

The Effects of Nuclear Weapons

Compiled and edited by
Samuel Glasstone *and* Philip J. Dolan

Third Edition

Prepared and published by the
UNITED STATES DEPARTMENT OF DEFENSE
and the
ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION



1977

PREFACE

When "The Effects of Atomic Weapons" was published in 1950, the explosive energy yields of the fission bombs available at that time were equivalent to some thousands of tons (i.e., kilotons) of TNT. With the development of thermonuclear (fusion) weapons, having energy yields in the range of millions of tons (i.e., megatons) of TNT, a new presentation, entitled "The Effects of Nuclear Weapons," was issued in 1957. A completely revised edition was published in 1962 and this was reprinted with a few changes early in 1964.

Since the last version of "The Effects of Nuclear Weapons" was prepared, much new information has become available concerning nuclear weapons effects. This has come in part from the series of atmospheric tests, including several at very high altitudes, conducted in the Pacific Ocean area in 1962. In addition, laboratory studies, theoretical calculations, and computer simulations have provided a better understanding of the various effects. Within the limits imposed by security requirements, the new information has been incorporated in the present edition. In particular, attention may be called to a new chapter on the electromagnetic pulse.

We should emphasize, as has been done in the earlier editions, that numerical values given in this book are not—and cannot be—exact. They must inevitably include a substantial margin of error. Apart from the difficulties in making measurements of weapons effects, the results are often dependent upon circumstances which could not be predicted in the event of a nuclear attack. Furthermore, two weapons of different design may have the same explosive energy yield, but the effects could be markedly different. Where such possibilities exist, attention is called in the text to the limitations of the data presented; these limitations should not be overlooked.

The material is arranged in a manner that should permit the general reader to obtain a good understanding of the various topics without having to cope with the more technical details. Most chapters are thus in two parts: the first part is written at a fairly low technical level whereas the second treats some of the more technical and mathematical aspects. The presentation allows the reader to omit any or all of the latter sections without loss of continuity.

The choice of units for expressing numerical data presented us with a dilemma. The exclusive use of international (SI) or metric units would have placed a burden on many readers not familiar with these units, whereas the inclusion of both SI and common units would have complicated many figures, especially those with logarithmic scales. As a compromise, we have retained the older units and added an explanation of the SI system and a table of appropriate conversion factors.

Preface

Many organizations and individuals contributed in one way or another to this revision of "The Effects of Nuclear Weapons," and their cooperation is gratefully acknowledged. In particular, we wish to express our appreciation of the help given us by L. J. Deal and W. W. Schroebel of the Energy Research and Development Administration and by Cmdr. H. L. Hoppe of the Department of Defense.

Samuel Glasstone

Philip J. Dolan

ACKNOWLEDGEMENTS

Preparation of this revision of "The Effects of Nuclear Weapons" was made possible by the assistance and cooperation of members of the organizations listed below.

Department of Defense

Headquarters, Defense Nuclear Agency
Defense Civil Preparedness Agency
Armed Forces Radiobiology Research Institute
U.S. Army Aberdeen Research and Development Center, Ballistic Research Laboratories
U.S. Army Engineer Waterways Experiment Station
Naval Surface Weapons Center

Department of Defense Contractors

Stanford Research Institute
General Electric, TEMPO
Mission Research Corporation

Department of Commerce

National Oceanic and Atmospheric Administration

Atomic Energy Commission/ Energy Research and Development Administration

Headquarters Divisions and the laboratories:

Brookhaven National Laboratory
Health and Safety Laboratory
Lawrence Livermore Laboratory
Los Alamos Scientific Laboratory
Lovelace Biomedical and Environmental Research Laboratories
Oak Ridge National Laboratory
Sandia Laboratories

CONTENTS

	Page
CHAPTER I—General Principles of Nuclear Explosions	1
Characteristics of Nuclear Explosions	1
Scientific Basis of Nuclear Explosions	12
CHAPTER II—Descriptions of Nuclear Explosions	26
Introduction	26
Description of Air and Surface Bursts	27
Description of High-Altitude Bursts	45
Description of Underwater Bursts	48
Description of Underground Bursts	58
Scientific Aspects of Nuclear Explosion Phenomena	63
CHAPTER III—Air Blast Phenomena in Air and Surface Bursts	80
Characteristics of the Blast Wave in Air	80
Reflection of Blast Wave at a Surface	86
Modification of Air Blast Phenomena	92
Technical Aspects of Blast Wave Phenomena	96
CHAPTER IV—Air Blast Loading	127
Interaction of Blast Wave with Structures	127
Interaction of Objects with Air Blast	132
CHAPTER V—Structural Damage from Air Blast	154
Introduction	154
Factors Affecting Response	156
Commercial and Administrative Structures	158
Industrial Structures	165
Residential Structures	175
Transportation	189
Utilities	195
Miscellaneous Targets	206
Analysis of Damage from Air Blast	212
CHAPTER VI—Shock Effects of Surface and Subsurface Bursts	231
Characteristics of Surface and Shallow Underground Bursts	231
Deep Underground Bursts	238
Damage to Structures	241
Characteristics of Underwater Bursts	244

Technical Aspects of Surface and Underground Bursts	253
Technical Aspects of Deep Underground Bursts	260
Loading on Buried Structures	263
Damage from Ground Shock	265
Technical Aspects of Underwater Bursts	268
CHAPTER VII—Thermal Radiation and Its Effects	276
Radiation from the Fireball	276
Thermal Radiation Effects	282
Incendiary Effects	296
Incendiary Effects in Japan	300
Technical Aspects of Thermal Radiation	305
Radiant Exposure—Distance Relationships	316
CHAPTER VIII—Initial Nuclear Radiation	324
Nature of Nuclear Radiations	324
Gamma Rays	326
Neutrons	340
Transient-Radiation Effects on Electronics (TREE)	349
Technical Aspects of Initial Nuclear Radiation	353
CHAPTER IX—Residual Nuclear Radiation and Fallout	387
Sources of Residual Radiation	387
Radioactive Contamination from Nuclear Explosions	409
Fallout Distribution in Land Surface Bursts	414
Fallout Predictions for Land Surface Bursts	422
Attenuation of Residual Nuclear Radiation	439
Delayed Fallout	442
Technical Aspects of Residual Nuclear Radiation	450
CHAPTER X—Radio and Radar Effects	461
Introduction	461
Atmospheric Ionization Phenomena	462
Ionization Produced by Nuclear Explosions	466
Effects on Radio and Radar Signals	479
Technical Aspects of Radio and Radar Effects	489
CHAPTER XI—The Electromagnetic Pulse and its Effects	514
Origin and Nature of the EMP	514
EMP Damage and Protection	523
Theory of the EMP	532
CHAPTER XII—Biological Effects	541
Introduction	541
Blast Injuries	548
Burn Injuries	560
Nuclear Radiation Injury	575

Characteristics of Acute Whole-Body Radiation Injury	583
Combined Injuries	588
Late Effects of Ionizing Radiation	589
Effects of Early Fallout	594
Long-Term Hazard from Delayed Fallout	604
Genetic Effects of Nuclear Radiation	609
Pathology of Acute Radiation Injury	614
Blast-Related Effects	618
Effects on Farm Animals and Plants	618
Glossary	629
Guide to SI Units	642
Index	644