Nuclear Weapons Databook

Volume I U.S. Nuclear Forces and Capabilities

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Thomas B. Cochran, William M. Arkin, and Milton M. Hoenig

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Foreword

Generation Upon Generation

The Nuclear Weapons Databook is for those who want to understand the nuclear arms race and are not frightened by numbers. This first volume is the most authoritative and complete reference work available on U.S. forces and capabilities. I expect it to join the classic government publication, The Effects of Nuclear Weapons, on the bookshelves of those who are interested in the technical issues relating to the nuclear arms race.

The comprehensive material on U.S. nuclear weapons and weapons-development programs presented in this volume will be used by professionals in Congress, academia, public interest groups, and the media in assessing nuclear weapons policy alternatives. They will find that the Databook will make them less dependent for their information upon the generosity of Executive Branch officials.

The Databook will also be extremely helpful to the increasingly large group of citizen-activists who wish to challenge, on a technical level, the arguments which are used to rationalize the continuation of the nuclear arms race.

Just leafing through Volume I of the Databook teaches one some important facts about the arms race. Many readers will be surprised to learn, for example, just how "nuclearized" the U.S. military establishment is. They will learn that, in addition to the relatively familiar "strategic" nuclear weapons systems which give the U.S. the capability to destroy the Soviet Union—or any other nation for that matter—from thousands of miles away, virtually every unit of the U.S. Armed Forces has the capability to deliver nuclear destruction at shorter ranges.

For example, the Army has nuclear weapons ranging from man-portable atomic demolition mines and nuclear artillery shells to nuclear-tipped surface missiles able to attack Moscow from West Germany. The Army, Navy, and Air Force all have anti-aircraft missiles with nuclear warheads. The Navy has nuclear depth charges which can be dropped from aircraft or shot by rockets from surface ships or submarines. And there are thousands of "tactical" bombs with yields ranging from one third to one hundred times that of the Hiroshima bomb.

Another message implicit in the Databook which struck this reader with particular force is the fact that there is always another generation of nuclear weapons under development.

Consider modern long-range cruise missiles. Breakthroughs in the development of tiny efficient jet engines and in terrain-recognizing microprocessors have finally made these miniature pilotless aircraft such effective nuclear weapons delivery vehicles that all the armed services are spending billions on them.

The Air Force is equipping its B-52G/H bombers to carry a total of over 3000 cruise missiles. Each of these precision-guided drones can carry a nuclear warhead with more than ten times the explosive power of the Hiroshima bomb to a target 1500 miles away. The Navy plans to deploy hundreds of nuclear-armed cruise missiles on its surface ships and on its attack submarines. (The latter are to be kept as an "enduring reserve" to strengthen the position of the U.S. in a post-nuclear war world.) The Air Force is also, amid furious controversy, attempting to deploy 464 cruise missiles in Western Europe.

Meanwhile, follow-on "advanced" cruise missiles are under development. In the short term, there will be evolutionary improvements to increase the range and reduce the radar reflectivity of the current generation of cruise missiles. And, in the longer term, an "advanced strategic air-launched missile" is planned which will travel at four times the speed of sound. We learn from the Databook that the program to develop a supersonic cruise missile was initiated in June 1974—less than one year after development work began on the current generation of cruise missiles!

We can also learn from the Databook that the many cycles of "modernization" of the U.S. nuclear arsenal have not increased its destructive power over the past 20 years. Overkill was achieved within a decade of Hiroshima. Since that time, the designers of strategic nuclear weapons systems have been concentrating on other areas—perhaps most ominously on first-strike capabilities.

I Edited by Samuel Classtone and Phillip J. Dolan, 3rd edition jointly published by the Departments of Defense and Energy, 1977.

As a result of these development programs, most missiles in the next generation of U.S. nuclear weapons will have the capabilities to destroy "hardened" military targets and most will be able to destroy many. The MX with its ten accurate warheads is designed to destroy up to ten Soviet missiles in their silos, for example. The submarine-launched TRIDENT II missile is to have similar capabilities.

Strikes with these new "war-fighting" nuclear weapon systems could hardly be described as "surgical," however. Paradoxically, as the accuracy of U.S. missiles is being dramatically increased, the power of their warheads is also being increased. For example, the TRI-DENT II is to carry warheads with ten times the explosive power of those on the POSEIDON missile which it is to replace. The total explosive power carried by TRI-DENT II would be hundreds of times greater than that of the bomb which destroyed Hiroshima. Tens of millions of innocent civilians would therefore certainly die if the U.S. were to attack the Soviet Union's "hard" military targets:

Perhaps the most important message of the Databook is implicit in the fact that it could be written. That fact proves that systematic research, using public sources such as the "sanitized" transcripts of Congressional hearings, can glean enough information to lay the basis for a fully informed public debate over U.S. nuclear weapons policy. In the past, when the public was willing to leave policy-making to the "experts," this fact was irrelevant. Now, when a large fraction of the public has concluded that the nuclear arms race is too important to be left to unsupervised experts, the availability of the information in the Databook will make a significant difference.

> Frank von Hippel June 1983

Preface

The Nuclear Weapons Databook is meant to be a current and accurate encyclopedia of information about nuclear weapons. It is intended to assist the many people who are today actively working on the problems of the nuclear arms race. In our society today, there is no greater threat to the human environment than a nuclear holocaust. Because of the obvious and terrifying consequences of the use of nuclear weapons, the Natural Resources Defense Council (NRDC) has followed every aspect of nuclear development, including nuclear weapons development, for over a decade, NRDC has long believed that accurate information is critical in understanding the imperative for and implications of arms control. Information about nuclear weapons, policy, plans, and implications remains shrouded in secrecy. Informed public decisions on nuclear arms questions can only occur if better and more information on the subject is available. The purpose of this Databook is to help overcome this barrier.

Since 1980, NRDC has sponsored the research required to produce this first of several volumes on all aspects of the production and deployment of nuclear weapons worldwide. As now planned the Nuclear Weapons Databook will consist of at least eight volumes:

- U.S. Nuclear Forces and Capabilities
- II. U.S. Nuclear Weapons Production Complex
- III. Soviet Nuclear Weapons
- IV. Other Foreign Nuclear Weapons
- V. Environment, Health, and Safety
- Command and Control of Nuclear Weapons VI. and Nuclear Strategy
- VII Arms Control
- The History of Nuclear Weapons. VIII.

Volume I of the Nuclear Weapons Databook is based as much as possible on original documentation, and the source of information is indicated in the extensive footnotes accompanying the text and fact sheets. The Databook, however, is only as useful as the accuracy of the information presented. We therefore strongly encourage the reader to contribute to this effort-to advise us of errors and new information. We also wish to be advised of additional subject areas that should be included in future editions and recommended changes in the format of the data presented. Experts who are willing to serve as contributors or reviewers of the various sections of the Databook, particularly subject areas not now covered, are also desired.

Please address all correspondence to the authors at the Natural Resources Defense Council, 1725 I Street, N.W., Suite 600, Washington, DC 20006 (202/223-8210).

The publication of the first volume of the Databook may appear to be imbalanced because of a lack of comparison with Soviet nuclear weapon systems. This "omission" simply reflects our view that publication of the U.S. material should not be held up pending work on foreign nuclear arsenals. Even upon publication of the third volume (now in preparation), this appearance of imbalance may continue due to the much more limited availability of data on the Soviet nuclear weapon system in open literature. Furthermore, the Databook is not intended to be another document on the assessment of U.S.-Soviet military balance. The basic material to be presented on both the U.S. and Soviet weapons systems is meant to serve as a step toward a more sophisticated understanding of the dynamics of the two systems.

> Thomas B. Cochran William M. Arkin Milton M. Hoenig

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How to Use the Nuclear Weapons Databook

The Databook is designed primarily for those who need to find basic facts about nuclear weapons. It is not designed to replace any existing reference books, but to supplement and hopefully contribute to the already existing volumes. Since the Databook is both factual and comprehensive, it will provide a more easily available and accessible source than either the numerous specialized publications which are known to the experts or the less authoritative and secondary sources of information which are commonly available.

Three chapters provide an overview and explain how nuclear weapons work. Six subsequent chapters contain an overview, fact sheets, and descriptions of nuclear warheads, delivery systems, and research programs. In these chapters, the development of the nuclear arsenal, from the oldest weapons to the newest to the future, is presented. It is hoped that in this way an understanding of the continual exploitation of technology for nuclear weapons can be clearly seen.

The Databook is not meant to be read straight through, although reading the first two and fourth chapters, along with the introduction to each of the remaining six chapters, can provide valuable background for using the Databook as a reference work. The table of Contents, page headings, and index should enable any user to quickly find any information needed. A detailed glossary and list of abbreviations and acronyms used in the book is provided; the abbreviation and acronym list is particularly important as the key to deciphering the shorthand source citations. Numerous tables and figures are used throughout the book to help illustrate the difficult technical material, and each fact sheet to the extent possible contains common information characteristics.

A sample fact sheet will contain numerous categories of information, some of which are well known and some of which are not. In each case, with a weapon or warhead, we have tried to provide information on the manufacturer, evolution, cost, characteristics, and use of the system. Many gaps in the data reflect the fact that we have been unable to get all details for every system.

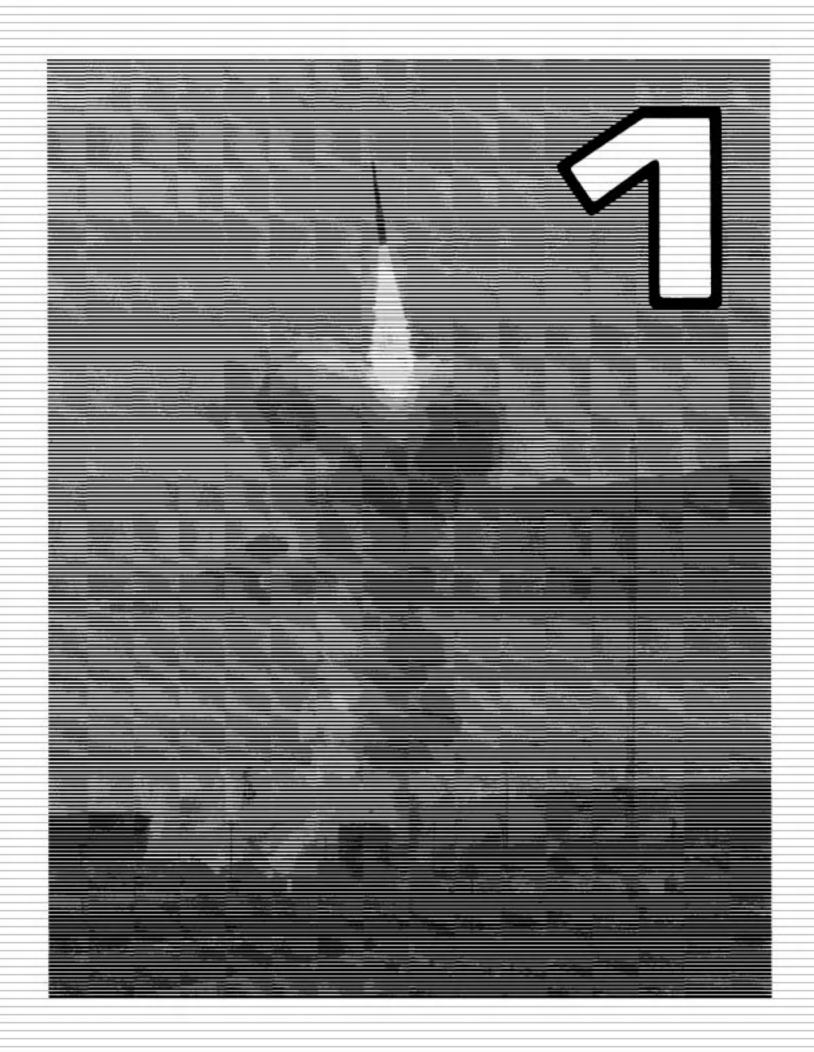
Do not let the details frighten you. You do not have to be a physicist or defense expert to use this book. There is an abundance of data that should be useful regardless of one's level of expertise.

The Dangerous Decade Ahead

For more than 30 years, the United States has conducted foreign relations in the shadow of nuclear arms; now the nuclear umbra is darker and more extensive than ever. There are many more weapons than ever before, but most significantly, the range, accuracy, targeting flexibility, and payload of intercontinental nuclear weapon systems have been markedly improved:

- · During the past decade, the warhead count of intercontinental nuclear weapons went up 200 percent.
- Their estimated explosive power (equivalent megatonnage) grew some 30 percent.
- Their pin-point targeting (hard target kill) potential increased 200 percent.

U.S. Joint Chiefs of Staff, U.S. Military Posture for FY 1982



Chapter One

The Nuclear Weapons System: An Overview

The dominant factor in East-West relations is the nuclear weapon. Since the first explosion of a nuclear device over the New Mexico desert in July 1945, nuclear weapons have gained a preeminent position in U.S. and Soviet military and foreign policies. This has led to the creation of large military infrastructures to support nuclear weapons.

Today, 38 years after the first atom bomb was exploded, there are approximately 26,000 nuclear warheads in the United States arsenal. Well over 200,000 people and an annual budget of over \$35 billion are involved in U.S. development and production of new warheads, the care for those already in the so-called "stockpile," and the planning for their use. This volume presents a detailed picture of the present and future nuclear weapons capabilities in the U.S., including the nuclear weapons arsenal, the military structure which exists to support and eventually use those weapons, and the state of current and future nuclear weapons technology.

U.S. policy governing the control and possible use of nuclear weapons has gone through significant changes over the past 38 years. The use of the new and powerful atomic weapon was not initially treated as a fundamental break from previous "conventional" military requirements, particularly strategic bombing. U.S. nuclear strategy then evolved to a position of "deterrence," where the maintenance of large nuclear arsenals and the mutual consequences of U.S. and Soviet nuclear warfare were thought to "assure" that nuclear weapons would never be used. Today, policy is based on the belief that the limited use of nuclear weapons is possible. Indeed, a "war fighting" strategy involving nuclear weapons is seen as the only credible deterrent.

However one interprets policy, the vast arsenal of weapons and trends in its technological development provide insight into the dynamics of the nuclear arms race and evidence of its increasing dangers. The terms "nuclear device," "nuclear warhead," and
"nuclear weapon" are often used interchangeably, but
the distinctions between them are noteworthy. A
nuclear explosive device (or simply "nuclear device") is
an assembly of nuclear and other materials and fuzes
which could be used in a test, but generally cannot be
reliably delivered as part of a weapon. A nuclear warhead implies further refinement in design and manufacture resulting in a mass produced, reliable, predictable
nuclear device capable of being carried by missiles, aircraft, or other means. A nuclear weapon is a fully integrated nuclear warhead with its delivery system.

Although definitions are often subject to transient political considerations, nuclear weapons are generally categorized according to their intended use, as "strategic," "theater," or "tactical."

Strategic (Nuclear) Weapons. The category of longrange weapons generally allocated for attacking the homeland of the enemy or protecting the homeland. This includes intercontinental missiles, both land based (ICBMs) and sea based (SLBMs); long-range heavy bombers and their carried weapons (bombs and airlaunched missiles); long-range cruise missiles not carried on bombers; and homeland defense missiles, that are both ground and air launched.

Theater (Nuclear) Weapons.² All other nuclear weapons earmarked for use in regional plans and confrontations where the intent is not merely tactical surprise or advantage, but the destruction of "targets"—bases and support facilites—that provide reinforcement for a battle. Theater weapons comprise bombs and depth charges on non-strategic aircraft, cruise missiles (air, sea and land based), short-range ballistic missiles used in surface-to-surface and surface-to-air missions, artillery projectiles, and atomic demolition munitions (nuclear land mines).

Nuclear Weapons and Delivery Systems: Definitions

Information on the history of the U.S. nuclear weapons stockpile is contained in David. Alan Rosemberg, "U.S. Nuclear Stockpile, 1945 to 1950." The Bulletin of the Atomic Scientists, May 1962, pp. 25-30. Milton Leitenberg, "Background Information on Tactical Nuclear Weapons," Toctical Nuclear Weapons," Toctical Nuclear Weapons, European Perspectives (SIPRI, 1976). Norman Polman, Strategic Weapons: An Introduction (New York: Ceane Russak, 1962 (Revised Editional).

^{2 &}quot;Theater" nuclear weapons and forces have undergone the most changes in terminology. They have been labeled both "intermediate-range" and "non-strategic" nuclear forces by the Reagan Administration due to the perceived negative connotation of the word "theater" in the European political debate which equates its use (as in "theater of war") with a postulated American policy to attempt to restrict the use of these weapons to Europe and spare U.S. territory in a nuclear war originating in Europe. In addition, "theater" is often used synonymously with "tactical," in referring to short-range weapons.

Table 1.1 Nuclear Warheads in the Stockpile (1983)

Warhead: / Reentry Vehicle Model	Weapon System
STRATEGIC OFFENSE	
W53/Mk-B	TITAN II
W58/Mk-11C	MINUTEMAN II
W62/Mk-12	MINUTEMAN III
WBB/Mk-3	POSEIDON C3
W69	SRAM
W78/Mk-4	TRIDENT I C4
W78/Mk-12A	MINUTEMAN (II
W90-1	ALCM
STRATEGIC DEFENSE	ALUM
W25	GENIE
TACTICAL	GEINIE
W31	HONEST JOHN/NIKE-HERCULES
W33	8-inch howitzer
W44	ASROC
W45-1	TERRIER
W48	155mm howitzer
W50	Carried Control of Con
	PERSHING 1a
W55	SUBROC
W70*	LANCE
W79*	8-inch howitzer
ATOMIC DEMOLITION MUNITIONS (ADMs)	
W45-3	Medium ADM
W54	Special ADM
BOMBS ¹	
B28	Tactical and Strategic Aircraft
B43	Tactical and Strategic Aircraft
B53	B-52 Aircraft
B61	Tactical and Strategic Aircraft
NUCLEAR DEPTH BOMB/BOMB	
857	ASW Patrol, Tactical and Strategic Aircraft
1 Two warheads—W66 and W71—are in inactive storage and are being retired.	"861-1"). Mod () is the first version of a weapon design. Subsequent modifications
2 All current nuclear bombs are referred to as "B-" followed by the workead program number, e.g., 8-61 (or simply 861). If the warhead of a nuclear weapon has other	of the weapon system are numbered. 3 The BSB and BS1 bombs have numerous known Mods.
applications, it is designated with a "W." Modification(s) to the major assembly	Enhanced radiation yield.

design of a warhead are designated by Mod. numbers (e.g., "B-61 Mod 1" or simply

Tactical (Nuclear) Weapons. Refers to those "theater" weapons, more precisely termed "short-range" and "battlefield" weapons, whose purpose is to affect directly the course of a tactical maneuver or a battle. Tactical weapons include bombs, short-range missiles, nuclear artillery, and atomic demolition munitions.

The Nuclear Stockpile Today

The U.S. nuclear weapons stockpile contains 24 warhead types (see Table 1.1). The oldest warhead is the W33, a gun assembly, low yield, fission nuclear artillery projectile, first deployed in 1956. The newest is the W80-1, a small thermonuclear warhead for the strategic

Air-Launched Cruise Missile (ALCM), deployed in 1981. The stockpile of about 26,000 nuclear warheads consists of eight strategic missile types, one strategic defensive warhead, eleven tactical warheads for missiles, artiflery and atomic demolition munitions, and five nuclear bomb types. The bombs are carried by both strategic and tactical aircraft.3

The nuclear weapons stockpile remained fairly constant throughout the 1970s, stabilizing at about 25,000; a marked increase in the rate of production and retirements of nuclear weapons which began in 1981, will significantly change the complexion of the stockpile. While the stockpile was made up predominantly of tactical

³ Only one of the bombs, the large, nine megaton B53, is solely carried by B-52 bombers.

Table 1.2 Strategic Nuclear Weapons (1983)

Delivery Platforms	Systems	Warheads
Bombers	FB-111, B-52	828, 843, 853, 857, 861, W69, W80-
Interceptors	F-4, F-15, F-106	W25
Land-Based Missiles	TITAN II, MINUTEMAN II, MINUTEMAN III	W53, W58, W62, W78
Submarine-Based Missiles	POSEIDON, TRIDENT I	W68, W76

warheads in the 1960s, the mix is now about evenly split between strategic and tactical weapons.

In the strategic forces, there are currently 2149 warheads on more than 1000 land-based strategic missiles, another 4960 on submarine-launched missiles, and 2580 allocated to be carried on strategic bombers (see Table 1.2). These weapons are referred to as the "force load-



Figure 1.1 MINUTEMAN III (LGM-30G) missie.

ings" and do not include maintenance spares or "weapons reserved for restrike (reserves) and weapons on inactive-status."³

Four warhead types are deployed with land-based strategic missile forces: the W53 nine megaton TITAN II warhead, the W56 1.2 megaton MINUTEMAN II warhead, the W62 170 Kt triple warhead on the MINUTE-MAN III, and the W78 335 Kt triple warhead on the MINUTEMAN III. Submarine missiles carry two warhead types: the W68 40-50 Kt warhead on the POSEI-DON (each can carry 7-14 warheads) and the W76 100 Kt warhead on the TRIDENT I (each missile carries 8 warheads). Bomber forces carry five nuclear bomb types depending on the mission and targets! the B28, with yields from 70-1450 Kt; the B43, with one megaton yield; the B53, with nine megaton yield; the B57, with a low Kt yield; and the B61, with a 300-500 Kt yield. The low yield W25 warhead on the GENIE air-to-air rocket is also deployed with fighter interceptor strategic units.

Theater and tactical nuclear warheads are currently deployed on a variety of rocket and missile systems, aircraft, artillery, and land mines (see Table 1.3). Their explosive yields vary from .01 kiloton to over one megaton. While virtually all strategic systems are armed only with nuclear warheads, most theater and tactical systems are dual capable—they can be armed with conventional or nuclear warheads. Only two systems are solely nuclear capable: the Navy SUBROC (W55) anti-submarine rocket and the Army PERSHING 1a (W50) missile.

Of the rockets and missiles, one free-flight rocket the HONEST JOHN (with W31 warhead)—remains deployed. Although retired from American forces, is still used in allied forces. Army surface-to-surface ballistic missiles include the 100+ km range LANCE (W70) and the 500+ km range PERSHING 1a (W50). Both the Army and Navy have nuclear armed surface-to-air missile systems that double as surface-to-surface systems: the Army NIKE-HERCULES (W31) and Navy ship-based

⁴ In the early 1960s when the stockpile had between 23,000 and 30,000 werboods, there were only about 7000 strategic warheads, most of which were bombs carried on B 47s and the new B-52s, DOD, FY 1984 Annual Report, p. 52.

Force loadings are defined as "those independently-targetable weapons associated with on-line ICBMs, SLBMs and I/E (unit equipment) strategic aircraft"; ACDA, FY 2879 ACIS, p. 31.

TERRIER (W45). Two nuclear armed Navy anti-submarine rockets (ASROC with W44 and SUBROC with W55 warheads) are deployed on a variety of ships and submarines. Two types of low yield atomic demolition munitions (ADMs) are in use by the Army, Marine Corps, and Navy: the medium atomic demolition munition (MADM) (W45) and the man-portable special atomic demolition munition (SADM) (W54).

The Air Force, Marine Corps, and Navy all fly nuclear capable aircraft (see Chapter Seven) and their aircraft for use in theater and tactical nuclear warfare are assigned three different nuclear bombs: the B43, B57, and B61. The most commonly deployed bomb is the newest and most versatile, the 300-500 kiloton yield B61, which by virtue of its design and low weight is able to be carried by every nuclear certified aircraft type. The B57, which doubles as a light weight bomb or depth charge, is carried by tactical fighters, maritime patrol aircraft, or helicopters. A fourth bomb, the B28, is in use by the Air Force and some NATO countries.

One of the major changes in the nuclear stockpile as new, more accurate weapons have been introduced has been the reduction in gross explosive megatonnage. The peak explosive capacity of the stockpile occurred in 1960. Since 1960, as the total number of warheads in the stockpile peaked and then decreased, a significant reduction in megatonnage resulted. Deployment of single warhead low vield missiles allowed a reduction in bombers with their larger yield bombs. According to one official report, "the total number of megatons was four times as high in 1960 than in 1980."7 With the introduction of many new warheads, "the stockpile yield will not change appreciably in the foreseeable future."

Nuclear Weapons Deployments

Nuclear weapons are in use in all four of the armed services for strategic contingency and regional war plans. Military equipment, units and personnel are all required to have special selection and certification before they can carry out nuclear duties. Nuclear weapons are available for different military missions-antiaircraft, ground attack, ship attack, anti-submarine warfare-each mission providing for the warheads and delivery systems to be kept during peacetime in various states of readiness. Over 9000 strategic weapons are kept on constant alert; a smaller number of theater nuclear weapons (tactical aircraft and PERSHING 1a missiles) are also maintained at a high state of readiness (so called "quick reaction alert"). Most other weapons are kept on a lower level of readiness, either in storage sites or, in the Navy, in ammunition lockers and special ships.

Nuclear weapons are widely dispersed. They are deployed at about 200 storage sites and bases, both inside the United States and in nine foreign countries (see Chapter Four). Within the United States, they are present in 34 states at a number of central storage sites, at naval bases, at strategic bomber and fighter interceptor bases, at research and development facilities, and in over 1000 underground silos (throughout ten states) holding nuclear armed intercontinental missiles. Over-

	Table 1.3		
Theater and	Tactical Nuclear Weapons	(1983)	

Delivery Platforms	Systems	Warheads	
Anti-Submanine Aircraft	P-3, S-3, NIMROD [UK]	B57	
Anti-Submarine Helicopters	SH-3	857	
Anti-Submarine Missiles	ASROC, SUBROC	W44, W55	
Artillery	155mm and 8-inch guns	W48, W33, W79	
Atomic Demolition Munitions	Medium ADM, Special ADM	W45, W54	
Attack Aircraft	A-4, A-6, A-7, F/A-18	B43, B57, B61	
Attack Submarines	SUBROC	W55	
Fighter Aircraft	F-4, F-15, F-16, F-100, F-104, F-111,	B28, B43, B57, B61	
	TORNADO (NATO)		
Surface Ships	ASROC, TERRIER	W44, W45	
Surface-to-Air Missiles	NIKE-HERCULES, TERRIER	W31, W45	
Surface to Surface Missiles	HONEST JOHN, LANCE, PERSHING 1a	W31, W70, W50	

Early History

seas, thousands of warheads are stored at over 100 locations, the majority of which are in West Germany.

United States policy in every administration since the Truman years has provided for the continued deployment of U.S. nuclear warheads abroad. The first formal agreements were concluded in 1954 with NATO allies in Europe, From 1958-1964, a large number of nuclear warheads were deployed overseas for the first time, and bilateral agreements were concluded with a number of nations covering the deployment and shared use of nuclear warheads. In Europe, there were about 7000 nuclear weapons by 1964, about the number estimated there today. In the Pacific, about 1000 nuclear weapons are estimated to be deployed at land bases.

History of the Nuclear Weapons Stockpile

During the first two decades of U.S. nuclear weapons history there was a massive scientific investment in nuclear weapons research and development. This resulted in significant advances in technology and a high level of weapons turnover as new weapons were continually deployed. Advances in nuclear warhead design, including progress in electronics miniaturization, resulted in more efficient uses of fissile materials and fabrication of small nuclear warheads (see Chapter Two). Small warheads and rapid developments in warhead delivery systems (particularly in missile technology) led to the wide adoption of nuclear weapons within U.S. military forces. Old technology was replaced with new capabilities, with new warhead designs taking advantage of the latest efficiency, control, and safety features. Each new delivery system incorporated additional "improvements": increased range, better accuracy, improved mobility, and greater lethality.

The practice has been that as new warheads are produced and enter the stockpile, old warheads are retired. Changes in the size of the stockpile thus have been and are still based upon differences in the build and retirement rates. In the last three decades, the retention period of warheads in the stockpile has tripled-the average age is now 13 years.9 The cost of retaining warheads has also greatly increased as weapons sophistication has increased. It is important to note, however, that the development of new warheads and the diversity of delivery modes and weapon systems is not merely a technological phenomenon. Each development also has been a response to the nuclear policy and strategy of the day.

Nuclear weapons developments have progressed through four periods: an early research oriented period (1945-1955), a peak production and growth period (1955-1967), a period of numerical stabilization during which significant operational refinements were made (1967-1980), and a second growth period in which a new generation of warheads is being produced and new technologies are being widely adapted (1980-present).

Early Years (1945-1955)

Atomic bomb developments immediately after World War II focused on perfection of implosion design (due to the scarcity of fissile material)10 and on improvements in the ballistics, efficiency, reliability, and explosive yield of the Fat Man design dropped on Nagasaki. (Fat Man became the basis for the Mk-III and Mk-IV nuclear bombs). During the first five years of the stockpile, the number of nuclear warheads grew slowly, limited by the availability of fissile materials.11 In 1945, the stockpile had only two weapons; in 1946, it had nine; in 1947, it had 13; and in 1948, it had 50.12

The practice developed of conserving the fissile materials by keeping them separate from the larger number of available bomb casings (this was also a method of control), and of utilizing the fissile materials taken from retired weapons in new warheads.13 The growth in the supply of fissile material and its more efficient use, the design of smaller and lighter warheads, the first test of a Soviet nuclear weapon in 1949, and the outbreak of the Korean War in June 1950 all influenced decisions to expand the nuclear arsenal and diversify the types of weapons. In January 1950, President Truman decided to place the thermonuclear (fusion) development program on a crash basis. Weapons research and production then proceeded quickly along two parallel courses: development of efficient, usable fission weapons (with yields up to several hundred kilotons), and development of more powerful fusion weapons (with yields from 1 Mt to 40 Mt).

⁹ DOD, FY 1984 Annual Report, p. 55

¹⁰ The Little Boy bomb (later Mk-I) dropped on Hiroshima was a gun assembly weepon, while the Fot Mon bomb dropped on Negaseki was an implosion weapon. Implosion weapons require less fissile material (see Chapter Two).

Senate Report No. 67-517, 5 August 1992, p. 2.
 In 1992, the State Department released an undated memorandum containing these early stockpile numbers as partial refutation of some reports of a nuclear weapons build-up.

¹³ The early generation of nuclear warheads were designed in such a way that the fissile material was separated and stored apart from the nuclear "cauing," both for safety and security reasons. The Atomic Energy Commission produced and maintained custody of the fissiles cores, while the military developed and maintained the bomb casings. This practice was discontinued in the mid 1950s when "complete" weapons, the final assembles, were first turned over to the Department of Defense and new integrated warhead types were designed and produced, eliminating the old separation requirement.

Table 1.4
U.S. Nuclear Warheads (1945-Present)

Designation				Lab		
TRINITY Test LITTLE BDY* Bomb FAT MAN Bomb Mk-I** Bomb Mk-II* Bomb	-Q100X000-		0.02072.0	Assign-		Retirement from Acti
EITTLE BOY* Bomb FAT MAN Bomb Mk-I* Bomb Mk-II* Bomb Mk-III* Bomb Mk-III* Bomb Mk-5† Bomb Mk-5† Bomb Mk-5† Bomb Mk-7† Bomb Mk-10* Bomb Mk-10* Bomb Mk-12* Bomb Mk-12* Bomb Mk-12* Bomb Mk-12* Bomb Mk-14* Bomb Mk-14* Bomb Mk-15* Bomb Mk-15* Bomb Mk-15* Bomb Mk-15* Bomb Mk-16* Bomb Mk-16* Bomb Mk-16* Bomb Mk-17*** Bomb Mk-18* Bomb Mk-19* Bomb Mk-18* Bomb Mk-19* Bomb Mk-18* Bomb Mk-19* Bomb Mk-18* Bomb Mk-19* Bomb Mk-18* Bomb Mk-19* Bomb Mk-18* Bomb Mk-18* Bomb Mk-18* Bomb Mk-18* Bomb Mk-18* Bomb Mk-19* Bomb Mk-18* Bomb Mk-18* Bomb Mk-18* Bomb Mk-18* Bomb Mk-19* Bomb Mc-18*	System	Service	Lab	ment (yr)	Stockpile Entry (yr)	Service (yr)
## FAT MAN Bomb Mk-III* Bomb Mk-III* Bomb Mk-III* Bomb Mk-III* Bomb Mk-III* Bomb Mk-5† Bomb REGULUS MATADOR Mk-6 Bomb BOAR Bomb CORPORAL HONEST JC ADM-8 [Mr. Mk-9* 280mm hor Mk-10* Bomb Mk-11* Bomb Mk-12* Bomb Mk-12* Bomb Mk-14* Bomb Mk-15* Bomb Mk-15* Bomb Mk-15* Bomb Mk-18* Bomb Mc-18* Bomb		_	LANL	1943	1945	1945 at Alamogordo*
Mk-II* Bomb Mk-III* Bomb Mk-III* Bomb Mk-III* Bomb Mk-5† Bomb Mk-5† Bomb Mk-5† Bomb Mk-7† Bomb Mk-7† Bomb Mk-7† Bomb Mk-7† Bomb Mk-7† Bomb Mk-7† Bomb Mk-8*† Improved to (Mod 3) Mk-9* 280mm hore Mk-10* Bomb Mk-12* Bomb Mk-12* Bomb Mk-12* Bomb Mk-13* Bomb Mk-14* Bomb Mk-15** Bomb Mk-15** Bomb Mk-18** Bomb		AF	LANL	1943	1945	1945 at Hiroshima ¹
Mk-III* Bomb Mk-III* Bomb Mk-III* Bomb Mk-III* Bomb Mk-5† Bomb PEGULUS I MATADOR Mk-6 Bomb Mk-7† Bomb BOAR Bomb CORPORAL HONEST JC ADM-8 [Mc Mk-8*] Improved b (Mod 3) Mk-9* 280mm hor Mk-10* Bomb Mk-11* Bomb Mk-12* Bomb Mk-13* Bomb Mk-13* Bomb Mk-14* Bomb Mk-15* Bomb Mk-15* Bomb Mk-15* Bomb Mk-18* Bomb Mk-18* Bomb Mk-18* Bomb Mk-18* Bomb Mk-18 Bomb Mk-19 Bomb Mk-10 Bomb Mk		AF	LANL	1943	1945	1945 at Nagasaki*
Mk-III* Bomb Mk-IV* Bomb Mk-5†* Bomb PEGULUS I MATADOR Mk-6 Bomb Mk-7†** Bomb BOAR Bomb CORPORAL HONEST JC ADM-8 [Mc Mk-8*† Improved b (Mod 3) Mk-9* 280mm hor Mk-10* Bomb Mk-11* Bomb Mk-12* Bomb Mk-13* Bomb Mk-13* Bomb Mk-14** Bomb Mk-15** Bomb Mk-18** Bomb Mk-18** Bomb Mk-18** Bomb Wk-18** Bomb Wk-18** Bomb Wk-18** Bomb Mk-18** Bomb Wk-18** Bomb		AF	LANL	1945	1945	1945-1948
Mk-III* Bomb Mk-IV* Bomb Mk-5†* Bomb Mk-5†* Bomb Mk-6 Bomb Mk-7†** Bomb BOAR Bomb CORPORAL HONEST JC ADM-8 [Mc Mk-8*† Improved to (Mod 3) Mk-9* 280mm hore Mk-10* Bomb Mk-11* Bomb Mk-11* Bomb Mk-12* Bomb Mk-13* Bomb Mk-14** Bomb Mk-15** Bomb Mk-15** Bomb Mk-18** Bomb Mk-19** Bomb Mk-10** Bom		AF	LANL	7	[cancelled]	1883087955
Mk-5†** Bomb REGULUS I MATADOR Mk-6 Bomb Mk-7†** Bomb BOAR Bomb CORPORAL HONEST JC ADM-8 [Mc Mk-8*† Improved L (Mod 3) Mk-9* 280mm hor Mk-10** Bomb Mk-11** Bomb Mk-12** Bomb Mk-13** Bomb Mk-14** Bomb Mk-15** Bomb Mk-15** Bomb Mk-18** Bomb Mk-18** Bomb Mk-18** Bomb Wk-18** Bomb Wk-18** Bomb Mk-18** Bomb Mk-19** Regulus I Bomb W23** 16-inch nav B24 Bomb W25 GENIE B28 Bomb W27 Regulus I B28†** Bomb W27 Regulus I B28†** Bomb W29 REDSTONE W29 REDSTONE W39† TALOS TADM W31† HONEST JC		AF	LANL	1943	1947	1950
Mk-5†** Bomb REGULUS I MATADOR Mk-6 Bomb Mk-7†** Bomb BOAR Bomb CORPORAL HONEST JC ADM-8 [Mr Mk-8*† Improved L (Mod 3) Mk-9* 280mm hor Mk-10** Bomb Mk-11** Bomb Mk-12** Bomb Mk-13** Bomb Mk-14** Bomb Mk-15** Bomb Mk-15** Bomb Mk-18** Bomb Mk-18** Bomb Mk-18** Bomb Wy-18** 280mm hor Bomb Mk-18** Bomb Mk-19** Regulus I Bomb B20 Bomb B21 Bomb B22 Bomb W23** 16-inch nav B24 Bomb W25 GENIE B26 Bomb T4* ADM B27 Bomb W27 REGULUS I B28†** Bomb W29 REDSTONE W29 REDSTONE W39† TALOS TADM W31† HONEST JC W31† HONEST JC		AF/N	LANL	1947	1949	1953
## REGULUS MATADOR		AF/N	LANL	1949	1952	1983
MATADOR Mk-6 Bomb Mk-7†" Bomb BOAR Bomb CORPORAL HONEST JC ADM-8 [Mr Mk-8*† Improved L (Mod 3) Mk-9* 280mm hor Mk-10* Bomb Mk-11* Bomb Mk-12* Bomb Mk-13* Bomb Mk-14** Bomb Mk-15** Bomb Mk-18** Bomb Mk-18** Bomb Wy-18** 280mm hor Bomb Mk-18** Bomb Mk-18** Bomb Mk-18** Bomb Mk-18 Bomb Wy-18** Bomb HOUND DO MACE By-18** Bomb Wy-18** Bomb HOUND DO MACE By-18** Bomb Wy-18** Bomb Wy-18** Bomb Wy-18** Bomb Wy-18** Bomb HOUND DO MACE By-18** Bomb	S.I.	N	LANL	1949	1952	1954
Mk-6 Bomb Mk-7†" Bomb BCAR Bomb CORPORAL HONEST JC ADM-8 [Mr Mk-8*† Improved L (Mod 3) Mk-9* 280mm hor Mk-10* Bomb Mk-11* Bomb Mk-12* Bomb Mk-13* Bomb Mk-13* Bomb Mk-14** Bomb Mk-15** Bomb Mk-18** Bomb Mk-18** Bomb W2-18** Bom		AF				
Mk-7†11 Bomb BCAR Bomb CORPORAL HONEST JC ADM-8 [Mr Mk-8*† Improved L (Mod 3) Mk-9* 280mm hor Mk-10* Bomb Mk-11* Bomb Mk-12*† Bomb Mk-13* Bomb Mk-13** Bomb Mk-15** Bomb Mk-16** Bomb Mk-18** Bomb Mk-19** 280mm hor B20** Bomb B21** Bomb B22** Bomb M23** 16-inch nav B24** Bomb M25** GENIE B26** Bomb M27** REGULUS I B28†1** Bomb W27** REGULUS I B28†1** Bomb W29** REDSTONE W29** REDSTONE W39†* TALOS TADM W31†* HONEST JC		AF/N	LANL	1949	1951	1961
BOAR Borns CORPORAL HONEST JO ADM-8 [Mr ADM-8 [Mr Mk-8*] Improved L (Mod 3) Mk-9* 280mm hor Mk-10* Bornb Mk-11* Bornb Mk-12*] Bornb Mk-13* Bornb Mk-13* Bornb Mk-15** Bornb Mk-16** Bornb Mk-18** Bornb Mk-19** Bornb Mk-19** Bornb Mk-19** Bornb Mk-19** Bornb Mk-19** Bornb Mk-10** Born		AF/N	LANL	1949	1952	1967
CORPORAL HONEST JO ADM-B (Mc ADM-B (with	N	LANL	1949	[never deployed]	1001
HONEST JO ADM-8 [Mr ADM-8 [Mr ADM-8 [Mr Mk-9* 280mm hor Mk-10* Bomb Mk-11* Bomb Mk-12* Bomb Mk-13* Bomb Mk-13* Bomb Mk-15** Bomb Mk-16** Bomb Mk-18** Bomb Mk-19** Bomb B20** Bomb B21** Bomb B22** Bomb M23** 16-inch nev B24** Bomb M25** GENIE B26** Bomb M27** REGULUS I B28†** Bomb W27** REGULUS I B28†** Bomb W29** REDSTONE W29** REDSTONE W39†* TALOS TADM W31†* HONEST JO		A	L-VIII	1040	1953	1967
ADM-B (Mc Mk-8*† Improved b (Med 3) Mk-9* 280mm hos Mk-10* Bomb Mk-11* Bomb Mk-12*† Bomb Mk-13* Bomb Mk-13** Bomb Mk-15** Bomb Mk-16** Bomb Mk-16** Bomb Mk-18** Bomb Mk-18* Bomb W-18** Bomb W-18** Bomb W-19** 280mm hos B20** Bomb B21** Bomb W23** 16-inch nev B24** Bomb W25** GENIE B26** Bomb T4** ADM B27** Bomb W27** REGULUS I B28†** Bomb W29** REDSTONE W29** REDSTONE W29** REDSTONE W29** REDSTONE W29** REDSTONE W39** TALOS TADM W31** HONEST JC		Â			1954	1967
Mk-8* Improved b		Ä			1954	1967
(Med 3) Mk-9# 280mm hose Mk-10# Bomb Mk-11# Bomb Mk-12* Bomb Mk-13* Bomb Mk-14## Bomb Mk-15## Bomb Mk-16## Bomb Mk-16* Bomb Mk-18* Bomb B20* Bomb B20* Bomb B21* Bomb B22* Bomb B22* Bomb M23# 16-inch nev B24* Bomb M25* GENIE B26* Bomb M25* GENIE B26* Bomb M27* REGULUS B28†** Bomb M27* REGULUS B28†** Bomb M28† B0mb M29† HOUND DOMACE B29* Bomb M29* REDSTONE M30† TALOS TADM M31† HONEST JC		N	LANL	1950	1951	1956
Mk-9# 280mm hos Mk-10# Bomb Mk-11# Bomb Mk-12" Bomb Mk-13 Bomb Mk-13 Bomb Mk-15## Bomb Mk-16## Bomb Mk-16## Bomb Mk-18 Bomb Mk-18 Bomb Mk-18 Bomb W29 REGULUS I B28 Bomb W27 REGULUS I B28 Bomb W29 REDSTONE W29 REDSTONE W29 REDSTONE W31† HONEST JC MK-10# Bomb W29 REDSTONE W31† HONEST JC MW-10# Bomb W29 REDSTONE W31† HONEST JC MW-11# BOMB W29 REDSTONE W31† HONEST JC MW-11# BOMB W31† HONEST JC MM-14# BOMB MK-12 BOMB W31† HONEST JC MM-14# BOMB MK-12 BOMB MK-13 BOMB MK-14# BOMB MK-14# BOMB MK-14# BOMB MK-14# BOMB MK-15# BOMB MK-15## BOMB MK-15## BOMB MK-16## BOMB MK-16### BOMB MK-16### BOMB MK-16### BOMB MK-16#### BOMB MK-16####################################		14	LANL	1900	1901	1906
Mk-10# Bomb Mk-11# Bomb Mk-12 Bomb Mk-13 Bomb Mk-13 Bomb Mk-14## Bomb Mk-15## Bomb Mk-16## Bomb Mk-16## Bomb Mk-18 Bomb Mk-18 Bomb Mk-18 Bomb W-19# 280mm hor 820 Bomb 821 Bomb 822 Bomb W23# 16-inch nev 824 Bomb W25 GENIE 826 Bomb T4# ADM 827 Bomb W27 REGULUS I 828† Bomb W27 REGULUS I 828† Bomb W28† HOUND DO MACE 829 Bomb W29 REDSTONE W30† TALOS TADM W31† HONEST JC		Α	LABI	1050	1050	1957
Mk-11* Bomb Mk-12* Bomb Mk-13* Bomb Mk-14** Bomb Mk-15** Bomb Mk-16** Bomb Mk-16** Bomb Mk-18** Bomb Mk-18* Bomb B20* Bomb B21** Bomb W23** 16-inch nev B24* Bomb W25* GENIE B26* Bomb T4** ADM B27* Bomb M27* REGULUS I B28†** Bomb W27* REGULUS I B28†** Bomb W28† HOUND DO MACE B29* Bomb W29* REDSTONE W30† TALOS TADM W31† HONEST JC	nowitzer		LANL	1950	1952	1857
Mk-12** Bomb Mk-13** Bomb Mk-14** Bomb Mk-15** Bomb Mk-16** Bomb Mk-18** Bomb Mk-18		AF/N	LANL	1950	(cancelled 1952)	4000
Mk-13 Bomb Mk-14** Bomb Mk-15** Bomb Mk-16** Bomb Mk-18** Bomb Mk-18 Bomb Mc28 Bomb Mc28 Bomb Mc28 Bomb Mc28 Bomb Mc29 Bomb		AF/N	LANL	1950	1956	1980
Mk-14** Bomb Mk-15** Bomb Mk-16** Bomb Mk-16** Bomb Mk-18 Bomb Mc-18 Bomb B20 Bomb B21 Bomb B22 Bomb Mc-18** 16-inch nev B24 Bomb Mc-18** ADM B27 Bomb Mc-18** ADM B27 Bomb Mc-18** Bomb M		AF/N	LANL	?	1954	1982
Mk-15** Bomb Mk-16** Bomb Mk-16** Bomb Mk-17*** Bomb Mk-18 Bomb W19* 280mm hor 820 Bomb 821 Bomb 822 Bomb W23* 16-inch nev 824 Bomb W25 GENIE 826 Bomb T4* ADM 827 Bomb W27 REGULUS I 828†** Bomb W28† HOUND DO MACE 829 Bomb W29 REDSTONE W30† TALOS TADM W31† HONEST JC		AF	LANL	?	(cancelled 1954)	
Mk-16** Bomb Mk-17*** Bomb Mk-18 Bomb Wr19* 280mm hore B20 Bomb B21 Bomb B22 Bomb W23* 16-inch nev B24 Bomb W25 GENIE B26 Bomb T4* ADM B27 Bomb W27 REGULUS I B28†** Bomb W28† HOUND DO MACE B29 Bomb W29 REDSTONE W30† TALOS TADM W31† HONEST JC		AF	LANL	1952	(cancelled 1954)	
Mk-17**** Bomb Mk-18 Bomb W-19** 280mm hos 820 Bomb 821 Bomb 822 Bomb W23** 16-inch nev 824 Bomb W25 GENIE 826 Bomb T4* ADM 827 Bomb W27 REGULUS I 828†** Bomb W28† HOUND DO MACE 829 Bomb W29 REDSTONE W30† TALOS TADM W31† HONEST JC		AF/N	LANL	1952	1955	1965
Mk-18 Bomb W19** 280mm hos 820 Bomb 821 Bomb 822 Bomb W23** 16-inch nev 824 Bomb W25 GENIE 826 Bomb T4** ADM 827 Bomb W27 REGULUS I 828†** Bomb W28† HOUND DO MACE 829 Bomb W29 REDSTONE W30† TALOS TADM W31† HONEST JC		AF	LANL	1952	(cancelled 1953)	792-2-2
W19* 280mm hose 820 Bomb 821 Bomb 822 Bomb W23* 16-inch nev 824 Bomb W25 GENIE 826 Bomb T4* ADM 827 Bomb W27 REGULUS I 828†* Bomb W28† HOUND DO MACE 829 Bomb W29 REDSTONE W30† TALOS TADM W31† HONEST JC		AF	LANL	1952	1954	1957
820 Bomb 821 Bomb 822 Bomb W23* 16-inch nav 824 Bomb W25 GENIE 826 Bomb T4* ADM 827 Bomb W27 REGULUS I 828† Bomb W28† HOUND DO MACE 829 Bomb W29 REDSTONE W30† TALOS TADM W31† HONEST JC		AF	LANL	1951	1953	1957
B21 Bomb B22 Bomb W23* 16-inch nav B24 Bomb W25 GENIE B26 Bomb T4* ADM B27 Bomb W27 REGULUS I B28†** Bomb W28† HOUND DO MACE B29 Bomb W29 REDSTONE W30† TALOS TADM W31† HONEST JC	howitzer	А	LANL	1953	1956	1983
822 Bomb W23* 16-inch nav 824 Bomb W25 GENIE 826 Bomb T4* ADM 827 Bomb W27 REGULUS I 828†** Bomb W28† HOUND DO MACE 829 Bomb W29 REDSTONE W30† TALOS TADM W31† HONEST JC		AF	LANL	?	(cancelled 1954)	21500
W23* 16-inch nev 824 Bomb W25 GENIE 828 Bomb T4* ADM 827 Bomb W27 REGULUS I 828†** Bomb W28† HOUND DO MACE 829 Bomb W29 REDSTONE W30† TALOS TADM W31† HONEST JC		ΑF	LANL	?	1955	1957
824 Bomb W25 GENIE 828 Bomb T4* ADM 827 Bomb W27 REGULUS I 828† Bomb W28† HOUND DO MACE 829 Bomb W29 REDSTONE W30† TALOS TADM W31† HONEST JC		?	LANL	?	(cancelled 1954)	
W25 GENIE B28 Bomb T4* ADM B27 Bomb W27 REGULUS I B28†** Bomb W28† HOUND DO MACE B29 Bomb W29 REDSTONE W30† TALOS TADM W31† HONEST JC	navel gun	N	LANL	1953	1956	1959
### Bomb ####################################		AF	LANL	1952	1954	1956
T4* ADM B27 Bomb W27 REGULUS I B28†** Bomb W28† HOUND DO MACE B29 Bomb W29 REDSTONE W30† TALOS TADM W31† HONEST JO		AF	LANL	1954	1957	(active)
### Bomb ####################################		AF	LANL	9	(cancelled 1955)	25°20'20'20'20'20'
W27 REGULUS I B28†" Bomb W28† HOUND DO MACE B29 Bomb W29 REDSTONE W30† TALOS TADM W31† HONEST JO		А	LANL	?	1957	1963
B28†" Bomb W28† HOUND DO MACE B29 Bomb W29 REDSTONE W30† TALOS TADM W31† HONEST JO	116	N	LANL/LLNL	1955	(cancelled 1958-9)	
B28†" Bomb W28† HOUND DO MACE B29 Bomb W29 REDSTONE W30† TALOS TADM W31† HONEST JO	SII	N	LANL/LLNL	1955	1958	1964
MACE B29 Bomb W29 REDSTONE W30† TALOS TADM W31† HONEST JC	This is a second	AF	LANL	1955	1958	(active)
MACE B29 Bomb W29 REDSTONE W30† TALOS TADM W31† HONEST JC	DOG	AF	LANL	1955	1958	1975
B29 Bomb W29 REDSTONE W30† TALOS TADM W31† HONEST JO		AF			1959	1969
W29 REDSTONE W30† TALOS TADM W31† HONEST JO		AF	LANL	?	(cancelled 1955)	
W30† TALOS TADM W31† HONEST JC	NE	A	LANL	?	(cancelled 1956)	
TADM W31† HONEST JC		N	LANL	1955	1959	1979
W31† HONEST JO		A/MC	27416		1959	1966
	JOHN	A	LANL	1954	1958	(active)
		Ä	SPE TE	100-1	1958	(active)
ADM	TOULLO	A/MC			1958	1985
W32 240mm hov	houstwee	A	LANL	?	(cancelled 1955)	- 300
W33° 8-inch howi		A/MC	LANL	1954	1956	(active)

Table 1.4 Continued U.S. Nuclear Warheads (1945-Present) Warhead Lab Designa-Assign-Retirement from Active tor Delivery System Service Lab ment (yr) Stockpile Entry (yr) Service (yr) 1976 LULU [Mk-101 1955 1958 W341 N depth bamb] HOTPOINT (Mk-104) N 1958 (retired) ASTOR N 1955 1958 1976 W35† ATLAS. ΑF LANL 1955 [cancelled 1957-58] TITAN (cancelled 1957-58) ΔF THOR ΔF [cancelled 1957-58] JUPITER Ā [cancelled 1957-58]. 836 AF/N LANL 1953 1962 Bomb W37 NIKE HERCULES A LANL 2 (cancelled 1959) W38 LLNL 1985 ATLAS D/E AF 1958 TITAN I AF 1960 1965 B39 Bomb AF LANL 1955 1957 1966 W39† SNARK AF LANL 1956 1958 1961 REDSTONE 1958 1965 A BOMARC AF LANL 1972 W40† 1956 1959 LA CROSSE A/MC 1959 1964 **B41** AF LANL/LLNL 1957 1960 Bomb 1976 W42† HAWK-A 2 (cancelled) FALCON ΑF SPARROW ΔF B43+ Bomb AF/N/MC LANL 1956 1961 (active) W44 ASROC LANI 1956 1961 [active] W45† MADM A/MC LLNL 1956 1965 (active) 1982 LITTLE JOHN (retired) TERRIER. N 1962 [active BULLPUP B AF/N 1978 W46 9 2 (cancelled 1958) Unknown W47 POLARIS A1/A2 N LLNL 1957 1980 1988 W48 155mm howitzer A/MC LLNL 1957 1963 [active] W491 AF LANL 1957 1958 1963 THOR JUPITER. A 1959 1963 ATLAS E/F AF 1960 1965 TITAN I 1960 1965 AF W50 PERSHING I Δ LANL 1958 1963 (active) W51 2 W52 SERGEANT LANL 1960 1962 1977 Δ B53 Bomb. AF LAN 1958 1982 (active) W53 TITAN II ΔF LANL 1980 1962 (active) FALCON 1972 W541 AF LANL 1959 1961 DAVY CROCKETT 1960 1971 Special ADM A/MC/N 1980 1984 (active) W55 LLNL 1959 1964 SUBROC N (active) W56 MINUTEMAN II AF LLNL 1960 1985 [active] 857 ASW Depth Bomb N/MC/AF LANL 1980 1983 (active) W58 POLARIS A3 N LLNL 1960 1964 1981 1989 W59 MINUTEMAN I AF LANL 1960 1961 WBD (cancelled 1984) TYPHOON N 861 Bomb AF/MC/N LANL 1963 1968 (active) WB2 MINUTEMAN III (Mk-12) LUNE 1964 AF 1970 [active] W64 LANCE (cancelled 1964)** A WBB SPRINT LANL 1968 1974 (inactive storage 1976)" 4 W67 MINUTEMAN III (cancelled 1967)" AF 2 POSEIDON N (cancelled 1987)** W68 POSEIDON LENL 1966 1971 (active) N

Table 1.4 Continued

U.S. Nuclear Warheads (1945-Present)

Warhead				Lab		
Designa-	202800020800	200020		Assign-	200000000000000000000000000000000000000	Retirement from Active
tor'	Delivery System	Service	Lab	ment (yr)	Stockpile Entry (yr)	Service (yr)
W69	SRAM	AF	LANL	1967	1970	(active)
W70	LANCE (Mod-1/2)	Д	LLNL	1969	1973	(active)
777119	LANCE (Mod-3)	А	LLNL	1976	1981	(active)
	[ER Warhead]			1.0000001		
W71	SPARTAN	А	LLNL	1968	1974	(inactive storage 1976)**
W72	WALLEYE	N	LANL	1969	1970	1979
W73	CONDOR	AF	?	9	(cancelled 1978) ²¹	
W74	155mm howitzer	A/MC	2	?	(cancelled 1973)**	
W75	8-inch howitzer	A/MC	2	?	(cancelled 1973) ²¹	
W7B	TRIDENT I	N	LANL	1973	1978	[active]
B77	Bomb	AF	LLNL	1974	(cancelled 1978)	C. 1975
W78	MINUTEMAN III	ΑF	LANL	1974	1979	(active)
	(Mk-12A)					
W79	8-inch howitzer	A/MC	LLNL	1975	1981	(active)
-19-70	(ER Warhead)					
WBD	ALCM [Mod-1]	AF	LANL	1976	1980	(active)
	SLCM (Mod-0)	N			[1984]	4 2 3
W81	STANDARD-2	N	LANL	1977	(1986)	_
WB2	155mm howitzer	A/MC	LUNE	1978	(1986)	_
	(ER Warhead)	130,0000	10000	10/10/100-1	1	
BB3	Bomb	AF/N	LLNL	1979	(1984)	2
WB4	GLCM	ΔF	LLNL	1978	(1983)	_
W85	PERSHING II	A	LANL	1979	(1983)	
	(air/surface burst)			1,41,4	1.0000	
WBB	PERSHING II	A	LANL	1979	(cancelled 1981)	
	[earth penetrator]				(00,00,00,00,00,00,00,00,00,00,00,00,00,	
W87	MX	ΔF	LLNL	1981	(1986)	_

Sources: National Atomic Museum, Albuquerque, NM: Los Alamos National Laboratory Los Alamos, NM: Livermore National Laboratory, Uvermore, CA: Correspondence

with Chuck Hansen, Mountain View, CA.

Gun-assembly weapons, All other LAML entries are implication weapons.

99 First Thermonuclear designs.

† Werhead modified for various applications:

1. All current nuclear bombs are referred to as "Br" followed by the warhead program: number, e.g., 861. If the warhead of a nuclear weapon has other applications, it is designated as "W." Prior to the 1960s nuclear weapons were assigned "Mark" ["Mk"] numbers. "Mk" is now used for neentry vehicles. "B" numbers were later. given to gravity bombs and one Atomic Demolition Munition (ADM), and "W" numbers to other warheads. The T4, another ADM, is the exception in this table warheads prior to number 18 have been left with the Mk prefix; all others are designated.

"W" or "8."

The W25 was the first weapon developed under formal procedures agreed on with the Department of Defense. Start of development for earlier weapons are esti-

3 Stockpile entry dates very according to different sources. Prior to essembly of werheads with nuclear materials, some dates refer to cosings only. "First Production Unit" date is officially used by DOD to refer to three distinct deliveries: the date the nuclear weapons trainer was delivered, the date a nuclear warhead was delivered for operational suitability testing by DGD, and the date the first production "warreserve unit" was delivered to DOD. The stockpile entry data listed is thought to correspond as closely as possible to the last date

- 4 TRINITY Test, Alamosprdo, NM, 16 June 1945 at 5:29 am.
- 5 Hiroshima, Japan, 6 August 1945, at 8:15 a
- 6 Nagasaki, Japan, 8 August 1945, at 11 02 am.
- Production model of Little Boy.
 First implesion design, cancelled because of inability to achieve efficiency and reliability.
- 9 First production model of Fat Mon.
- 1D First standard production model nuclear weapon. Mk-IV was developed to improve the performance of the Mk-III.

 11 First light weight (3000 lb) tactical gravity bomb.
- 12 Versatile tection gravity bomb (1700 lb) designed for employment on tectical aircraft, cernied internally and externally, one varient, called "Betty," was a Navy depthbomb.
- 13 Light weight (1000 lb) bomb capable of delivery at supersonic speeds.
- 14 First droppable thermonuclear bomb to be tested. It weighed 21 bons. 15 Earlier versions of 828 bomb have been retired.
- 18 Weapons never tested; SASC, FY 1981 DOE, p. 150.

 17 Damenting of the SPRAT and SPARTAN massics began in FY 1983.
- 18 Weapons never tested, SASC, FY 1981 DOE, p. 150.
- 20 Dismanding of the SPRINT and SPARTAN missiles began in FY 1983. 21 Wespons never tested 8680, FY 1983 1995
- Weapons never tested; SASC, FY 1981 DOE, p. 150 DO BAY
- 23 ibid

Table 1.5
Inactive Nuclear Delivery Systems (1945-present)

System	Warheads	Yield'	Active'
AIRCRAFT'			
AD-4B-SKYRAIDER	Mk-7, Mk-8	7	1953-?
AD-5N SKYRAIDER	Mk-7, Mk-8	?	1951-?
AJ-1 SAVAGE	Mk-IV, Mk-5, Mk-6, Mk-7,	2D Kt-Mt	1950-1961
	Mk-8, Mk-15		1000 1001
AJ-2 SAVAGE	Mk-5	7	1949-1960
A-1 SKYRAIDER	2	2	1962-?
A-3 SKYWARRIOR	Mk-5, Mk-15, B27, B28, B43	40 Kt-Mt	1955-1970
A-5 VIGILANTE	B27. B28. B43	Mt range	1962/3-1970
8-29 SUPERFORTRESS	Mk-III, Mk-IV, Mk-5, Mk-B	4D Kt range	1945-1956
B-38 (ND NAME)	Mk-III, Mk-IV, Mk-5, Mk-6,	4D Kt-24 Mt	1949-1958
D-00 (IAD IANAE)	Mk-17, B18, B24, B36, B39	45 100-24 100	1545-1555
8-45 TORNADO	Mk-5, Mk-7	•	1948-1959
B-47 STRATOJET	Mk-5, Mk-6, Mk-15, B18, B28,	40 Ke 40 Me	1951-1966
B-47 STRATOOLT	B36, B41, B53	40 Kt-10 Mt	1901-1900
8-50 SUPERFORTRESS	Mk-III, Mk-IV, Mk-5, Mk-6	40 Kt range	1948-1965
8-57 INTRUDER*	Mk-7, B43	10 Kt-1 Mt	1955-?
B-58 HUSTLER	B39, B43, B53	7.76 . 7.76 . 7 . 4.776	1960-1970
		Mt range	
B-66 DESTROYER	B28, B43	Mt range	1956-1965
XB-70A VALKYRIE	B41, B53	10 Mt	Test only
FJ-48 FURY	Mk-7, Mk-8, Mk-12	10-80 Kt	1954-1962
F2H-2B BANSHEE	Mk-8	20-50 Kt	1949-?
F3H-2N DEMON	?	Kt-range	1956-1964
F9F-8B COUGAR	Mk-12	Kt range	1952/3-7
F-84G THUNDERJET ¹	Mk-7	10-60 Kt	1948-1970
F-86H SABRE	Mk-7, Mk-12	10-60 Kt	1952-?
F-89A/B/C/D/H/J SCORPION		Low Kt	1951-1968
F-100A/C/F SUPERSABRE	Mk-7, B23, B43	10 Kt-1 Mt	1954-?
F-101A/C-V00D00	Mk-7, B23, B43, FALCON, GENIE	10 Kt-1 Mt	1957-1980
F-102A DELTA DAGGER	FALCON, GENIE	Low Kt	1954-?
F-105 THUNDERCHIEF	828, 843, 861 BULLPUP	Low Kt-1 Mt	1958-1982
P2V3C NEPTUNE	Mk-IV, W34	20 Kt range	1949-?
P2V5 NEPTUNE	W34	Low Kt	1950-?
P5M2 MARLIN	W34	Low Kt	1952-1967
S-2 TRACKER	W34	Low Kt	1952-?
ARTILLERY		400	1000
(280mm)	W9, W19	15 Kt	1952-1963
[16-inch howitzer]	W23	10-15 Kt	1956-1959
M44, M53, M59, M114	W48	Sub Kt	1963-?
(155mm)	******	DOD IN	1500-1
M55, M115 (203mm)	W33	Sub-12 Kt	1956-?
NAVAL WEAPONS	VVGG	500-12 Kt	1500-7
ASTOR	W34	low Kt	1963-?
REGULUS I	W5	40-50 Kt	1952-1954
REGULUS II	W27	low Mt	1958-1964
TALOS	W30		
TACTICAL MISSILES	VVJU	5 Kt	1959-1979
	10/05	90 V+	0.4070
BULLPUP B	W45	20 Kt	?-1976
CORPORAL	W7	10-80 Kt	1953-1967
DAVY CROCKETT	W54	Sub Kt	1960-1971
FALCON	W54	1.5 Kt	1961-1972
HONEST JOHN	W7	10-60 Kt	1954-1974
JUPITER	W35, W49	5 Mt	1959-1963
LACROSSE	W40	low Kt	1959-1964
LITTLE JOHN	W45	1-10 Kt	1982-?
MACE A/B	W28	1 Mt	1959-1969

Table 1.5 Continued

Inactive Nuclear Delivery Systems (1945-present)

System	Warheads	Yield*	Active ²
MATADOR	W5	40-50 Kt	1951-?
REDSTONE	W29, W39	Mt range	7-1965
SERGEANT	W52	60 Kt	1962-1977
THOR	W35, W49	500 Kt range	1958-1963
WALLEYE	W72	100 Kt	1970-1979
STRATEGIC MISSILES			
ATLAS D/E/F	W35, W38, W49	500 Kt-1 Mt	1958-1965
BOMARC	W40	400-500 Kt	1958-1972
BOMARC B	W40	400-500 Kt	1959-1972
HOUND DOG	W28	1 Mt range	1958-1975
MINUTEMAN I	W59	1 Mt	1961-1969
POLARIS A1	W47	800 Kt	1960-1966
POLARIS A2	W47	800 Kt	1960-1968
POLARIS A3	W58	200 Kt	1964-1981
SNARK	W39	Mt range	1958-1965
SPARTAN	W71	5 Mt	(1974)
SPRINT	W66	low Kt	(1974)
TITAN I	W35, W38, W49	1 Mt range	1960-1965

^{1.} Yield for aircraft is estimate of yield of each bomb the aircraft was certified to carry and not total yield.

2 With nuclear weapons

3. Aircraft information is derived from Jane's All The World's Aircraft 1953-54, 1956 87; Robert Jackson, World Military Aircraft Since 1945 (NY: Scrioners, 1974); Lloyd S. Jones U.S. Bombers (CA: Aarc Publishers, 1974).

4. British version was called "CANBERRA."

5. The F-84F "THUNDERSTREAK" was not nuclear capable.

Fission warhead development from 1945-1955 was oriented toward replacements for the Mk-III and Mk-IV bombs (deployed in small numbers in 1947 and 1949, respectively). In the early 1950s, small, light weight "implosion" design bombs for tactical use (Mk-5, Mk-7, and Mk-12), strategic bombs of reduced weight, higher efficiency and yield (Mk-6, Mk-13, and Mk-18), and "penetrator" naval depth bombs (Mk-8 and Mk-11) were all produced and deployed. The first very high yield fusion bomb was the Mk-18, deployed in 1953 for interim use pending development of "deliverable" thermonuclear weapons (such as the Mk-15 and Mk-17 bombs which entered the stockpile in 1954-1955, and the Mk-14 and Mk-16, which were cancelled during the same period) (see Table 1.4).

As new nuclear bombs were being developed and deployed, the bomber force was also being upgraded and expanded. In March 1946, when the Strategic Air Command (SAC) was first established, it had 148 B-29 bombers. Two years later, two new bomber types were added to SAC, the B-36 and B-50, and the size of the bomber force grew to over 500. In 1951, the medium range B-47 was introduced, and SAC established forward bases closer to the Soviet Union, in Europe, North Africa, and Asia. The Korean War then further spurred weapons developments, and, in 1955, the new B-52 bomber was introduced, bringing the bomber force total to over 1500.

The first warhead types were all aircraft delivered bombs; it was not until 1952 that the first non-aircraft delivered "tactical" nuclear warhead was deployed (the Mk-9 atomic artillery projectile for a 280mm Army cannon). In 1953-1955, the Mk-7 bomb warhead was deployed on three different tactical weapons-as the warhead on the Army's CORPORAL and HONEST IOHN rockets, and as the first Atomic Demolition Munition (nuclear land mine).

Peak Production Years (1955-1967)

By 1955, both nuclear bombs and tactical weapons were firmly established as parts of the U.S. nuclear arsenal. The majority of the warheads in the stockpile were bombs, carried by a huge intercontinental and mediumrange bomber force. Three factors in the 1950s contributed to a change in the size and composition of the stockpile. First, with Savannah River and Hanford reactors producing at full capacity, the supply of fissile material became sufficient for the production of a large number of warheads. Second, the breakthrough in the development of the thermonuclear weapon in 1953 created the ability to obtain very high yields with relatively

high yield-to-weight ratios. Third, development of long range ballistic missiles received high priority and eventually displaced bombers as the central element of strategic nuclear forces.

Around 1955, a phenomenal jump in warhead production occurred as a result of a wide variety of nuclear delivery systems entering the military and the large number of nuclear bombs built to serve the strategy of massive retaliation. The number of warheads produced was massive; some 30,000 new warheads entered the stockpile from 1955-1967. By 1957, there were some 5000 warheads in the stockpile. From 1958-1960, approximately 11,000 warheads were added to the nuclear arsenal. In 1967, the number reached its all time peak at just over 32,000. As proven designs were mass produced and the features of the current U.S. military force structure began to take shape in the 1960s, rapid turnover of old designs ceased and attention was instead directed towards large scale production of new, smaller, safer, and more capable warheads.

During the 1955-1967 period, 54 warhead types and modifications entered the stockpile. They consisted of twelve new nuclear bomb designs (including three depth bombs), but by far the majority were warheads for tactical weapons and new strategic missile warheads. The new tactical warheads included four nuclear artillery warheads (W19, W23, W33, and W48), three warheads for air-launched missiles (W25 for GENIE, W45 for BULLPUP, and W54 for FALCON), five atomic demolition munitions (T4, W30, W31, W45, and W54), eight warheads for Army short-range missiles (W29 and W39 for REDSTONE, W31 for HONEST JOHN and NIKE-HERCULES, W40 for LA CROSSE, W45 for LIT-TLE JOHN, W50 for PERSHING 1, W52 for SERGEANT, and W54 for DAVY CROCKETT), and five warheads for naval anti-air or anti-submarine missiles (W30 for TALOS, W34 for ASTOR, W44 for ASROC, W45 for TERRIER, and W55 for SUBROC).

In September 1955, President Eisenhower assigned highest national priority to the development of ballistic missiles. Over the next ten years, eleven warheads would be deployed for strategic missiles: W27 for the REGULUS, W28 for the HOUND DOG and MACE, W38 for the ATLAS and TITAN, W39 for SNARK, W40 for BOMARC, W47 and W58 for POLARIS, W49 for THOR, JUPITER, ATLAS and TITAN, W53 for TITAN II, and W56 and W59 for MINUTEMAN. The liquid fuel ATLAS D was the first intercontinental ballistic missile (ICBM), deployed in April 1958, with a thermonuclear warhead in the megaton range. ATLAS D was first joined by two

intermediate range missiles (IRBMs), the THOR and JUPITER in 1958-1959, and then in 1960 by the TITAN I ICBM, and the Navy's POLARIS. Strategic cruise missiles (REGULUS, MACE, SNARK) had received some attention prior to the accelerated development of the ballistic missile, but were eventually replaced by the longer range, higher payload, more accurate, and more reliable ballistic missiles.

Stockpile Stabilization and Refinement (1967-1980)

In 1967, after the number of nuclear warheads in the stockpile had reached its peak, a decrease in the number of warheads began to take place as the strategic force structure was fixed in numbers and missile delivery technology stabilized. Research and production efforts were oriented towards still smaller and more accurate warheads to supply the largely unchanged missiles or bomber delivery vehicles. In 1968, the oldest weapon in the stockpile was 11 years and the average age was 7 years.

The reduction of warheads in the stockpile came as strategic missile forces with fixed numbers of warheads began to partially replace the larger number of old strategic bombers with their duplicative bomb loads. During the 1960s, changes in nuclear strategy, particularly the incorporation of constant ground and air alert operations, forced the creation of more flexible arming systems and stricter reliability requirements for warheads. In 1968, after the two serious nuclear weapons accidents involving bombers loaded with nuclear weapons in Thule, Greenland, and Palomares, Spain (see Figure 1.2), air alert operations ceased and safety considerations in warhead design became a primary consideration.

Although there was a slight net increase in the stockpile in 1970-1973 with the introduction of multiple warheads in the POSEIDON (W68) and a portion of the
MINUTEMAN (W62) strategic missile force, the stockpile again began to decrease. This was due to retirements of large numbers of bombs, U.S. based nuclear air
defense warheads (NIKE-HERCULES (W31), GENIE
(W25), and FALCON (W54)), and the retirement and
reductions of some nuclear armed tactical air and sea
launched missiles as new conventional weapons were
deployed. In addition, the efficiency of new nuclear
weapons designs contributed to further reductions in
the stockpile through the 1970s. Short-range land-based
Army missiles—SERGEANT (W52) and HONEST JOHN
(W31)—and older aircraft bombs were replaced on a less

than one-for-one basis by new, more capable, and versatile warheads using multiple yields rather than the previously required larger number of duplicative fixed yield warheads." The reduction in numbers, therefore, was not a reduction in capability. In fact, the new variable yield warheads were directed against a larger number of potential targets than older single yield warheads.

Throughout the remainder of the 1970s, the number of warheads built was less than the number retired. In 1980, thirteen years after the stockpile peaked, the warheads were much older-the oldest was 23 years and the average age was 12.11 It was not until after 1980 that a dramatic increase in warhead production again occurred.

New Generation of Nuclear Warheads (1980-Present)

During 1976-1978, the Department of Energy was "in a very low build mode."18 The rate of production increased in FY 1980 and 1981 and "accelerated" in FY

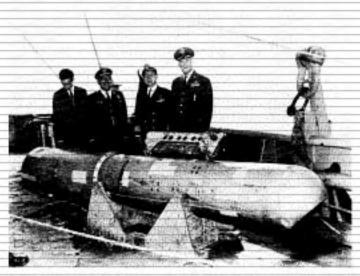


Figure 1.2 B28RI nuclear bomb recovered from 2500 feet of water off the coast of Palomares, Spain, A B-52 bomber carrying four 828s collided with its serial refueler on 17 January 1966 and dropped its four bombs, scattering nuclear materials in the Spanish countryside. Three bombs were recovered on land, and the last was recovered in the sea.

1982.19 The Nuclear Weapons Stockpile Memorandum signed by President Carter in October 1980 (for the period 1981-1983) called for a further "dramatic increase in warhead production"20-a "very sharp increase."21 It was originally stated in 1981 that with this increase "the stockpile will remain well below the historic highs established in the late sixties"22 and that the "total magnitude" of the stockpile would not change "in any great consequence."23 More recently, in March 1982, a Defense Department official stated, "... over the next 5 years there will be an increase in the total number of nuclear warheads deployed, both strategic and tactical, on the order of several thousand."24

The magnitude of the increase in nuclear weapons production is reflected in the growth of the Department of Energy budget for warhead research, development, testing and production. The current FY 1984 nuclear weapons budget request is \$6.8 billion, contrasting sharply with the FY 1980 level of \$2.8 billion. The increase from FY 1981 (\$3.7 billion) to FY 1982 (\$5 billion) represents the largest single year increase in the history of the weapons program.25

The first Stockpile Memorandum of the Reagan Administration, signed in March 1982, approved changes in the mix of warheads, but authorized only a slight increase over the Carter plans. It is estimated that 16,000 new warheads will be produced through 1990 (see Table 1.7) and an additional 12,000 are identified in current research and development programs through the 1990s. An increasing gap between the production and retirement rate is expected, due primarily to two factors: many older weapons will be upgraded as part of a "stockpile improvement program" in which warhead safety and security will be increased, and many old warheads will remain in the stockpile while a determination is made on the deployment of their replacements.46

As in the 1950s, the availability of nuclear fissile materials is claimed to be a constraining factor in the current plans for large growth in the stockpile. Actually, warhead production through at least the mid-1980s is possible with the present supply of materials from retired weapons and new materials production. It is only in the early 1990s that potential material shortages have even been projected. This is mainly due to four factors: one. many new warhead designs require a different mix in

¹⁶ Warhead design in the older weapons could only produce one yield per warhead. This meant that each yield desired required a different warhead. Newer designs could produce variable yields in one warhead (the so-called "dial-a-yield") and thus newer warheads with "selectable" yields could replace a larger number of less versatile older, single yield wacheods-

¹⁷ HAC: PY 1982 EWDA: Part 7, pp. 106-107

¹⁸ HAC, FY 1982, EWDA, Part 7, p. 100.

¹⁹ Ibid., p. 196. 20 HASC, FY 1982 DOE, p. 85.

²¹ HAC. FY 1992 EWDA. Part 7, p. 100.

²² HASC, FY 1982 DOE, p. 35. 23 HAC, FY 1982 EWDA, Part 7, p. 160. 24 SASC, FY 1983 DXXI, Part 7, p. 4235. 25 HASC, FY 1982 DOE, pp. 12-15; HAC, FY 1982 EWDA, Part 5, p. 1. 26. This is particularly the case with large numbers of W33 6-inch artillary warhands deployed in Europe. They are being kept in the stockpile pending the resolution of a European deployment decision on the new enhanced radiation yield W79. According to the Senate Appropriations Committee (Report No. 87-673, 6 December 1962), "the DOE and DOD is grave concerns about the safety and the military usefulness of this atomic projectile. "the DOE and DOD have

Future Developments

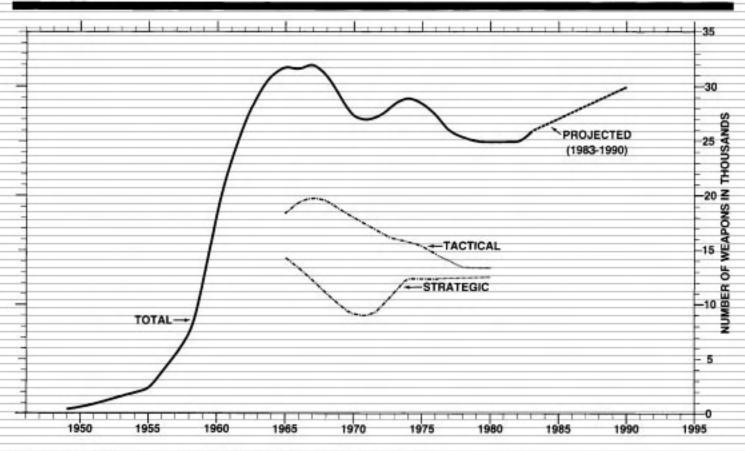


Figure 1.3 U.S. nuclear stockpile, 1949 to present (with future projections)

the materials utilized (more plutonium and tritium; see Chapter Two); two, the contingency plans for production exceed the maximum historic high of the stockpile in 1967; three, many warheads which may be built (and represent additional planning requirements) are still only being considered (a new anti-ballistic missile system, for instance); and four, present plans are to build up a reserve of fissile material should large scale production of warheads be necessary in the future.

Future Nuclear Weapons Developments

A separate agency of the government, the Department of Energy (DOE), it is responsible for nuclear weapons development. DOE's relationship to the Department of Defense is very intimate, and it has shown a direct interest in lobbying and supporting continuing nuclear weapons development and production. As such, its independent position may not accomplish what it was originally intended to accomplish, namely, to keep the critical resource of nuclear weapons under civilian control.

The typical life of a nuclear warhead extends through seven "phases." covering some 30 years (see Table 1.8).21 The research and engineering phases (phases 1-4) typically take as much as nine years. The formal research phases draw upon a continuing advanced concepts and basic scientific research program within the laboratories. Production and stockpiling can take place over as much as an 8-25 year period. Underground testing initially occurs during the first three phases. The initial outlay of large amounts of research, production, and construction money occurs during phase 3. Once a warhead has been approved for production, it enters phase 4 and then advances to phase 5 when full scale production actually begins.

The current programs of nuclear weapons research continues the trend towards greater miniaturization, accuracy, and concurrently lower yields. Development of new warheads incorporating upgraded safety, control, and security features is also a high priority. In recent years, two new innovations have been applied to the stockpile. The first innovation is the widespread adoption of the enhanced radiation (ER) capability (see

²⁷ The DOE is the successor agency to the Energy Research and Development Administration (ERDA) and the Atomic Energy Commission (AEC).

²⁶ HASC, FY 1981 DOE, p. 185; HASC, FY 1860 DOE, p. 56-57.

Table 1.6 U.S. Nuclear Weapons Stockpile

Year	Number of Warheads
1945	2
1946	9
1947	13
1948	50
1949	250
1950	450
1951	650
1952	1000
1953	1350
1954	1750
1955	2250
1956	3550
1957	5450
1958	7100
1959	12.000
1960	18,500
1961	23.000
1962	26,500
1963	29,000
1984	31,000
1985	31.500
1966	31,500
1967	35.000
1968	31.000
1989	29.000
1970	27,000
1971	27.000
1972	27,500
1973	28,500
1974	29.000
1975	28.500
1976	27.500
1977	26.000
1978	25,500
1979	25,000
1980	25.000
1981	25,000
1982	25,000
1983	26.000

Stockpile numbers for 1945-1948 are taken from an undated State Depart ment memorandum circulated in 1982, and David Alan Rosenberg, "U.S. Nuclear Stockgle, 1945-1950," The Bulletin of the Atomic Scientists, May 1982. Authors' estimates of the ourners size of the stockgile and historical triends are derived from SAC, FY 1981 EWDA, Part S, pp. 798-798, 806; JCAE. Development, Use and Control of Nuclear Energy for the Common Defense and Security and For Peaceful Purposes, Second Annual Report, 3D June 1976, pp. 135-136, HASC, FY 1962 DOE, p. 142; DOD, FY 1964 Annual Report, p. 55. For the years 1949-1958 the estimate is rounded to the nearest multiple of 50 warheads, and for the years following 1958 to the nearest 500 warheads.

Chapter Two), which has been built into the W70-3 LANCE warhead (production completed in 1982) and the new W79 8-inch artillery warhead. An ER yield is

also planned for the W82 155mm artillery warhead (scheduled to begin production in 1984) and under consideration as the warhead for the SENTRY anti-ballistic missile. The second development is in the W87 warhead planned for the PEACEKEEPER/MX (and possibly TRI-DENT II) missile, which allows a quick conversion to significantly higher yield (an increase from 300 to 475 kilotons). The W87 also utilizes much smaller amounts of fissile material for equivalent yield compared to reentry vehicle warheads developed as late as in the 1970s.

Nine warheads will be in production in 1983-1984: B61-3 and -4 bombs, the W76 warhead for the TRIDENT I, the W78 warhead for the Mk-12A reentry vehicle on the MINUTEMAN III, the W79 enhanced radiation warhead for 8-inch artillery, the W80-0 warhead for the Sea-Launched Cruise Missile, the B83 bomb, the W84 warhead for the Ground-Launched Cruise Missile (GLCM), and the W85 warhead for the PERSHING II missile. One of these weapons, the W78, will complete its production run in 1983. Four other warheads will be in the engineering development phase in 1983; the W81 warhead for the STANDARD-2 missile, the W82 enhanced radiation warhead for 155mm artillery, the W87 warhead for the PEACEKEEPER/MX missile, and the SENTRY/Low Altitude Air Defense System anti-ballistic missile warhead (see Table 1.9).

According to the Department of Energy, 10-20 percent of a weapon system's cost is for the nuclear warhead," but this estimate can vary greatly. The cost of each new nuclear artillery warhead in 1973 was \$400,000 (8-inch) and \$462,000 (155mm). This is far less than the total system cost of artillery, including thousands of guns with high levels of manning and support, all capable of firing the same nuclear projectiles." The cost of the new W84 warhead for the Ground-Launched Cruise Missile (GLCM) was recently estimated at \$1.1 million each, or approximately 17 percent of the \$3.678 billion GLCM program." In contrast, each new W82 enhanced radiation 155mm artillery warhead under development is estimated to cost over \$3 million.

Many warheads, both in the research and production phase, have problems associated with need, scheduling, cost, and effectiveness. These problems rarely receive public attention, but on occasion some have been revealed in Congressional reports. For example, both the House and Senate Appropriations Committees stated in FY 1983 that "some build levels appear excessive in relation to military capabilities and requirements, as well as realistic assessments of deployment

²⁹ HAC, FY 1982 EWDA, Part 7, p. 160.

³⁰ Military Applications of Nuclear Technology, Part 2, p. 181.

The W84 program was quoted in Congressional bearings at \$600 million for \$60 warheads: RAC, FY 1002 DOD, Part 7, p. 740; program cost in Defense Department estimate as of \$0

To	Table

Projected Nuclear Warhead Production, 1983 to mid-1990s

In Production (1983)	Number Planned
B61 Bomb	1000
W76 TRIDENT I	1600
W79 8-inch artillery shell (ER warhead)	800
W80 Air-Launched Cruise Missile	4000
W80 Sea-Launched Cruise Missile	1000
883-Bemb	2500
W84 Ground-Launched Cruise Missile	560
W85 PERSHING II	300
SUBTOTAL	11,760
Planned (1983-1988)	
W81 STANDARD-2	500
W82 155mm artillery shell [ER Warhead]	1000
W87 MX Warhead	1055
Surface and Air Delivered ASW Weapon	1250
Subsurface Delivered ASW Standoff Weapon	400
SUBTOTAL	42051
Future Systems (Late 1980s-1990s)	
TRIDENT II	5000*
SENTRY (ABM)	500
New Strategic Air-Launched Missile	1200
Corps Support Wespon System	500
Advanced Tactical Air Delivered Weapon	2500
Advanced Cruise Missile Technology	(3000)5
Advanced Mobile ICBM	3000
Bomber Defense Missile	2
SUBTOTAL	12,700
Alternate Systems	
Tactical Air-to-Surface Munition	[1500]
MaRV for TRIDENT II	(7500)*
TOTAL WARHEAD PRODUCTION	28,665*

Number includes Advanced Cruise Missile Technology Warhead, which will replace

requirements in the current world political climate."32 The committees also questioned the rate of the retirement program "particularly for those systems that would alleviate materials production requirements and those systems that are considered to be near or at a state of obsolescence," and the "unrealistic scheduling requiring mid course corrections" of PERSHING II (W85), cruise missiles, and the W82 155mm artillery warhead.

Funding for individual warheads has also been held up by Congress. Only minimal caretaker funds have been appropriated for the SENTRY anti-ballistic missile warhead, thus stopping production plans. Funding for the W82 155mm artillery warhead has been reduced by

the Armed Services and Appropriations Committees in the FY 1983 budget. The Senate Appropriations Committee cited "uncertainty of deployment" and "extremely high costs" and noted that "it is premature to proceed to spend billions of dollars on these nuclear artillery warheads at this time."33 Funding for the W87 MX warhead has been reduced by Congress "for reasons related to test status and capability to produce."24 The FY 1983 Appropriations Conference Report provided no funds for proposed W31 NIKE-HERCULES warhead modifications. Finally, the House Appropriations Committee deleted funds for the W81 STANDARD-2 missile warhead request in FY 1983 "pending resolution of differences with respect to the adequacy of the design."35

ALCM warheads on a one-for-one basis.

2 Not all of these warheads will be produced in the 1980s.

³ Does not include W87 production for TRIGENT II. 4 Not all of these warheads will be produced in the 1980s.

⁵ Number includes Advanced Cruise Missile Technology Warflead, which will replace

ALCM werheads on a cre-for-one basis.

5 This number does not include Alberhale Systems.

• Competing werhead programs for TRICENT SLBM upgrade and TRICENT I (instead of W87).

³² House Report No. 97-859, 21 September 1982, p. 59. Senate Report No. 97-673, 6 December 1962, p. 88. 88 SAC, Report No. 87-679, 6 December 1982, p. 92.

³⁴ HAC, Report No. 67-345, 19 November 1981, p. 19. 35 Senate Report No. 97-850, 21 September 1982, p. 61.

	Muclear We	apons Development Phases
Phase		Activity
Phase 1	Weapons Conception	Studies by DOE/DOD/interested services generating interest in new weapon idea or concept warranting formal program review.
Phase 2	Program Study or Feasibility Study	DOE impact report to DDO, Draft Military Characteristics [MC] and Stockpile-to-Target (STS) sequences prepared by DDO; Phase 2A: Design definition and cost study, form DOE/DOO project offices, select laboratory design team.
Phase 3	Development Engineering or Full-Scale Development	Approved DOD development request, with approved MCs and STS; nomenclature assigned; quantitative requirements set with development an production milestones.
Phase 4	Production Engineering	Tooling and processing: prototyping, construction of production facilities.
Phase 5	First Production	Evaluation and testing for weapon acceptance.
Phase 6	Quantity Production and Stockpile	Weapons produced and deployed and stored by DOD.
Phase 7	Retirement	Disposal of weapons and related material and recovery of nuclear materials

These phases are defined in a joint ASC-DOD agreement dated 21 March 1953, see also HAC, FY 1990 DOD, Part 4, p. 658.

Strategic Weapons Developments

Six hundred MINUTEMAN III missiles, each armed with W62 or W78 warheads of 170 and 335 kilotons, will remain deployed through the 1990s. Fifty MINUTEMAN II missiles will be replaced with MINUTEMAN III missiles, but the remaining 400 will retain their W56 one megaton warheads until the PEACEKEEPER/MX missile is deployed. Plans are to deploy 100 PEACEKEEPER missiles, each with 10 W87 warheads, initially with a yield of about 300 kilotons. A new small, single warhead strategic missile is being developed as a successor to the MX (see Chapter Five).

Plans to deploy a large scale ballistic missile defense system have been accelerated, although the initial nuclear armed system, called SENTRY (formerly the Baseline Terminal Defense System (BTDS) or Low Altitude Air Defense System (LoADS)), has been terminated.

Deployment of 31 POSEIDON submarines, 19 with POSEIDON missiles carrying 10 W68 warheads and 12 with TRIDENT I missiles carrying eight W76 warheads, will continue through the end of the 1980s, when some of the 30 year old submarines will be retired. Deployment of at least 20 TRIDENT submarines will continue through the 1980s and 1990s. The first eight TRIDENT submarines will be initially deployed with 24 TRIDENT I missiles. In 1988-1989, the remaining submarines will be deployed with the TRIDENT II D5 missile.

The bomber force will continue through the 1980s with about 250 B-52G/H and about 50 FB-111 aircraft armed with nuclear bombs and Short-Range Attack Missiles (SRAM) (W69). The bomber force will increasingly

be supplied with Air-Launched Cruise Missiles (ALCM) (W80-1) until a new "Advanced Cruise Missile" is deployed in the late 1980s. The first of 100 B-1B bombers capable of carrying gravity weapons, SRAMs, and ALCMs will be deployed in FY 1985. In the early 1990s. 130-150 nuclear armed "Advanced Technology" (STEALTH) bombers (ATB) are planned for deployment. B-52G bombers will begin phasing out in 1990. B-52Hs will remain through the 1990s and the FB-111 will be transferred to the tactical inventory as the ATB is deployed.36 A new nuclear armed missile, a versatile

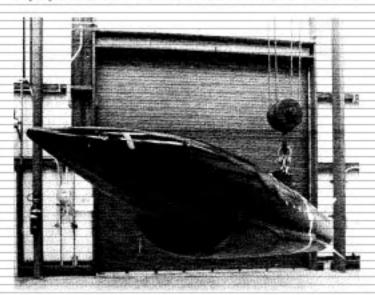


Figure 1.4 Advanced Strategic Air-Launched Missile (ASALM) propulsion technology prototype:

Table 1.9 Nuclear Weapons Research and Development Programs (1983)

	5-17-5-5-5	First Deployment		HILL HOLLOWS CONTROL
Warhead Program	Status'	Planned	Number Planned	Weapon Application
W80 Sea-Launched Cruise Missile	Phase 3/4	1984	1000	New weapon
W81 STANDARD-2 Missile	Phase 3/4	1984-5	500	Replacing W45 and for AEGIS
				shipboard air defense systems
W82 155mm Artillery Projectile	Phase 3	1986	1000	Replacing W48 [ER warhead]
883 Modern Stretegic Bomb	Phase 3/4	1984	2500	Replacing B28, B43 and B53
W84 Ground-Leunched Cruise Missile	Phase 3/4	1983	560	New weapon
W85 PERSHING II Missile	Phase 3/4	1983	300	Replacing W50
W87 MX Warhead	Phase 3	1986	1055	Warhead for MX/Mk-21
	× A11,2-3,17,2	KVTRT;	77020	Advanced Ballistic Reentry
				Vehicle (ABRV)
Surface and Air Delivered Anti-	Phase 2	late 1980s	1250	Replacing B57 and W44 in new
Submarine Warfare Weapon*				ASW standoff weapons
Maneuvering Reentry Vehicle	Phase 2	late 1980s	(5000)	Alternate for Navy MaRVs.
(MaRV)				option to replace W68, W76,
				or W87
SENTRY ABM Warhead*	Phase 2/3	1988	500	New ABM weapon
New Strategic Air-Launched	Phase 2	late 1980s	1200	Air-to-Air/Ground Missile
Missile*				Warhead, replacing W69
Corps Support Weapon System	Phase 2	1988	500	Replacing W70
Advanced Tactical Air Delivered	Phase 1	1990	2500	New Multi-Purpose Guided
Weepon			2000	Tactical Bomb
TRIDENT II Submarine-	Phase 2/3	1989	(5000)	Alternate for replacing W76
Launched Warhead			(0000)	and W87: for TRIDENT II/Mk-
End for the Type French				Advanced Ballistic Reentry
				Vehicle (ABRV)
Tactical Air-to-Surface	Phase 1	early 1990s	1500	New weapon
Munition Warhead (TASM)			1000	
Advanced Cruise Missile	Phase 1/2	1986-1987	3000	Augmenting and replacing WB
Technology Warhead (ACMT)				
Subsurface Delivered ASW	Phese 2	lete 1980s	400	Replacing W55
Standoff Weapon®	, ,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,	1000	400	. reporting troop
Advanced Mobile ICBM®	Phase 2	late 1980s	3000	New weapon for small ICBM
Bomber Defense Missile®	Phase 1	1990s	2	New weapon

¹ Status in FY 1983-84. Phoses refer to stage of development (see Table 1.8). Wertread program was formerly called Anti-Submarine Wartone Weapon for Com-mon ASROC and SUBROC replacement. Surface and Subsurface Warhead develop-

long-range air-to-air and air-to-ground bomber defense weapon called the Advanced Strategic Air-Launched Missile (ASALM), is under development to replace SRAM, with possible deployment in the early 1990s. In FY 1984, another new nuclear warhead program for a "Bomber Defense Missile" was started.

The most significant development within strategic forces is the planned addition of a second sea based system, the cruise missile. As many as 1000 Sea-Launched Cruise Missiles (SLCMs), armed with the W80-0 nuclear warhead, will be deployed on submarine and surface ships as part of a "strategic reserve force" 37 starting in the summer of 1984.

Strategic defensive forces will be upgraded during the 1980s with the replacement of older F-106 and F-4 interceptors with newer model F-4, F-15, and F-16

ment has now been splik [see Subsurface Delivered ASW Standoff Weapon].

3. Alternative workend program competing for TRIDENT II SUBM programs.

4. Formerly Low Albitude Air Defense System (LoADS); also referred to as the Baseline Terminal Defense System (BTDS).

Warhead program was formerly called Lethel Neutralization System and Advanced Scrategic Air-Launched Missile (ASALM).
 Alternative warhead program competing for TRIDENT II SLBM programs.
 New warhead development program in FY 1984.

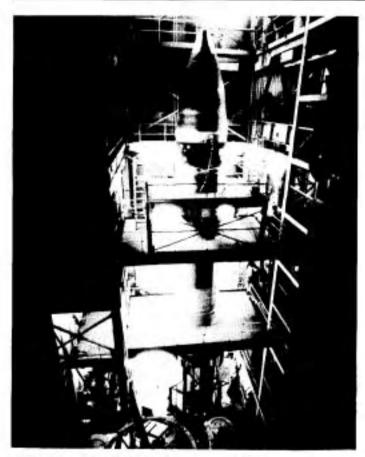


Figure 1.5 MX missile undergoing stress test.

interceptors. The nuclear armed GENIE anti-bomber missile with the low yield W25 warhead will continue in use and a potential replacement in the form of a nuclear warhead for the Navy's PHOENIX air-to-air missile is possible.

Theater and Tactical Weapons Developments

Theater nuclear modernization trends include increased long-range capability, mobility and dispersal, and more precise guidance and targeting capabilities. These new theater weapons "permit the use of lower yield nuclear weapons while attaining military effects commensurate with the earlier generation of less accurate higher yield weapons."28

Beginning in late 1983, unless political or arms control developments intervene, 572 new long-range, accurate, low yield theater missiles will be deployed in Europe-108 operational PERSHING II missiles with W85 warheads and 464 Ground-Launched Cruise Missiles with W84 warheads. New tactical nuclear capable aircraft

are also being deployed, including the F-16, F/A-18, and TORNADO fighters. These aircraft are all capable of being armed with the new versions of the 300-500 kiloton high speed delivery nuclear bomb, the B61, which is in production. An interim replacement for the nuclear strike F-4 and F-111 tactical fighters is under development. An enhanced version of the F-16 or F-15 will be chosen as the Derivative Fighter Aircraft, pending development of an Advanced Technology Fighter in the 1990s (see Chapter Seven).

The development of more capable precision battlefield conventional weapons has had little influence on the reduction or retirement of the bulk of the shortrange tactical nuclear weapons. About 5000 low yield nuclear artillery warheads-the W33 8-inch and W48 155mm projectiles-are currently a part of the stockpile. These two warheads will be replaced in the 1980s with the W79 and W82 warheads. The new 155mm artillery warhead (W82) is under development with an enhanced radiation yield. The short-range LANCE missile, which has both fission and enhanced radiation versions of the W70 warhead, was introduced into U.S. and NATO forces in the mid-1970s, replacing the HONEST JOHN and SERGEANT missiles. The LANCE will continue in active forces until it is itself replaced with a "Corps Support Weapon System" being jointly developed in the Joint Tactical Missile System program by the Army and the Air Force. The NIKE-HERCULES air defense missile with the W31 nuclear warhead will be withdrawn from Europe during the 1980s and replaced with conventional "improved HAWK" and PATRIOT missiles.

A new generation of tactical nuclear weapons for the Navy is under development and will be deployed during the 1980s. The Sea-Launched Cruise Missile (SLCM), armed with both nuclear (W80-0) and conventional warheads, will be widely deployed on Navy ships and submarines starting in 1984. In its nuclear role, the SLCM will be a long-range strike weapon for attacking land targets, and will thus introduce a new capability to the surface and subsurface Navy. Two anti-submarine warfare (ASW) nuclear warheads are under development as late 1980s replacements for ASROC (W44) deployed aboard surface ships, SUBROC (W55) aboard attack submarines, and B57 nuclear depth bombs. The new ASW weapons will be longer range and more accurate than either ASW missile currently deployed and will provide a standoff capability to replace the B57 nuclear depth bomb currently used in maritime patrol and antisubmarine operations. Another alternative for B57 replacement is to arm the versatile HARPOON cruise missile with a nuclear warhead.

Theater Developments

An earlier trend within the Navy toward reducing reliance on nuclear weapons for fleet air defense has been reversed. A significant cutback in fleet levels in 1970, a decision to reduce nuclear loading factors because of the marginal utility of the older systems, and phase-out of the nuclear armed TALOS in 1979, led to a steady decline from the late 1960s onward in the number of ships equipped with nuclear air defense systems. Since 1975, the number of nuclear warheads for surfaceto-air missiles have been significantly reduced to only a small percentage of the ships' storage capacities." Now, ships intermittently carry a nuclear warhead (W45) for the TERRIER missile, but beginning in the mid-1980s, large numbers of the new nuclear armed STANDARD-2 missile, with the low yield W81 warhead, will begin deployment.



Chapter Two

Nuclear Weapons Primer

Nuclear Fission and Fusion

A nuclear weapon is a device in which most or all of the explosive energy is derived from either fission. fusion, or a combination of the two nuclear processes:2

(1) NUCLEAR FISSION is the splitting of the nucleus of an atom into two (or more) parts. Certain isotopes of uranium and plutonium (and some other heavier elements), when bombarded by neutrons, will split into atoms of lighter elements and in the process will emit, on average, two or more neutrons from each nucleus and considerable energy-about ten million times as much, atom for atom, as is obtained from ordinary chemical combustion.*

(2) NUCLEAR FUSION is the joining (or fusing) of the nuclei of two atoms to form a single heavier atom. At extremely high temperatures-in the range of tens of millions of degrees—the nuclei of isotopes of hydrogen (and some other light elements) can readily combine to form heavier elements and in the process release considerable energy. While a number of thermonuclear reactions are identified in the literature," the most relevant to nuclear weapons is the reaction between deuterium (H-2 or D) and tritium (H-3 or T), two hydrogen isotopes, because the deuterium-tritium (D-T) reaction proceeds more rapidly at realizable temperatures than the other fusion reactions.4

Atom for atom, the energy released in fusion is less than that released in fission," but the atoms involved in fusion are much lighter, so in theory, the maximum energy obtainable from fusion is about three or four times as great per unit weight as the maximum energy obtainable from nuclear fission.* Pure fission weapons of low yield are the simplest practical nuclear weapons to design and construct. Some low yield weapons, e.g., older nuclear artillery shells, are the pure fission type. Weapons of very high yield and weapons that have the highest yield-to-weight ratio use a combination of fission and fusion reactions.* Most weapons in the U.S. stockpile are probably of this type.

Fission Weapons

Chain Reaction

In a fission device (a weapon or a reactor), it is necessary to achieve a chain reaction, whereby neutrons emitted by fissioning nuclei induce fission in other fissionable nuclei. The neutrons from the fissions, in turn, induce fission in still other fissionable nuclei, and so on. When uranium-235 (U-235) fissions, an average of about 2.56 neutrons are released; an average of about 2.9 to 3.0 neutrons are released when a nucleus of plutonium-239 (Pu-239) fissions.46 A portion of these neutrons is captured by nuclei that do not fission, and others

 This section is derived from Ted Greenwood, George W. Rathiens and lack Ruina. "Nacle ar Power and Weapons Proliferation" (London: International Institute for Strategic Stud ies, Adelphi Poper No. 130. Winter, 1998, pp. 2-6. Other useful primers, although not an exhaustive list, include: Semmel Glasstone and Philip]. Dolan, The Effects of Nuclear Weapons, 3-d ed. (Washington U.S. DOD and U.S. DOE, 1977), Chapter I. Philip Moerison.

"The Physics of the Bomb." Atomic Energy (Harmandsworth, Middleser, U.K., Penguin Books, 1980), pp. 2-29, 301-125, 194-201; Edward Teller, et al., The Constructive Use of Nuclear Explosives (N.Y.: McGraw Hill, 1988), pp. 1-61; R. Serber, et al., "The Los Alamos Primer," LA-1, April 1949, Robert W. Selden, "An Introduction to Fission Explosives," LLL, UCID 19884, July 1969; J. Carson Mark, et al., "Nuclear Weapons," Nuclear Proliferation and Sologuards (N.Y.: Praeger Publishers, 1977, Chapter VI, pp. 139-145, M.B. Neyman and K.M. Sadidenko, "Thermonuclear Weapons," translation by Technical Information Center (Wright Patterson AFB, OH, October 1980). Torsten Magnusson, "Design and Effects of Atomic Weapons' (U.S. Joint Publication Research Service, 8295, 22 May 1961); Howe Morfand, "The H-bomb Secret," The Progressive, November 1979, pp. 14-23; (read with "Emats," The Progressive, December 1979, p. 36) and The Secret that Exploded (New York: Random House, 1981): numerous encyclopedia articles by authors including Edward Teller. Hans Bethe, John S. Foster. 2 While all nuclear weapons deployed contain chemical high explosive material to initiate

the nucleus reaction. It is theoretically possible to use electromagnetic energy (i.e., light

from lasers) instead of chemical explosives.

3 Approximately 200 MeV (3.2 x 10 ** joules) is released in each fission, but only about 160 MeV is immediately available as explosive energy (from gamma rays and the kinetic energy of flasion products and neutrons, and from only a small fraction of the decay energy of flasion products). Based on the latter value, an explosion equivalent to 1 kiloton (Kr) of TNT (defined as the release of 10° calories) is obtained by the fasion of 1.45 x 10° nuclei. Thus, the complete fasion of one kg of fissionable material produces a 17.5 Kt explosion, or 1 Kt is released from the complete fasion of 0.05° kg (87 grams or 2 ounces); see, Glasstone and Dolan, sp. cit., pp. 12-13.

4 The principal thermonuclear reactions involving isotopes of hydrogen include

(ii) $D + T \rightarrow He^{+}(3.52 \text{ MeV}) + \pi (100 \text{ MeV})$ (iii) $D + D \rightarrow He^{+}(3.52 \text{ MeV}) + \pi (2.45 \text{ MeV})$ (iii) $D + D \rightarrow He^{+}(0.02 \text{ MeV}) + \pi (2.45 \text{ MeV})$ He* (3.52 MeV) + n (14.07 MeV)

(iii) T + T → He⁺ + 2n + 11.4 MeV The (D + D) reaction proceeds with approximately equal probability via the two channels. 5 See for example, Neyman and Sadilenko, op. cit. p. 8.

6. The (D-T) reaction is reaction (i) in footnote 4. It is about 100 times more probable than the (D + D) reaction (ii) in the temperature range 10-100 KeV (1 KeV = 11.6 million K). Alternately, a given reaction rate can be achieved at a lower temperature for the (D-T) reaction than for other fusion fisels; Booth, et al., "Prispects of Generating Power with Laser-Driven Fusion," Proceedings IEEE, 64, October 1976, p. 1461. 7, 17.6 MeV for the D-T reaction compared to 200 MeV for fission of a unusum or plutonium.

8 Compared to 200 MeV for fission, approximately four times for fusion of deuterium with tritium nuclei and approximately three times for fusion of deuterium nuclei or deuterium. and tritism nuclei from lithium-6 deuteride; see Glassione and Dolan. op. cit., p. 21, for

9 Although possible in principal, pure fusion weapons-that is, where the high temperature necessary for fusion is not obtained from a fission explosion-have not as yet been developed in practical form and may never be. One of the objectives of the U.S. inertial confinement fusion research program probably is to determine the feasibility of using lasers to

produce a practical pure fusion weapon.

10 These values are for fission induced by 1 MeV neutrons. The average number of neutrons per fission decreases slightly as the energy of the neutron inducing the fission drops, see. USAEC, Recotor Physics Constants, ANL-6900, July 1963, pp. 20-23, and A.M. Weinberg and E.P. Wigner. The Physical Theory of Neutron Chain flexctore (Chicago: University of Chicago Press. 1966), p. 129.

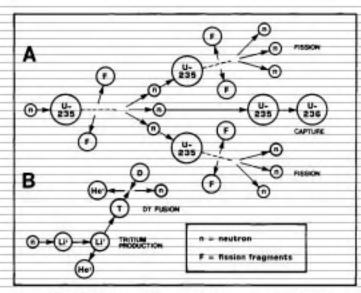


Figure 2.1 (a) Fission chain reaction in uranium-235. (b) Fusion of deuterium and tritium into helium (upper right). Here, the tritium is produced by absorption of a neutron in lithium-6 (lower left).

escape the material without being captured. What is left can cause further fissions. If more than one neutron per fission remains for the chain reaction, more fissions are achieved in the next "generation" than in the previous one. To achieve a high efficiency in a nuclear explosion, a very rapid growth in the number of fissions is soughtthat is, a rapidly multiplying chain reaction. This means, among other things, that an effort must be made to keep down the leakage of neutrons out of the fissile material and to avoid neutron absorbing impurities in the fissionable material.

Fissionable Materials

Many heavy atomic nuclei are capable of being fissioned; but only a fraction of these are fissile, which means fissionable by slow (or zero energy) neutrons, as well as fast (highly energetic) neutrons. Since the neutrons resulting from nuclear fission are emitted with a wide range of energies, nuclei which fission only from the capture of fast neutrons would generally not be able to sustain a chain reaction." From a practical point of view, fission weapons must be made using fissile materials,12 principally U-235, Pu-239, U-233, or some combination of these.

Uranium as found in nature consists primarily of two isotopes, U-235 and U-238, with U-235 (the fissile isotope) occuring only 0.711 percent in abundance, while U-238 constitutes 99.3 percent. Plutonium does not occur naturally except in minute concentrations. Therefore the fissile isotope Pu-239 is made artificially in nuclear reactors from U-238.13

To date only U-235 and Pu-239 seem to be used as the fissile material in stockpiled nuclear weapons. Other fissile isotopes of uranium and plutonium, e.g., U-233 and Pu-241, occur only in trace amounts in nuclear weapons. Because U-233 and Pu-241 are more difficult and costly to produce in quantity than U-235 and Pu-239, they are not used as primary fissile material. U-233 and Pu-241 are also more radioactive, can complicate weapons fabrication, and can degrade the reliability of other weapon components.14 U-238 is used to contribute to the yield of some fission and thermonuclear weapons; Th-232 does not appear to be used.

Fission weapons are made using grades of enriched uranium (from an enrichment plant) or plutonium (produced in a reactor) which contain the fissile isotopes U-235 and Pu-239, respectively, in levels which provide efficient reactions and use a minimum of materials. However, fission weapons do not require uranium or plutonium pure in the isotopes U-235 and Pu-239 to make an explosion, nor do they require uranium or plutonium in the form of a metal. Theoretically, uranium weapons cannot be made using uranium enriched to less than about 5-6 percent U-235. In the range 6-10 percent U-235, very large quantities-thousands of kilograms-of uranium would be required. The fissile uranium material of current nuclear weapons is 93.5 percent enriched U-235.15

In theory plutonium compounds containing 6-10 percent (or even less) Pu-239 are usable for weapons. In practice, plutonium is produced from U-238 in a reactor

U-238 and Thorium-232 (Th-232), both abundant in nature, are also fissionable but only by fast neutrons, so they cannot sustain a chain reaction by themselves. Nevertheless, these two materials can contribute to the yield in both fission and thermonuclear explosions where the many excess high-energy neutrons generated by other fission and by fusion reactions can cause them to fission (see below: Fusion Weapon Design, Thermonuclear Weapon Design).

Generally these would include isotopes of heavy elements with an even isotope number, e.g. U-336; U-238. Pa-240 is an exception in that it is not fissile and yet can sestain a chain reaction with fast neutrons.

¹² Generally these would include isotopes of heavy elements with an odd isotope number. eg., U-235; Pu-239; Pu-241

heta' Np-233 heta" Pu-239 18 In the reaction: U-238 (n. gamma) U-259 -23.5m 2.36d 14 U-233 is produced in nuclear reactors from Thorium-232 in the reaction:

The U-233 is used as the primary fuel in some types of nuclear reactors. Interest in U-233 as a nucleur weapons usable material stems from concern that, like highly-enriched uranium (U-235) and plutonium. U-239 may be diverted from its use in civil activities and used in weapons. (The U.S. has tested U-233 weapons.) 15 SASC, PY 1983 DOD, Part 7, p. 4979.

Critical Mass

to a purity of about 93.5 percent Pu-239 for weapons use. The element Pu-240, a byproduct of plutonium production, is an undesirable element for weapons design because of its high spontaneous fission rate. Consequently, in reactors used for the production of plutonium for weapons, the period of time that the U-238 is left in the reactor is restricted to limit buildup of Pu-240 (to about 6 percent) while creating the fissile Pu-239.

Although one basic difference between U-235 and Pu-239 for weapons design is that U-235 occurs in nature, a larger amount of U-235 is required to make an explosion of equal yield to a plutonium weapon. Plutonium-239 (Pu-239) is more expensive to produce and must be made artificially, but it can be used to obtain a higher yield-to-weight ratio, smaller weapons size, and decreased weight.

From 1945-1947, the U-235/Pu-239 production ratio in the U.S. was approximately 8 to 1. It was therefore highly desirable to utilize U-235 and achieve the maximum efficiency in the use of both U-235 and Pu-239. Consequently, composite fission cores containing both U-235 and Pu-239 were developed; these fission cores were actually stockpiled at the end of 1947 for use in the Mark III implosion type bomb, although the percentage of plutonium needed to achieve maximum effect was then unknown. There is still some six to seven times more U-235 in the U.S. weapons stockpile than Pu-239 (see Nuclear Weapons Databook, Volume II). Most U.S. nuclear weapons contain both Pu-239 and U-235.

Critical Mass

Small amounts of fissile material will not sustain a chain reaction because a large fraction of neutrons leak out, making them unavailable to cause fission in other nuclei. The minimum mass of material necessary to sustain a chain reaction is called the critical mass and is dependent on the type of fissile material, its density, and its geometry. A mass that is less than the critical amount is said to be subcritical, while a mass greater than the critical amount to achieve a multiplying chain reaction is referred to as supercritical.

Because a sphere has the highest volume-to-surface ratio of any solid shape and, therefore, the least number of escaping neutrons per unit of material, it is the shape for which the critical mass is smallest. The critical mass of a bare sphere of U-235 at normal density is approximately 52 kilograms (kg), that of U-233 about 16 kg, and that of certain dense metallurgical phases of Pu-239 as low as 10 kg.¹⁵

The critical mass can be lowered in several ways. The fissile material may be surrounded by a shell of other material to reflect some of the neutrons which would otherwise escape. Practical reflectors can reduce the critical mass by a factor of two or three so that about 5-10 kg of either Pu-239 or U-233 and about 13-25 kg of U-235 at normal density can be made critical."

The critical mass is also lowered if the material is compressed to increase its density. Consequently, an efficient practical fission bomb, which depends on extremely high compression of the nuclear core, could use significantly smaller amounts of fissile materials

10 Weapon-grade plutonium is defined as plutonium containing less than 7 percent Pu-240; fuel-grade plutonium is 7 percent to less than 19 percent Pu-240; and reactor-grade is 19 percent or greater in Pu-240 content.

17 Pu-340 is the most troublesome of plutonium isotopes for bomb design, but not because of its Inability to sustain a chain reaction. Pu-240, in fact, has a bace sphere fast neutron critical mass of 40 kg, less than that of U-230. Although when Pu-240 is mixed with Pu-230 it raises the critical mass of the mixture, the undestrable supects of Pu-240 arise primarily from the fact that it fissions spontaneously with a much shorter fission half-life than Pu-239.

For one kilogram of U-235, spontaneous fission produces approximately one neutron per second. The apontaneous fission rates of weapons-grade plutonium are 80,000 and 200,000 times higher. Another [smaller] source of neutrons is the alphan reaction. In this case, radioactive decay of the fissile incoops yields alpha particies, some of which then collide with impurities such as boron, carbon, or exygento yield neutrons.

The classic problem presented by background neutrons is that of preintitution of the nuclear-fission chain reaction, in order to assemble fissionable material to produce a nuclear explosion, a subcritical mass (or masses) of material must be rapidly moved into a configuration which has a level of superchiticality sufficient to produce a significant nuclear yield before it blows itself spart. Freintilation in a nuclear explosive is defined as the initiation of the neutron chain reaction before the desired degree of supercriticality has been achieved. Because the nuclear yield depends upon the degree of supercriticality at the time the chain reaction is initiation, perintilation will result in a lower yield. However, initiation is a statistical process and can be understood using statistical techniques.

Preintitation, by itself doer not necessarily make an explosive unreliable. Preintitation does result is a statistical uncertainty in the yaeld. Another way to state this is that the probable nuclear yield is statistically distributed between predictable upper and lower limits, which are likely to be more than a factor of 10 apert. For a well-understood design properly constructed, however, the most probable yield range could be predicted within each closer limits. [Mark. op. cit. p. 1413]

Because of their particular sensitivity to premittation, gun devices (see Fasion Wespon. Gesign) are never designed with plutonian of any quality. For low-technology [implesion] devices using high neutron background materials the probable yields could be lower by a factor of 3 to 10 or more [depending on the design] than using low-neutron background materials (i.e., U-23), U-255 and weapons-grade plutonium). Military useful weapons with reliable yields in the hilloton range run be constructed using low technology, [emphases odded) [Mark, up. cit., p. 142.]

The U.S. tested a recapon constructed with reactor-grade plutoniem is 1967. Hod the first U.S. rather device (Trinity test, 19 July 1945) been constructed with reactor-grade plutonium its yield would have exceeded 1 kiloton. Using high-technology, or sophisticated do sign techniques, the problems presented by prognition can be largely overcome. Fuel-grade and reactor-grade plutonium are not used in U.S. reapone, but not primarily because of presinitation. Pu-240 (and Pa-241) are more radioactive than Pu-239 and therefore generate more heat-that must be dissipated if the integrity of the device is to be maintained for extended periods of time. Pu-240 is also more hazardous to handle then Pu-339, thus complicating further the manufacture of weapons using reactor-grade and fact-grade rather than respon-grade plutonium.

16 Pu in alpha phase [M. = 17 kg for Pu in delta phase]. The critical mass of Pu-239 is lower.

18 Pu in alpha phase JM. = 17 kg far Pu in delta phase). The critical mass of Pu-232 is lower than that of U-235 because it has a higher fasion, cross-section—that is, each Pu-232 nucleus is more likely than a U-235 nucleus to capture a neutron and fasion—and it produces on the average more neutrons per fission than U-235.

19 M. = 266 bg for sphere of 94 percent U-235 serrounded by 1.74 inches natural uranium: M. = 8.4 kg for sphere of alpha phase Pu-239 (4.5 percent Pu-246) surrounded by 1.6 inches natural uranium: and M. = 7.6 kg for sphere of 38 percent U-233 surrounded by 1.1 inches natural uranium. Lower values of M. can be achieved with other reflecting materials and/or thicker reflections.

20 For a spherical mass of fasile material of radius, it, and uniform density, a

(p- K)...... = constant

If a fixed core mass, M, is uniformly compressed, the density is given by $\rho = 3M/4\pi R^2$

consequently, the critical mass is approximately proportional to the reciprocal of the square of the density, i.e.,

 $M_{\rm critical} = K/\rho^2$

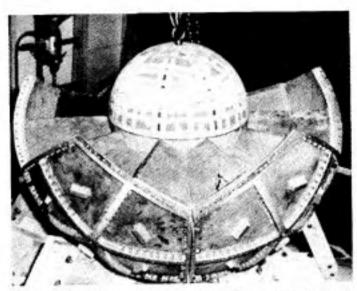


Figure 2.2 Interior components of Fat Man type implesion bomb. The spherical shell of twelve pentagonal sections contains explosive "lenses" surrounding a uranium tamper and plutonium core.

than mentioned above. On the other hand, to obtain an appreciable fission yield more than one critical mass may be necessary. Thus, different types of nuclear weapons use different amounts of nuclear materials, and the reflected critical mass values discussed aboveabout 15 kg of U-235 and 5 kg of Pu-239-indicate only the order of magnitude of the actual amount of fissile material that may be required for a nuclear weapon. Most weapons in the U.S. arsenal are believed to use only a fraction of a critical mass (at normal density)-a "fractional crit"-as the fissile component.21 Other things being equal, fission weapons of higher yield require larger quantities of fissile material; therefore, the actual amount of fissile material in a weapon depends on the desired yield and the sophistication of the design.

Fission Weapon Design

An explosion is the release of a large quantity of energy in a small volume in a short period of time. There are numerous ways to assemble nuclear fissile materials to make them explode. For an efficient bomb or weapon the goal is to achieve a rapidly multiplying chain reaction that within a very short time-a few microsecondsinvolves a very large number of atomic nuclei.

The fission chain reaction can be viewed as a sequence of stages or "generations," each marked by the fissioning of nuclei by neutrons produced in the preceding generation. The "generation time" is the average time between the emission of a fast neutron and its absorption by another fissionable nucleus, taking into account that neutrons are also lost by leakage and capture in other materials. The value of the generation time is roughly 0.01 microsecond (a "shake")™ and varies depending on the kind of fissionable material used, the design of the weapon, and the densities achieved during the explosion.23

The energy release from a fission device takes place over a number of generations, depending on how many neutrons from fission in one generation remain to produce fissions in the next generation. In the fission of a single nucleus, between 2.5 and 3 fast neutrons are emitted. If, for example, 2 of these survive to produce other fissions, then the energy release from a device with a yield in the range 1 to 100 Kt would occur in about 53 to 58 generations.24 Moreover, 99.9 percent of the energy release occurs in about the last 7 generations, which is roughly the last .07 microsecond of the explosion.

The energy release, or yield, is proportional to the number of nuclei fissioned, which is equivalent to the number involved in the chain reaction. To achieve a significant yield, the mass of the assembled fissile material must be several critical masses in order to obtain and maintain a rapidly multiplying chain reaction and avoid disassembly (i.e., becoming subcritical) before much material has been fissioned. This can be achieved by assembling two (or more) subcritical mass elements, or by changing the density and geometry of a fissile mass, initially subcritical, to reduce its critical mass. Higher yields (larger explosions) are obtained by design techniques which increase the mass above critical, and increase the time the fissile material is held together before the energy released by the nuclear explosion blows the weapon materials apart, stopping the chain reaction.

To keep the weapon from exploding and becoming subcritical before a reasonable fraction of its fissionable

²¹ The idea of using a fraction of a critical mass ("fractional crit") for an atomic explosion was originated by Hans A. Bethe from implesion calculations during the Manhattan project. After fission bombs had been thoroughly developed by postwar Los Alamos Laboratocy the fractional crit became a practical possibility. It was strongly advocated by the Laboratory and the AEC in 1946-1949; see Hans A. Bethe, "Comments on the History of the H-Bomb." 1954, reprinted in Los Alomos Science, Fall 1982, p. 45.

²² Glasstone and Dolan, op. cit., pp. 16, 27. 23 For a bare sphere critical assembly of U-235 the generation time is .66 shake. It is 2.0 shakes for a critical assembly with a U-205 apherical core and a thick natural unusion reflector. and .35 shakes for a bare sphere critical assembly of plutonium; John D. Orndoff. Nucleon Science and Engineering: 2, 450-460 (1957).

²⁴ A yield of 1 Kt requires the fissioning of 1.45 x 10th nuclei. If 1 + x neutrons per fission from one generation produce fastors in the next generation, the population of fission producing neutrons after a generations is given by exp[xn] for a chain initiated by a single neutron (Glassione and Bolan, op. cit.). In the example in the text above, x=1. For Limits Boy and For Mon, the fission devices detonated over Japan, x is estimated to have been less than 0.7 neutrons per fission. For neutron leakage data, see George D. Kerr in V.P. Bond and J.W. Thiessen, eds., Reevaluations of Dosimetric Factors, Hiroshimo and Negosoki. op. cit., pp. 64, 65.

Fusion Weapons

nuclei undergoes a nuclear reaction, the fissile material is surrounded by a heavy material called a tomper. The same material may be used for both the tamper and the reflector; consequently, these terms are often used interchangeably. If constructed of fissionable material, e.g., U-238, the tamper will contribute to the fission yield as a result of the fissioning of its nuclei by the fast neutrons coming from the interior (see also Thermonuclear Weapon Design).

Two basic nuclear weapon design approaches that are used to achieve a supercritical mass of fissile material are the implosion technique and the gun assembly technique. In the implosion technique, a peripheral charge of chemical high explosive (HE) is uniformly detonated in a manner designed to compress (implode) a subcritical mass into a supercritical configuration. For example, an implosion device might consist of a spherical core of fissile material (a fraction of a critical mass) surrounded by a material that acts as both a tamper and a reflector; the tamper is then surrounded by high explosives. When detonated, the explosive sets up an implosion, or ingoing shock wave, that can create overpressures of millions of pounds per square inch in the core, increasing the density by a factor of two or more and thereby making the previously subcritical mass supercritical. The material occupying the volume within the surrounding high explosive charge, including the fissile core and the tamper/reflector, is commonly referred 'n as the "pit."

The implosion technic ue is commonly used in nuclear weapons where the fissionable material is Pu-239, U-235. or a composite of the two. It was used in the first U.S. nuclear test (Trinity, 16 July 1945) and also in Fat Man. the second nuclear weapon dropped on Nagasaki, Japan; the spherical assembly consisted of a thick charge of high explosive to compress a subcritical mass of Pu-239 surrounded by a thick layer of U-238 that served as both the tamper and reflector.

The gun device involves the assembly of two (or more) masses of fissionable material, each less than a critical mass. A conventional explosive is used to propel the subcritical pieces of fissionable material together. thereby assembling a supercritical mass. For example, a subcritical mass of fissionable material can be propelled down a tube, i.e., shot down a "gun barrel," into a second subcritical mass. This approach was used in Little Boy, the U-235 weapon dropped on Hiroshima, Japan. For that weapon, the second mass was held in a tamper consisting of a thin layer of tungsten carbide on the inside and steel on the outside. The W33 artillery fired atomic projectile now in the U.S. weapons stockpile

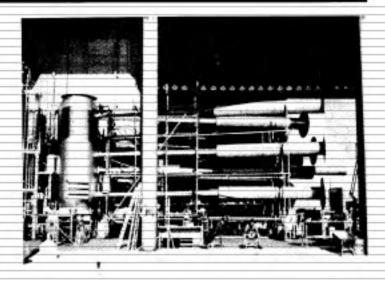


Figure 2.3 The Mike device, the first successful thermonuclear test, had a reported weight of 62 tons, due in part to the cryogenic equipment needed to maintain its thermonuclear fuel, deuterium, at liquid temperatures. Tested 31 October 1952 in Operation Ivy, at Elugelab, Enewetak Atoll, Mike had a yield of 10.4 megatons

utilizes the gun assembly technique. Gun devices are conceptually relatively simple and can be designed with high confidence. Their design almost of necessity requires the use of U-235, rather than plutonium. Because an implosion device can generally be made with higher efficiency (higher yield for same amount of material) than a gun device, most fission devices in the U.S. stockpile, even those utilizing U-235 alone, use the implosion rather than the gun assembly technique.

Fusion Weapons

Fusion Reactions

"Thermonuclear" weapons, also referred to as "fusion" or "hydrogen" weapons, are usually defined as atomic weapons in which at least a portion of the release of energy occurs through nuclear fusion. The fusion reaction rates are extremely sensitive to temperature and are extremely small at normal temperatures. Only at 10-100 million degrees Kelvin—the interior of the sun is 14 million degrees Kelvin-are the rates sufficiently high to make fusion weapons (or reactors) possible; hence the term "thermonuclear." In thermonuclear weapons, the required temperatures and the required density of the fusion materials are achieved with a fission explosion.

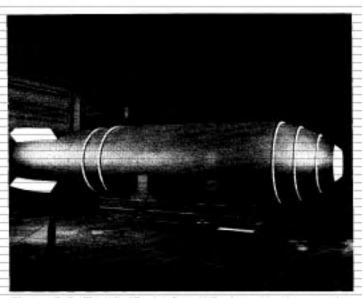


Figure 2.4 The Mk-17, the first U.S. droppable thermonuclear bomb to be tested, weighed 21 tons and had a yield in the megaton

Thermonuclear Fuels

As noted previously, the D-T reaction is the principal source of fusion energy in thermonuclear weapons.25 It is not necessary, however, to use elemental deuterium and tritium, which are gases at ordinary temperatures. directly in a thermonuclear weapon. The principal thermonuclear material is likely to be lithium-6 deuteride. which is a solid chemical compound at normal temperatures. In this case the tritium is produced in the weapon itself by neutron bombardment of the lithium-6 isotope during the course of the fusion reaction.** Since tritium decays radioactively (5.5 percent is lost each year),** lithium-6 deuteride has the added advantage of a longer storage life compared to tritium. Once fusion burn has been initiated, the action of fast neutrons on the isotope lithium-7, in the material lithium-7 deuteride, could be the source of additional tritium.26

By incorporating thermonuclear fuel, typically deuterium and tritium gas (or lithium hydrides) directly into (or proximate to) the core of fissile material, the efficiency of the fission bomb can be improved; that is, one can obtain a much higher yield from a given quantity of fissile material, or alternatively the same yield with a much smaller quantity. This process is called "boosting."29 The fusion process itself may add only slightly to the yield of the device. Far more important to the yield is the extra quantity of free neutrons produced as a result of the fusion reaction.30 These in turn produce additional fissions in the plutonium or uranium in the weapon, resulting in the increased efficiency. Thus, in boosted weapons, the thermonuclear fuel is used primarily as a source of neutrons to help the fission reactions, rather than as a direct source of yield. Boosted weapons are therefore basically fission weapons.

Thermonuclear Boosted Fission Weapons

Because tritium decays radioactively, the effectiveness of the boosting process can degrade with time. Consequently, in stockpiled weapons which use tritium gas, the tritium is periodically replaced to ensure that a sufficient amount will be available.

Thermonuclear Weapon Design

In thermonuclear weapons, the fusion material can be incorporated directly into (or proximate to) the fissile core-for example in the boosted fission device-or external to the fissile core, or both. In the latter cases, radiation from a fission explosive is contained and used to transfer energy to compress and ignite a physically separate component containing the fusion material (and in some cases fissile material). The fissile core is referred to as the primary, and the component with the fusion material external to the primary is called the secondary. The weapon in this case would be said to have two

The radiation from the fusion secondary can be contained and used to transfer energy to compress and ignite a third, or tertiary, stage, and the tertiary could similarly ignite a fourth, and so on. There is no theoreti-

26 Tritium is bred from lithium-6 in the reaction:

LE + n -> Het + T + 48 MeV.

When this reaction is combined with reaction (i) in footnote 4 of this chapter, the net thermonuclear reaction is:

LP + D - 2 He* + 22.4 MeV

27 Tritium has a half-life of 12.33 years.

 $\mathbf{L} \mathbf{F} + \mathbf{n} \rightarrow \mathbf{T} + \mathbf{H} \mathbf{e}^* + \mathbf{n}$

This tritium borus was verified in 2864; see Lee Bowen, A History of the Air Force Atomic Energy Program 1943-1963 (Washington: USAF Historical Division), Vol. IV, p. 46.

contributed only a small amount to the 225 Kt yield.

30 Complete fusion of 1 kg of D-T releases about 15 times as many free neutrons as the complete fesion of 1 kg of uranium or plutonium. Alternatively, fusion produces up in 5 times more free neutrons than faction for the same energy.

²⁵ A notable exception is the first full-scale American thermonuclear explosion (Mike Shot, Operation Ivy. Eneroetak Atoll. 31 October 1982), which used liquid deuterium and had a yield of 10.4 megatom (80), but this was a nuclear "device" designed for experimental purposes, not a prototype for an operational bumb.

²⁹ The boosting principle was recognized at least as early as November 1945 when possibilities of this general type were included in a patent application filed at Los Alamos. The designation "booster" only became general after its use by Educard Teller in September 1947; J. Carson Mark. "A Short Account of Los Alamos Theoretical Work on Thermonuclear Weapons, 1946-1960," LA-9947-MS, (Los Alamos: LASL, July 1974). p. 9. Teller in 1947 invented a "booster" design using liquid deuterium and tritium as the thermonuclear fuel. The design of this device was frozen in October 1950, and It was tested on 34 May 1951 in Shot Item of the Greenhouse series J. Carson Mark. The Bulletin of the Atomic Scientists, March 1965, p. 47. The detonation of this 45 5 Kt device was a major contribution to the development of thermonuclear weapons. Shot George, an earlier denonation of this series (on 6 May 1951) produced the first significant U.S. thermonuclear reaction. George was an experiment using a fission bomb to ignite a small quantity of deuterium and tritium that

Enhanced Radiation Weapons

cal limit to the number of stages that might be used and, consequently, no theoretical limit to the size and yield of a thermonuclear weapon. A thermonuclear weapon with a separate primary and secondary may, but does not necessarily, take advantage of boosting the primary.

While uranium-238 cannot maintain a self-sustaining fission explosion, it can be made to fission by an externally maintained supply of fast (highly energetic) neutrons from the fission or fusion reactions. Thus the yield of a nuclear weapon can be increased by surrounding the device with U-238, in the form of either natural or depleted uranium. This approach is particularly advantageous in a thermonuclear weapon where there is an abundance of fast neutrons from the fusion reaction. In a thermonuclear device, this U-238 blanket is sometimes referred to as the third stage of what would otherwise be a two stage weapon.

In general, the energy released in the explosion of a large thermonuclear weapon stems from three sources—a fission chain reaction, the first stage: "burning" of thermonuclear fuel, the second stage: and the fission of the U-238 blanket (if one exists), the third stage—with, very roughly, half the total energy stemming from fission and the other half from fusion. However, to obtain tailored weapons effects or to meet certain weight or space constraints, different ratios of fission-yield-to-fusion-yield may be employed, ranging from nearly pure fission yield weapons to a weapon where a very high proportion of the yield is from fusion.

Enhanced Radiation Weapons (Neutron Bombs)**

The "neutron bomb" is a thermonuclear device designed to maximize the lethal effects of high energy neutrons produced by the fusion of deuterium and tritium and to reduce the blast (the kinetic energy of charged particles) from the explosion. In this weapon

the burst of prompt nuclear radiation (neutrons and gamma rays) is enhanced by minimizing the fission yield relative to the fusion yield. This is accomplished, in part, by the elimination of (or substitution for) U-238 components, particularly the U-238 tamper and blanket. Thus, the neutron bomb is referred to as an "enhanced radiation" (ER) weapon.

The neutron bomb uses deuterium with tritium, rather than lithium-8 deuteride, as the fusion material to maximize the release of fast neutrons. Each reaction of one deuterium nucleus with a tritium nucleus gives rise to a neutron with an energy of approximately 14 million electron-volts (or a "14 MeV neutron"). Such neutrons from fusion are up to six times more numerous per kiloton of energy release than are neutrons escaping from the fission chain reaction in a fission bomb.³¹

Consequently, for a given explosive energy release, it is possible for a lethal dose of nuclear radiation to be delivered on the battlefield for a somewhat greater distance in the case of a neutron bomb than for a fission weapon. The lethal radius of a neutron bomb's radiation dose for a low altitude burst is about 700 meters. This is about twice the lethal radius of a fission weapon with an equal yield and about the same lethal radius as a fission weapon with ten times the yield.

For intermediate and large yields, the destructive radius of the blast generally far exceeds that of nuclear radiation. The blast damage radius drops off more rapidly with decreasing yield than the lethal radius of the radiation. Only in the energy range of 1 Kt and below would the radiation kill radius of an ER weapon (due to high-energy neutrons) considerably exceed the destructive radius of the same weapon due to blast." Although a 1 Kt ER weapon has a lethal radius for nuclear radiation equal to that of a 10 Kt fission weapon, the fission weapon has a considerably greater radius for blast damage to urban structures."

^{36.} A pressure of 4 psi (pounds per square inch) produces a moderate level of blast damage to urban structures, boths? radiation and labor damage radii in maters for low altitude boost (150 maters) are as follows [Cohen, op. cr., and S.T. Cohen, Strotegic Review, Winter 1978, p. 8]:

	Redius (m)	
Weapon	8000 red	4 psi
I KI ER	690	550
1 Kt fasion	360	632
30 Kr fission	600	1220

³¹ White other fissionable materials such as U-234, U-236, and Th-232 could also be used, U-238 is used because it is readily available as tails from the artichment plants (in quantities for more plentiful than U-234 or U-236), and it has a higher fission cross section than Th-232

³² See Richard L. Garwin, "Trends in the Technological Development of Nuclear Weapons Systems," Third Draft of Chapter 2 for 1980 UN Report on Nuclear Weapons, 37 March 1980, pp. 30-30; Rierbert Scortile, pr., "The Neutron Bornh," The Arms Rose and Arms Control, SePRI, 1982, p. 113, and S.T. Cohen, The Neutron Bornh (Cambridge, Mass. Institute for Poreign Policy Analysis, Inc., November 1970, p. 66. \$\frac{\pi}{2}\$.

tute for Foreign Policy Analysis. Inc., November 1976, p. 66 ff.
33. The energy released from a typical flow-yield; fasion both consists of 50 percent blast, 35, percent thermal radiation (health). 5 percent prompt radiation (garmen-rays, x-rays, and seutrons), and 40 percent residual radiation (failout), whereas an ER weapon consisting of half fasion and half fusion releases energy as 40 percent blast, 25 percent thermal, 30 percent pointp. and 5 percent residual radiation. Perc Kaplan, "The Neutron Bomb, The Bulletin of the Aronic Scientific, Chendre 1961, p. 6.

Bulletin of the Atomic Scientists, October 1981, p. 6.

34. Estimates used by the U.S. Army (and the joint Chiefs of Stuff) are that a dose of 8000 rads is necessary to inflict "immediate permanent incapacitation" on a human being. The "military radies" for each attential radies) is the distance from ground zero inside of which the dose is greater or equal to this value. Following are the dose radii for tank crows for doses of 8000 and 680 rads. At 680 rads personnel will become functionally impaired within 2 hours of exposure. Badia are in meters for a burst height of 180 meters. [Cohes. op. cit.] Socialle, op. cit.]

³⁵ Theoretically, the pressure at a given distance from an explosion is proportional to the cabe root of the energy yield see Glassoone and Dolan, op. etc., p. 100. Thus, a doubling of the blast kill radius results from an 8-fold increase in yield; the same 8-fold increase of yield adds only about 400 m to the prompt lethal radius of nuclear radiation effects for a neutron bomb. The difference in scaling occurs because the neutrons and gamma rays are stongly absorbed in the atmosphere while the blast wave is only slightly attenuated.

A 1 Kt neutron weapon is more costly to manufacture than a 10 Kt fission weapon. A neutron weapon also has more constraints on its delivery, in part because of the need to maintain the tritium supply.

Third Generation Weapons

A new "third generation" of advanced nuclear weapon concepts is now emerging.™ These weapons are described as being highly selective in their effects and suited to "purely defensive" use for destroying an adversary's offensive systems. Development is being led to by the Lawrence Livermore National Laboratory to with participation of other weapons laboratories. The new designs are to be ready for introduction in the 1990s.45

Among third-generation concepts are the following:

- An x-ray laser pumped by x-rays from a nuclear explosion for use as a defense against incoming enemy ballistic missiles above the earth's atmosphere, or as an antisatellite weapon.48
- Enhanced radiation (ER) weapons of very low yield (50-100 tons) guided by radars into the path of incoming ballistic missiles high in the atmosphere. Compared to these weapons, the ER weapon for battlefield use is characterized by officials as a "crude forerunner"44 of a third-generation ER weapon; the ER warhead of the SENTRY anti-ballistic missile system (now under intensive development at Livermore) is described as a device "at the beginning of the defensive use of nuclear weapons."43
- EMP weapons specially designed to create a large electromagnetic pulse (EMP) to burn out enemy communications, utilizing directed or non-directed EMP created by a nuclear explosion above the atmosphere.

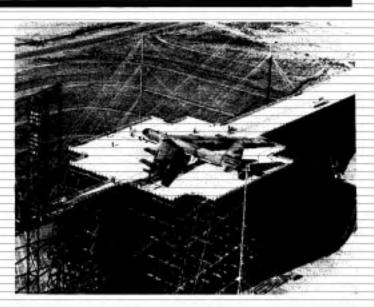


Figure 2.5 8-52 sits atop the TRESTLE electromagnetic pulse simulator at Kirtland Air Force Base, New Mexico. Ten million volts of EMP energy are created to simulate effects from nuclear explosions on aircraft and electrical equipment.

The realm of advanced technologies now includes a directed form of EMP using a "high power microwave coherent beam of immense peak power." The Department of Defense Directed Energy Program (under DARPA) includes "radio frequency weapons" as one of its three major programs. "6

The feasibility of reliable "defensive" nuclear weapons has been questioned by some familiar with weapons design. Skepticism about the use of the x-ray laser as a new weapon has been particularly keen.4" One critic has noted that "in the nuclear area, the offense will continue to have the advantage and can negate any defensive weapon with relatively little effort."48 It has been suggested that should a defensive breakthrough occur, "it will probably not involve either nuclear fission or fusion in an essential way."49

For both ER and fission weapons, prompt radiation is the predominant battlefield effect The radiation-kill radius for tank crews is significantly larger for both the 1 Kt ER and 10 Kl fastion weapons than the radius at which the tanks themselves will be damaged by blast. (For a discussion of bartlefield strategies see Scorille, op. 68).

37. The first generation was in the 1940s and 1950s when the first nuclear bombs and warhoods.

were developed. The second generation came in the 1960s with the development of compact high-yield workeads. 38 Iudith Miller, New York Times, 29 October 1982; FAS Newslyster, October 1982; p. 6.

Edward Teller, Science, 24 December 1982, p. 1270.

^{41.} As stated in the Directors' Comments of the FY 1982-1987 Lascrence Livermore Institutional Plan (1962, p. 2., later recalled), "Increased demand for modern nuclear weapon systems. coupled with significant developments in the design of a new nuclear weapon for hallistic missile defense applications and a concept for directing the energy of a nuclear weapon, strengthens our recommendation for additional attention in the areas of nuclear design and

⁴² Dr. Richard Wagner, HASC 97-41, April 1982.

⁴³ The nucleur pumped x-ray laser was reported to have been successfully tested under-ground at the Nevada Test Site by Lawrence Livermore scientists; see AWAST, 33 February

⁴⁴ Quote from Judith Miller, New York Times, op. cit.
45 Edward Teller in quoted in FAS Newsletter, op. cit., p. 8.
46 Letter of Charles E. Kinney, Science 82, March 1989, p. 21.
47 For example, by Richaed Garwin, as reported by David Proliman. Son Francisco Ghroniele.
25 September 1982. High E. DelWitt states that a variety of countermeasures could make the x-ray laser ineffective. For example, the enemy ballistic missile could release large pieces of metal chaff having the same radar image as the missile itself; see Hugh E. DeWitt. awnence Livermore National Laboratory, in letter to Devid Saxon, President, University of California, 3 October 1982.

⁴⁶ Hans A. Beibe, Science, 24 December 1982, p. 1270. Bethe is reported to have later said. after reviewing theoretical designs and studies for the x-ray leser at LLNL, that "this is the one and only one proposal that makes scientific sense," but "to translate this into an operational device is a fantastic business", R. [effrey Smith, Science, 1 July 1985, p. 30. 69 Herbert F. York, Science, 21 January 1983, p. 236.

Warhead Features

A nuclear weapon consists of a nuclear warhead package of fissile and/or fusion materials. Typically, it also contains a sequencing microprocessor; chemical high explosives; a neutron actuator; an arming system, the component which serves to ready (prearm), safe, or resafe (disarm) the warhead; a firing system; a fuzing mechanism (radar, pressure sensitive, time) which regulates the detonation of the warhead; and control and safety devices; all of which may or may not be an integral part of a warhead package, depending on its design and age.

Warhead Safety and Control

Depending upon its age and deployment location, each warhead contains safety and control devices which are to prevent accidental, unauthorized use (prearming, arming, launching, firing) or inadvertent use of nuclear weapons. In some cases, the safeguard and arming features are no more than a wire seal, a switch, and a lock; however, the modern weapons (and all weapons deployed outside the United States) have a series of complementary features, including locked containers and code controlled arming and fuzing systems. In addition, the "two-man rule"-which requires a minimum of two authorized personnel (each capable of detecting incorrect or unauthorized procedures) present during any functions where people come in contact with nuclear weapons or code materials related to their release-enforces adherence to safety and security procedures.™

The most significant control feature of the warhead, the Permissive Action Link (PAL), is the incorporation of a coded switch or lock device in the arming line. A PAL is a coded "lock" that requires the insertion of a proper number (manual combination or electronic digits) in order to "open" (unlock) circuits to arm the weapon. With the newer PALs, after the repeated unauthorized entry of false numbers, the weapon locks, certain key components are made unusable, and the warhead would have to be returned to the assembly plant for repair. Each typical PAL device (Category D) costs about \$50,000.

Each successive generation of PAL devices since their introduction—the latest is the "Category F" PAL—has represented more than just an increase in safety. The evolution of PAL from the original single code combination lock device for warheads (still deployed on some

Table 2.1
Warhead Safeguard Features

Commend	inertial nonviolent code activated dis-
Disable	abling device which destroys critical
77,344,7	warhead components, rendering the
	warhead useless, integrated into the
	storage container
Electical Safety	surge capacitors, exclusion region,
	for weak link/strong link system
Environmental	barometric pressure sensor for arm-
Sensing Device	ing bombs and artillery projectiles
(ESD)	
Permissive Action	mechanical combination lock
Link ²	2.0,24.712,27.000 (0.00,20)
Category A	
Category B	ground and airplane operated 4 digit
	coded switch, later version with limit-
	ed try
Category C	single 6 digit coded switch, with limit-
	ed try
Category D	multiple code 6 digit coded switch,
	with limited try
Category F	multiple code 12 digit coded switch,
	with limited try
Unique Signal	arming-safing signal encoder for
Generator	firing system requiring unique electri-
	cal signal
Weak Link/	exclusion region for warhead electri-
Strong Link	cal system preventing inadvertent or
2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2	accidental electrical surges and firing

ACDA, FY 1978 ACIS, p. 96; ACDA, FY 1979 ACIS, p. 121; SASC, FY 1978 ERDA, p. 100.
 ACDA, FY 1979 ACIS, pp. 92, 130, SASC, FY 1981 DOE, pp. 74-76.

older weapons) to the present 12 digit electronic "multiple-code coded switch" made it possible to control the release of individual warheads and specified yields, each with a uniquely generated code. Thus the "safety" features also serve to support the evolving limited nuclear war strategies.

The other safety and control systems incorporated into the warheads or containers besides the PAL—command disable feature, electrical safety, weak link/strong link, unique signal generator, etc.—are described in Table 2.1, Warhead Safeguard Features. Many newer weapons also contain "insensitive high explosives" (IHEs), a more stable chemical compound than previously used high explosives to "guard against detonation from fire, small arms, aircraft crash, or inadvertent release in flight."" IHEs, which are more expensive and

U.S. Army, Operations for Nuclear Copuble Units, PM 100-30 (March 1980), p. 11.
 SABC, FY 1982 DOE, pp. 388-387; background is also provided in Military Applications of Nuclear Technology, Part 1: pp. 44ff.

⁵² ACDA, FY 1979 ACIS, p. 92, ACDA, FY 1978 ACIS, p. 96

⁸³ ACDA, FY 1676 ACIS, p. 136.

⁵⁴ ACDA, FY 1979 ACIS, p. 92-

heavier than previously used high explosives, will only be integrated into weapons which are transported frequently. According to the Sandia Corporation, "insensitive high explosives minimize the risk of detonation . . . thereby reducing the risk of scattering of plutonium."50 The IHEs, first incorporated into the B61 Mod 3 and 4 bombs, are now in the W80 cruise missile warhead and programmed for most future warheads.14

Selectable Yields

There is little in the open literature describing how the yields of current nuclear weapons are varied. The actual designs probably incorporate one (or more) of the following procedures.

In a pure fission device, the yield can be varied by varying the timing of the initiation of the chain reaction or by interchanging pits. In modern weapons, the chain reaction is initiated by a neutron gun.

In a boosted fission weapon, or a thermonuclear weapon with a boosted primary, the yield can be varied readily by carefully selecting the amount of tritium gas bled into the fissile core from an external reservoir.87

In thermonuclear weapons with one (or more) fusion stages, the yield is varied by tritium control or by interchanging the pits. In addition, mechanical measures that dictate whether or not additional fusion stages ignite could be used, although there is no evidence in the open literature that this is done. The yield of some older bombs in the U.S. stockpile, e.g., the B28, appears to be varied by interchanging the pits. This procedure, which is performed on the ground, is less flexible than selecting the yield by tritium control, the approach used in more modern weapons.

Weights and Yields of Nuclear Weapons

The first nuclear explosive device, called the Godget, had a plutonium core weighing about 13.5 lb (6.1 kg) which was imploded by some 5000 lb of high explosive.55 The Godget was tested at the Trinity Site's 100 foot tower in Alamogordo, New Mexico (16 July 1945,

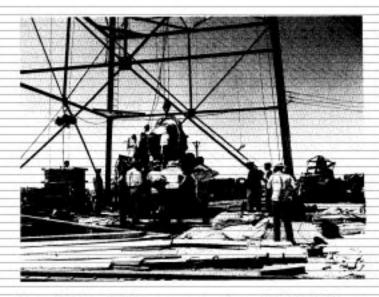


Figure 2.6 The 100 foot tower at ground zero of the Trinity Site at Alamogordo, New Mexico. It was built to test the "Gadget" contained (without its plutonium core) in the crate at the base of the tower

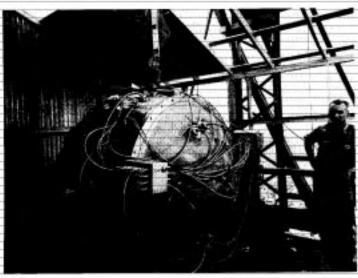


Figure 2.7 The "Gadget"-prototype for the Fat Man weapon design—at the top of the tower at the Trinity Site shortly before its test on 16 July 1945.

⁵⁵ SASC, PY 1981 DOE, p. 74

⁵⁶ RASC, FY 1960 DOR, p. 348.
57 Both tritium gas and deuterium gas in a selected volume ratio could be bled into the weapon's "pit" during the aemitg sequence.

⁵⁶ Major Gen. Lealie R. Groves, Memorandum for the Secretary of Wer. 18 July 1945, TOP SECRET (DECLASSIFIED) reprinted as Appendix P to Martin J. Sherwin, A World Destroyed (New York: Alfred A. Knopf, 1975); see also James W. Kunetke, City of Five. (Englewood Claffs, N.J.: Prentice-Hall, Inc., 1978), p. 784.

Weights and Yields

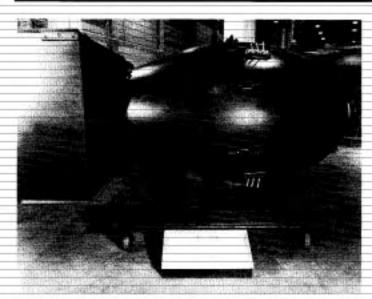


Figure 2.8 Plutonium fission weapon of the Fat Man type. Fat Man was the atomic bomb that was dropped on Nagasaki, Japan on 9 August 1945, Its yield was 22 kilotons

5:29 am), with a yield of 22 ± 2 Kt.39 The following description is from Kunetka.40 "While the actual size of the plutonium core was about that of a grapefruit, the uranium tamper and explosive charges added considerably to the bomb's size. The core, tamper, and high explosives were held in place by a metal sphere made of twelve pentagonal sections. These were bolted together to form a sphere ..."

Fat Man, the nuclear weapon which was dropped on Nagasaki, Japan (estimated 503 meters or 1650 ft.41 9 August 1945, 11:02 am), was based on the same design as the Gadget; the weapons' names are often interchanged. Fat Man included stabilizing fins and a protective eggshaped outer shell, or bomb casing, 60 inches in diameter. The bomb was 12 feet long and weighed 10,800 th with fins. 72 The yield of the Fat Man has been wellestablished at 22±2 Kt.69

Little Boy, the nuclear weapon dropped on Hiroshima, Japan (estimated 580 meters or 1903 ft,4 6 August 1945, 8:15 am), contained 60 kg of highly enriched uranium and utilized the gun assembly technique." The



Figure 2.9 Nuclear weapon of the Little Boy type. Little Boy was dropped over Hiroshima, Japan on 6 August 1945, the first nuclear weapon ever delivered. It was 120 inches long, 28 inches in diameter and weighed 9000 pounds.

gun barrel had a diameter of over 6 inches, was 6 feet in length, and weighed about one-half ton (or less than one-fifth the weight of standard guns of that calibre). The bomb with its casing was 10 feet long, 28 inches in diameter, and weighed 8900 lb.** The yield of the Hiroshima Little Boy is uncertain, with estimates ranging from 12 Kt to 15 Kt.

The explosive yields of the first two implosion devices, the Gadget and Fat Man, both about 22±2 Kt, corresponded to an efficiency** of about 17 percent in utilization of the 6 kg of plutonium,[∞] whereas the 12 to 15 Kt Little Boy gun device had an efficiency of only about 1.3 percent. In order to achieve these efficiencies in the first U.S. designs, considerable weight was allocated to the chemical explosive and tamper. The yieldto-weight ratios were 0.0045 Kt/kg for the Fat Man, and 0.003 Kt/kg for the Little Boy, both very low compared to modern designs (see Figure 2.15).

The Mark III (based on Fat Man) was the only stockpiled implosion bomb from 1945 to 1948. In late 1948 the Mark IV assembly began entering the stockpile. Unlike

⁵⁹ Recvaluation by D. Eilers; see John Malik in V.P. Bond and J.W. Thissen, eds., Resvaluation of Dosimetric Fectors, Hiroshimu and Nagasaki, CONF-810028 (DE 81025-279) (Washington: U.S. DOE, Technical Information Center, 1982), p. 100. Nevada Operations Office. gives 19 Kt from an earlier evaluation, "Announced United States Nuclear Tests July 1945-December 1981." NVO-200 Rev-2 (U.S. DOE, Office of Public Affairs, Nevada Operations Office, January 1982)

⁶⁰ Kunetka, op. cit., p. 123

⁶¹ Malik, op. cit., p. 105. 62 Robert T. Duff, Director, Office of Classification, DOE, letter to David A. Rosenberg, 4 December 1980.

⁶³ Malik, op. ett., pp. 96, 100, 107. Nevada Operations office gives 23 Kt based upon an cardier evaluation: see U.S. DOS, Nevada Operations Office, op. cit., p. 22.

⁵⁴ Malik, op. cit. 85 John McPhee, The Curve of Binding Energy (New York: Farner, Strauss and Giroux, 1974).

⁶⁷ Malik, op. cit., pp. 98, 307. Malik gives values of 12±4 Kt deduced from blast effects, 18±3. Kt from thermal effects and a "auggested best value" of 15±3 Kt. Kerr (op. cit., p. 66) prefers an earlier value of 12.5±7 Kt. U.S. DOE, Nevada Operations Office, op. cit., quotes a value of 13 Kt. "[Robert] Opperheimer gave the Little Boy a good chance of 'optimal performance'; only a 12 percent chance of less than this: a 8 percent chance of an explosion under 5000 tons; and a 2 percent chance of one under 1000 tons of TNT'; Memorandum. from Robert Oppenheimer to General Leslie Geoves and William Passon. 23 July 1945; quoted by Kenetka. op. cit., p. 178.

⁶⁸ Since complete fission of 1 kg of Pu or U corresponds to 17.5 Kt.

 ^{∈ =} Y/17.8M
 where C = efficiency, Y = yield in K2 and M = mass in kg.

⁶⁰ For Fot Mon it is assumed that 80 percent of the yield was from fission occurring in the Pu-230 core and 20 percent in the U-238 tamper. See Kers, op. ok., p. 81.



Figure 2.13 The Army's 280mm atomic cannon, which was designed to fire the Mark-19, the first nuclear artillery shell.

The largest fission device ever detonated, the Super Oralloy Bomb, had a yield of 500 Kt.⁷³ This is larger than most thermonuclear weapons currently in the U.S. stockpile." At yields over approximately 50 Kt, thermonuclear weapons can be produced at much lower cost and much less weight than pure fission weapons. Consequently, one does not expect to see high yield fission weapons stockpiled.

The first successful test of a thermonuclear device was on 31 October 1952 with the 10.4 Mt Mike shot at Enewetak Atoll. The largest thermonuclear device tested was reportedly 58 Mt, a Soviet atmospheric test at approximately 12,000 feet at Novaya Zemlya, on 30 October 1961 76

As noted previously, only the practical considerations of weight and size limit the yield of deliverable thermonuclear weapons. The first deliverable thermonuclear warhead in the U.S. stockpile was the B17 bomb (retired in 1957) which weighed almost 21 tons and had a yield of several megatons." The largest warhead presently in the U.S. stockpile is the B53 bomb (and W53 warhead on the TITAN II missile) which has a yield of 9 Mt and a weight of 8850 lb, or a yield-to-weight ratio of about 2.2 Kt/kg, some 400 times that of Fat Man.

⁷³ Defense Nuclear Agency. "The Radiological Cleanup of Enswetak Atall" (Washington, D.C. 1981) p. 49. Event King, during Operation by 15 November 1952 (air drop detention). at 1500 feet). The Super Oralloy Somb was designed by Theodore Taylor at LANL: McPhan. p. cit., p. 8.

⁷⁴ For example, the thermonuclear W7E warhead—used on 300 MINUTEMAN III ICEMs—has a yield of 335 KI, the highest yield of any currently deplayed U.S. strategic missile, except for the 9 Mt TITAN II (WS3) warheads which are soon to be retired.

⁷⁵ U.S. DOE, Nevada Operations Office, op. cit. The weight of the Mike device has been

reported as 62 fone. Neyman and Sadillerike, op. cit., p. 20.
76 Harbert F. York, The Advisors (Sen Francisco: W&L Freeman and Company, 1876), p. 63.
see also Classione, 1984 Ed., Appendix B, p. 661A.

as also Grassone, 1994 Ed., Appendix 6, p. 601A.
7. National Alomic Museum, Albaquerque, NM, See Table T.4 for list of U.S. warheads: the B17 may have been tested as the Cherokee Shot in Operation Redwing (airdrop 4320 feet, at Bikini Atoll, 30 May 1986). The Cherokoe Shot was the first air drop by the U.S. of a thermonucleus weapon. See U.S. DOE, op. cit.

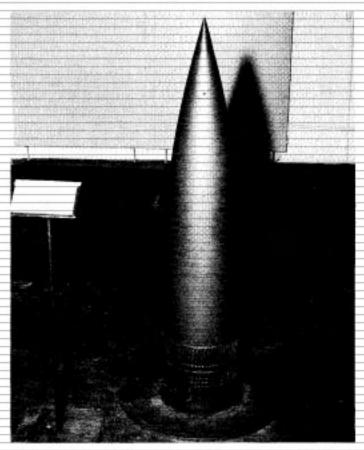
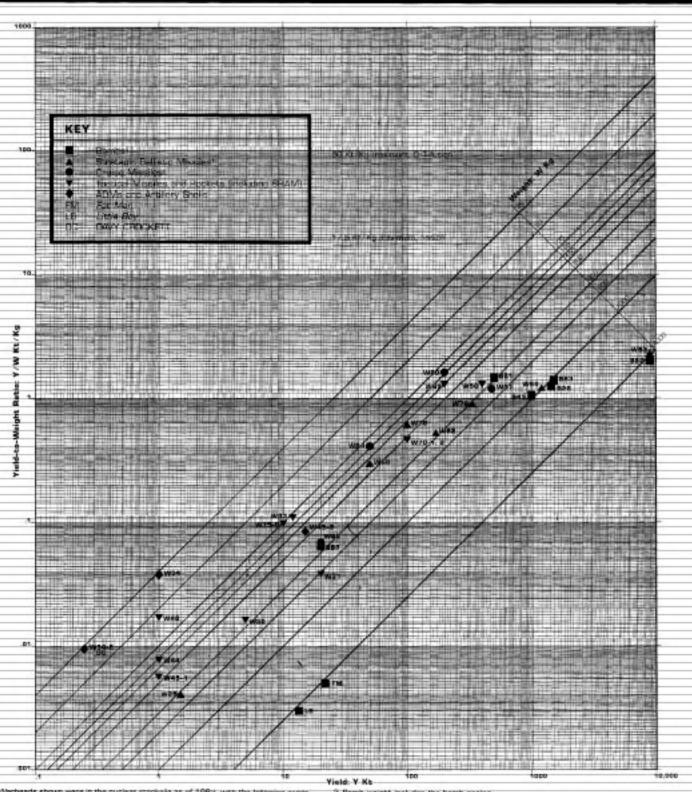


Figure 2.14 W19, a projectile for the Army's 280mm howitzer, was the first nuclear artillery shell. It was an oralloy weapon utilizing the gun assembly technique.

Modern thermonuclear weapons with yields above 100 Kt can be expected to have yield-to-weight ratios in the 1-3 Kt/kg range. This is still far below the theoretical limit of 80 Kt/kg represented by the complete fusion of deuterium-tritium material.18 Figure 2.15 shows a plot of yield-to-weight ratio versus both yield and weight for nuclear warheads and bombs currently in the stockpile. The strategic missiles and bombs with yields greater than about 100 Kt (concentrated in the upper right portion of the figure) show yield-to-weight ratios in the range 0.3-2.5 Kt/kg. The low-yield tactical nuclear weapons (in the lower left portion of the figure) all have substantially smaller yield-to-weight ratios in the 0.004 to 0.1 Kt/kg range.

Yield-to-Weight Ratios



[†] Werheeds shown were in the nuclear scookpie as of 1982, with the following exceptions. Retired: W54-2 DWY CROCKETT (DC), Little Boy (LB), Fat Man (FM). Planned editions: W84 BLCM, W85 PERSHING II, W87 MX, and B84 Modern Strytegic.

- Borno weight includes the borno casing.
 Bellietic missile weight consists of the workead package with the recentry vehicle and.
- a fraction of the bus. 5 For cruise missiles, weight is for warhead pockage only.

Figure 2.15 Yield-to-Weight Ratios vs. Yield and Weight for Current Stockpile Nuclear Weapons and Bombs.

Maximum yields are used where warhoods have variable yields. Data for yields and weights are subject to some degree of uncertainty.