{14} r_i + \frac{.1}{P_2}\sum_{i=15}^{n} r_i\right], \qquad (7)$$

for $n \geq 15$, and

$$E_n = R\left[\frac{.9}{P_1}\sum_{i=1}^{n}(.975)^{n-i}\, r_i + \frac{.1}{P_1}\sum_{i=1}^{n} r_i\right], \tag{8}$$

for $n \leq 14$.

The model is further refined by the following assumptions:

1. The unit field intensity decay is described by $t^{-1.2}$.

2. All of the fallout arrives at the same time (t_a in hours).

Hence, the i^{th} day unit-reference unsheltered dose is:

$$r_i = \int_{24(i-1)+t_a}^{24i+t_a} t^{-1.2}\, dt, \tag{9}$$

where t_a is the time of arrival of fallout and is measured in hours.

V. APPLICATION I OF THE MODEL: CHARACTERIZATION OF THE SHELTER IN WHICH THE PEAK ERD OCCURS (Discussed in Chapter 3, Section III)

The question for which we seek an answer in this section is as follows: What constraints are necessary and sufficient to guarantee that the maximum ERD will occur in the second shelter under the modus operandi and parameter selections presented in the preceding Section IV? That is, under what conditions are we guaranteed an $n_o \geq 15$ (a second period day) such that,

$$E_{n_o} = R\left[\frac{.9(.975)^{n_o-14}}{P_1}\sum_{i=1}^{14}(.975)^{14-i}r_i + \frac{.9}{P_2}\sum_{i=15}^{n_o}(.975)^{n_o-i}r_i\right.$$

$$\left. + \frac{.1}{P_1}\sum_{i=1}^{14}r_i + \frac{.1}{P_2}\sum_{i=15}^{n_o}r_i\right] \geq \frac{\mathrm{Max}[E_n,\ n \leq 14]}{P_1} \qquad (10)$$

where $\mathrm{Max}[E_n,\ n \leq 14]$ denotes the maximum unsheltered ERD received in shelter one?

Equivalently, when are we guaranteed the existence of an $n_o \geq 15$ such that,

$$\frac{P_1}{P} \geq \frac{\dfrac{\mathrm{Max}[E_n,\ n \leq 14]}{R} - \left(.9(.975)^{n_o-14}\sum_{i=1}^{14}(.975)^{14-i}r_i + .1\sum_{i=1}^{14}r_i\right)}{.9\sum_{i=15}^{n_o}(.975)^{n_o-i}r_i + .1\sum_{i=15}^{n_o}r_i}\ . \qquad (11)$$

Computer calculations show that if $t_a = 2$, the right hand side of the inequality has a minimum of 3.74. Hence, the maximum ERD occurs in period two if and only if $\frac{P_1}{P_2} \geq 3.74$ for a time of arrival of two hours.

Similar arguments show that the maximum ERD occurs in shelter two in the following cases where t_a indicates the time of arrival of fallout.

TABLE D-I

Ratio for Determining the Shelter Period Containing

Peak ERD As a Function of Time of Arrival

Time of Arrival	$t_a = 1$	$t_a = 2$	$t_a = 3$	$t_a = 4$	$t_a = 5$
$\frac{P_1}{P_2} \geq$	5.04	3.74	3.10	2.68	2.39

The significance of these results is given in Chapter 3, Section III.

VI. DISCUSSION OF A CURRENT METHOD OF CALCULATING ERD

A 96 hour total dose may be a reasonable approximation of ERD for many practical applications. Here this approximation is discussed and in Sections VII and VIII this approximation is demonstrated.

Some current theories of ERD hypothesize that biological recovery begins four days or 96 hours after the onset of exposure. Devaney (Reference D-b) asserts that under the following assumptions ERD reaches a maximum at D + 6 days:

(1) Time of arrival of fallout is H + 1 hour.

(2) Recovery begins four days after onset of exposure.

(3) The level of protection is constant or the maximum ERD occurs while in the first level of protection.

Logical consequences derivable from Devaney's conclusion and assumptions are the following:

(i) The maximum ERD is at least as large as the four day total dose.

(ii) The maximum ERD is no larger than the six day total dose when we assume a time of arrival of one hour.

If a decay exponent of -1.2 is assumed, the four day total dose is approximately 95 percent of the six day total dose. Using the above hypotheses, the four day total dose is frequently used to approximate the ERD. Rough calculations indicate that if time of arrival of fallout is two hours, then the four day dose would be at least 90 percent of the six day dose. (The assumption that maximum ERD occurs on D + 6 is also made in this case.) Therefore, the practice of using the four day total dose as an approximation for ERD (when time of arrival of two hours or less is assumed) seems to have some validity. As the time of arrival is increased, however, the approximation becomes questionable. The method of calculation for the four day dose is very simple. Therefore, it is desirable to use the four day total dose as an approximation to ERD whenever the required degree of accuracy permits. The required degree of accuracy depends upon the anticipated use of the data and also of course, upon the deviation from some accepted standard or model.

Application II will use the four day total dose in order to calculate ERD without the assumption of a constant level of protection.

Application III in the sequel will be concerned with the deviation of the four day dose from the mathematical model presented in this report. The amount of deviation will give an indication of how well the model approximates the theory.

VII. APPLICATION II OF THE MODEL: IMPROVEMENT OF FALLOUT CASUALTY ASSESSMENT PROCEDURE IN THE JUMBO III SYSTEM

(Discussed in Section III, Chapter 2 and Section III, Chapter 3)

A. Jumbo III ERD Calculations

The Jumbo III system proposes to compute a peak unsheltered ERD. This peak unsheltered ERD is then to be multiplied by a reduction factor in order to determine the peak ERD for a person in shelter. The reduction factor to be used is the reciprocal of the protection factor of the building in which the person is sheltered. The net ERD will then be used to enter a casualty curve. The critical step in the proposed Jumbo III procedure is the determination of a peak ERD for an unsheltered person. In view of the discussion in Section V, if $t_a \leq 2$ hours, the four day total dose may be used as an approximation to the unsheltered ERD providing that residence is maintained in one primary shelter for at least six days, after which time residence is maintained in shelter of sufficiently good quality to guarantee that ERD will never exceed the maximum ERD of the first six days. This section will examine the conditions under which the assumption of maximum ERD in the primary shelter is not valid and suggest a procedure to be used in Jumbo III in such a case.

B. SPAN Modus Operandi

The SPAN program, explained in Chapter 2, proposes to perform casualty computations under the following assumptions:D-1/

1. Shelters Stocked - All PF category 2 to 8 shelters are occupied continuously for 14 days after attack. For the next 46 days, to D + 60 days, controlled living is achieved providing an equivalent protection factor (EPF) of 12.5 (see EPF discussion in Section X). After D + 60 an average environment protection factor of 10 is maintained to D plus one year. A time of arrival of fallout of two hours is assumed.

2. Shelters Marked Only - PF category 2 to 8 shelters are occupied continuously for 3 days after attack. To D + 60, controlled living provides a factor of 12.5 and after D + 60 an average PF of 5 is maintained.

C. Period of Peak

The midpoint of each of the shelter categories is used as P_1 in Equation (7). The third shelter seems to be irrelevant for the values considered. If this convention is adopted, then Application I of the model indicates the categories in which the peak ERD is in shelter two. This information is depicted in Table II.

The peak ERD occurs in shelter two for each of the eight categories; therefore, the assumption of maximum ERD in shelter one is not valid for the SPAN modus operandi. Equation (7), programmed at RTI for IBM 1620,

D-1/ The modus operandi described herein will be referred to in succeeding sections as the "SPAN Operation" or the "SPAN modus operandi."

provides a method which is valid for calculation of maximum ERD in the case where the maximum occurs in shelter two.

D. Dose - ERD Conversion Factor (PF' - see Chapter 3, Section III)

The Equation (7) program, specialized for the SPAN *modus operandi*, has provided a maximum ERD for Dose - ERD Conversion Factor use. The "Dose - ERD Conversion Factor" is a number (PF') such that if (PF') is divided into the 96 hour unsheltered dose the result will be E, the appropriate maximum ERD.

Observe that if the maximum ERD occurs in shelter period one, the Dose - ERD Conversion Factor is the protection factor of shelter one. For maximum ERD occurring in the second period a PF not equal to PF' is required. Table III exhibits the factors for the living patterns in the stocked shelters of the SPAN program.

An adjustment in the form of the equation is possible for an analogous consideration of SPAN for the marked shelters, but was not performed.

TABLE D-II

Period of Peak ERD for Each NFSS Shelter Category and the SPAN Modus Operandi

Category	P_1	$\frac{P_1}{12.5}$	Shelter Period of Peak
2	56	4.40	2
3	85	6.80	2
4	125	10.00	2
5	200	16.00	2
6	375	30.00	2
7	750	60.00	2
8	1000	80.00	2

TABLE D-III

Dose - ERD Conversion Factors for the SPAN Modus Operandi

Category	P_1	Period of Peak	Dose-ERD Conversion Factor (PF')
2	56	2	55.00
3	85	2	72.22
4	125	2	86.55
5	200	2	100.87
6	375	2	114.34
7	750	2	123.00
8	1000	2	125.36

VIII. APPLICATION OF THE MODEL: EVALUATION OF THE FOUR DAY TOTAL DOSE ASSUMPTION

Previous sections have attempted to justify the total four day dose as an approximation to the maximum ERD under suitable constraints.

Observe that the model in the form of Equation (7) has assumed certain values for the parameters. As a partial check on how well this mathematical model fits present theory, we have calculated the maximum unsheltered ERD via the model and compared it with the four day total unsheltered dose. The four day total unsheltered dose is 2.997R, where R is the H + 1 intensity with an assumed time of arrival of fallout of one hour. The model under identical restraints calculates the maximum unsheltered ERD at 2.851R. Thus, the unsheltered ERD as calculated by the model deviates from the four day total dose by approximately 5 percent. Observe that the mathematical model has a built-in assumption that recovery begins after one day of exposure, while the theory leading to the conjecture that the four day total dose is a good approximation to the maximum ERD under suitable constraints assumes this recovery begins after four days. Note also that the biological recovery rate, the recoverable fraction, the non-recoverable fraction, and the field decay rate are all educated guesses. A 5 percent error is rather insignificant in view of the approximations of the parameters.

IX. APPLICATION IV OF THE MODEL: INVESTIGATION OF VARIATION OF TIME OF PEAK ERD WITH VARIATION OF TIME OF ARRIVAL

Devaney (Reference D-b) asserts that under the following assumptions ERD reaches a maximum at D + 6 days:

1. Time of arrival of fallout is H + 1 hour.

2. Recovery begins four days after onset of exposure.

3. The level of protection is constant.

Section VIII above indicates how well the model presented in this report fits the four day total dose assertion. The model will also be used to predict times of peak ERD for times of arrival different from one hour.

The model in Equation (7) form reduces to the following form when a constant level of protection is assumed.

$$E_n = R\left[\frac{.9}{P_1}\sum_{i=1}^{n}(.975)^{n-i}\,r_i + \frac{.1}{P_1}\sum_{i=1}^{n} r_i\right] , \qquad (12)$$

where

$$r_i = \int_{24(i-1)+t_a}^{24i+t_a} t^{-1.2}\,dt$$

and where t_a = time of arrival of fallout measured in hours.

The following table summarizes the result of programming the model on an IBM 1620 digital computer to determine the day of peak ERD for some selected values of t_a.

TABLE D-IV

Day of Peak ERD vs. Time of Arrival

t_a	Day of Peak ERD
1	6
2	7
3	8
4	8
5	9

We observe that the model agrees with Devaney's assertion for $t_a = 1$ hour.

X. EQUIVALENT PROTECTION FACTOR

A person subjected to a radiological environment may find it necessary to spend portions of the day in several shelters of varying protection factors. The equivalent protection factor for a day's activity will be an "average" protection factor for the day which will allow consideration of 24 hour time increments. The Equivalent Protection Factor for a day's activity is defined as the protection factor of a hypothetical shelter which would allow the same 24 hour total dose to its occupants as was obtained by persons participating in the day's activity. Observe that if residence is maintained continuously throughout the day in one shelter, the equivalent protection factor for the day is the protection factor of the shelter.

Let (D) be the 24 hour unsheltered dose recevied on the k^{th} day. Let (t_i, t_{i+1}), $i = 1, 2, \ldots, n$; be the time intervals of the day spent in shelters S_1, S_2, ---- S_n with respective protection factors P_1, P_2, ..., P_n. Denote the unsheltered total dose received in the time interval (t_i, t_{i+1}) by Δ_i. The Equivalent Protection Factor (EPF) for the day is given by the following expression:

$$EPF = \frac{D}{\sum_{i=1}^{n} \frac{\Delta_i}{P_i}} = \frac{1}{\frac{1}{D} \sum_{i=1}^{n} \frac{\Delta_i}{P_i}} = \frac{1}{\sum_{i=1}^{n} (\frac{\Delta_i}{D}) \quad \frac{1}{P_i}} . \qquad (13)$$

It is important to observe that Δ_i is a function of the time of day as well as the length of the time interval. For example, the unexposed dose acquired during the first hour of the day may be much greater than the unexposed dose acquired during the last hour of the day. This is especially true if the day in question is earlier than D + 7 days. For any day after the 14th day, it appears that essentially equal doses are acquired for periods of equal length regardless of the time of exposure. Hence $\frac{\Delta_i}{D}$ is approximately equal to F_i, where F_i is the fraction of the day spent in shelter i. Therefore, for days after day D + 7 Equation (13) yields:

$$EPF = \frac{1}{\sum_{i=1}^{n} \frac{F_i}{P_i}} . \qquad (14)$$

Example: Suppose that a person's activity on a D + 10 day in a fallout environment consists of the following:

(a) Eight hours (1/3 day) at work in a building with protection factor = 50

(b) Fourteen hours (7/12 days) in shelter with protection factor = 100

(c) Two hours (1/12 day) travel time with protection factor = 2.

In this example $$EPF = \frac{1}{\frac{1}{3x50} + \frac{7}{12x100} + \frac{1}{12x2}} = 18.$$

VII. APPENDIX D REFERENCES

D-a. Myron B. Hawkins. The Application of the Equivalent Residual Dose Concept to Operational Planning Techniques. Civil Defense Research Project. Berkeley: University of California, October 10, 1962.

D-b. John F. Devaney. Operations in Fallout. Washington, D. C.: Executive Office of the President, Office of Civil and Defense Mobilization, June 1961.

Appendix E

A Test of the Transportation Problem Solution as a Shelter Allocation Procedure: Durham, N. C.

I. INTRODUCTION

Section IV of Chapter 3 contains a discussion of a procedure for allocating shelter spaces based upon the Transportation Problem formulation, (References E-a and E-b). It was explained there that the allocations obtained are optimistic approximations for systems evaluation use and not necessarily estimates of realistic shelter utilization. In some cases, however, additional constraints are added to make the assignments more realistic, or even pessimistic. Thus, the real situation has probably been bracketed. This appendix includes a discussion of the test data, the various matrices prepared using the test data, and the method used to prepare the results for analysis. Results of the various allocations are converted into fatalities, and analyses using these fatality results are presented as examples of how such procedures may serve in CD system evaluation.

II. TEST DATA

Shelter and population numbers and locations were obtained for Durham, North Carolina. Residential population data were collected in summary by city block and by standard location (SL), (Reference E-c). Block maps and census tract maps with shelter facility locations on them were used to identify population centers for each block or SL and to measure rectangular distances (along city streets) to each shelter center. Since this task was performed prior to completion of the NFSS survey of Durham, numbers of spaces by PF Category (1-8) were obtained from an RTI survey report, (Reference E-d). These data were used in the various tests of the allocation procedure. Input was arranged in the format required by the IBM library program used in obtaining solutions on the IBM 1620 computer, (References E-a and E-b).

III. TEST MATRICES

A. Matrix Size

Cost matrices of N population origins by M shelter destinations were prepared with a cost element (C_{ij}) for each possible move from origin to destination. The cost matrix shown in Figure E-1 is a generalized example of matrices prepared in the test. Matrices were prepared of the following sizes:

1. 21 x 9 - to represent the 21 Durham SL's (P_i) with population and the 9 SL's (S_i) containing shelter.

2. 78 x 9 - to represent the 78 grid squares (P_i) with population and the 9 facility locations. Each of the 78 grid squares was considered sufficiently small (approximately 0.29 square miles) to assume uniform population within them. Facilities were found by inspection to be centrally located in their SL's.

3. 21 x 45 - in which SL's containing population and shelter were again employed, but a separate destination was prepared for each PF category in an SL which had an entry in the Phase 1 summary.

B. Objective Functions

Tests were made using different cost functions and matrix modifications. The objectives are listed below followed by the matrix or matrices in which they were used.

1. <u>Gross-Time</u> - in which the objective is to minimize the "Gross-Time" (sum of individuals' times) to move all people to shelter and the cost function is movement time. Speed of movement is a control variable in this and all other tests. Speed and distance set the cost of moving from P_i to S_j (21 x 9 and 78 x 9 matrices).

FIGURE E-1

Cost Matrix for the Transportation Problem

Population Origins to Shelter Destinations

Destination / Origin	S_1	S_2	S_3	S_4. . . .	S_j	People
P_1	C_{11}	C_{12}	C_{13}	.	.	m_1
P_2	C_{21}	C_{22}	.	.	.	m_2
P_3	C_{31}	.	.	.	.	m_3
P_4	.	.	.	.	.	m_4
P_5	.	.	.	.	.	m_5
.						.
.						.
.						.
P_i	.	.	.	.	C_{ij}	m_i
Spaces	n_j	n_2	n_3	n_4. . . .	n_j	

S_j - A facility or facility group destination.

P_i - A population group origin.

C_{ij} - Cost in time or fatalities to move from origin P_i to destination S_j.

n_j - Spaces available at S_j.

m_i - People in Group P_i.

2. Net-Time - in which the "Net-Time" of movement under fallout is the cost factor and minimizing net-time is the objective. The results are dependent upon the time of arrival of fallout. This arrival time is subtracted from total movement time to determine the cost factor in the matrix (21 x 9 matrix).

3. Fatalities - in which the probability of becoming a fatality in a move from P_i to S_j is the cost factor. This requires that PF values of shelters be considered.[E-1/] Thus, it uses the 21 x 45 matrix.

4. Net-Time, Restricted - in which the net time cost factor is biased so that all persons with available shelter in their own SL will use such shelter rather than moving on to other standard locations. This prevents persons near shelter from moving to a neighboring SL to make room for others traveling in from remote locations. It produces less than an optimum solution (inadequate use of high PF shelters and excessive travel for people distant from shelters) but approximates a not unlikely shelter plan (21 x 9 matrix).

5. Net-Time, Minimum Exposure - in which a maximum number are moved to shelter before fallout arrives, and those still unsheltered after arrival are allocated to minimize net-time under fallout (21 x 9 matrix).

C. Case of Unequal Numbers of Shelter Spaces and Population

Before continuing a discussion of the results, one more modification of the matrices must be explained. The Transportation Problem requires an equal number of items at origins and at destinations. Cities will seldom have equal numbers of people and shelter spaces. The matrices can be arranged to handle such an inequality by using a dummy row or column. For example, in Durham there are excess spaces. A fictitious row is added (P_n) with a number of people equal to the excess of shelter. The cost of moving from (P_n) to any destination is arranged to prohibit the preferred assignment of these hypothetical people (infinite cost).

E-1/ This is the only objective function which considers the shelter PF.

Allocations of space to these hypothetical people show the amount and location of excess space for the particular allocation. An excess of population can be handled in a similar fashion by adding hypothetical shelter or by including basements and houses in the list of total shelter spaces.

IV. FATALITY COMPUTATIONS

Assignments were made to Durham NFSS facilities by the Dennis Computer Program for the Transportation Problem (Reference E-a and E-b). This program is available from IBM for the IBM 1620 and other computers. An IBM 1620 was used in this test.

Outputs for the various shelter allocations listed the numbers of people assigned to each SL containing shelter except for the fatality method (Matrix 3). In this latter method, assignments were made both to SL and to PF category within the SL. For all other methods, people were assigned to PF categories starting with the highest available and continuing down until all were assigned a PF.

Fatalities were then computed by determining the approximate peak ERD and referring to the NREC curve for percentage fatalities versus ERD, (Reference E-c). In determining the ERD, two activities were considered: movement through fallout with PF = 1, and stay in shelter with the PF of the assigned shelter.

V. TEST RESULTS

A. General

Test results are presented in Table E-I, which shows the number of fatalities resulting for each of 12 applications of the Transportation Procedure formulation using Durham data. Fatalities were computed for each of five sets of fallout environment parameters (Time of Arrival and Initial Intensity).

The two specific questions for which answers were desired were:

1. Is an SL sufficiently small an accumulation unit to be used in obtaining distributions of people in shelters?

TABLE E-1

Fatalities in the Sample City Under
Various Plans & Environments

Population 78,500

ALLOCATION METHOD	FALLOUT ENVIRONMENT PARAMETERS Time of Arrival (HR) A 1	B 1	C 1½	D 1½	E 3
	Intensity at H + 1 (R/HR) 1000	5000	1000	5000	5000
1. Minimum Movement Time, Standard Location as Accumulation Unit	27560	49480	9280	34260	9250
2. Minimum Movement Time, Small Grid Squares as Accumulation Unit	25530	42980	7820	28880	14810
3. Minimum Movement Time After 1 Hour	24630	50350	5130	27150	9860
4. Minimum Movement Time After 1 Hour with Preference for Own S. L.	27570	49480	8640	33800	9860
5. Maximum Number in Shelter Before 1 Hour	25760	49060	9130	34530	9251
6. Minimum Movement Time After 1½ Hours	25970	53170	3540	27110	10460
7. Minimum Movement Time After 1½ Hours with Preference for Own S. L.	32220	52170	6670	35560	10460
8. Maximum Number in Shelter Before 1½ Hours	24880	51260	4420	26990	10460
9. Minimum Fatalities Planned for: 1 Hour Arrival, 1000 R/HR	21430	57140	5540	32020	9580
10. Minimum Fatalities Planned for: 1 Hour Arrival, 5000 R/HR	34280	46050	2180	37500	7950
11. Minimum Fatalities Planned for: 1½ Hour Arrival, 1000 R/HR	25540	56490	1850	34950	9920
12. Minimum Fatalities Planned for: 1½ Hour Arrival, 5000 R/HR	22770	54730	8090	25870	7960

2. Is there a significant difference in the fatalities as a consequence of the choice of the objective function?

B. Accumulation Unit

Unfortunately, the first question was not adequately answered by the test cases set up for its examination. Allocation methods (1) and (2) in Table E-I were intended for an examination of this question. Method (1) uses the SL as the accumulation unit, and method (2) uses the much smaller grid square. Each allocation was based upon minimizing movement time. The resulting fatalities are much too dissimilar to give an unequivocal answer to our question. With shorter arrival times, the grid square method produces fewer fatalities because there is less movement through fallout. With an arrival time of 3 hours, there is little or no movement under fallout for either method and the greater employment of high PF shelter by the SL method resulted in fewer fatalities. Although the test result does not answer the question for which it was intended, it shows the importance of considering both movement and PF of shelter in finding a minimum fatality solution, as well as in performing realistic shelter assignments.

It was intended that SL and grid square allocations be compared for the fatality method as well, but time did not permit the completion of these cases. Instead, the SL accumulation unit was chosen for future work, not on the basis of test cases, but because of its availability in convenient form for rapid use. The test cases did not indicate any advantage to be obtained from use of a unit smaller than an SL; but if such an advantage is later found, the Transportation Procedure formulation can be easily modified to accept any such accumulation unit.

C. Choice of Objective Function

The answer to the second question, "Is there a significant difference in the fatalities as a consequence of the choice of the objective function?" is definitely, yes. By inspecting Table E-I, column by column, the number of fatalities for each attack may be found. Comparing the minimum number in each column with the maximum number (e.g., maximum fatality numbers), it is found that the difference ranges from 13% to 80%, a significant difference. Thus, the minimum fatality solution cannot be approximated by some less detailed method minimizing some other objective function such as movement time.

D. An Illustration of Output Analysis for Such Case Studies

An extraction was made from Table E-I, Rows 9, 10, 11, and 12 to produce the matrix in Table E-II. The entries are simplified by reporting in units of one thousand. Thus, letting the allocation method represent a shelter allocation policy, Table E-II contains the "best" policy for each attack. Inspection of Table E-II will illustrate several points of importance. For example, if the sample city's civil defense system is designed to minimize the number of fatalities under the worst attack and the expected attack occurred (reference intensity of 5000 R/Hour, warning time of one hour), the expected number of fatalities would be approximately 46,000 people (the second row, B column entry). If, instead, the intensity of radiation that occurred was one fifth as much as the planned level, there would be thirteen thousand more casualties occurring than if the civil defense plans had been prepared for the actual level of radiation. (See column A, row 1, vs. column A, row 2, Table E-II.) A similar result occurs if, for example, the time of arrival was 1½ hours instead of a planned 1 hour. (See the difference in column D, row 2 vs. column D, row 4, Table E-II.)

TABLE E-II

Fatalities in the Sample City

Under the Minimum Fatality Shelter Allocation Policy

SHELTER ALLOCATION POLICY Minimum Fatalities Planned for:	ATTACK PARAMETERS Time of Arrival (HR) A 1	B 1	C 1½	D 1½	E 3	
	Intensity at H + 1 (R/HR) 1000	5000	1000	5000	5000	Max. Row Values
(9) 1 Hour Arrival, 1000 R/HR	21	57	6	32	10	57
(10) 1 Hour Arrival, 5000 R/HR	34	46	2	38	8	46
(11) 1½ Hour Arrival, 1000 R/HR	26	56	2	35	10	56
(12) 1½ Hour Arrival, 5000 R/HR	23	55	8	26	8	55
Min. Column Value	21	46	2	26	8	

E. Illustrative Sample Application of Game Theory

Different types of analysis can be performed on the data in Table E-II, each being based on a different assumption. For example, consider the situation described in Table E-II as a matrix game (Reference E-f). To do this let us assume the attacker's objective is to kill as many as possible in the sample city by fallout. (This is not the assumption of the previous section.) Further, the attacker is rational and intelligent and has as possible strategies the five attacks listed in Table E-II. The defense can prepare an optimum plan in response to each of the first four attacks. These are the rows in Table E-II. The entries in the matrix are the outcomes in number of fatalities, given each attack and each defense. Since the attacker will attempt to kill as many as possible, the (B) attack will invariably be launched. Now, since the defense will attempt to save as many as possible, row 10 is the "best" defense action because any deviation from defense (10) by the defender or attack (B) by the attacker will benefit the other side. The matrix thus contains Von Neumann's "saddle point" (Reference E-f, p.158), indicating the existence of a "pure" strategy as demonstrated in the example.

The preceding strategy analyses, as well as the generation of data on the sample city, should be considered as only indicative of possible applications of analytical decision theory procedures for evaluation of metropolitan civil defense systems.

VI. SUMMARY

The test case described above was limited in that a single city was examined, only 5 sets of attack environment parameters were used, and simplified fallout fatality computations were obtained. However, it demonstrated a procedure for modeling the movement of people to shelter which takes into account the distance from shelter, the speed of movement, and the protection factor of the shelter; and obtains a solution which will minimize fatalities for any hypothesized fallout environment. The test results were also useful in demonstrating types of analysis which may be made using output such as will be obtained from the Mainline Program (see Chapter 3, Section III).

Plans for future work under a follow-on contract (Reference E-8) include further examinations using data from other cities to verify or improve the ability of the model to predict a realistic distribution of people in shelter.

VII. APPENDIX E REFERENCES

E-a. International Business Machines Corporation. The Transportation Problem - Indirect Addressing. IBM 1620 Program Library. White Plains, N. Y.

E-b. J. B. Dennis. A High Speed Technique for the Transportation Problem. ACM Journal, Volume 5, April 1958. pp. 132-153.

E-c. U. S. Bureau of the Census. U. S. Census of Population and Housing: 1960 - Durham, N. C. City Blocks. Report HC(3)-294, Washington: U. S. Government Printing Office, 1961.

E-d. Research Triangle Institute. A Fallout Shelter Survey of Durham, N. C., performed by RTI personnel in a test of NFSS procedures and computer PF calculations. Results are available only as an internal memorandum report. The survey was performed under OCD Contract Number SD-96. October, 1961.

E-e. Joseph Coker. Nuclear Attack Hazard and Resource Evaluation Models. Executive Office of the President, Washington: National Resource Evaluation Center, October 18, 1961.

E-f. R. Duncan Luce and Howard Raiffa. Games and Decisions. New York: John Wiley & Sons, Inc., 1957.

E-g. Office of Civil Defense, Department of Defense, Contract Number OCD-PS-64-56 with the Research Triangle Institute. Washington: September 30, 1963.

Appendix F

Statistics Used In Selecting Sample Cities For The Mainline Program

This appendix contains the tables referred to in Chapter 3, Section VI. They contain the statistics used in selecting sample cities for the Mainline Program.

The tables included are:

Table F-I - Strata Members

Table F-II - Cities Stratified Only On Shelter Density

Table F-III - Representative SMSA's Selected At Random

Table F-IV - Representative Cities Taken By Stratifying Only On Shelter Density

Table F-V - Multiple SMSA's

TABLE F-I

Strata Members

Stratum	SMSA	Shelter Density Spaces/Person	Population Density People/Sq.Mi.
1	New York, N. Y.	5.577	24697
2	Boston, Mass.	2.391	14586
	Chicago, Ill.	2.452	15836
	Jersey City, N. J.	2.343	21239
	Washington, D. C. - Maryland - Virginia	3.586	12442
3	Baltimore, Md.	1.294	11886
	Buffalo, N. Y.	1.264	13522
	Cleveland, Ohio	1.612	10789
	Detroit, Mich.	1.163	11964
	Harrisburg, Pa.	1.256	10486
	Newark, N. J.	1.874	17170
	Pittsburgh, Pa.	1.322	11171
	Reading, Pa.	1.140	10227
	San Francisco - Oakland, Calif.	1.635	11013
	Trenton, N. J.	1.224	15428
	Philadelphia, Pa. - N. J.	1.751	15743
	St. Louis, Mo. - Ill.	1.706	12296
4	Altoona, Pa.	.518	7712
	Canton, Ohio	.389	7946
	Johnstown, Pa.	.484	9634

TABLE F-I (Continued)

Stratum	SMSA	Shelter Density Spaces/Person	Population Density People/Sq.Mi.
4	Racine, Wis.	.562	7959
	Charleston, S. C.	.393	12926
	York, Pa.	.466	11597
5	Omaha, Neb. - Iowa	1.706	5891
	Hartford, Conn.	2.282	9321
	Indianapolis, Ind.	2.064	6689
	Milwaukee, Wis.	1.865	8137
	Nashville, Tenn.	1.682	5892
	New Haven, Conn.	1.594	8494
	Richmond, Va.	1.694	5945
	Rochester, N. Y.	2.461	8753
	Atlantic City, N. J.	2.462	5178
	Cincinnati, Ohio - Ky.	1.844	6501
6	Worcester, Mass.	1.137	5043
	Wichita, Kan.	1.029	4907
	Tulsa, Okla.	1.045	5475
	Toledo, Ohio	1.432	6598
	Syracuse, N. Y.	1.016	8642
	Seattle, Wash.	1.354	6295
	Peoria, Ill.	1.057	6787
	Miami, Fla.	1.078	8529
	Lincoln, Neb.	1.065	5060
	Lexington, Ky.	1.211	4832

TABLE F-I (Continued)

Stratum	SMSA	Shelter Density Spaces/Person	Population Density People/Sq.Mi.
6	Denver, Colo.	1.185	6956
	Bridgeport, Conn.	1.030	8757
	Akron, Ohio	1.363	5387
	Louisville, Ky. - Ind.	1.404	6841
	Portland, Oreg. - Wash.	1.310	5546
	Wilmington, Del. - N. J.	1.257	6065
7	Springfield, Ohio	.928	5269
	South Bend, Ind.	.913	5565
	New Britain, Conn.	.933	6000
	New Bedford, Mass.	.784	5365
	Lowell, Mass.	.697	7031
	Lansing, Mich.	.933	5085
	Lancaster, Pa.	.702	8364
	Jacksonville, Fla.	.995	6657
	Grand Rapids, Mich.	.608	7267
	Flint, Mich.	.650	6587
	Erie, Pa.	.721	7364
	Dayton, Ohio	.765	7808
	Columbus, Ohio	.969	5296
	Binghamton, N. Y.	.785	6967
	Columbia, S. C.	.896	5295
	Billings, Mont.	.694	5683

TABLE F-I (Continued)

Stratum	SMSA	Shelter Density Spaces/Person	Population Density People/Sq.Mi.
8	Augusta, Ga. - S. C.	.583	4708
	Albuquerque, N. M.	.430	3580
	Baton Rouge, La.	.477	4917
	Corpus Christi, Texas	.477	4436
	Laredo, Texas	.463	4435
	Lima, Ohio	.484	6149
	Macon, Ga.	.513	4651
	Ogden, Utah	.497	3714
	Rockford, Ill.	.456	4873
	Chattanooga, Tenn. - Ga.	.587	3542
9	Savannah, Ga.	.395	3596
	San Jose, Calif.	.314	3747
	Pueblo, Colo.	.379	5332
	Muskegon, Mich.	.311	5369
	Lawton, Okla.	.392	5141
	Kenosha, Wis.	.345	6723
	Fresno, Calif.	.269	4683
	Eugene, Oreg.	.310	3516
	Brockton, Mass.	.340	3387
	Bakersfield, Calif.	.302	3553
	Saginaw, Mich.	.324	5920
	Columbus, Ga. - Tenn.	.324	4423

TABLE F-I (Continued)

Stratum	SMSA	Shelter Density Spaces/Person	Population Density People/Sq.Mi.
10	Stockton, Calif.	.240	3769
	Orlando, Fla.	.207	4177
	Odessa, Tex.	.146	5117
	Muncie, Ind.	.224	5577
	Lake Charles, La.	.092	3889
	Bay City, Mich.	.181	5584
11	Topeka, Kans.	1.494	3310
	Springfield, Ill.	1.384	3891
	St. Joseph, Mo.	1.544	2876
	Roanoke, Va.	1.391	3735
	Portland, Maine	1.355	3360
	Madison, Wis.	1.932	3549
	Green Bay, Wis.	1.534	3743
	Durham, N. C.	1.725	3559
	Austin, Texas	1.424	3776
	Atlanta, Ga.	1.367	3802
	Ann Arbor, Mich.	1.991	4915
	Des Moines, Iowa	1.677	3240
	Kansas City, Mo. - Kans.	2.210	3664
12	Cedar Rapids, Iowa	1.115	2789
	Dallas, Texas	1.275	2428
	Fort Worth, Texas	1.046	2536

TABLE F-I (Continued)

Stratum	SMSA	Shelter Density Spaces/Person	Population Density People/Sq.Mi.
12	Houston, Texas	1.099	2860
	Knoxville, Tenn.	1.226	4403
	Midland, Texas	1.147	2735
	New Orleans, La.	1.163	3157
	Salt Lake City, Utah	1.025	3377
	Stamford, Conn.	1.084	2414
	Terre Haute, Ind.	1.228	2935
	Waterbury, Conn.	1.101	3882
13	Tuscaloosa, Ala.	.714	3018
	Tacoma, Wash.	.775	3115
	Spokane, Wash.	.917	4223
	Sioux Fall, S. D.	.947	3851
	Shreveport, La.	.997	4566
	Scranton, Pa.	.794	4405
	San Antonio, Texas	.706	3662
	Reno, Nev.	.620	4362
	Montgomery, Ala.	.694	4226
	Memphis, Tenn.	.917	3881
	Jackson, Miss.	.876	3106
	Kalamazoo, Mich.	.612	3406
	Jackson, Mich.	.719	4830
	Great Falls, Mont.	.832	4856
	Fort Wayne, Ind.	.895	4396
	Sacramento, Calif.	.808	4250

TABLE F-I (Continued)

Stratum	SMSA	Shelter Density Spaces/Person	Population Density People/Sq.Mi.
13	Dubuque, Iowa	.806	4162
	Decatur, Ill.	.721	3960
	Colorado Springs, Colo.	.780	4203
	Charlotte, N. C.	.921	3111
	Charleston, W. Va.	.900	3021
	Birmingham, Ala.	.714	4576
	Winston-Salem, N. C.	.923	3573
	Evansville, Ind. - Ky.	.970	4423
	Wheeling, W. Va. - Ohio	.844	4944
14	Amarillo, Texas	.692	2518
	Asheville, N. C.	.912	2508
	El Paso, Texas	.736	2414
	Greenville, S. C.	.806	2724
	Manchester, N. H.	.847	2759
	Meriden, Conn.	.781	2206
	Raleigh, N. C.	.990	2804
	Sioux City, Iowa	.939	1805
	Springfield, Mo.	.878	2763
	Waco, Texas	.685	2622
	Waterloo, Iowa	.858	2123
15	Fall River, Mass. - R. I.	.474	2948
	Wichita Falls, Texas	.547	2727

TABLE F-I (Continued)

Stratum	SMSA	Shelter Density Spaces/Person	Population Density People/Sq.Mi.
15	Tyler, Texas	.444	2799
	San Angelo, Texas	.478	1980
	Pittsfield, Mass.	.562	1415
	Phoenix, Ariz.	.435	2343
	Lynchburg, Va.	.507	2382
	Lubbock, Texas	.460	1716
	Las Vegas, Nev.	.513	2607
	Fort Smith, Ark.	.567	2145
	Texarkana, Texas - Ark.	.322	2283
16	Albany, Ga.	.382	2430
	Huntsville, Ala.	.269	1427
	Mobile, Ala.	.374	1326
	Monroe, La.	.368	2885
	Norwalk, Conn.	.301	2744
	San Diego, Calif.	.384	2979
	West Palm Beach, Fla.	.305	3006
17	Tucson, Ariz.	.248	3003
	Santa Barbara, Calif.	.165	2983
	Pensacola, Fla.	.228	2823
	Gadsden, Ala.	.223	1892
18	Oklahoma City, Okla.	1.583	1009

TABLE F-II

Cities Stratified Only On Shelter Density

SMSA	Stratum
Odessa, Texas	1
Lake Charles, La.	
Bay City, Mich.	
Santa Barbara, Calif.	
Canton, Ohio	2
Charleston, S. C.	
Savannah, Ga.	
San Jose, Calif.	
Pueblo, Colo.	
Muskegon, Mich.	
Lawton, Okla.	
Kenosha, Wis.	
Fresno, Calif.	
Eugene, Oreg.	
Brockton, Mass.	
Bakersfield, Calif.	
Saginaw, Mich.	
Stockton, Calif.	
Orlando, Fla.	
Muncie, Ind.	
Albany, Ga.	
Huntsville, Ala.	
Mobile, Ala.	

TABLE F-II (Continued)

SMSA	Stratum
Monroe, La.	2
Norwalk, Conn.	
San Diego, Calif.	
West Palm Beach, Fla.	
Tucson, Ariz.	
Pensacola, Fla.	
Gadsden, Ala.	
Altoona, Pa.	3
Johnstown, Pa.	
Racine, Wis.	
York, Pa.	
Albuquerque, N. M.	
Baton Rouge, La.	
Corpus Christi, Texas	
Laredo, Texas	
Lima, Ohio	
Macon, Ga.	
Ogden, Utah	
Rockford, Ill.	
Wichita Falls, Texas	
Tyler,Texas	
San Angelo, Texas	
Pittsfield, Mass.	
Phoenix, Ariz.	

TABLE F-II (Continued)

SMSA	Stratum
Lynchburg, Va.	3
Lubbock, Texas	
Las Vegas, Nev.	
Fort Smith, Ark.	
New Bedford, Mass.	4
Lowell, Mass.	
Lancaster, Pa.	
Grand Rapids, Mich.	
Flint, Mich.	
Erie, Pa.	
Dayton, Ohio	
Binghamton, N. Y.	
Billings, Mont.	
Tuscaloosa, Ala.	
Tacoma, Wash.	
Scranton, Pa.	
San Antonio, Texas	
Reno, Nev.	
Montgomery, Ala.	
Kalamazoo, Mich.	
Jackson, Mich.	
Decatur, Ill.	
Colorado Springs, Colo.	
Birmingham, Ala.	
Amarillo, Texas	

TABLE F-II (Continued)

SMSA	Stratum
El Paso, Texas	4
Meriden, Conn.	
Waco, Texas	
Springfield, Ohio	5
South Bend, Ind.	
New Britain, Conn.	
Lansing, Mich.	
Jacksonville, Fla.	
Columbus, Ohio	
Columbia, S. C.	
Spokane, Wash.	
Sioux Falls, S. D.	
Shreveport, La.	
Sacramento, Calif.	
Memphis, Tenn.	
Jackson, Miss.	
Great Falls, Mont.	
Fort Wayne, Ind.	
Dubuque, Iowa	
Charlotte, N. C.	
Charleston, W. Va.	
Winston-Salem, N. C.	
Asheville, N. C.	
Greenville, S. C.	

TABLE F-II (Continued)

SMSA	Stratum
Manchester, N. H.	5
Raleigh, N. C.	
Sioux City, Iowa	
Springfield, Mo.	
Waterloo, Iowa	
Detroit, Mich.	6
Reading, Pa.	
Worcester, Mass.	
Wichita, Kans.	
Tulsa, Okla.	
Syracuse, N. Y.	
Peoria, Ill.	
Miami, Fla.	
Lincoln, Neb.	
Denver, Colo.	
Bridgeport, Conn.	
Cedar Rapids, Iowa	
Fort Worth, Texas	
Houston, Texas	
Midland, Texas	
New Orleans, La.	
Salt Lake City, Utah	
Stamford, Conn.	
Waterbury, Conn.	

TABLE F-II (Continued)

SMSA	Stratum
Seattle, Wash.	7
Baltimore, Md.	
Buffalo, N. Y.	
Harrisburg, Pa.	
Pittsburgh, Pa.	
Trenton, N. J.	
Lexington, Ky.	
Springfield, Ill.	
Roanoke, Va.	
Portland, Maine	
Atlanta, Ga.	
Akron, Ohio	
Dallas, Texas	
Knoxville, Tenn.	
Terre Haute, Ind.	
New Haven, Conn.	8
Toledo, Ohio	
St. Joseph, Mo.	
Topeka, Kans.	
Green Bay, Wis.	
Austin, Texas	
Cleveland, Ohio	9
Nashville, Tenn.	
Richmond, Va.	
Durham, N. C.	

TABLE F-II (Continued)

SMSA	Stratum
Des Moines, Iowa	9
Newark, New Jersey	10
Milwaukee, Wis.	
Madison, Wis.	
Ann Arbor, Mich.	
Indianapolis, Ind.	11
Boston, Mass.	12
Jersey City, N. J.	
Hartford, Conn.	
Chicago, Ill.	13
Rochester, N. Y.	
Atlantic City, N. J.	
New York, N. Y.	14
Oklahoma City, Okla.	15

TABLE F-III

Representative SMSA's Selected At Random

Stratum	SMSA	Avg.Strata Shelter Density	Avg.Strata Population Density	Shelter Density Standard Deviation	Population Density Standard Deviation
1	New York, N. Y.	5.577	24697	0	0
2	Boston, Mass.	2.395	17220	.055	1745
3	Detroit, Mich.	1.378	12366	.232	2185
4	Charleston, S. C.	.468	9629	.071	2010
5	Richmond, Va.	2.013	7301	.334	1460
6	Peoria, Ill.	1.154	6405	.138	1410
7	Columbus, Ohio	.810	6350	.127	1005
8	Baton Rouge, La.	.474	4602	.032	746
9	Bakersfield, Calif.	.334	4633	.032	1095
10	Orlando, Fla.	.181	4686	.045	764
11	Atlanta, Ga.	1.568	3646	.208	472
12	Knoxville, Tenn.	1.137	3047	.071	596
13	Charlotte, N. C.	.808	3946	.109	577
14	Waterloo, Iowa	.829	2477	.100	302
15	Tyler, Texas	.501	2235	.045	450
16	Mobile, Ala.	.340	2400	.032	671
17	Tucson, Ariz.	.216	2675	.032	460
18	Oklahoma City, Okla.	1.583	1009	0	0

TABLE F-IV

Representative Cities Taken By Stratifying Only On Shelter Density

Stratum	SMSA	Shelter Density	Population Density
1	Odessa, Tex.	.146	5117
2	Bakersfield, Calif.	.302	3553
3	Ogden, Utah	.497	3714
4	Montgomery, Ala.	.694	4226
5	Spokane, Wash.	.917	4223
6	Lincoln, Neb.	1.065	5060
7	Akron, Ohio	1.363	5387
8	Toledo, Ohio	1.432	6598
9	Richmond, Va.	1.694	5945
10	Milwaukee, Wis.	1.865	8137
11	Indianapolis, Ind.	2.064	6689
12	Hartford, Conn.	2.282	9321
13	Rochester, N. Y.	2.461	8753
14	Oklahoma City, Okla.	1.583	1009
15	New York, N. Y.	5.577	24697

TABLE F-V

Multiple SMSA's

Albany - Schenectady - Troy, N. Y.

Beaumont - Port Arthur, Texas

Brownsville - Harlingen - San Benito, Texas

Champaign - Urbana, Ill.

Fitchburg - Leominister, Mass.

Fort Lauderdale - Hollywood, Fla.

Galveston - Texas City, Texas

Gary - Hammond - East Chicago, Ind.

Greensboro - High Point, N. C.

Hamilton - Middleton, Ohio

Lewiston - Auburn, Maine

Little Rock - N. Little Rock, Ark.

Lorain - Elyria, Ohio

New London - Groton - Norwich, Conn.

Newport News - Hampton, Va.

Provo - Orem, Utah

Los Angeles - Long Beach, Calif.

Allentown - Bethlehem - Easton, Pa. - N. J.

Davenport - Rock Island - Moline, Iowa - Ill.

Duluth - Superior, Minn. - Wis.

Fall River, Mass. - R. I.

Fargo - Moorhead, N. D. - Minn.

Huntington - Ashland, W. Va. - Ky. - Ohio

TABLE F-V (Continued)

Lawrence - Haverhill, Mass. - N. H.

Norfolk - Portsmouth, Va.

Minneapolis - St. Paul, Minn.

Patterson - Clifton - Passaic, N. J.

Providence - Pawtucket, R. I. - Mass.

San Bernadino - Riverside, Calif.

Springfield - Chicopee, Mass.

Steubenville - Weirton, Ohio - W. Va.

Tampa - St. Petersburg, Fla.

Utica - Rome, N. Y.

Youngstown - Warren, Ohio

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is used to simulate the movement of people to shelter within a city. The solution to the problem when so formulated allocates people to shelter in a manner to maximize survivors (or other objective functions). Tests over a range of fallout environments using this information show that the minimum fatality allocation to shelter is particularly sensitive to fallout "build-up," movement through fallout, and shelter PF's. An equivalent residual dose (ERD) model which computes ERD in a time-varying radiation environment is programmed for the IBM 1620 and 7072. It has been found that the peak ERD after emergence may exceed the peak ERD in the initial shelter. The shelter allocation model and the peak ERD model form the basis for the "Mainline Computer Program," a procedure for computing the survivors added by alternative CD system improvements. This program is currently being developed into a working tool for CD systems evaluation.

CD SYSTEMS, SYSTEMS EVALUATION, NATIONAL FALLOUT SHELTER SURVEY, DAMAGE ASSESSMENT, VULNERABILITY ANALYSIS, RADIOLOGICAL DOSAGE, FALLOUT CASUALTIES, DIGITAL COMPUTER APPLICATIONS (SIMULATION MODELS, TRANSPORTATION MODELS, SHELTER ALLOCATION).

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