Nuclear Weapons Databook

Volume II
U.S. Nuclear Warhead Production

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U.S. Nuclear Warhead Production

by

Thomas B. Cochran, William M. Arkin, Robert S. Norris,
and Milton M. Hoenig

A book by the
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Preface

The *Nuclear Weapons Databook* is meant to be a current and accurate encyclopedia of information about nuclear weapons It should assist the many people who are actively working on the problems of the nuclear arms race 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 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 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 three of several volumes on all aspects of the production, deployment and potential employment of nuclear weapons worldwide As now planned the *Nuclear Weapons Databook* will consist of at least nine volumes:

- I U S Nuclear Forces and Capabilities
- II U S Nuclear Warhead Production
- III U S Nuclear Warhead Facility Profiles
- IV Soviet Nuclear Weapons
- V British, French and Chinese Nuclear Weapons and Nuclear Weapons Proliferation
- VI The History of Nuclear Weapons
- VII Command and Control of Nuclear Weapons and Nuclear Strategy
- VIII Arms Control
- IX Environment, Health and Safety

Volume II and its companion, Volume III, like Volume I are based as much as possible on original documentation, and the source of information is indicated in the extensive footnotes accompanying the text 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 Please advise us also of other subject areas that should be included in future editions and any changes that could improve the format We would like to hear from experts willing to serve as contributors or reviewers of the various sections of the *Databook*, particularly in subject areas not now covered

Please address all correspondence to the authors at the Natural Resources Defense Council, 1350 New York Avenue, N W Suite 300, Washington, D C , 20005 (202/783-7800)

Volumes II and III of the *Databook* series describe the research, testing, and manufacture of U S nuclear warheads, focusing on the complex of facilities and the activities they perform Volume II is comprised of five chapters Chapter One provides an historical overview of the forty-year evolution of the U S nuclear warhead stockpile, noting its size, cost, growth, and diversity Chapter Two reviews the major laboratories, material production facilities, component production facilities, and test sites Chapter Three discusses the production of nuclear materials, estimates their inventories, and surveys initiatives underway to increase them Chapter Four describes the missions and functions of major civilian and military officials who decide upon the acqusition of nuclear warheads Chapter Five reviews the major technologies and processes used to produce nuclear materials

Volume III is comprised of profiles of thirty-four facilities where warhead research and development, testing, and production take place

These volumes of the *Databook* are designed primarily for those who need basic facts about U S nuclear warhead production It is meant for both layman and specialist Chapters I, II, and IV of Volume II give a general introduction to warhead development and production Chapters III and V, and the Appendices, entail more technical examinations of the nuclear fuel cycle, noting the types and quantities of material produced, and the technologies and processes involved Each facility profile in Volume III provides details on the facility's history, weapon and non-weapon activites, management, budgets, and personnel 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 is provided in Volume II Numerous tables and figures are used throughout the books to help illustrate the difficult technical material

Many gaps in data reflect the fact that we have been unable to get all the details about the history and activities of the warhead complex We hope that what is provided will be useful

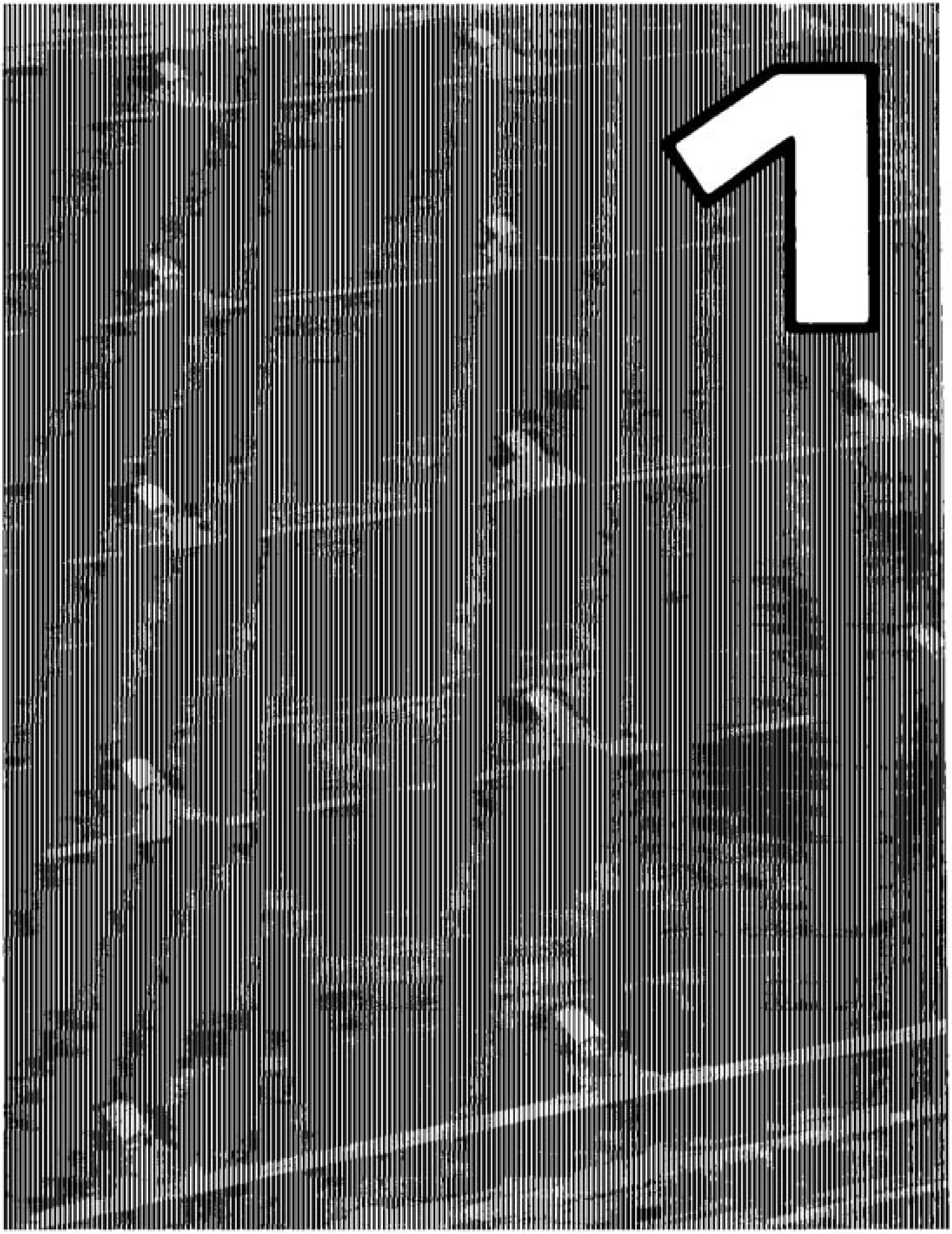
Acknowledgments

Volumes II and III of the *Nuclear Weapons Databook* could not have been compiled without the invaluable assistance of many institutions and individuals We are grateful to the U S Departments of Energy and Defense for their responsiveness to our numerous requests for information The Department of Energy's Operations Offices at Albuquerque, Oak Ridge, and Savannah River were particularly helpful The Arms Control Association, Federation of American Scientists, and the Center for Defense Information made available to us extensive data from their files

Frank von Hippel contributed valuable information and insights Robert Del Tredici also helped in making available a number of photographs We want to thank reviewers David Albright of the Federation of American Scientists, Gerald Brubaker, and assistance provided by Chuck Hansen Valuable research assistance was provided by Jeffrey I Sands of the Natural Resources Defense Council, and Richard W Fieldhouse of the Institute for Policy Studies Nevertheless, responsibility for all facts and analyses in the *Databook* remains solely that of the authors

The Natural Resources Defense Council and the authors wish to acknowledge gratefully the support and encouragement given to the *Nuclear Weapons Databook* by The Bydale Foundation, the Columbia Foundation, The Field Foundation, the George Gund Foundation, the W Alton Jones Foundation, The New Hope Foundation, the Ploughshares Fund, the Charles H Revson Foundation, the Rockefeller Family Fund, the Samuel Rubin Foundation, the Wallace Genetic Foundation, Mrs Philip S Weld, and an anonymous donor

We appreciate the continuing encouragement and support of the entire Board of Trustees and Staff of the Natural Resources Defense Council Very special thanks goes to Adrian W DeWind, Chairman of the Board, for his invaluable guidance and assistance We also want to recognize James Marshall, a member of the Board until his death in August 1986, and Joan K Davidson, NRDC Honorary Trustee, for their exceptional support and commitment John H Adams, Executive Director of NRDC, and S Jacob Scherr, Senior Staff Attorney, have also been enormously helpful We are deeply indebted to Barbara J Pratt, who prepared numerous Freedom of Information Act requests Wayne E Nail designed the Databook series and coordinated production Finally, we would like to thank Carol Franco, President of Ballinger Publishing Company, for her unfailing support of the *Databook* project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Chapter One

The Warhead Production Complex: An Overview

The United States has been engaged in the design, testing and manufacture of nuclear warheads since 1940 Four agencies or departments have overseen these activities—Manhattan Engineer District (1942-46), Atomic Energy Commission (1947-74), Energy Research and Development Administration (1975-77), Department of Energy (1977-) Together, they have spent approximately $89 billion ($230 billion in FY 1986 dollars) (See Table 1 1 and Figure 1 1) Meanwhile, the Department of Defense (DOD) has spent an estimated $700 billion ($1 85 trillion in FY 1986 dollars) on the nuclear delivery systems (aircraft, missiles, ships) and other support costs [1]

Since the inception of the Atomic Energy Commission (AEC) in 1947, U S policy has been to separate the developer and producer of nuclear warheads from the military forces that would employ them This separation still exists The relationship between the "producer" and the "consumer" has changed, however In the early days the AEC was a coequal, if not predominant, influence on warhead policy The AEC had physical custody of the weapons, even at deployment sites Only if the weapons were to be used would custody be relinquished to the military Over the years the AEC lost its physical custody over deployed warheads; its status diminished and its responsibilities were redefined

Custody and the Division of Responsibility

The battle over the custody of deployed warheads was fought over the acrimonious issue of civilian versus military control Technology and geopolitics favored the latter Already by the 1950s nuclear systems so permeated acquisition, deployment, and employment policy that it was only a matter of time before the military wou'd gain control of the warheads [2] Though the military eventually won it did so only in stages over a period from 1947 to 1967 The AEC grudgingly transferred, first, non-nuclear components, then nuclear components and complete warheads These were followed by low yield (under 600 kilotons) warheads, then high yield warheads, and finally a reserve [3]

The first step was taken on 14 June 1950 when President Truman approved the transfer of ninety Mk-4 non-nuclear assemblies for training purposes to Armed Forces Special Weapons Project bomb assembly teams In July 1950, several weeks after the outbreak of the Korean War, President Truman "directed the AEC on a case by case basis to transfer the custody of bomb capsules (minus their nuclear explosives) to the Air Force and Navy for deployment to selected overseas locations "[4] In the spring of 1951 Truman directed the AEC to deliver to the DOD a small quantity of nuclear components to be positioned on Guam [5] In the following year the military quest for custody intensified, under pressure from the Joint Chiefs and with support of the Secretary of Defense This eventually led to presidential approval on 10 September 1952 of certain concepts concerning atomic weapons The most important of these was that the Department of Defense should have custodial responsibility for stocks of atomic weapons outside the continental United States and for such numbers inside the United States as "may be needed to assure operational flexibility and military readiness " while the AEC should maintain custodial responsibility for the remainder [6]

1 Figures are outlays computed by using the methodology in *The Defense Monitor* XII 7: 3 with Tables 6 4 6 5 6-11 in Office of the Assistant Secretary of Defense (Comptroller) *National Defense Budget Estimates for FY 1986* March 1985

2 The Joint Chiefs of Staff (JCS) stated in a memo to the National Security Council on 6 February 1952 that:

> The steadily increasing quantity of completed atomic weapons has among other things contributed to a broad and far-reaching evolution in the United States military concepts in the fields of strategy and tactics as well as in the size nature mission training and equipment of our armed forces for war The Strategic Air Command (SAC) as now constituted and equipped, has to a large extent developed around the atomic weapon Furthermore, developments now underway in the Tactical Air Command (TAC) and in Naval and Marine aviation are pointed toward full exploitation of their capabilities in this field The acquisition by the United States of its foreign bases has been dictated largely by atomic weapon considerations The atomic weapon now influences among other things, the configuration of all aircraft which are to be capable of carrying the atomic weapon, the design and modification of aircraft carriers, the mission and equipment of guided missile units and the development of guidance systems bombing systems, and certain special types of artillery It must be recognized therefore that the atomic weapon has become such an integral part of our plans and preparations for the conduct of a major war that it constitutes a vital element in the attainment of full military preparedness on the part of the United States

Foreign Relations of the United States 1952 1954 Volume II National Security Affairs Part 2 (Washington: Government Printing Office 1984), p 864

3 DOD *History of the Custody and Deployment of Nuclear Weapons July 1945 through September 1977* Prepared by Office of the Assistant to the Secretary of Defense (Atomic Energy) February 1978 declassified with deletions 1984

4 Steven L Rearden *The Formative Years 1947 1950: History of the Office of the Secretary of Defense* (Washington DC: Government Printing Office 1984) p 432

5 DOD, *History of the Custody and Deployment of Nuclear Weapons* pp 18 111

6 *Ibid* p 21 In the same 10 September document other concepts clarified responsibilities while marking a shift in the AEC/DOD relationship "The Department of Defense should state its military requirements for numbers and types of atomic weapons including the desired military characteristics thereof The Atomic Energy Commission should propose rates of production and production goals for weapon material in the light of stated military requirements and of the Commission s capabilities for meeting these requirements " Six months later a formal agreement would be drawn up that extensively defined the responsibilities of the AEC and DOD This agreement (with amendments) continues to establish today s procedures; see An Agreement Between the AEC and the DOD for the Development Production and Standardization of Atomic Weapons 21 March 1953

Figure 1 1 Atomic Energy Defense Activities 1940-90

The introduction of thermonuclear weapons into the stockpile brought new issues and procedures In 1955 President Eisenhower authorized that thermonuclear warheads under 600 kilotons (Kt) should be transferred to DOD Those over that amount (even those dispersed to military units) would continue to remain in AEC custody In 1959 Eisenhower directed the transfer of custody to the DOD of all weapons dispersed to the DOD This included, for the first time, those with yields in excess of 600 Kt The total number of weapons transferred to the DOD at that time constituted approximately 82 percent of the stockpile By the mid-1960s the AEC retained only a small reserve of warheads For fiscal year 1966 this constituted 1800 warheads, or about 6 percent of the stockpile Since these warheads were already at eight DOD storage sites, a cost saving could be achieved by eliminating the duplication in staffing On 10 February 1967 President Johnson directed the AEC to deliver this final reserve to the DOD With this accomplished, DOD achieved complete custody of deployed warheads

The DOD works in unison with the Department of Energy (DOE) on every aspect of the life cycle of a nuclear warhead Each is assigned distinct responsibilities In the early years the AEC dominated nuclear weapons policy because of the limited warhead types available, their ability to produce them, extreme compartmentalization and secrecy, and their custody of the weapons Today, even with its ability to design a nuclear warhead for virtually any kind of system and its huge production complex, DOE's role has been reduced to that of providing engineering support to meet DOD's demands The military services and commands, with DOD approval, establish the military characteristics (e g , dimension, weight, yield) and requirements for nuclear warheads The DOD develops and produces delivery vehicles and support equipment, and trains and deploys forces for their use

The DOE is responsible for the design, test, manufacture, assembly, and retirement of warheads It produces the "special nuclear material" (uranium, plutonium, tritium) and warhead components, certifies the technical

1

Warhead Budgets (1940–90)

Table 1 1

Atomic Energy Defense Activities: 1940-90

FY	Current dollars (in millions)	Constant FY 1986 dollars (in millions)
1940 NDRC[a]	0 5	4 8
1941 & 1942	15	135
1943	77	676
1944	730	6234
1945	859	6598
1946	366	2458
1947 (MED Part)	186	1264
1947 (AEC Part)	69	463
1948	475	2827
1949	566	3255
1950	463	2675
1951	679	3570
1952	1525	7255
1953	1682	7801
1954	1791	7707
1955	1731	7668
1956	1478	6764
1957	1765	7618
1958	1973	8129
1959	2100	8635
1960	2119	8287
1961	2114	8209
1962	2074	8102
1963	2041	7690
1964	1902	7008
1965	1620	5842
1966	1466	5076
1967	1277	4290
1968	1336	4286
1969	1389	4199
1970	1415	3995
1971	1385	3666
1972	1373	3413
1973	1409	3314
1974	1486	3287
1975	1506	2981
1976 + TQ[b] ERDA	2000	3642
1977	1936	3310
1978	2070	3338
1979 DOE	2541	3816
1980	2878	3985
1981	3398	4168
1982	4309	4979
1983	5171	5786
1984	6120	6620
1995	7098	7368
1986	7152	7152
1987	7708	7404
1988	8400	7797
1989	9000	8094
1990	9350	8204

a The National Defense Research Committee (NDRC) was established by Executive Order on 7 June 1940 The Office of Scientific Research and Development was established by Executive Order on 28 June 1941

b The FY 1976 figure includes the transition quarter from 1 July to 30 September 1976 ($435 million current $755 million constant)

Sources Richard G Hewlett and Oscar E Anderson Jr *The New World, 1939/1946* (University Park, Pennsylvania The Pennsylvania State University Press 1962) pp 723-24; Richard G Hewlett and Francis Duncan *Atomic Shield* Volume II 1947-1952 (Washington, D C : AEC 1972), pp 676-77; Semiannual and Annual Atomic Energy Commission Reports to Congress; Office of Management and Budget To calculate FY 1987 constant dollars multiply FY 1986 dollars by 104 1 percent quality of the stockpile through constant monitoring Both DOD and DOE review safety standards and logistic procedures

Numbers and Types

From 1945 to 1986 the nuclear weapon production complex has manufactured approximately 60,000 warheads of 71 types for 116 kinds of weapons systems Forty-two types have been fully retired, leaving twenty-nine in the current stockpile Of the seventy-one warhead types deployed the Air Force used forty-three, the Navy/Marines thirty-four, and the Army twenty-one Table 1 2 and Figure 1 2 summarize the production and retirement history of each of the seventy-one warhead types Twenty-nine "candidate" warhead types were cancelled before completing development An unknown number of warheads, probably several dozen, never advanced beyond Phase 1 or 2 "paper studies" Over 820 (to 31 December 1985) devices have been exploded in tests [7]

The Complex

The warheads are designed, tested, and manufactured in a U S government owned-contractor operated (GOCO) complex The complex spreads over thirteen states, covers a land area of 3900 square miles and employs some 90,000 people The major facilities are listed in Table 1 3 Appendix A lists the principal corporations, industrial firms, research organizations, and universities involved as DOE contractors, subcontractors, or in program support related to the research, development, production, and testing of nuclear weapons [8]

The warhead complex conducts four basic activities: weapons research and design, nuclear materials production, warhead component production, and warhead testing Two laboratories—Los Alamos National Laboratory (LANL) in New Mexico, and Lawrence Livermore National Laboratory (LLNL) in California—design nuclear warheads and conduct basic research on weapons systems and military applications of atomic energy and advanced sciences A third laboratory—Sandia National Laboratory (SNL) in New Mexico—provides engineering support to Los Alamos and Livermore for the design of non-nuclear warhead components Army, Navy, and Air Force laboratories supplement the DOE laboratories They conduct research on delivery techniques, nuclear effects, and safety

Much of the work in the complex is devoted to the production of nuclear materials for warheads—namely, fissionable plutonium and uranium, and the fusion materials deuterium, tritium, and lithium Large stocks of these materials had been produced by the mid-1960s, when the stockpile of U S warheads peaked Only plutonium and tritium are in production today One nuclear production reactor at the Hanford Reservation in Washington makes plutonium while four operating reactors at the Savannah River Plant (SRP) in Aiken, South Carolina, are designed to produce plutonium and tritium The four reactors dedicated to plutonium, one at Hanford and three at SRP, currently produce approximately two metric tons (MT) of plutonium annually This is plutonium augmented by stocks and recovery from retired warheads and scrap The inventory of weapon grade plutonium primarily in warheads totals some 93 MT

The tritium stockpile is estimated to be 70 kilograms (kg) With one reactor at SRP dedicated to tritium production approximately 11 kg of tritium are currently produced annually Since 5 5 percent of the tritium inventory decays radioactively each year, new production currently contributes a net of about 7 kg per year

Highly enriched uranium (93 5 percent U-235) metal for weapons (often called oralloy) has not been produced by the United States since 1964 The oralloy stockpile has been declining since that time as small quantities have been used as fuel for production and research reactors, and in test explosions Currently some 500 MT of oralloy is in or reserved for warheads This stockpile will increase in FY 1988 when DOE plans to resume oralloy production for warheads and fuel

Production of deuterium ceased in 1982 with the closing of the heavy water plant at Savannah River Similarly, there has been no enriched lithium production at the Oak Ridge Y-12 Plant since the early 1960s The requirements for these two materials have in recent years been met using material recovered from retired warheads and from existing stocks

The nuclear warhead components are manufactured at seven DOE-owned facilities The Rocky Flats Plant in Golden, Colorado processes plutonium and assembles "pits," containing the plutonium and enriched uranium cores These are used in fission weapons and as fission primaries in thermonuclear weapons The Y-12 Plant in Oak Ridge, Tennessee manufactures uranium components for the primary stage and the principal nuclear components in secondary stages of thermonuclear weapons The components in secondary stages are fabricated from lithium deuteride and uranium The Savannah River Plant in Aiken, South Carolina manufactures tritium and loads it into metal reservoirs (bottles) for incorporation into warheads The Mound Facility in Miamisburg, Ohio makes the detonators and various parts of the firing circuits The Pinellas Plant in St Petersburg, Florida manufactures neutron generators And the Kansas City Plant in Kansas City, Missouri manufactures electronic, plastic, rubber, and other non-nuclear parts All of these components are shipped to the Pantex Plant near Amarillo, Texas Pantex manufactures the chemical high explosive components and assembles

7 774 is the number of announced tests of which (at least) eighteen were joint U S /UK tests (see Appendix B)

8 'If the DOE defense complex were a commercial industry it would rank as one of the top 20 in the country' HASC FY 1986 DOE p 1 For additional details on the industry see Kenneth A Bertsch and Linda S Shaw, *The Nuclear Weapons Industry* Investor Responsibility Research Center Washington D C 1984; and Linda S Shaw Jeffrey W Knopf and Kenneth A Bertsch *Stocking the Arsenal: A Guide to the Nation s Top Military Contractors* Investor Responsibility Research Center Washington D C 1985

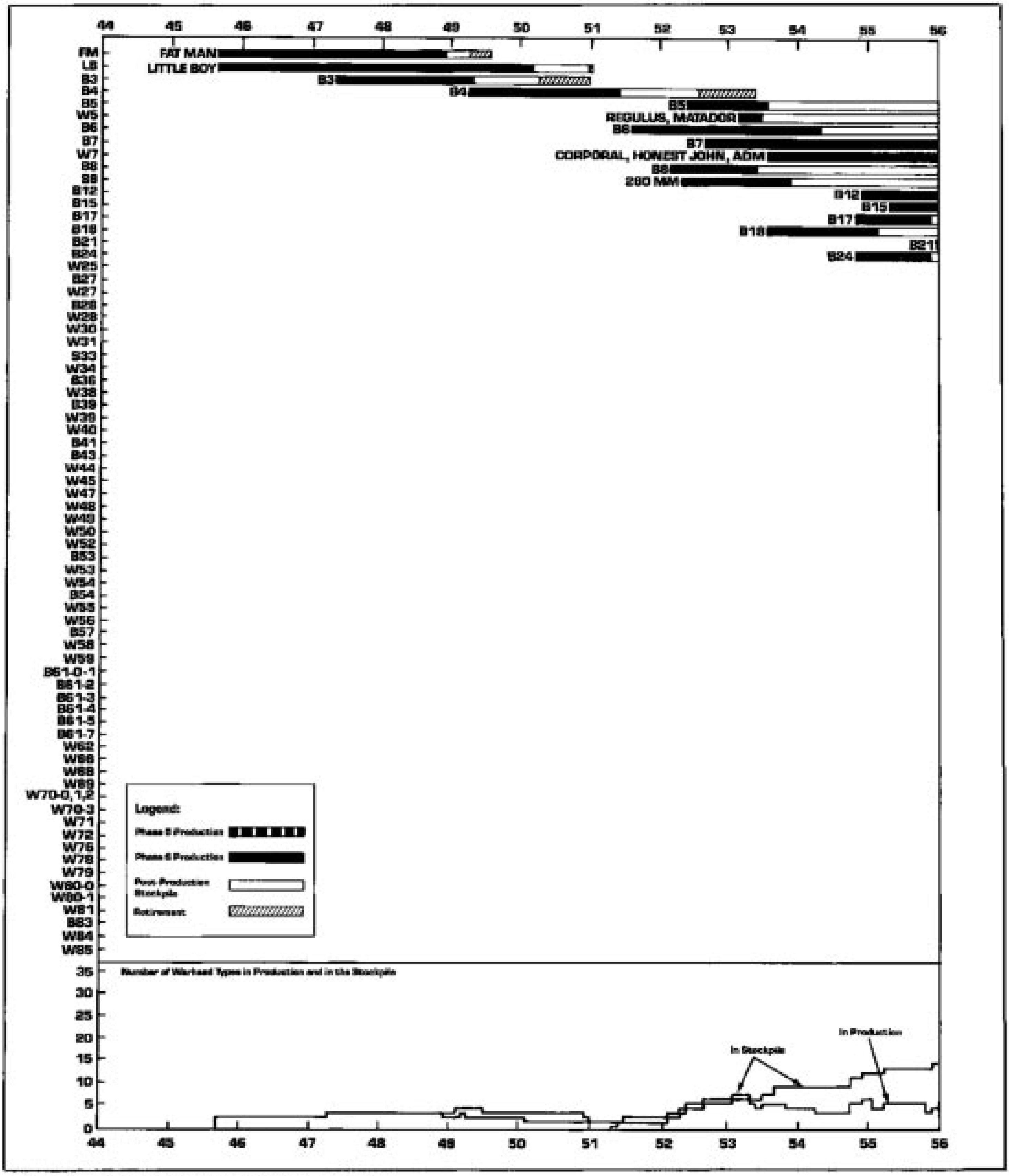
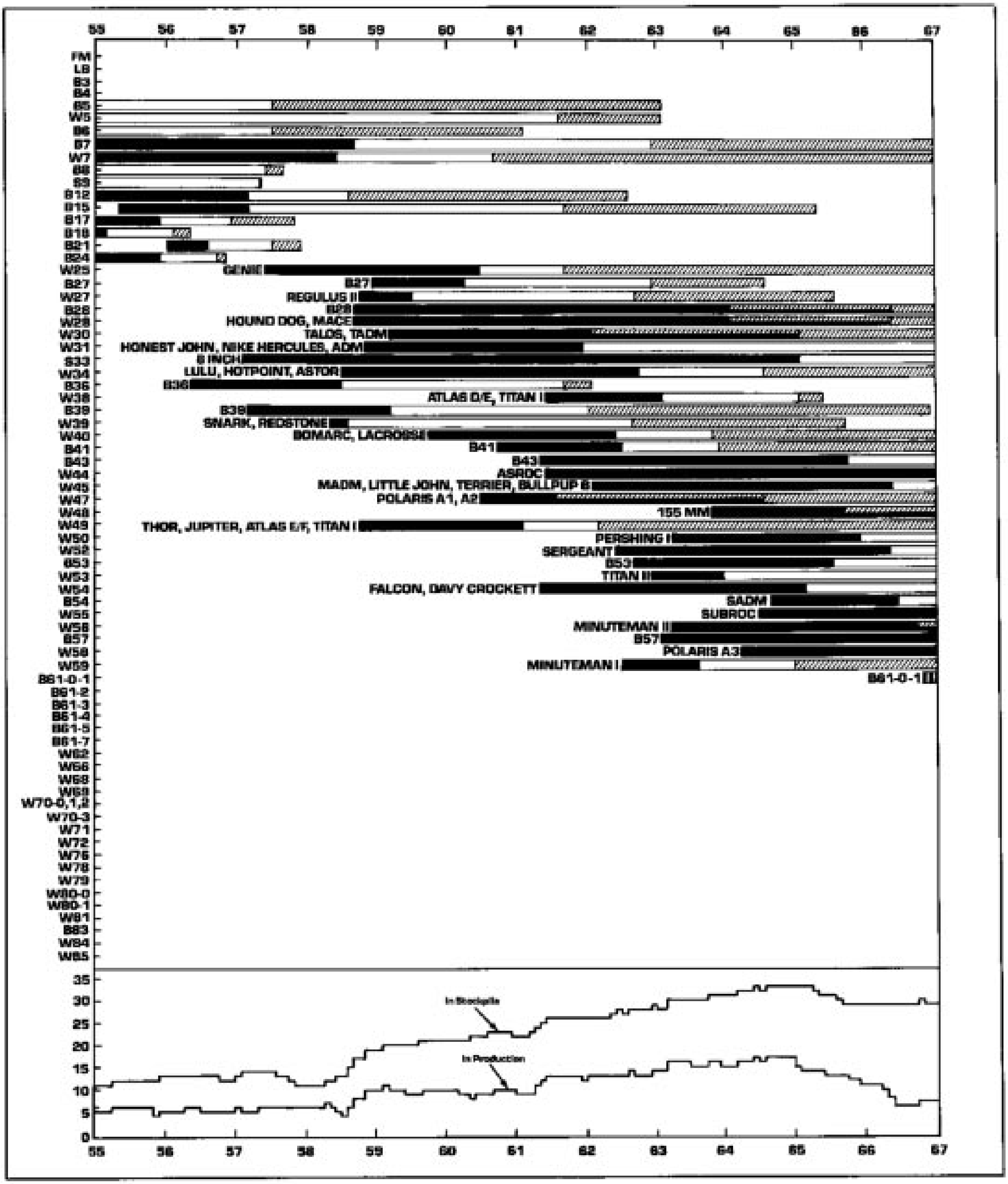


Figure 1.2 U S Nuclear Warhead Production 1945-85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GENIE
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REGULUS II
B28
HOUND DOG, MACE
TALOS, TADM
HONEST JOHN, NIKE HERCULES, ADM
8 INCH
LULU, HOTPOINT, ASTOR
B36
ATLAS D/E, TITAN I
B39
SNARK, REDSTONE
BOMARC, LACROSSE
B41
B43
ASROC
MADM, LITTLE JOHN, TERRIER, BULLPUP B
POLARIS A1, A2
155 MM
THOR, JUPITER, ATLAS E/F, TITAN I
PERSHING I
SERGEANT
B53
TITAN II
FALCON, DAVY CROCKETT
SADM
SUBROC
MINUTEMAN II
B57
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Warhead Production (1945–85)

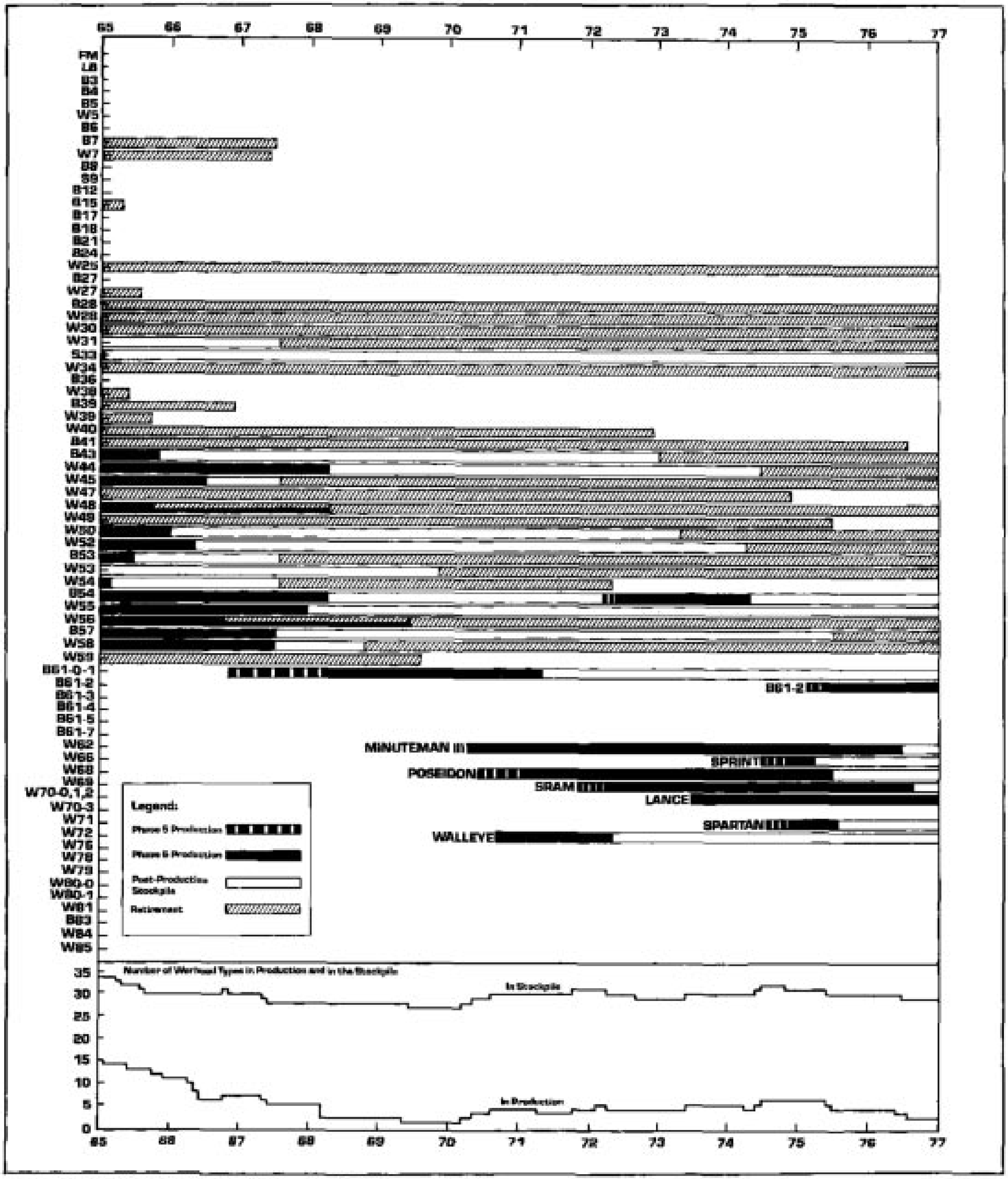
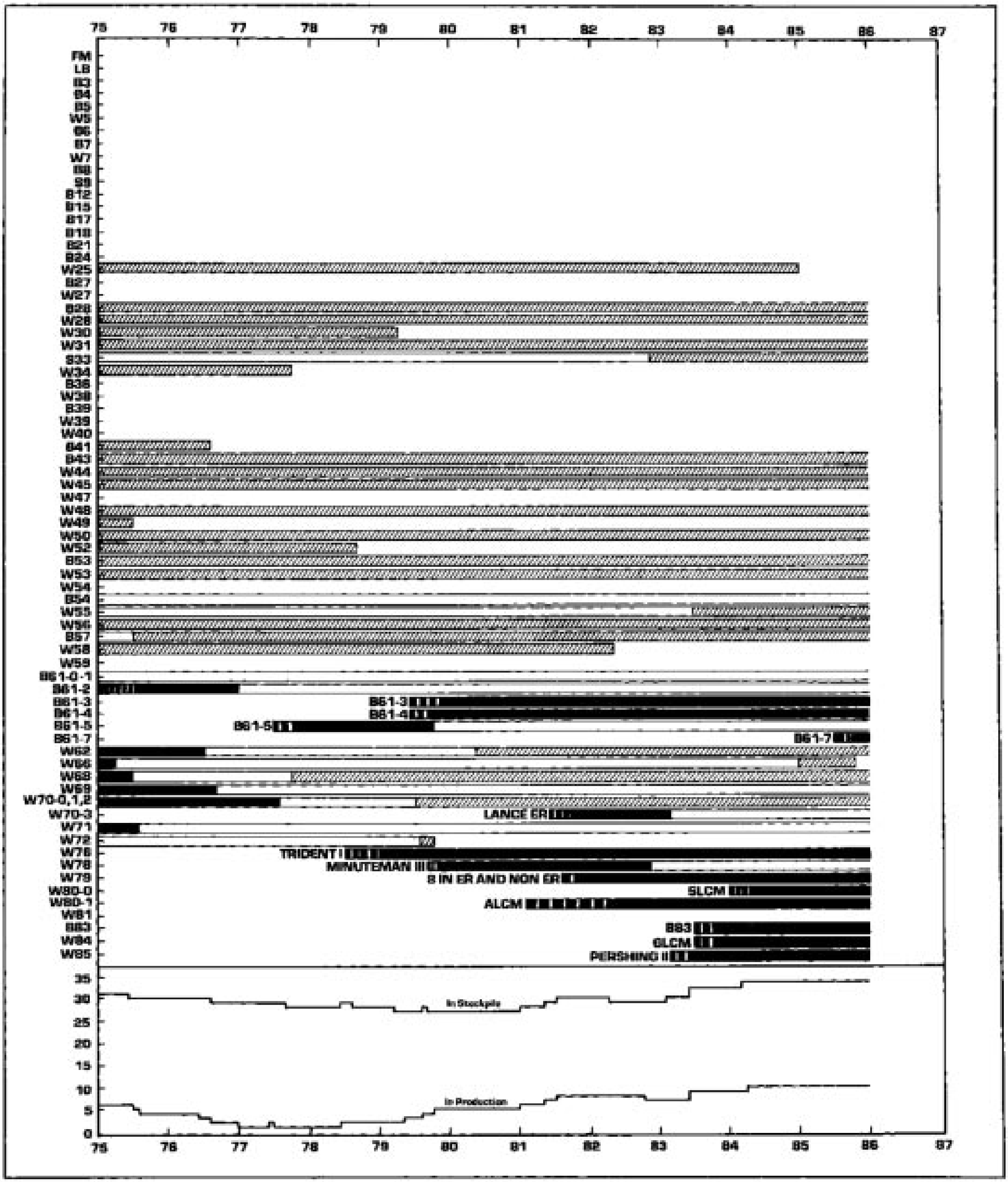


Figure 1.2 U.S. Nuclear Warhead Production 1945-85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In Production

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Warhead Production (1945–85)

Table 1.2

U.S. Nuclear Warhead Production 1945–85

			Dates of Warhead Phases								
			Phase 3	Phase 4	Phase 5	Phase 6		Phase 7			
Warhead Designator	Delivery System	Laboratory	Development Engineering	Production Engineering	First Production	Quantity Production (begin)	Quantity Production (complete)	Retirement (begin)	Retirement (complete)	Cancelled	Number Built
FM	Bomb	LANL	6/43			6/45	12/48	3/48	7/49		20
LB*	Bomb	LANL	6/43			8/45	2/50	1/51	1/51		5
Mk III(B3)	Bomb	LANL	8/45			4/47	4/48	3/50	12/50		120
Mk IV(B4)	Bomb	LANL	8/45			3/49	5/51	7/52	5/53		550
Mk 5(B5)	Bomb	LANL	5/48			5/52	7/53	6/57	1/63		140
Mk 5(W5)	REGULUS I	LANL	5/48			2/53	8/53	7/61	1/63		35
	MATADOR										65
Mk 6(B6)	Bomb	LANL	1/51			7/51	4/54	6/57	1/61		1100
Mk 7(B7)	Bomb	LANL	11/50			6/52	6/58	11/62	6/67		470
Mk 7(W7)	CORPORAL	LANL	11/50			7/53	5/58	9/60	5/67		300
	BETTY (Mk 90 Depth Bomb)										225
	BOAR Bomb										225
	HONEST JOHN										300
	ADM B										300
Mk 8(B8)*	Bomb (Impact Steel)	LANL	3/50			2/52	5/53	5/57	6/57		40
Mk 8(W8)*	REGULUS I	LANL	3/50				Cancelled			3/55	0
Mk 9(B9)*	280mm howitzer	LANL	10/50			4/52	11/53	5/57	5/57		80
TX 10(B10)*	Bomb (Air Burst Steel)	LANL	5/51					Cancelled in Favor of B12		5/52	0
Mk 11(B11)*	Bomb (Navy Mk 91)	LANL/DOD	10/51			7/53	Cancelled	?		5/55	40
Mk 12(B12)	Bomb	LANL	9/52			12/54	2/57	7/58	7/62		250
Mk 12(W12)	TALOS/BOMARC	LANL	12/54					Cancelled in Favor of W30		11/55	0
TX 13(B13)	Bomb	LANL	8/54					Cancelled in Favor of B18		8/54	0
TX 13(W13)	SNARK/NAVAJO	LANL	8/54				Cancelled			9/54	0
EC14**	TN Bomb	LANL	8/52			2/54	4/54	9/54	10/54		5
Mk 15(B15)**	TN Bomb	LANL	10/53			4/55	2/57	9/61	4/65		1200
Mk 15(W15)**	SNARK/REDSTONE	LANL	8/55					Cancelled in Favor of W39		1/56	0
EC16**	TN Bomb	LANL	6/52			3/54	3/54	4/54	4/54		5
EC17**	TN Bomb	LANL	10/53			5/54	9/54	10/54	11/54		5
Mk 17(B17)**	TN Bomb	LANL	10/53			10/54	11/55	11/56	10/57		200
Mk 18(B18)	Super Oralloy Bomb	LANL	9/52			7/53	2/55	1/56	4/56		90
B19	280mm howitzer	LANL/DOD	4/53			3/56	Cancelled	?	?		80
B20	TN Bomb	LANL	?					Cancelled in Favor of B15		8/54	0
B21	TN Bomb	LANL	3/54			12/55	7/56	6/57	11/57		275
B22	TN Bomb	LANL	8/53					Cancelled in Favor of B21		4/54	0
B23*	16 inch naval gun	LANL/DOD	8/53			12/56	?	10/62	10/62		50
EC24	TN Bomb	LANL	10/53			4/54	9/54	10/54	11/54		10
B24	TN Bomb	LANL	10/53			10/54	11/55	9/56	10/56		105
EC25	GENIE	LANL	11/54			11/56	12/56	7/57	7/57		20
W25	GENIE	LANL	11/54	12/56		5/57	5/60	8/61	12/84		3150
B26	TN Bomb	LANL	5/54					Cancelled in Favor of B21			0
B27	TN Bomb (Mk 101)	LLNL	9/55	3/57		11/58	3/60	11/62	7/64		700
W27	REGULUS II	LLNL	9/55	9/56		9/58	6/59	8/62	7/65		25
B28‡	TN Bomb (Navy Mk 113)	LANL	8/54	1/57		8/59	5/66	1/64	active		4500
W28‡	HOUND DOG	LANL	8/54	1/57		8/59	5/66	1/64			600
	MACE										100
B29	TN Bomb	LANL	9/54					Cancelled in Favor B15/39		8/55	0
W30†	TALOS	LANL	4/55	3/57		2/59	1/65	1/62	3/79		300
	TADM										300
W31	HONEST JOHN	LANL	12/54	3/57		10/58	12/61	7/67	active		1650
	NIKE HERCULES								active		2550
	ADM										300
B32*	240mm howitzer	LANL/DOD						Cancelled in Favor of W48		5/55	0
B33*	8 inch howitzer	LANL/DOD	12/54			1/57	1/65	FY83	active		1000
W34	LULU (Mk 101 depth bmb)	LANL	4/53	1/57		6/58	9/62	7/64	9/77		2000
	HOTPOINT (Mk 105 bomb)										600
	ASTOR (Mk-45 torpedo)										600
W35	ATLAS	LANL	7/58					Cancelled in Favor of W49		12/57	0
	TITAN									0	
	THOR									0	
	JUPITER									0	
B36	TN Bomb	LANL	5/54	5/55		4/56	5/58	8/61	1/62		940
W37	NIKE HERCULES	LANL	4/56					Cancelled in Favor of W31		10/56	0
W38	ATLAS E/F	LLNL	2/59	11/59		5/61	1/63	1/65	5/65		110
	TITAN I										70
B39	TN Bomb	LANL	8/55	3/56		2/57	3/59	1/62	11/66		700
W39	SNARK	LANL	1/56	3/58		4/58	7/58	8/62	9/65		30
	REDSTONE										60
W40	BOMARC	LANL	5/56	2/58		9/59	5/62	10/63	11/72		350
	LA CROSSE										400
B41	TN Bomb	LLNL	2/57	10/58		9/60	6/62	11/63	7/76		500
W41	Unnamed ICBM	LLNL	11/56			--	Cancelled			7/57	0
W42	HAWK	LLNL	5/57			-	Cancelled			6/61	0
	FALCON										0
	SPARROW										0
	EAGLE										0
B43	TN Bomb (Navy Mk 112)	LANL	10/56	2/58		4/61	10/65	12/72	active		1000
W44	ASROC	LANL	11/56	6/59		5/61	3/68	6/74	active		574
W45	MADM (Mod 3)	LLNL	11/56	10/59		1/62	6/68	7/67	FY84		350
	LITTLE JOHN										500
	TERRIER										750
	BULLPUP B										100
B46	TN Bomb	LANL	7/57					Cancelled in Favor of B53		10/58	0
W46	TITAN II	LANL	7/57			-- --		Cancelled in Favor of W53		10/58	0
EC47	POLARIS A1	LLNL	8/57			4/60	6/60	6/60	6/60		300
W47†	POLARIS A1/A2	LLNL	8/57	11/58		6/60	7/64	7/61	11/74		1060
W48†	155mm howitzer	LLNL	7/57	1/61		10/63	3/68	9/65	active		1060

Table 1.2
U.S. Nuclear Warhead Production 1945–85

			Dates of Warhead Phases[c]								
			Phase 3[d]	Phase 4	Phase 5	Phase 6		Phase 7			
Warhead Designator[a]	Delivery System	Laboratory[b]	Development Engineering	Production Engineering	First Production	Quantity Production (begin)	Quantity Production (complete)	Retirement (begin)[e]	Retirement (complete)	Cancelled	Number Built[f]
W49	THOR	LANL	12/57	1/58		9/58	1/61	2/62	6/75		35
	JUPITER										30
	ATLAS D										30
W50	PERSHING I	LANL	6/58	6/61		3/63	12/65	4/73	active		280
W51	DAVY CROCKETT	LLNL	6/56					Cancelled in Favor of W54		1/59	0
	FALCON										0
W52	SERGEANT	LANL	5/56	7/61		5/57	4/66	3/74	8/78		300
B53	TN Bomb	LANL	12/58	7/60		8/62	6/65	7/67	active		340
W53	TITAN II	LANL	10/60	3/61		12/62	12/63	10/69	active		60
W54	FALCON	LANL	1/59	8/59		4/61	2/65	7/67	4/72		1000
	DAVY CROCKETT										400
B54	Special ADM	LANL	8/60	6/62		8/64	6/66	FY67	active		260
W55	SUBROC	LLNL	3/59	11/61		6/64[l]	4/74	FY83	active		285
W56	MINUTEMAN I/II	LLNL	12/60	9/61		3/63	5/69	9/66	active		1000
B57	ASW Depth Bomb/Bomb	LANL	1/60	1/61		1/63	5/67	6/75	active		3100
W58	POLARIS A3	LLNL	8/60	11/62		3/64	6/67	9/68	4/82		1400
W59	MINUTEMAN I	LANL	12/60	1/61		6/62	7/63	12/64	6/69		150
W60	TYPHON	LLNL	10/61				Canceled			3/64	0
B61 0, 1	TN Bomb	LANL	1/63	5/65	10/66	1/68[m]	4/71		active		2600
B61 2	TN Bomb	LANL	8/71	6/72[n]	3/75	8/75	1/77		active		↓
B61 3	TN Bomb	LANL	4/72[o]	12/76	5/79	10/79			active		↓
B61 4	TN Bomb	LANL	4/72[o]	12/76	5/79	8/79			active		↓
B61 5	TN Bomb	LANL	6/75	6/75	6/77	9/77	9/79		active		↓
B61 6	TN Bomb	LANL	4/84								↓
B61 7	TN Bomb (Modified B61 1)	LANL	5/79	3/82	5/85	9/85			active		↓
B61 8	TN Bomb	LANL	4/84								↓
W62	MINUTEMAN III (MK 12)	LLNL	6/64	3/67	3/70	3/70	6/76	4/80			1725
W63 (ER)	LANCE	LLNL	7/64					Cancelled in Favor of W70		11/66	0
W64 (ER)	LANCE	LANL	7/64					Cancelled in Favor of W63		9/64	0
W65 (ER)	SPRINT	LLNL	10/65					Cancelled in Favor of W66		1/68	0
W66 (ER)	SPRINT	LANL	1/68[q]	1/72	6/74	10/74	3/75	FY85	6/85		70
W67	MINUTEMAN III	LANL	6/66				Canceled			12/67	0
	POSEIDON										0
W68	POSEIDON	LLNL	12/66	5/68	5/70	12/70[r]	6/75	6/77	active		5250
W69	SRAM	LANL	1/67	1/69	10/71	2/72	9/75		active		1200
W70 0, 1, 2	LANCE	LLNL	4/69[s]	12/70	6/73	6/73	7/77[t]	7/79	active		900
W70 3 (ER)	LANCE	LLNL	4/76	4/76[u]	5/81	6/81	2/83		active		380
W71	SPARTAN	LLNL	3/68	1/72	7/74	10/74	7/75	inactive	storage		30
W72	WALLEYE	LANL	5/69	5/69	8/70	9/70	4/72	7/79	9/79		300
W73	CONDOR	LANL	7/69				Canceled			9/70	0
W74	155mm howitzer	LANL	3/70				Canceled			6/73	0
W75	8 inch howitzer	LLNL	6/71				Canceled			6/73	0
W76	TRIDENT I	LANL	5/73	11/75	6/78[v]	11/78			active		3000
B77	TN Bomb	LLNL	5/74				Canceled			12/77	0
W78	MINUTEMAN III (Mk 12A)	LANL	7/74	3/77[w]	8/79	9/79	10/82		active		1000
W79 (ER)	8 inch howitzer	LLNL	1/75	3/77[x]	7/81	9/81	[t]10/83		active		325
W79 (non ER)	8 inch howitzer	LLNL					8/86		active		225
W80 0	SLCM	LANL	6/76	3/82	12/83	3/84			active		100
W80 1	ALCM	LANL	6/76	1/79	1/81	2/82			active		1200
W81	STANDARD 2	LANL	10/77								0
W82 (ER)	155mm howitzer	LLNL	2/78				Canceled			10/83	0
W82 (non ER)	155mm howitzer	LLNL	?	5/86							0
B83	TN Bomb	LLNL	1/79	9/80	5/83	8/83			active		500
W84	GLCM	LLNL	9/78	12/80	6/83	9/83			active		150
W85 AB/SB	PERSHING II	LANL	5/79	9/80	2/83	5/83			active		120
W86 EP	PERSHING II	LANL	5/79				Canceled			9/80	0
W87	MX/PEACEKEEPER	LLNL	2/82	10/83	4/86	7/86					0
W88	TRIDENT II	LANL	3/84		[f]4/89	7/89					0
Wxx											
									TOTAL		60252

* Gun Assembly Weapons. All others are implosion weapons.
** First Thermonuclear designs.
† Warhead has more than one mod or yield option. Retirement (Phase 7) begins for certain mod(s)/yield(s) prior to the completion of other mod(s)/yield(s) of the same warhead.
a All current nuclear warheads are designated either "B" or "W" followed by a number. Gravity bombs are designated with a "B." Warheads with other applications, for example, for missiles, use the designation "W." Prior to the 1960s nuclear warheads were assigned "Mark" ("Mk") numbers. Other designations in the Table include "FM" for FATMAN, "LB" for LITTLE BOY, "TX" for a few experimental (but cancelled) warheads, "EC" for Emergency Capability, and "B" for some atomic artillery shells.
b LANL: Los Alamos National Laboratory; LLNL: Lawrence Livermore National Laboratory; LANL/DOD: cosponsors for several gun assembly warheads.
c Month, year. For a description of Phases see Chapter Four.
d The W25 was the first warhead developed under the 1953 DOD/AEC Agreement.
e There is frequently some ambiguity in defining when the retirement of a warhead begins. The start of Phase 7 may indicate the date when retirements of warheads for quality assurance sampling began, or it may indicate the date when all of the warheads of that type were removed from the stockpile for dismantlement.
f Authors estimates.
g Replaced by B17.
h Replaced by B17.
i Original 1/58. Withdrawn 3/58 and Reaccepted 8/58.
j Ibid.
k Original FPU 6/58. Withdrawn 6/58 and Reaccepted 9/59.
l Originally FPU 1/64, Withdrawn 4/64 and Reaccepted 6/64. SUBROC was produced in two runs. The original production run was completed in 3/68. The second Phase 4 authorization date was 3/70. Phase 3 began 2/72 and Phase 5 began 5/72 and was completed 4/74.
m Originally began Phase 5 1/67. Withdrawn 5/67 and Reaccepted 1/68.
n Phase 4 activities were suspended in 6/73 and reauthorized in 1/74.
o Phase 3 activities were rescheduled in 11/74 as a result of a 17 month slip in the commencement of Phase 6.
p Ibid.
q Development efforts on the W65 before cancellation could be considered applicable to the W66 program.
r Originally began Phase 6 on 6/70, withdrawn 9/70 and reaccepted 12/70.
s Development effort on the W63 before cancellation could be considered applicable to the W70 program. The original Phase 3 was 11/66, which was suspended in 1/68 and reinstated in 4/69.
t Production completed for W70 2. Other mods presumed to be completed earlier.
u Phase 4 activities for the W70 3 (and W79) were suspended 30 September 1977 and reinstated 1 November 1978.
v Phase 5 date represents partial build only.
w Phase 4 was first authorized 11/75, suspended 2/76 and reauthorized 3/77.
x Phase 4 activities for the W79 (and W70 3) were suspended 30 September 1977 and reinstated 1 November 1978.

Sources: DOE, Table B, "Cumulative History of Weapons Programs Key Dates and Time Spans," 31 December 1984; Table C, "Cumulative History of LANL/DOD and EC Programs and Weapons Programs Suspended or Cancelled," 31 December 1983; Letter from Col. Virgil D. Kempton, DOE Office of Military Application, to Robert S. Norris, 21 February 1986.

Table 1 3

Research, Test, and Production Facilities

LABORATORIES

Los Alamos National Laboratory (LANL)
Los Alamos, New Mexico

Lawrence Livermore National Laboratory (LLNL)
Livermore, California

Sandia National Laboratories (SNL)
Albuquerque, New Mexico

MATERIALS PRODUCTION FACILITIES

Feed Materials Production Center (FMPC)
Fernald, Ohio

Ashtabula Plant
Ashtabula, Ohio

Y-12 Plant
Oak Ridge, Tennessee

Hanford Reservation
Richland, Washington

Savannah River Plant
Aiken, South Carolina

Idaho National Engineering Laboratory (INEL)
Idaho Falls, Idaho

Oak Ridge Gaseous Diffusion Plant
Oak Ridge, Tennessee

Paducah Gaseous Diffusion Plant
Paducah, Kentucky

Portsmouth Gaseous Diffusion Plant
Piketon, Ohio

WEAPONS PPODUCTION FACILITIES

Rocky Flats Plant
Golden, Colorado

Y-12 Plant
Oak Ridge, Tennessee

Savannah River Plant
Aiken, South Caroina

Mound Facility
Miamisburg, Ohio

Pinellas Plant
St Petersburg, Florida

Kansas City Plant
Kansas City, Missouri

Pantex Plant
Amarillo, Texas

TEST SITES

Nevada Test Site
Nye County, Nevada

Tonopah Test Range
Nye County, Nevada

Source: Adapted from HASC FY 1982 DOE p 57

all the components into finished warheads These are then delivered to the Department of Defense

Currently U S (and UK) nuclear explosive devices and finished warheads are tested at the Nevada Test Site The nearby Tonopah Test Range is used to test mock warhead performance such as bomb drops with parachutes and the ballistics of artillery shells and rockets Supplementing these facilites are the DOD-operated Eastern and Western Test Ranges in Florida and California and the White Sands Missile Range in New Mexico

The DOE and DOD divide the life cycle of a warhead into seven distinct phases Phases 1 and 2 are early warhead conception and feasibility studies that explore interest in a new weapon and define military characteristics Phase 2A provides more exact cost and design data Then a laboratory design team is selected Initiation of Phase 3—development engineering—means that DOD has approved the design A "B" or "W" number is assigned, and quantities and timetables are set As the warhead reaches Phase 4 special machines and facilities are built throughout the warhead component complex, and with Phase 5 the First Production Unit (FPU) is made If final checks are positive the warhead moves into Phase 6 This entails its mass production period and its time in the stockpile Phase 7 begins when a coordinated program of physical removal of warheads from the stockpile is initiated and ends when warheads are returned to DOE for disassembly When Phase 7 is completed all warheads of a given type have been removed from the stockpile A warhead type may remain in Phase 7 for a brief or extended period of time This depends on whether forces are rapidly or gradually drawn down, or the rate at which modified warheads replace or augment the originals (see Figure 1 3)

The stockpile is constantly in flux, with warheads being produced, retired, or modified every day The capacity of the complex and the tempo of the activity have varied greatly over the past four decades The current capacity to produce, retire, or modify—each activity is approximately equivalent in terms of labor, space, and time—is 3500 to 4000 units (warheads) per year[9] To accomplish this the DOE was granted a budget for FY 1986 of $7 2 billion and has requested $36 billion for the following four years These budgets (even in current dollars) exceed those of the Manhattan Project and approach the peak spending years in the late 1950s and early 1960s While the budgets are at near record highs the production rates are not In the early 1960s the rate (and the capacity of the complex) was about 6,000 units per year, mostly in new production By contrast only a few hundred warheads a year were produced during 1977-78

The level of activity is also reflected in the number of different warhead types being produced at any one time Between June and December 1967, near the peak of the stockpile size, seventeen different types of warheads (for

9 A retrofit or modification may require partial or complete disassembly and reassembly which may be as much as double the workload of building a new warhead or retiring an old one HASC, FY 1979 DOE p 464 The Databook volumes use the following format for citing Congressional hearings: Committee Fiscal Year Department or Appropriation Bill Part page

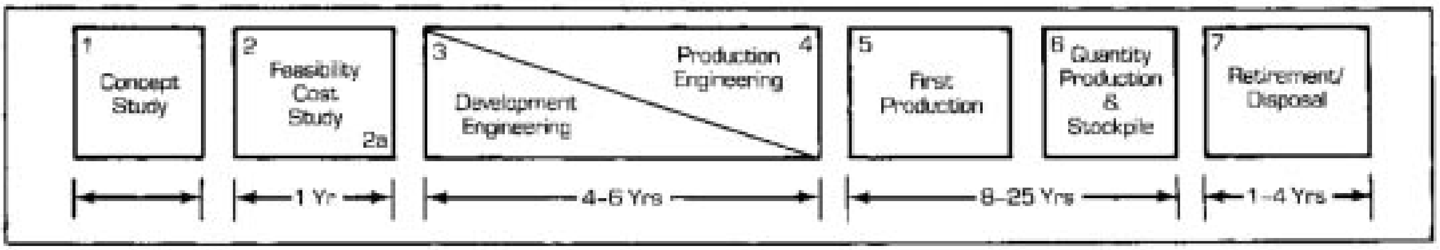


Figure 1 3 DOE Warhead Phases

twenty-three kinds of weapon systems) were being produced simultaneously By contrast during most of 1977 and part of 1978 only one warhead type (the B61 bomb) was being produced

Current Decisionmaking

Policy questions involving the purchase of nuclear weapons, their deployment, employment, and control are important responsibilities of a relatively small group at the highest levels of the U S government The president, his advisers within the executive office and, certain department secretaries make up the core group, supported by deputy, under and assistant secretaries

Key documents prepared by offices primarily within the Department of Defense establish requirements for nuclear weapons The most important acquisition policy document is the Nuclear Weapons Stockpile Memorandum (NWSM) Approved each year, the NWSM authorizes precise numbers of warheads to be built, modified, and retired It also specifies nuclear material requirements over short-, middle-, and long-range periods

From Laboratory to Assembly Line

Building the Infrastructure

During the period 1945-1955 the U S government reorganized and expanded the process and infrastructure devoted to nuclear warhead development and production Legal responsibilities and relationships were spelled out in several key laws These include the Atomic Energy Acts of 1946 and 1954, the National Security Act of 1947, and the 1953 AEC/DOD Agreement to develop and produce atomic weapons As a result various civilian and military bureaucracies were formed, the most important being the Atomic Energy Commission, the Congressional Joint Committee on Atomic Energy, the Military Liaison Committee of DOD and the AEC, and the Armed Forces Special Weapons Project of DOD

For some time after World War II nuclear materials were in limited supply Building more warheads required more oralloy and plutonium Government incentives stimulated exploration for uranium ore Production expansion occurred in two phases, the first associated with expansion of the atomic warhead stockpile, and the second with thermonuclear warhead production To the original three Manhattan Project reactors at Hanford (B, D, F) were added five more (H, DR, C, KW, KE) between October 1949 and April 1955 In January 1950, President Truman decided to proceed with the hydrogen bomb and to supply the huge amounts of tritium then thought to be needed The Savannah River Plant was built in response, adding five more reactors (R, P, L, K, C) between December 1953 and March 1955 Uranium enrichment at Oak Ridge was expanded and supplemented by two more gaseous diffusion plants at Paducah, Kentucky (1954) and Portsmouth, Ohio (1956) Uranium processing facilities were added at Ashtabula (1952) and Fernald, Ohio (1953)

When the Atomic Energy Commission was created there were three facilities in the nuclear warhead production complex; Los Alamos Scientific Laboratory for research, a Sandia branch of Los Alamos at Albuquerque for ordnance design, development, and testing, and the Rock Island Arsenal that produced mechanical bomb components

For several years after the war, activity at Los Alamos was greatly reduced [10] This was followed by a period of sustained growth in laboratory and warhead facilities The Los Alamos ordnance division at Albuquerque was reorganized into the Sandia laboratory in 1949 A second design laboratory at Livermore, California was established in 1952 Facilities to mass produce nuclear and non-nuclear warhead components were built in the late 1940s and early 1950s at the Mound facility in Miamisburg, Ohio (1948), the Kansas City Plant (1949), and the Rocky Flats Plant in Golden, Colorado (1950) Two final assembly plants—in Burlington, Iowa; and one near Amarillo, Texas—were built in 1947 and 1951 During this period growth in expenditures and employment was dramatic, driven by an intensifying Cold War (see Tables 1 1 and 1 4)

10 The delays in creating the AEC contributed despite the best efforts of General Groves and others to the dissipation of the highly trained staffs in the MED project Some scientists returned to campuses others to industry or private research The morale of those remaining often working in facilities at Los Alamos and Hanford that were rapidly deteriorating was understandably poor The wartime momentum behind the research and development effort had been lost Samuel R. Williamson Jr with the collaboration of Steven L. Rearden The View from Above: High-Level Decisions and the Soviet-American Strategic Arms Competition 1945 1950 (Office of OSD Historian, October 1975) pp 21-22

Table 1 4

AEC Employment for Warhead Production

Fiscal Year (End)	Total	AEC	Operating Contractor	Construction Contractor
1949	62,529	4578	38,253	19,698
1950	63,739	4941	39,095	19,703
1951	99,126	5646	47,745	45,735
1952	149,371	6662	58,101	84,608
1953	148,799	6894	71,775	70,130
1954	141,949	6123	73,312	62,514
1955	112,555	6013	82,936	23,606
1956	110,197	6637	90,238	13,322
1957	119,455	6910	98,176	14,369
1958	121,059	7107	103,290	10,662
1959	121,928	6855	105,155	9,678
1960	122,718	6907	104,612	11,199
1961	122,989	6846	103,313	12,830
1962	126,623	6863	106,394	13,366
1963	135,278	7120	115,012	13,146
1964	136,620	7268	117,257	12,095
1965	133,912	7329	114,783	11,800
1966	133,550*	7400	112,000	14,150*
1967	133,189*	7550*	112,000*	13,639*
1968	132,828*	7700	112,000	13,125*
1969	132,467	7467	111,000	14,000
1970	122,548	7548	106,000	9000
1971	115,008	7408	99,000	8600

Source: AEC Semiannual and Annual Reports to Congress

*Authors interpolated values

Early Warheads

After LITTLE BOY and FAT MAN were dropped on Hiroshima and Nagasaki presumably only two additional warheads were added to the stockpile by the end of 1945 (see Table 1 5)[11] These were literally custom-built, experimental laboratory products, not only designed but largely fabricated and assembled by the scientists who conceived them at Los Alamos

Through 1947 the stockpile grew slowly as each warhead continued to be hand-assembled Using the FAT MAN design for the first bombs, the immediate objective was to reengineer it for easier production Certain critical components were in short supply, particularly high-explosive castings and initiators Acceptable castings finally became available in April 1947 They were incorporated into the MARK III, the first production model FAT MAN that entered the stockpile the same month By the end of June 1947 there were thirteen warheads in the stockpile, including at least nine FAT MAN models (stockpiled through 30 June 1946), and as many as four MARK IIIs (See Table 1 5) But the MARK III was judged to be deficient as an operational weapon It was too large and too heavy, an awkward shape, too complex in fuzing and firing mechanisms, had lengthy assembly proce-

11 The United States possessed on August 8 after the second atom bomb had been dropped on the city of Nagasaki no further stocks of nuclear weapons on hand Further bombs were likely to become available only by the end of the year

H L Stimson The Decision to Use the Atomic Bomb *Harper's Magazine* February 1947

By the next day, [10 August 1945] rumors of impending Japanese surrender spread everywhere on Tinian We continued to prepare the next weapon for delivery but General Le May on orders from President Truman was advised not to proceed with delivery unless he received specific instructions

Bernard J O Keefe *Nuclear Hostages* (Boston Houghton Mifflin Company 1983) p 102 O Keefe has indicated that he does not know whether the fissile core for the third weapon was at Tinian at that time Bernard J O Keefe, private communication to Thomas B Cochran 25 June 1985 Assembly of the non-nuclear parts of the third bomb began [after 9 August] on Tinian However Truman had not approved shipment of the nuclear material although Tibbets [pilot of the Enola Gay] said recently that it had gone as far as California ' On August 10 Groves in Washington reported to Marshall that the next Fat Man bomb would be ready for delivery on the first suitable weather after 17 or 18 August according to declassified documents That was one week earlier than originally planned Groves wrote Walter Pincus Debates Doubts Among the Creators Washington Post 21 July 1985, p A-12 General Leslie M Groves says ' Some of the vital parts for two additional FAT MEN were flown out [to Tinian] in two B 29s belonging to the 509th, which had been held at Albuquerque especially for this purpose Now It Can Be Told (New York: DeCapo Press, 1983, originally published 1962) p 341 A recent study says ' a third plutonium bomb [GADGET and FAT MAN being the first two] was ready for use on August 24, two weeks after Japan s surrender ' Ferenc Morton Szasz The Day the Sun Rose Twice: The Story of the Trinity Site Nuclear Explosion July 16 1945 (Albuquerque New Mexico: University of New Mexico Press 1984) p 152

Table 1 5

U.S. Nuclear Weapon Stockpile, 1945-50

Stockpile as of	Nuclear Components: Gun-type	Nuclear Components: Implosion-type	Non-Nuclear Components: Gun-type	Non-Nuclear Components: Implosion-type
30 June 1945[a]	0	2	0	2
30 June 1946	0	9	0	9
30 June 1947	0	13	0	29
30 June 1948	0	50	2	53
30 June 1949	?	?	12	220
30 June 1950	?	?	29	660

a Figures are for a later date presumably 31 December 1945

Sources: Steven L Rearden *The Formative Years 1947-1950: History of the Office of the Secretary of Defense* (Washington DC: Government Printing Office 1984) p 439; David Alan Rosenberg U S Nuclear Stockpile 1945 to 1950 *The Bulletin of the Atomic Scientists* (May 1982): 26

dures,[12] and aeronautical and structural weaknesses of the empennage

As warhead research progressed, an early technological innovation was the use of fissile cores made of a composite of plutonium and uranium These cores made more effective use of the plentiful and cheaper stocks of highly enriched uranium By the end of 1947 these cores were stockpiled for use in MARK III bombs [13] Another technological innovation was the levitated core that made for greater efficiency using the same quantity of fissile material [14] Levitation and composite cores were tested in *Operation Sandstone* in April and May of 1948 in what were the first tests of new warhead designs since the *Trinity* shot almost three years earlier The immediate military result of using these new designs was to "make possible within the near future a 63 percent increase in the total number of bombs in the stockpile and a 75 percent increase in the total yield of these bombs "[15] Both features were incorporated in the MARK IV built from March 1949 to April 1951

The MARK IV was the first mass-produced bomb Conversion to industrial-scale weapon production was practically completed in 1949 [16] It required (1) expanded production facilities for a continuous flow of components, (2) new designs based in part on work done during the war, (3) improved and standardized component design, and (4) standard storage and handling procedures [17]

In May 1948 Los Alamos began development engineering on the MARK 5, the first light weight (3200 lb) bomb intended for "tactical" use It entered the stockpile in May 1952 and was followed closely by five additional tactical nuclear warheads One was the versatile MARK 7 which served as the warhead for the Bureau of Ordnance Atomic Rocket (BOAR) bomb Others were a Navy antisubmarine depth bomb (nicknamed "Betty"), the Army's CORPORAL and HONEST JOHN short-range missiles, and the first Atomic Demolition Munition (ADM—i e , nuclear land mine) This initial flurry of tactical nuclear weapon development also produced the first atomic artillery shell, the MARK 9 for the Army's 85-ton 280mm howitzer

The predominant warhead type during this period remained the more simple aircraft-delivered bomb Twelve of the fifteen new warheads introduced from 1947-1955 were bombs, most of which went to the Air Force and its Strategic Air Command With a legacy of strategic bombing and the dropping of atomic bombs on Hiroshima and Nagasaki, the Air Force and SAC took an agressive lead in controlling and monopolizing atomic forces The mass produced 70 Kt B6 bomb, which entered production in July 1951, was the principal strategic bomb until the introduction of thermonuclear weapons beginning in 1954 By the end of 1955, SAC had over 1300 B-36, B-47, and B-52 bombers, and a comparable number of bombs of five types

New Technologies and the Proliferation of Missions—mid-1950s to late 1960s

By the mid-1950s the infrastructure for the production complex was in place In ten years, the manufacture of nuclear warheads had gone from a time-consuming

12 It required a team of forty-eight men forty eight hours to assemble one bomb

13 R D Little *History of the Air Force Participation in the Atomic Energy Program 1943-1953 Volume II: Foundations of an Atomic Air Force and Operation Sandstone 1946-1948* (Air University Historical Liaison Office) p 478

14 Here the fissile core is separated from the high explosive and tamper by an air gap The core is held at the center of the pit by thin structural elements

15 Little *Foundations of an Atomic Air Force* p 494

16 AEC Report to Congress January 1950 p 9

17 AEC Report to Congress, February 1948 p 6

laboratory exercise to an assembly line process The next period would see the end of Air Force dominance, and the rivalry among the services to define new applications and missions for nuclear weapons Each service transformed many or most of its conventional roles and missions into nuclear ones

Thermonuclear Warheads

Thermonuclear warheads transformed the stockpile In the early 1950s the Atomic Energy Commission pursued parallel development of fission warheads with yields from 1 to 40 megatons (Mt) The principle of boosting the yield of fission weapons with small quantities of deuterium and tritium was first recognized as early as November 1945 (see *Nuclear Weapons Databook*, Volume I, p 27) A boosted device was first tested on 24 May 1951 in shot *Item* in the Greenhouse test series It produced a 45 5 Kt yield Full-scale development of the B18, the highest yield pure fission bomb (500 Kt) to enter the U S stockpile, was initiated at Los Alamos in August 1952 It was tested at shot *King* in Operation *Ivy* on 15 November 1952, and the warhead entered the stockpile in July of the following year [18] These high yield fission warheads were retired in less than three years as they were quickly replaced by more efficient, multistage thermonuclear designs

An extensive literature describes the events surrounding the decision to build the hydrogen bomb [19] It was first suggested by Edward Teller in 1942 Less well known are details of the chronology, and specifics of the actual testing and production of thermonuclear warheads themselves

The first significant U S thermonuclear reaction was shot *George* on 8 May 1951 in the *Greenhouse* series at Enewetak Atoll in the Pacific *George* was designed to test the ignition of thermonuclear fuel using a fission explosion [20] A large fission yield was used to ignite a relatively small amount of liquid deuterium-tritium (D-T) in close proximity to the fission device While yield from the ignition of the D-T mixture far exceeded expectations, it contributed only a small amount to the 225 Kt yield of shot *George*

The most difficult and central problem remained—whether and under what conditions burning might proceed in thermonuclear fuel [21] The solution to the "Super problem," proposed by Edward Teller and Stanislaw Ulam in January 1951, was based on radiation implosion [22] The thermonuclear fuel surrounded by a heavy tamper (e g , uranium-238) would be imploded by the absorption of soft x-radiation produced in a cavity[23] into which the radiation from the explosion of the fission primary is channeled, thereby achieving the thermodynamic conditions required for rapid thermonuclear burn A theoretical design based on the Teller-Ulam approach was completed in June of 1952 It was tested on 31 October 1952 with the 10 4 Mt *Mike* shot in *Operation Ivy* at Enewetak While this was the first successful test of a thermonuclear device, it was not a deliverable weapon The device reportedly weighed sixty-five to seventy tons, due in part to the cryogenic equipment needed to maintain its thermonuclear fuel, deuterium, at liquid temperatures (see *Nuclear Weapons Databook*, Volume I, Figure 2 3)

The Teller-Ulam approach looked so promising, however, that conceptual designs of deliverable thermonuclear bombs were begun prior to the *Mike* shot The first two deliverable warhead candidates (the EC16 and EC14)[24] entered development engineering in June and August of 1952 respectively They comprised part of an effort to provide an "emergency capability" of bombs and modified B-36 bombers to deliver them [25] In October 1953 three other thermonuclear warheads entered development engineering, the EC17, EC24, and the smaller B15 Just prior to *Bravo*, the first test in the *Castle* series, the first thermonuclear warhead entered the stockpile on an "emergency" basis In March, April, and May, concurrent with the *Castle* series, the EC16, EC24, and EC17 were also produced in small numbers providing the planned-for emergency capability

The first two shots of the *Castle* series, the 15 Mt *Bravo* test of an experimental device, and the *Romeo* test of the 11 Mt EC14 demonstrated the practicability of lithium-deuteride (dry bombs) As a result the EC16, a liquid deuterium bomb with a complex cryogenic cooling system, was withdrawn from the test series and another device substituted The *Castle* series also yielded information that enabled the design of lighter thermonuclear weapons and significantly reduced the requirements for tritium production The *Castle* test results led to several decisions: to produce the 21-ton, high yield (13 5 megaton) B17 and B24 (from October 1954 to November 1955); to produce the lighter weight (7600 lb), lower yield B15

18 "[T]he TX-18 (the development version of the B18) was conceived as an emergency device" Lee Bowen *History of the Air Force Atomic Energy Program Volume IV The Development of Weapons* (Washington D C : U S Air Force Historical Division History 1955 declassified with deletions June 1981) p 75 "It would be an interim bomb pending the development and stockpiling of thermonuclear weapons" Ibid p 77

19 Hans A Bethe "Comments on the History of the H Bomb," *Los Alamos Science* (Fall 1982): 46; Richard G Hewlett and Francis Duncan *Atomic Shield, 1947/1952: Volume II: A History of the United States Atomic Energy Commission* (Washington D C : U S Atomic Energy Commission 1972) pp 521 53; Herbert F York *The Advisors: Oppenheimer Teller and the Superbomb* (San Francisco: W H Freeman and Company 1976); Barton J Bernstein "Truman and the H-bomb," *The Bulletin of the Atomic Scientists* (March 1984): 12 14; McGeorge Bundy "The Missed Chance to Stop the H-Bomb" *The New York Review of Books* (13 May 1982): 13 22; Atomic Energy Commission, "Thermonuclear Weapons Program Chronology" Historian s Office Department of Energy 142 pages

20 Stanley A Blumberg and Gwinn Owens *Energy and Conflict The Life and Times of Edward Teller* (New York G P Putnam s Sons 1976) p 258

21 Carson Mark "A Short Account of Los Alamos Theoretical Work on Thermonuclear Weapons 1946 1950" Los Alamos Scientific Laboratory LA-5647 MS July 1974, p 2

22 The approach was first set forth in a still classified internal Los Alamos report by Frederic de Hoffman dated 1 February 1951 See Blumberg and Owens *Energy and Conflict* pp 259 60

23 The cavity made of material with a high atomic number is often referred to as a "hohlraum" the hollow cavity of blackbody theory familiar to physicists

24 Six warheads have been given the "EC (emergency capability)" status four of them thermonuclear bombs; see Table 1 2

25 Bowen The Development of Weapons pp 211-24

(from April 1955 to February 1957); and to cancel and dismantle the EC14 and EC16 and to dismantle the EC17 and EC24

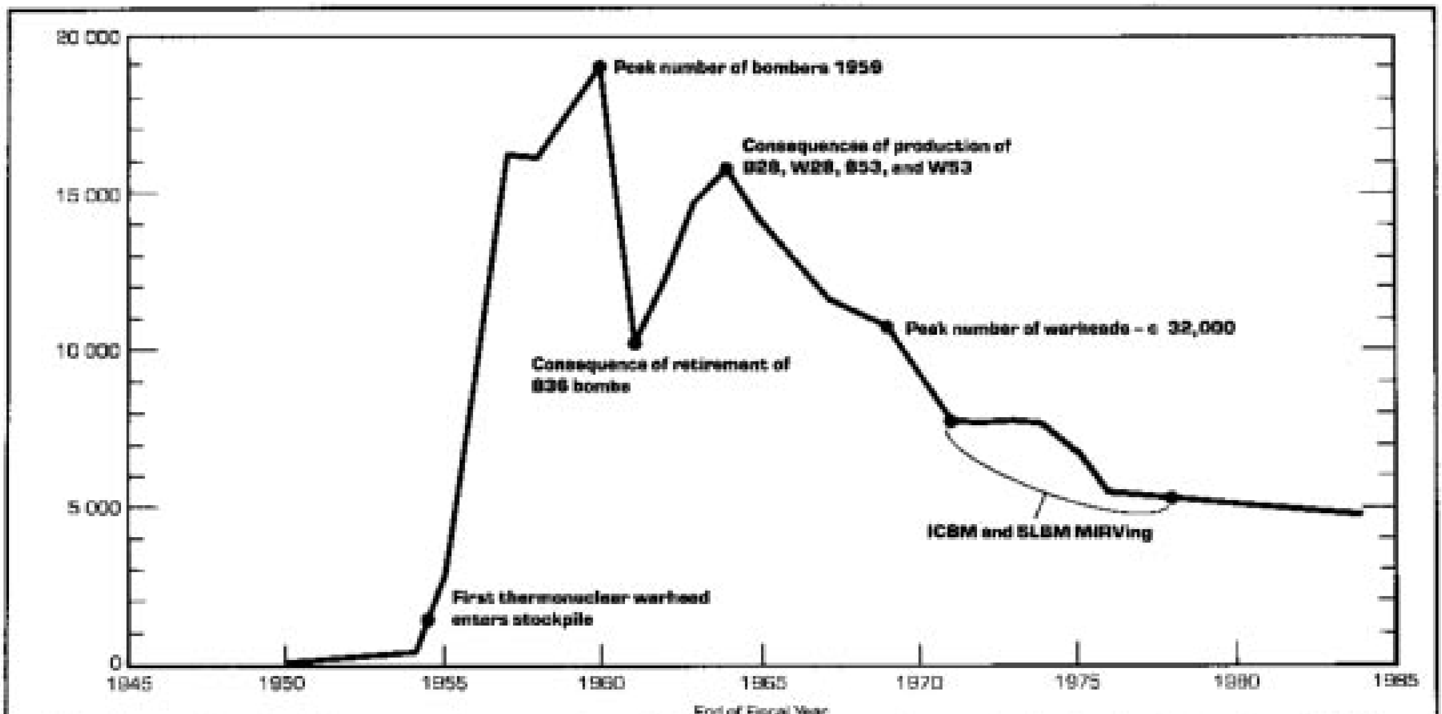
Beginning with the stockpile entry of the B21 in December 1955 and the B36 in April 1956, thermonuclear warheads were produced in larger numbers Megatonnage of the stockpile rose correspondingly Figure 1 4 and Table 1 6 show the total yield of the stockpile from 1950 to 1984 Between 1955 and 1960 the megatonnage grew enormously, peaking at about 19,000 megatons Approximately one half of the megatonnage was concentrated in 2 to 3 percent of the warheads This is evidenced by the sudden retirement of B36 bombs between August 1961 and January 1962, dropping the total to about 10,000 Mt [28] The decrease in megatonnage reflected a desire to cover more targets and rely on bombs with a laydown capability The former was accomplished by substituting several smaller bombs for one large bomb From mid-1961 to mid-1962, while the strategic bomber force remained constant, the number of bombs on alert doubled Over the next two-and-one-half years (1962 to mid-1964) the megatonnage rose again by about 5500 Mt This growth primarily reflected the production of thousands of B28s and W28s and hundreds of B53s and W53s

Early Development of ICBMs and IRBMs

Ballistic missile development had almost as much influence as thermonuclear warheads on military force structures, war plans, and the composition of the stockpile With varying degrees of enthusiasm each service pursued programs to take advantage of the new technology

The Air Force ballistic missile program in the early fifties had low priority and was poorly financed The only available warheads at the time were too heavy and had too low a yield In late 1953 the AEC succeeded in developing the B15, a high yield, "light weight" thermonuclear warhead which shifted the intercontinental and intermediate-range ballistic missile program to a higher level of priority In 1955 President Eisenhower assigned the highest national priority to developing these missiles

The Army was the first to field a long-range ballistic missile with the REDSTONE in 1958 Intense interservice rivalry led to a 26 November 1956 memorandum by the Secretary of Defense delineating ballistic missile program responsibilities As a result the Army was limited to missiles under one hundred miles, effectively removing them as users of ballistic missiles



Note: The curve showing the relative megatonnage by year was supplied by DOE The vertical scale was added by the authors by scaling the relative values for end FY 1980 to 10 000 megatons The uncertainty in this scaling is estimated to be less than 10 percent

Figure 1.4 Total Megatonnage of U S Nuclear Weapons Stockpile, 1950-84

28 In Figure 1 4 and Table 1 6 the drop in megatonnage occurs in FY 1961 reflecting the fact that the B36 bombs were removed from service in FY 1961 although not dismantled until the following fiscal year Some B15 bombs were also retired during this period

Table 1 6

Total Megatonnage of U.S. Nuclear Weapons Stockpile, 1950-84

End of FY	Yield (Megatons)
1950	77
1951	103
1952	128
1953	154
1954	396
1955	2819
1956	9152
1957	16,335
1958	16,142
1959	17,764
1960	19,000
1961	10,272
1962	12,203
1963	14,820
1964	15,756
1965	14,134
1966	13,053
1967	11,856
1968	11,045
1969	10,929
1970	9114
1971	7994
1972	7955
1973	7916
1974	7800
1975	6797
1976	5561
1977	5484
1978	5366
1979	5329
1980	5291
1981	5059
1982	5020
1983	4924
1984	4866

Note: Numerical values are obtained by scaling the relative values obtained from DOE to 19 000 megatons as of the end of FY 1960 The uncertainty in this scaling is estimated to be less than 10 percent

The THOR was the first Air Force ballistic missile deployed Sixty of the single-stage, liquid-fuel, 1500 nautical mile (nm) missiles were deployed at four sites in the United Kingdom between 22 June 1959 and 22 April 1960 The missiles were turned over to the Royal Air Force while the 1 44 Mt W49 warheads remained in custody of the Strategic Air Command [27]

The Army developed the JUPITER missile to compete with the THOR Because of the range limitation imposed on the Army the JUPITER was transferred to the Air Force which operated squadrons in Italy and Turkey

The ICBM programs led to the Strategic Air Command's first generation of the ATLAS D/E/F and TITAN I On 31 October 1959 the first American ICBM, an ATLAS D equipped with a W49 warhead, was placed on strategic alert at Vandenberg Air Force Base, California Overall thirty ATLAS D, twenty-seven ATLAS E, and seventy-two ATLAS F ICBMs were put on alert between 31 October 1959 and 20 December 1962 They carried the W49 and higher yield W38 3 75 Mt warheads Fifty-four TITAN I ICBMs became operational between 20 April 1962 and 16 August 1962 with W38 warheads

The second generation of missiles soon followed Eight hundred MINUTEMAN I ICBMs were deployed between 11 December 1962 and 15 June 1965, the first 150 probably with W59 warheads, the rest with the 1 2 Mt W56 An additional two hundred MINUTEMAN II ICBMs deployed between 25 April 1966 and 21 April 1967 brought the MINUTEMAN force to one thousand, a limit set by Secretary of Defense McNamara on 11 December 1964, and the number ever since Three hundred more MMIIs were added by 27 May 1969 (and 300 MMIs withdrawn) bringing the force to 500 of each kind, each with the W56 warhead The other second generation ICBM was the TITAN II Fifty-four were deployed at three bases between June and December 1963, all carrying the 9 Mt W53 warhead

Serious Navy interest in the ballistic missile dated from 1955 when recommendations were made to have a sea-based (and Army land-based) intermediate-range version [28] Initially the Navy was directed to adapt the Army's huge liquid-fueled JUPITER IRBM missile for surface ships and eventually submarines Given the eventual prospect of lighter weight warheads and the problems associated with ship-basing of the JUPITER, a smaller solid-fuel missile was proposed instead In the fall of 1956 the AEC certified that it could deliver to the Navy a light enough warhead, with sufficient yield, for a 30,000 lb missile In December the Navy's participation in the JUPITER program ended and the POLARIS program officially began

Over the next three years deployment dates for the POLARIS A1 SLBM were rescheduled and advanced In November 1957 (the month following Sputnik), to indicate the high priority given the program a directive specified deployment of the A1X test missile by April 1960 if emergency measures were invoked The AEC gave the missile's warhead (the W47) an "early capability" status, and a few were in fact ready in April of 1960

The concentrated effort to develop submarines, missiles, warheads, support facilities, and equipment led to the deployment of the first Fleet Ballistic Missile submarine, the USS *George Washington* (SSBN 598) on 15 November 1960 from Charleston, South Carolina It car-

27 The THORs in the United Kingdom were phased out between 29 November 1962 and 15 August 1963 A small number of THOR missiles with the W49 warheads were kept until 1975 as a ground-based anti-satellite system on Johnston Island in the Pacific

28 For prior Navy interest in ballistic and cruise missiles see Berend Derk Bruins U S Naval Bombardment Missiles, 1940-1948: A Study of the Weapons Innovation Process Ph D dissertation Columbia University 1981)

ried sixteen POLARIS A1 missiles, each with a W47 warhead An estimated 300 W47 warheads were produced between June 1960 and July 1964 for A1 POLARIS and the longer range A2 missiles

While the A1 and A2 missiles were similar the POLARIS A3 was 85 percent new with a 2500 nm range It was the first missile able to carry multiple warheads The warhead, the W58, was produced between March 1964 and June 1967 The POLARIS A3 force peaked between October 1967 and February 1969 with twenty-eight SSBNs carrying 448 SLBMs with 1344 W58 warheads

Other Missions

Throughout the period one of the most significant influences on the stockpile was the development of lighter weight, smaller volume warheads All services took advantage of these innovations and adapted them to a variety of tactical missions

The Army deployed nuclear land mines (ADMs), widely adopted 155mm and 203mm artillery, and several kinds of short-range nuclear missiles

The Navy developed a series of nuclear anti-submarine weapons including a nuclear torpedo, nuclear depth bombs, and nuclear anti-submarine missiles

Precipitated by the "bomber gap," air defense became one of the most expansive areas of nuclear warhead growth during this period Most studies focus on the Air Force's and SAC's use of the gap to justify more bombers for themselves An overlooked consequence was the enormous growth in nuclear armed air defense weapons

The first nuclear air defense warhead was the GENIE air-to-air rocket Its W25 warhead was one of only six given the emergency capability status, and several were ready in November 1956 GENIE was followed by the NIKE-HERCULES surface-to-air missile deployed in 1958, the BOMARC long-range surface-to-air missiles deployed in 1959, and the FALCON air-to-air missiles deployed in the early 1960s The Navy deployed the nuclear armed TALOS in 1959 and the TERRIER in 1966 as nuclear surface-to-air missiles

In the United States a huge air defense infrastructure was built By the early 1960s it included 2612 interceptor aircraft, 274 NIKE-HERCULES batteries, 439 BOMARC missiles, hundreds of radars, manned with 207,000 personnel [29]

Combined production of warheads for the various air defense missiles totaled some 7000, a significant percentage of the stockpile at that time As early as 1959 the intelligence community realized that its early estimates of thousands of Soviet bombers were in error [30] Nonetheless the momentum behind the air defense program was unstoppable

By the late 1950s and early 1960s the warhead production complex was operating at peak capacity in more than twenty facilities Spending peaked in 1960 with warhead production rates 5000 to 6000 a year between 1959-1961 Uranium enrichment and plutonium production peaked between 1961 and 1963 at some 60 MT of highly enriched uranium[31] and 7 5 MT of plutonium equivalent (plutonium and tritium) per year

Early in the Kennedy administration a decision was made to scale back warhead and material production In his State of the Union address of January 1964 and again in April 1964 President Johnson announced a staged cutback in the production of highly enriched uranium and weapon-grade plutonium [32] This led to the initial shutdown of four reactors between June 1964 and April 1965 and an immediate 25 percent reduction in the operation of the gaseous diffusion plants [33] The Clarksville Center in Tennessee and the Medina Center in Texas closed in late September 1965 and early spring 1966 respectively Their functions were transferred to the Burlington and Pantex plants The Weldon Springs feed processing facility was shut down by the end of 1966 with its functions transferred to Fernald Seven more reactors shut down between 26 June 1967 and 28 January 1971 (see Table 3 1) By 1969 gaseous diffusion plants had decreased their total output by almost 60 percent

Stabilization—late 1960s-1980

Qualitative Developments

After the enormous warhead buildup—the numerical high was reached in 1967—the stockpile stabilized in numbers and underwent qualitative changes

The most notable feature of this period was the MIRVing of most of the ballistic missile force between 1970 and 1978 with almost 7000 W62 and W68 warheads MIRVing was facilitated by improved warhead yield-to-weight ratios and sophisticated reentry vehicle guidance systems The "need" for more warheads was driven by war plans with greater numbers of targets [34] As one student of targeting has said:

> It is apparent that, throughout the entire period since 1945, the number of Soviet installations which U S target planners have considered necessary to target has exceeded the weapons available for employment against them Indeed, there is no doubt that, to some extent at least, target lists have been generated in order to provide an argument for larger strategic nuclear forces [35]

29 HASC Continental Air Defense Hearing 22 July 1981 p 25

30 John Prados, *The Soviet Estimate: U S Intelligence Analysis & Russian Military Strength* (New York: The Dial Press 1982) p 40

31 This estimate assumes that two thirds of the uranium enrichment in 1961 was for weapons

32 ACDA, *Documents on Disarmament 1964* pp 4 165 66 See also AEC *Report to Congress* January 1964 pp 40-41, AEC *Report to Congress*, January 1965 pp 17 44 The Soviet Union and United Kingdom made simultaneous announcements of their own cut backs See *Documents on Disarmament 1964* pp 166-71

33 AEC Report to Congress January 1966, p 73

34 The specific targeting requirements of U S nuclear war plans have had and continue to have an influence on the composition of the stockpile As the United States was able to see more and more of the Soviet Union through airplane and satellite overflights more and more targets were found which in turn generated the "need" for more warheads The number of potential targets has increased from about 70 in 1949 to more than 40 000 today; Desmond Ball "Targeting for Strategic Deterrence" *Adelphi Paper* 185 (London: IISS 1983): 25

35 Ibid p 40

Nonetheless MIRVs were rationalized at the time because of cost effectiveness and the necessary ability to overwhelm a future Soviet anti-ballistic missile system [36]

In the plan to MIRV missiles during the mid-1960s, both the Air Force and Navy would use the W67 warhead in the Mk-17 reentry vehicle (RV) This foundered as each service wanted its own reentry vehicle, leading to cancellation of the multimegaton W67 in December 1967 The Air Force chose instead the W62, with the Mk-12 RV; the Navy chose the W68 with the Mark-3 RV

The first MINUTEMAN and POSEIDON MIRV tests took place on 16 August 1968 They were successful By mid-1970 the first of 550 new MINUTEMAN III missiles were being deployed, an effort that would continue until 1975 Each missile had three W62 170 Kt warheads for a total of 1650

More dramatic in terms of sheer numbers was the Navy's MIRVing of its submarine fleet from March 1971 to September 1978 replacing POLARIS missiles with POSEIDONs on thirty-one SSBNs Approximately 5000 W68 (50 Kt) warheads were built in a five-year period between May 1970 and June 1975 adding some 3500 warheads to the Navy's strategic arsenal

A second technological innovation during this period, variable yield warheads, had major repercussions on the stockpile Prior to the development of the B61 bomb and the LANCE warhead, yields were either fixed or changeable only through a time-consuming alteration on the ground With the introduction of variable yield warheads the yield could be selected ("dial a yield") at the point that firing orders are received and fuzing takes place [37] A warhead with several yield options permited the retirement of several single yield warheads

During this period the number of warhead types in simultaneous production averaged only three or four, at certain times dropping to one [38] Spending fell to less than half that of the peak years

Upward Bound—1980-1990s

Reviving the Production Complex

Beginning in the late 1970s several political and international factors would result in once again increasing the size of the stockpile The period 1977-1981 was one of growing international tension between the United States and the Soviet Union The waning of detente, the invasion of Afghanistan, the failure to ratify SALT II, and the election of Ronald Reagan each contributed to recommendations to increase the capacity of the warhead production complex and the number of warheads

At the same time new goals and guidelines were established for nuclear employment policy (Presidential Directive-59, signed by President Carter on 26 July 1980) and were used to justify new warheads as well as to rationalize those in development

The concern over the ability to produce the large number of nuclear warheads in research and development led to DOE deliberations about the adequacy of the production complex Air, ground, and sea-launched cruise missiles, the MX, TRIDENT I, and PERSHING II ballistic missiles, neutron weapons, and new bombs were scheduled for deployment between 1979 and 1986 For these warheads and others it was projected that there would not be enough fissile materials or sufficient capacity in the complex The United States had faced this situation in the late forties and early fifties when constraints of the supply of nuclear material limited the numbers of warheads that could be produced To some who studied the problem in the late 1970s it appeared that material shortages might again constrain the quantitative and qualitative composition of the stockpile

During 1977 and 1978 the Senate and House Armed Services Committees visited DOE facilites and issued reports that found DOE lacking a comprehensive program to meet the pending warhead schedule Executive branch committees were formed to examine the problem further [39] In June 1979 the DOE submitted a report to Congress that identified deficiencies in the production complex and provided a five-year plan to correct them A National Security Council-directed policy review committee concluded in 1980 that the nuclear materials capacity must be expanded A joint DOD/DOE study by the Long Range Resources Planning Group was directed to "Develop and propose guidance for a 20-year nuclear weapon program for DOD and DOE resource planning" and to "review U S nuclear weapon acquisition and planning policies, procedures and practices, and recommend improvements" to upgrade the production complex [40]

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36 The following interchange in the summer of 1968 shows the priorities Senator Mike Mansfield (D-MT) asked Dr John S Foster Jr the director of defense research and engineering:

> Is it not true that the U S response to the discovery that the Soviets had made an initial deployment of an ABM system around Moscow and possibly elsewhere was to develop the MIRV system for MINUTEMAN and POLARIS?

Dr Foster replied:

> Not entirely The MIRV concept was originally generated to increase our targeting capability rather than to penetrate ABM defenses In 1961-62 planning for targeting the MINUTEMAN force it was that the total number of aim points exceeded the number of MINUTEMAN missiles By splitting up the payload of a single missile [deleted] each [deleted] could be programmed [deleted] allowing us to cover these targets with [deleted] fewer missiles [Deleted] MIRV was originally born to implement the payload split-up [deleted] It was found that the previously generated MIRV concept could equally well be used against ABM [deleted]

Quoted in Ralph E Lapp, *Arms Beyond Doubt: The Tyranny of Weapons Technology* (New York: Cowles Book Company 1970) p 21

37 This innovation has been adopted in most tactical warheads such as the W79 W80 W84 and W85

38 back in the late 1970s we were virtually quiescent in terms of warhead production HAC FY 1986 EWDA Part 7 p 11

39 SASC FY 1981 DOE p 75 HAC, FY 1980 EWDA, Part 7 pp 2616-18

40 Long Range Nuclear Weapon Planning Analysis for the Final Report of the DOD/DOE Long Range Resource Planning Group 15 July 1980 p x The Final Report is referred to as the Starbird Report

Higher warhead production levels were already set in the Nuclear Weapon Stockpile Memorandum (NWSM) for FY 1980-82, signed by President Carter on 5 January 1979 [41] The FY 1981 budget, sent to Congress in February 1980, had requested money for many new initiatives President Carter bequeathed to President Reagan an already increased set of production goals and programs These levels were set in Carter's last NWSM for FY 1981-1983, signed on 24 October 1980, and in his FY 1982 budget

Upon entering office President Reagan provided his own FY 1982 budget that was an across-the-board addition to Carter's For the Atomic Energy Defense Activities portion of the DOE budget Reagan increased the request by almost $300 million to just over $5 billion The Materials Production request went from $837 million to $931 million [42] During the next six months the Reagan Administration began to put its own stamp on the military budget and nuclear weapon programs On 2 October 1981 President Reagan unveiled a five-part strategic weapon modernization program These included new bombers, TRIDENT submarines, TRIDENT and MX missiles, and improvements in communication and control systems, and in strategic defense [43]

Reagan's programs were more ambitious than Carter's in terms of warhead production and spending (see Table 1 7) Some weapons were revived, many others had increased goals, and in a few there were decreases: the B-1 bomber got a second life, the number of cruise missiles was increased, while the number of MX missiles was cut in half Theater and tactical programs were not overlooked In August 1981 Reagan announced that enhanced radiation weapons would be produced New naval nuclear weapons were envisioned, and the PERSHING II and GLCM became top priorities to meet a December 1983 deployment deadline

On 17 March 1982 President Reagan signed his first NWSM It was notable in several respects Rather than the three-year (near-term) and eight-year (long-term) periods of past memoranda, the March 1982 version

Table 1 7

Atomic Energy Defense Activities, 1978-89—Budget Outlays

(in millions of dollars)

FY	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
Weapons Research, Development, Test, and Production	1142	1387	1814	2186	2642	2983	3513	4054	4070	4368	4820	5165
Weapons Materials Production and Waste Management	530	685	745	984	1207	1663	2001	2396	2372	2594	2756	2953
Naval Reactor Development	231	258	241	283	339	410	465	480	530	556	616	660
Other Research Programs	167	211	78	-55[a]	121	135	141	168	180	190	208	222
TOTAL	2070	2541	2878	3398	4309	5171	6120	7098	7152[b]	7708	8400	9000

From the beginning of the Carter Administration (FY 1978) through the end of Reagan's first term (FY 1985) the budget for nuclear warheads has more than tripled from slightly over $2 billion to slightly over $7 billion In constant dollars this represents a real increase of 120 percent Most pronounced within the budget is a more than fourfold increase (in current dollars) for materials production, a real increase of 190 percent The total budget is planned to increase another 10 percent in real terms during the second term

a Includes negative undistributed cost outlay adjustments

b Figures for 1988-89 are estimates

Source: OMB *Budget of the United States Government* Volumes FY 1980-FY 1987 (Washington D C : Government Printing Office 1979-86)

41 HAC FY 1980 EWDA Part 7 p 2178

42 Compare the Carter Budget Justifications in HAC FY 1982 EWDA Part 6 with Reagan's in HAC FY 1982 EWDA Part 5

43 SASC, Strategic Force Modernization Programs Hearings October/November 1981; SASC Modernization of the U S Strategic Deterrent Hearings October/November 1981

Table 1 8

Nuclear Warheads in Full Scale Production and Research and Development
(1985-1990s)

WARHEADS IN PRODUCTION

Number	Description and Date[a]	Est. Total	Est./Year
B61-3	Tactical Bomb (10/79)	1000	125
B61-4	Tactical Bomb (05/79)[b]	1000	125
W76	TRIDENT I (06/78)	3200	320 [c]
W79	8-inch Artillery (07/81)	625 [d]	100
W80-1	Air-Launched Cruise (01/81)[e]	3100	350
W80-0	Sea-Launched Cruise (03/84)	750	90
B83	Strategic Bomb (06/83)[f]	3000	425
W84	Ground-Launched Cruise (06/83)	500	125
W85	PERSHING II (02/83)	125	60
W87	MX Missile (04/86)[g]	525-1050	175-350

WARHEADS IN R&D

W81	STANDARD-2 Surface-to-Air Missile
W82	155mm Artillery Fired Atomic Projectile (Production period 1989-92 to produce approximately 300)
W88	TRIDENT II (First deliveries FY 1989)
Wxx	SEA LANCE Antisubmarine Warfare/Standoff Weapon (ASW/SOW)[h]
Wxx	Antisubmarine Warfare/Vertical-Launch ASROC (ASW/VLA)[i]
Wxx	Antisubmarine Warfare/Nuclear Depth/Strike Bomb (ASW/ND/SB)[j]
Wxx	Tactical Follow-on Missile[k]
Wxx	SRAM II (Phase 2 scheduled for completion May 1986)
Wxx	Small Intercontinental Ballistic Missile (SICBM) (Phase 2 scheduled for completion March 1986)
Wxx	Ballistic Missile Defense (BMD)—Nuclear Option
Wxx	Tactical Air-to-Surface Missile (TASM)
Wxx	Earth Penetrator Weapon (EPW)

a Date indicates First Production Unit

b B61-3 4 are to replace older Navy B43s B57s and older Air Force tactical bombs; HASC FY 1986 DOE pp 56 67

c The rate is not constant For the first five years the rate was probably around 400 per year for the twelve LAFAYETTE/FRANKLIN and first two OHIO class SSBNs all of which deployed between October 1979 and the summer of 1983 The rate is probably around 240 per year for the last five years for the next six OHIO class SSBNs The First W76 warhead for the TRIDENT I SLBM was produced in June of 1978 and is likely to be produced until 1988 Approximately 3200 are needed initially for six FRANKLIN six LAFAYETTE and the first eight OHIO class SSBNs Under current plans eventually the force of 20 TRIDENT SSBNs carrying 480 TRIDENT II SLBMs would have a mix of lighter weight (212 lb for the Mk-4 reentry body) lower yield (100 Kt) W76 warheads with heavier (substantially less than 500 pounds for the Mk-5 reentry body), higher yield (475 Kt) W88 warheads The quote is from HAC FY 1986 EWDA Part 7 p 290 On mixing the two warheads, see HAC FY 1985 DOD Part 8 p 111; HAC FY 1985 EWDA Part 7 p 414 *AWST* (3 September 1984) 290; *Aerospace Daily* (13 March 1985): 65-66 On the yield, see *AWST* (17 January 1983): 26; *AWST* (5 March 1984): 17; SAC FY 1984 DOD Part 1, p 475

d Production of the enhanced radiation version of the W79 was halted by Congress in October 1984 The W79 will complete production in FY 1986

e The W80-1 will also be used for the Advanced Cruise Missile

f The B83 Strategic Bomb is replacing the B28 B43 and B53

g The first ten MX ICBMs are scheduled to be operational in December 1986 Production of the 300 Kt W87 warhead will begin during spring/summer of 1986 and if one hundred missiles are deployed slightly over 1000 warheads would be produced during a three year period At the end of 1985 Congress limited the number of MX missiles to be deployed to 50

h To replace the W55 SUBROC warhead Phase 3 is expected to begin by August 1986

i To replace the W44 ASROC warhead

j To replace B57 nuclear depth bomb and some B61 mods for the Navy

k Formerly called JTCAMS

defined annual requirements for the first five years, planning directives for the next five years, and long-range planning projections for an additional five years [44] In terms of nuclear warhead production, reports indicated a rise of only 380 for the first five-year period over the already increased Carter goals [45] While the projected number of warheads did not go up appreciably, a different mix of warheads coupled with technological developments drove projected nuclear material production requirements higher Smaller warheads with higher yield-to-weight ratios require additional plutonium,[46] and more tritium would be needed for several planned enhanced radiation warheads

The material production goals were reinforced in President Reagan's second NWSM, for FY 1983-88, approved on 18 November 1982 In approving the Memorandum President Reagan stated that:

44 DOE FEIS L-Reactor p 1-2

45 Judith Miller Reagan Endorses Rise in Atomic Warheads by 380 Over Carter Goal *New York Times* (22 March 1982) B 11

46 HASC FY 1985 DOE p 119

> as a matter of policy, national security requirements shall be the limiting factor in the nuclear force structure Arbitrary constraints on nuclear material availability shall not be allowed to jeopardize attainment of the forces required to assure our defense and maintain deterrence [47]

Also apparently included were requirements for creating "sufficient reserves" of special nuclear materials [48] These reserves were said to be needed "as insurance against unforseen SNM production interruptions and to allow for [a warhead production] surge capacity "[49] The plutonium reserve requirement was set at some 5 metric tons

The third Reagan NWSM was signed on 16 February 1984 It contains stockpile projections for the periods FY 1984-99 [50] Reagan's fourth NWSM was approved in mid-February 1985, and contains stockpile projections for FY 1985-2000 [51] The warheads currently in production and under development are shown in Table 1 8

Nuclear Warhead Technologies and Future Production

Among the warheads being worked upon at Los Alamos and Livermore are the so-called "third generation" weapons [52] Third generation weapons are sometimes referred to as "tailored weapons" in that the effects of the warhead are altered to achieve a particular objective The enhanced radiation (ER) warhead—or, as it is sometimes called, the "neutron bomb"—was the first of these kinds of weapons The concept evolved in 1958 and its development is credited to Samuel T Cohen, then a physicist at the Rand Corporation [53] The neutron bomb is a thermonuclear device designed to maximize the lethal effects of high energy neutrons produced by fusion of deuterium and tritium while reducing the blast effects (see *Nuclear Weapons Databook*, Volume I, p 28)

In 1960 Livermore Laboratory, then led by Edward Teller, lobbied hard in the Pentagon to establish military requirements for development of "pure radiation" tactical warheads [54] Though the proposal was rejected by the Eisenhower Administration research on two ER concepts (code named DOVE and STARLING) remained a high priority at Livermore [55] Livermore successfully tested a device underground in early 1962 [56] "By the spring of 1963 sufficient progress had been made to allow testing of a device that could be 'weaponized' to fit into a battlefield delivery system "[57] It appears that the W63 and W64 were radiation warheads for the LANCE missile, each under development at Livermore and Los Alamos respectively Both entered Phase 3 in July 1964 The W64 was cancelled two months later in favor of the W63, which in turn was cancelled in November 1966 in favor of the non-ER W70-0, which entered Phase 3 in April 1969 [58]

In October 1965 the W65, an ER warhead for the SPRINT anti-ballistic missile, entered Phase 3 The Livermore-designed warhead was cancelled in January 1968 in favor of the Los Alamos-designed W66, which entered Phase 3 the same month The W66 was tested underground at Nevada in the late 1960s and entered production in June 1974 The W66 warheads were recently retired

Two battlefield enhanced radiation warheads are currently in the stockpile: the W70-3 for the LANCE missile, of which approximately 380 were produced between May 1981 and February 1983; and the W79 for the 8-inch artillery shell that began production in July 1981 and will complete production in FY 1986 [59]

Theoretically, effects of nuclear explosions such as heat, blast, or radiation could be tailored to achieve a particular military purpose LANL and LLNL have studied ways to heighten the electromagnetic pulse (EMP) effect that would be useful to knock out command, control, and communications [60]

Another third generation weapon is the X-ray laser Here laser rods are energized by the radiation of a small nuclear explosion Prototype X-ray laser devices developed at Livermore laboratory are known as EXCALIBUR and SUPER EXCALIBUR At least five small undergound nuclear test explosions have reportedly been conducted using the X-ray laser device—on 14 November 1980, 26

47 DOE FEIS L Reactor, Volume 1 p 1 2
48 DOD, FY 1984 Annual Report p 277 There was no mention of a reserve the year before See DOD FY 1983 Annual Report pp III 141-42
49 The Nuclear Weapons Production and RD&T Complex—DOE Support of DOD Requirements Office of the Assistant to the Secretary of Defense (Atomic Energy) December 1982, p 2 See also HASC FY 1984 DOE pp 126 27
50 HAC FY 1985 EWDA Part 6 pp 554-55 and 761; Memorandum for the President FY 1984 FY 1989 Nuclear Weapons Stockpile signed by Donald Paul Hodel Secretary of Energy and Caspar W Weinberger Secretary of Defense dated 27 December 1983 declassified with deletions The seven page memorandum is supplemented by six enclosures: (1) FY 1984-1989 Nuclear Weapons Stockpile Plan and FY 1990 1994 Projections (three pages); (2) Long Range Planning Projection FY 1995 through FY 1999 (one page); (3) Summary of Builds and Retirements (two pages); (4) Information Concerning Force Planning and Stockpile Adjustments (seven pages); (5) Nuclear Materials Supply/Demand Analysis (six pages); (6) Proposed Approval Memorandum (three pages)
51 HASC FY 1986 DOE p 226; SAC FY 1986 EWDA Part 2 p 1258
52 Fission weapons introduced in 1945 and fusion weapons introduced in 1954 are considered the first and second generations
53 S T Cohen *The Neutron Bomb: Political Technological and Military Issues* (Cambridge, Massachusetts: Institute for Foreign Policy Analysis, Inc November 1978) pp 6-7; Sam Cohen *The Truth About the Neutron Bomb* (New York: William Morrow & Company 1983)
54 George B Kistiakowsky The Folly of the Neutron Bomb *The Atlantic* (June 1978): 4
55 The two concepts were a fission fusion device which is the principle of the several types of enhanced radiation warheads that are in the U S arsenal (W70 3 W79 W66) and a pure fusion device which has eluded successful development
56 Cohen The Truth op cit p 55
57 Ibid , p 82
58 JCAE Military Applications of Nuclear Technology Part 2, pp 40-41; Cohen *Neutron Bomb: Political Technological and Military Issues* pp 32-33
59 As of mid-1985 the W79 continued in production though not apparently in the enhanced radiation version; HAC, FY 1985 EWDA Part 7 p 56
60 Walter Pincus New Nuclear Bombs Studied Washington Post (16 April 1983): A 1; HASC FY 1986 DOE, p 101

March 1983, 16 December 1983, 23 March 1985, and 28 December 1985 [61]

DOE is interested in and is conducting research on certain other types of Nuclear-Driven Directed Energy Weapons (NDEW)—for example, visible-light weapons, microwave weapons, charged-particle beam weapons, and nuclear explosive powered kinetic-energy weapons [62]

In addition to the third generation research work a number of innovations in second generation warhead technology continues The three most notable developments are safety improvements, improvements in yield-to-weight and yield-to-volume ratios, and "insertable nuclear components"

In the safety area the major innovation since the late 1970s has been the development and introduction of insensitive high explosives in nuclear warheads This was precipitated by several serious nuclear weapon accidents in the 1950s and 1960s in which the chemical high explosive detonated Other improvements were also made in the safety of firing circuits and fuzing mechanisms, as well as new control devices, known as Permissive Action Links (PALs)

A continuing trend in warhead development has been the improvement in yield-to-weight and yield-to-volume ratios (resulting in the more efficient use of nuclear materials) and the further miniaturization of warheads

The miniaturization of electronic components for warheads has allowed the development of 155mm (6-inch) nuclear artillery shells, small cruise missile warheads, and small but high yield reentry vehicles

An aggressive research program in new warhead design has led to the development of "insertable nuclear components" (INC), thus allowing a missile to accommodate either a nuclear or conventional warhead of the same size and weight Current "dual capable" missile systems require either different warhead sections or separate missiles to deliver nuclear or conventional charges INCs would allow a missile the same flexibility as dual capable artillery, where the same gun can fire either kind of round They are being examined for use on ships and submarines where space is limited

In addition to plans for future types of warheads, several initiatives are underway to augment further the supply of nuclear materials and assure production into the next century As mentioned above, DOE plans resume the production of highly enriched uranium (oralloy) as early as FY 1988 to meet new requirements for reactor fuel Projected demand for tritium has lessened since early in the Reagan administration, but substantial quantities will be required for existing enhanced radiation warheads, to compensate for radioactive decay If additional ER warheads are produced, tritium requirements will go even higher

DOE will continue to produce plutonium to meet increases in stockpile numbers, decreases in retirements (a major source of plutonium), additional "reserves," and design demands (smaller size and higher yield-to-weight and yield-to-volume ratios) that require more plutonium per warhead

At Savannah River, DOE is planning to introduce new reactor fuel to increase the efficiency of plutonium production The N-Reactor at Hanford will reach the end of its projected operating life in about 1997-98 Plans are either to build a New Production Reactor (NPR) (for plutonium or tritium) or to refurbish the N-Reactor completely

The DOE plans to build a Special Isotope Separation (SIS) plant at Hanford sometime in the 1990s This plant would purify plutonium for warhead use using laser isotope separation Initially the SIS plant will enrich the existing small stocks of DOE-owned low-grade plutonium, after which it will be used in a massive effort to purify the some 100 MT in the warheads

61 *AWST* (23 February 1981): 25-27; David Perlman, "Top Secret Plan for Laser Weapon," *San Francisco Chronicle* (23 September 1982): 1; Judith Miller, "New Generation of Nuclear Arms With Controlled Effects Foreseen," *New York Times* (28 October 1982): A-1; Patrick E Tyler, "How Edward Teller learned to love the nuclear-pumped X-ray laser," *Washington Post* (3 April 1983): D-1; *AWST* (13 June 1983): 15; William J Broad, "X-Ray Laser Weapon Gains Favor," *New York Times* (15 November 1983): C 1; William J Broad "The Young Physicists: Atoms and Patriotism Amid the Coke Bottles," *New York Times* (31 January 1984): C-1; William J Broad "Gains Reported On Use of Laser For Space Arms," *New York Times* (15 May 1985): A-1; *Scientific American* (July 1985): 58; William J Broad "New Atomic Weapons are being Designed at a Furious Pace," *New York Times* (16 July 1985): C-1; R Jeffrey Smith, "Experts Cast Doubt on X-ray Laser," *Science* (8 November 1985): 646-48; William J Broad, "Space Weapon Test Failure Reported," *New York Times* (1 November 1985): B7; William J Broad, *Star Warriors* (New York: Simon and Schuster, 1985); Robert Scheer "Scientists Dispute Test of X-Ray Laser Weapon," *Los Angeles Times* (11 November 1985): 1

62 Office of Technology Assessment *Anti-Satellite Weapons, Countermeasures, and Arms Control* (Washington D.C.: GPO 1985), pp. 70-71; *Scientific American* (February 1986): 54 58 DOE Strategic Defense Initiative funding for FY 1986 concentrated almost entirely in nuclear driven directed energy devices was $288 million The request for FY 1987 is $603 million and the projection for FY 1988 is $811 million


2

Chapter Two
The Production Complex Today

The United States currently produces, modifies, and retires some 3000 to 4000 nuclear warheads per year while maintaining a stockpile of 25,000 to 26,000 warheads A government complex of nineteen facilities in thirteen states, with thousands of subcontractors and vendors, perform the majority of the work Specifically, the complex comprises three national laboratories, nine material production facilities, seven warhead production facilities (two are colocated) (see Figure 2 1 and Table 2 1), and two test sites DOE and DOD operate a number of major testing areas for warheads and delivery systems Both agencies operate scores of research facilities which also contribute to the development of nuclear weapons

This chapter provides a broad picture of these activities and traces a nuclear warhead through its development and manufacture

Laboratories

The United States operates three nuclear weapon laboratories through the Department of Energy (DOE) Several other DOE laboratories contribute nuclear weapon research, as do several Department of Defense (DOD) laboratories

The Department of Energy nuclear weapon laboratories are the Los Alamos National Laboratory (LANL) and Lawrence Livermore National Laboratory (LLNL)—both performing nuclear warhead design—and Sandia National Laboratories (SNL), an engineering laboratory responsible for the development of non-nuclear components LANL, LLNL, and SNL are now all broad-based, multiprogram laboratories specializing in the physical sciences and engineering with a large number of professionals in numerous fields

The principal nuclear weapon missions of LANL and LLNL are threefold First, they are to explore advanced weapons concepts and to improve understanding and exploitation of nuclear weapon physics Second, they design and fabricate test devices and diagnostic equipment used at the Nevada Test Site Thirdly, the two laboratories develop warheads or bombs for existing or proposed weapon systems, and monitor their reliability after entering the stockpile Sandia's principal mission is the research, development, and engineering of non-nuclear components of nuclear weapons, such as fuzes, timers, safety and control devices, and parachutes

Approximately one half of the staff and over two thirds of the budget of the national laboratories support nuclear weapon work (see Table 2 2) The efforts of over 11,000 employees and a budget of $1 8 billion (FY 1986) are devoted to warhead activities at the three laboratories

Los Alamos National Laboratory

In January 1943, a wartime laboratory was established at Los Alamos, New Mexico to design, assemble, and test the first nuclear bombs [1] After the expenditure of $1 7 billion and work by tens of thousands of scientists, engineers, and employees the first bomb was exploded on 16 July 1945 at the *Trinity* site near Alamogordo, New Mexico *Trinity* was followed by the destruction of Hiroshima and Nagasaki, Japan, in August 1945

In the years after the war, Los Alamos continued to develop fission weapons In 1952 it tested the first thermonuclear (fusion) device at Enewetak Atoll in the Pacific Until 1958 all weapons that entered the stockpile were designed by LANL Out of seventy-one types of nuclear warheads, Los Alamos has designed fifty-three Of the twenty-nine types currently in the stockpile, LANL has designed seventeen In recent years, the laboratory has designed warheads for the TRIDENT (W76), MINUTEMAN III (W78), sea- and air-launched cruise missiles (W80-0,1)

LANL is organized into seven substantive areas: (1) chemistry, earth and life sciences; (2) engineering sciences; (3) experimental physics; (4) theoretical and computational physics; and three defense programs [2] The Weapons Development Program has sections devoted to

1 The literature on the U S effort during World War II to develop nuclear weapons is vast For a sampling of first hand accounts and histories, see General Leslie R Groves, *Now It Can Be Told: The Story of the Manhattan Project* (New York: Harper 1962); Jane Wilson Ed *All in Our Time: The Reminiscences of Twelve Nuclear Pioneers* (Chicago: Educational Foundation for Nuclear Science 1975); Lawrence Badash Joseph O Hirschfelder and Herbert P Broida eds., *Reminiscences of Los Alamos, 1943 1945* (Dordrecht Holland: D Reidel Publishing Company, 1980); Alice Kimball Smith and Charles Weiner, eds *Robert Oppenheimer Letters and Recollections* (Cambridge Massachusetts: Harvard University Press 1980); Montgomery Cunningham Meigs *Managing Uncertainty: Vannevar Bush James B Conant and the Development of the Atomic Bomb 1940-1945* (Ph D dissertation, University of Wisconsin Madison 1982); Vincent C Jones, *Manhattan: The Army and the Atomic Bomb*, U S Army Center of Military History (Washington D C : GPO 1985); Henry DeWolf Smyth, *Atomic Energy for Military Purposes: The Official Report on the Development of the Atomic Bomb under the Auspices of the United States Government 1940 1945* (Princeton, New Jersey: Princeton University Press 1945); *Project Y: The Los Alamos Story Part I, Toward Trinity* by David Hawkins *Part II, Beyond Trinity*, by Edith C Truslow and Ralph Carlisle Smith (Los Angeles: Tomash Publishers 1983); Richard G Hewlett and Oscar E Anderson, Jr *The New World 1939 1946* (University Park Pennsylvania: The Pennsylvania State University Press 1962); James W Kunetka *City of Fire: Los Alamos and the Birth of the Atomic Age 1943 1945* (Englewood Cliffs New Jersey: Prentice Hall, Inc 1978); Ferenc Morton Szasz *The Day the Sun Rose Twice: The Story of the Trinity Site Nuclear Explosion July 16 1945* (Albuquerque, New Mexico: University of New Mexico Press 1984); Anthony Cave Brown and Charles B MacDonald, eds , *The Secret History of the Atomic Bomb* (New York: Dell Publishing Co , Inc 1979); Fletcher Knebel and Charles W Bailey II *No High Ground* (New York: Harper & Row 1960); Martin J Sherwin *A World Destroyed* (New York: Knopf 1975); Los Alamos Science Winter/Spring 1983 Volume 4 Number 7

Figure 2 1 Map of DOE Field Facilities and Operations

advanced weapons technology, test operations, and weapons programs National Security Programs has sections devoted to arms control and verification, defense construction, and special projects Defense Research Programs has sections devoted to strategic defense, and fusion research and applications (see Figure 2 2)

Lawrence Livermore National Laboratory

Lawrence Livermore National Laboratory was established as a second nuclear weapons design laboratory in 1952 to increase the U S effort to develop thermonuclear weapons [3] After the public announcement on 23 September 1949 that the Soviet Union exploded its first atomic bomb on 29 August, there followed intense debate about the appropriate U S response On 31 January 1950, President Truman announced his decision to proceed with the development of the hydrogen bomb, which led to a faster effort at LANL and ultimately the establishment of LLNL The Los Alamos H-bomb program was accelerated, new design ideas and calculations were developed, and tests were conducted to verify them Instrumental in the promotion of a second lab were Ernest O Lawrence and Edward Teller Their efforts and others resulted in the Atomic Energy Commission's approval to establish a branch of the University of California's Radiation Laboratory at Livermore The site was selected in February 1952, activated in July, and officially opened in September under its first director, Herbert F York (see Table 2 3)

Although Lawrence Livermore was established in 1952 to primarily to develop thermonuclear weapons, its first successful warhead type was not deployed until 1958 (B27 and W27) And not only did Los Alamos design and develop the first thermonuclear warheads but Lawrence Livermore had four serious test failures ("fizzles") in the 1950s Since about 1960 most weapons entering the stockpile have resulted from keen competition between the laboratories "There are dozens of instances in which an approach by one laboratory was surpassed by the other, or in which an approach discarded as infeasible or not useful by one was picked up

2 Los Alamos National Laboratory Institutional Plan FY 1985 90 p 153

3 For background on the establishment of LLNL see Richard G Hewlett and Francis Duncan *Volume II Atomic Shield, 1947 1952: A History of the United States Atomic Energy Commission* (Washington D C : Atomic Energy Commission 1972) pp 581 84; Herbert F York *The Advisors: Oppenheimer Teller and the Superbomb* (San Francisco: W H Freeman and Company 1976) pp 121 35; Edward Teller *The Legacy of Hiroshima* (Garden City New York: Doubleday & Co 1962) pp 54 76; Moving In Energy and *Technology Review* (February 1982): 19-29

Table 2 1

Principal DOE Warhead Facilities

(1985)

Facility	Current Operating Contractor	Date of Initial Operation	Employment[a]
LABORATORIES			
Los Alamos National Laboratory (LANL) Los Alamos, New Mexico	University of California	1947	3198
Lawrence Livermore National Laboratory(LLNL) Livermore, California	University of California	1952	4322
Sandia National Laboratories (SNL) Albuquerque, New Mexico Livermore, California (SNLL)	Sandia Corporation subsidiary of AT&T Corporation	1945	4138
		subtotal:	11,658
MATERIALS PRODUCTION FACILITIES			
Feed Materials Production Center Fernald, Ohio	Westinghouse Materials Co of Ohio	1953	1083
Ashtabula Plant Ashtabula, Ohio	Reactive Metals, Inc	1952	116
Y-12 Plant Oak Ridge, Tennessee	Martin Marietta Energy Systems, Inc	1944	7213
Hanford Reservation Richland, Washington	Rockwell Hanford Operations, United Nuclear Industries, Inc	1944	8561
Savannah River Plant Aiken, South Carolina	E I duPont de Nemours and Company	1950	15,120
Idaho National Engineering Laboratory (INEL) Idaho Falls, Idaho	Exxon Nuclear Idaho, Inc and EG&G Idaho, Inc	1949	2735
Oak Ridge Gaseous Diffusion Plant Oak Ridge, Tennessee	Martin Marietta Energy Systems, Inc	1943	3869
Paducah Gaseous Diffusion Plant Paducah, Kentucky	Martin Marietta Energy Systems, Inc	1954	1289
Portsmouth GDP Piketon, Ohio	Goodyear Atomic Corporation	1956	3109
		subtotal:	43,095
WARHEAD PRODUCTION FACILITIES			
Rocky Flats Plant Golden, Colorado	Rockwell International	1951	5891
Y-12 Plant Oak Ridge, Tennessee	Martin Marietta Energy Systems, Inc	1944	7213
Savannah River Plant Aiken, South Carolina	E I duPont de Nemours and Company	1950	360
Mound Facility Miamisburg, Ohio	Monsanto Research Corporation	1948	2364
Pinellas Plant St Petersburg, Florida	General Electric Co	1957	1926
Kansas City Plant Kansas City, Missouri	Bendix Corporation	1949	7853
Pantex Plant Amarillo, Texas	Mason & Hanger-Silas Mason Co , Inc	1951	2749
		subtotal:	28,456
TEST SITES			
Nevada Test Site Nye County, Nevada	Reynolds Electrical & Engineering Co ; Edgerton, Germeshausen, & Grier, Inc ; Holmes & Narver, Inc ; Fenix & Sisson	1951	8414
Tonopah Test Range Nye County, Nevada	Reynolds Electrical and Engineering Company (site service)	1957	b
		TOTAL	91,623

a March 1985 warhead related

b Included in SNL figures

Table 2 2

Laboratory Full-time Equivalent Staffing Levels 1974-85

	Total Laboratory Employment (Total full-time equivalents (FTEs))											
FY	**1974**	**1975**	**1976**	**1977**	**1978**	**1979**	**1980**	**1981**	**1982**	**1983**	**1984**	**1985**
LLNL	5340	5555	6008	6335	6733	7012	7016	7217	7370	7451	7550	7800
LANL	4660	5071	5640	6035	6370	6802	6939	7116	7184	7102	7101	7300
SNL	6380	6383	6400	7269	7468	7600	7811	7900	7927	7989	8100	8150
TOTAL	16,380	17,009	18,048	19,639	20,571	21,414	21,766	22,283	22,481	22,542	22,751	23,250

	Weapons Activities Employment[a] (Total full-time equivalents (FTEs))											
FY	**1974**	**1975**	**1976**	**1977**	**1978**	**1979**	**1980**	**1981[b]**	**1982**	**1983**	**1984**	**1985**
LLNL	3351	3163	3065	3159	3183	2879	2717	2897	3704	3957	3955	3948
LANL	2267	2230	2228	2415	2380	2331	2281	2434	3000	3015	3105	3174
SNL	4100	4202	3912	3780	3755	3562	3589	3533	3806	3883	3899	3979
TOTAL	9718	9595	9205	9354	9273	8772	8587	8864	10,510	10,855	10,959	11,101

a Includes weapons research development and testing and inertial confinement fusion programs

b Inertial confinement fusion program FTEs added to weapon activities totals

Source: HAC FY 1985 EWDA Part 6 p 268

by the other and brought to a successful conclusion "[4]

From the laboratory's first budget of $3 5 million (FY 1953) and a staff of 698, LLNL has grown to a budget of almost $700 million and a staff of 8500 Approximately one half of the staff and almost 70 percent of the budget are devoted to programs associated with nuclear weapons The laboratory conducts weapon research, development, testing, nuclear safeguards and security, inertial confinement fusion, special isotope separation, verification technology, and defense waste management

LLNL is organized into nine programs Defense Systems is composed of four programs: nuclear design, military applications, weaponization, and nuclear testing (see Figure 2 3) These programs perform most of LLNL weapon work Nuclear Design includes A and B Divisions, which are responsible for new weapon designs and concepts The R Program is concerned with directed energy aspects of nuclear weapons

Military Applications has two major subunits The D Division evaluates new warhead designs—conceived of by Nuclear Design—for possible military application The Nonnuclear Ordnance program investigates nonnuclear weapon systems Military Applications also oversees warhead development through Phases 1 and 2 and into early Phase 3

The Weaponization Program's W Division is responsible for late Phase 3 through Phase 7 of the warhead development process Physics designs are converted to blueprints that will be used by the production facilities to make the warhead components The program is also responsible for stockpile surveillance and retirement

Nuclear Testing consists of five divisions The L Division is responsible for the physics diagnostics experiments on the nuclear tests The Nuclear Chemistry Division analyzes radioactive gases and solids produced by the explosion The Earth Sciences Department is concerned with the containment of underground nuclear explosions Field Operations and Containment programs are responsible for conducting safe nuclear tests Finally, the LLNL-Nevada organization supports various aspects of the work at the Nevada Test Site (NTS)

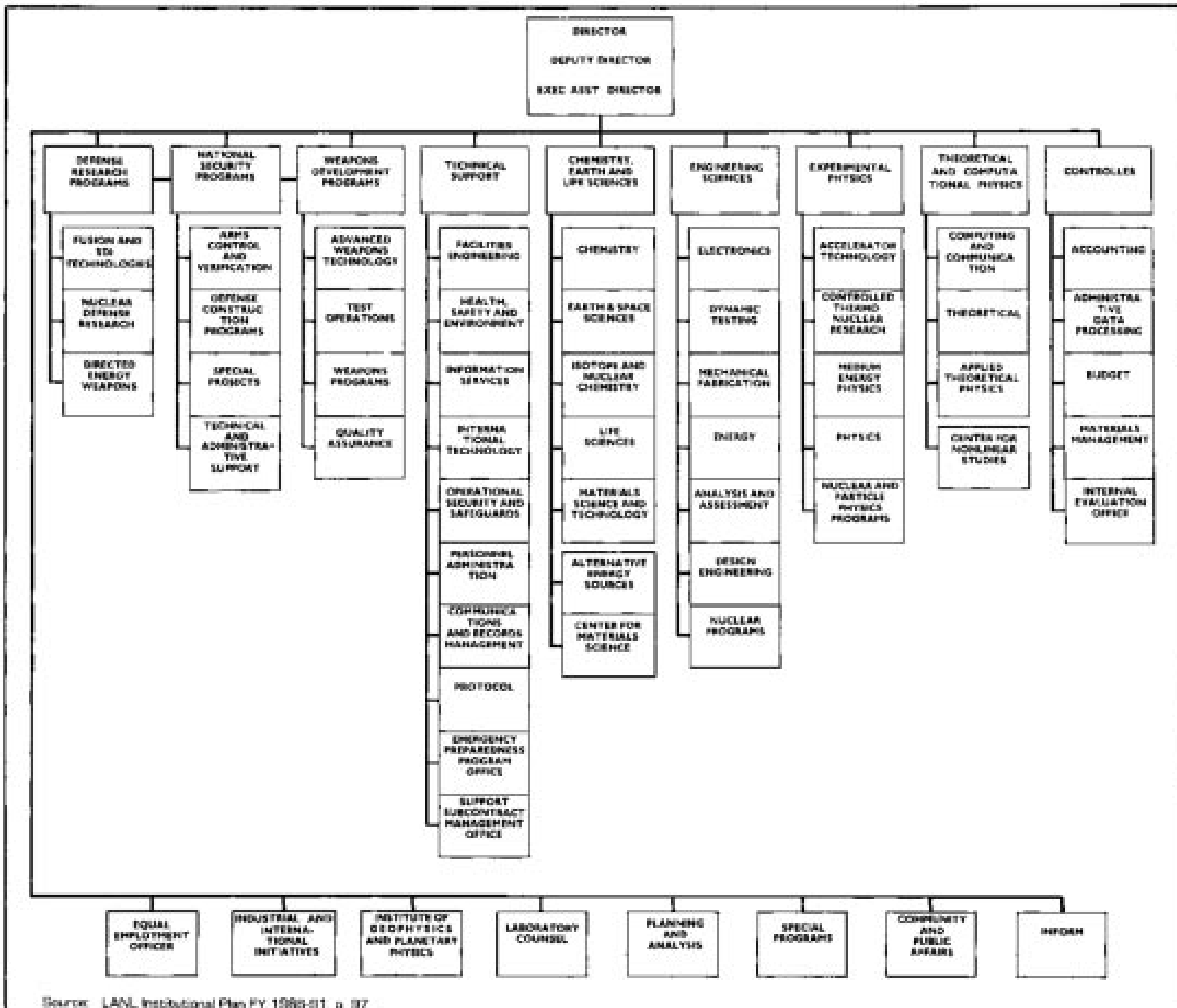
Additional support for Defense Systems comes from other groups at LLNL Within the Physics Department, X Division does inertial confinement fusion target design Chemistry, Engineering, and Computations also support Defense Systems Special Projects, or Z Division, studies the nuclear weapon activities of foreign countries, offering expertise and assessment to the Deputy Assistant Secretary for Intelligence and other government departments concerned with these issues

LLNL has developed warheads for the POLARIS (W47 and W58), POSEIDON (W68), MINUTEMAN II (W56), and MINUTEMAN III (W62) ballistic missiles Its most recent weapons are the B83 "modern strategic bomb," the W84 warhead for the ground-launched cruise missile, the W87 warhead for the MX missile, and the Short Range Attack Missile (SRAM II) In earlier phases are the W82 155mm artillery-fired atomic projectile and Small ICBM warheads

4 ERDA *Funding and Management Alternatives for ERDA Military Application and Restricted Data Functions* January 1976 p 32 See also Walter Pincus "Labs in Intense Bitter Rivalry for Defense Business" Washington Post (12 December 1978): 1 Of the twenty-nine cancelled warhead designs nine were designed by Livermore

2

Lawrence Livermore National Laboratory



Source: LANL Institutional Plan FY 1986-91 p 97

Figure 2 2 Organizational chart of Los Alamos National Laboratory

Both LLNL and LANL explore advanced weapon concepts Their recent work has focused on tailoring the effects of a nuclear weapon explosion, the so-called third generation weapons Research at Livermore has, for example, led to a reduced-residual-radioactivity (RRR) weapon that reduces fallout, "rainout," and thermal collateral damage [5] Livermore scientists are also developing the nuclear-pumped X-ray laser for anti-ballistic missile and anti-satellite applications [6]

5 Energy and Technology Review (August 1980): 18
6 AWST (23 February 1981): 25 27; David Perlman Top Secret Plan for Laser Weapon San Francisco Chronicle (25 September 1982): 1; Judith Miller New Generation of Nuclear Arms With Controlled Effects Foreseen, New York Times (28 October 1982): A 1; Patrick E Tyler, How Edward Teller learned to love the nuclear-pumped X-ray laser Washington Post (3 April 1983): D 1; AWST (13 June 1983): 15; William J Broad X Ray Laser Weapon Gains Favor New York Times (15 November 1983): C 1; William J Broad The Young Physicists: Atoms and Patriotism Amid the Coke Bottles New York Times (31 January 1984): C-1; William J Broad Gains Reported On Use of Laser For Space Arms New York Times (15 May 1985): A 1; Scientific American (July 1985): 58 William J Broad New Atomic Weapons are being Designed at a Furious Pace New York Times (16 July 1985): C-1; R Jeffrey Smith, Experts Cast Doubt on X-ray Laser Science (8 November 1985): 646-48; William J Broad Space Weapon Test Failure Reported New York Times (1 November 1985): B7; William J Broad Star Warriors (New York: Simon and Schuster 1985); Robert Scheer Scientists Dispute Test of X-Ray Laser Weapon Los Angeles Times (11 November 1985): 1

Table 2 3
Directors of Los Alamos and Livermore Laboratories
(1943-85)

LANL	
J Robert Oppenheimer	1943-1945
Norris Bradbury	1945-1970
Harold Agnew	1970-1979
Donald M Kerr	1979-1985
Siegfried S Hecker	1985-present
LLNL	
Herbert F York	1952-1958
Edward Teller	1958-1960
Harold Brown	1960-1961
John S Foster, Jr	1961-1965
Michael M May	1965-1971
Roger E Batzel	1971-present

Sandia National Laboratories

Sandia Laboratories dates back to the Manhattan Project In July 1945, Oxnard Field near Albuquerque, New Mexico was transferred to the Manhattan Engineer District, to be used as an engineering and assembly site for the nuclear weapon components produced at Los Alamos Personnel from the Ordnance Engineering (Z) Division at Los Alamos were transferred to Albuquerque ("Sandia Base") to assemble atomic bombs and to design new weapons in cooperation with other Los Alamos divisions

President Truman asked the Bell System to manage Sandia activities On 1 November 1949, a new entity, Sandia Corporation (a wholly owned subsidiary of Western Electric Company) assumed direction of Sandia Laboratories, which was previously operated as a branch of Los Alamos by the University of California From a few buildings in the late 1940s, Sandia has grown to a giant facility with over 8500 employees and a $1 billion budget Today Sandia continues to work in close conjunction with the two design laboratories at every phase of a weapon's life cycle

Sandia is primarily an ordnance engineering laboratory; it designs the non-nuclear parts of a nuclear weapon These include the electronics, arming, fuzing, and firing systems, neutron generators, command and control devices, security and safety features, and new delivery concepts See Figure 2 4 for an organizational chart

The main facility is located on what is now Kirtland Air Force Base, at Albuquerque In 1956, to better support LLNL programs, Sandia also established a lab at Livermore Sandia also operates the Tonopah Test Range (TTR) northwest of the Nevada Test Site, at the north end of Nellis Air Force Base Though some field testing takes place at Sandia's Albuquerque and Livermore sites, the most hazardous tests are conducted at Tonopah Each year the Air Force and Sandia conduct over a hundred subsonic or supersonic air drops of simulated bombs or weapons at TTR [7] Figure 2 5 shows a FB-111 dropping a B83 bomb with a parachute retarding its fall Sandia and the Army also conduct about 150 artillery firings (155mm and 8-inch projectiles) per year as well as the firing of ground-launched rockets Tests of nuclear earth-penetration warheads such as the W86 PERSHING (cancelled in September 1980) are also conducted (see Figure 2 6)

Other DOE Laboratories

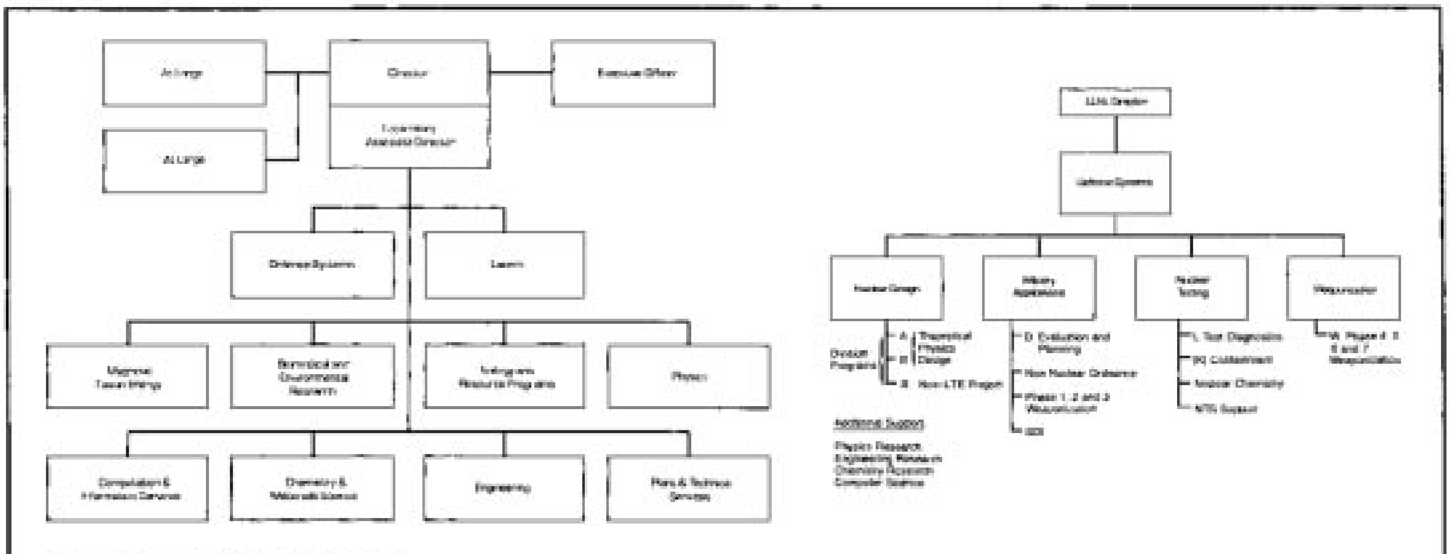
Two other DOE laboratories are dedicated to weapons activities: the Savannah River Laboratory (SRL) and the New Brunswick Laboratory SRL provides development and technical support to the Savannah River Plant (SRP) in all areas of the nuclear fuel cycle The New Brunswick Laboratory specializes in analytical chemistry of nuclear materials and plays a role in nuclear materials safeguards

Several DOE multipurpose laboratories whose primary mission is not weapon related also carry out limited weapon related research and production activities Three of these are nuclear energy laboratories, and five are energy research laboratories The nuclear energy laboratories include the Hanford Engineering Development Laboratory (HEDL) at the Hanford Reservation, Washington; the Idaho National Engineering Laboratory (INEL) in Idaho; and the Pacific Northwest Laboratory (PNL) in Richland, Washington, adjacent to the Hanford Reservation

INEL processes, at the Idaho Chemical Processing Plant (ICPP), highly enriched uranium (HEU) from naval and other government reactors and domestic and foreign research and test reactors The recovered HEU is recycled as fuel to operate the plutonium (and tritium) production reactors at the Savannah River Plant Both HEDL and PNL conduct limited research on nuclear waste management, while PNL also conducts research on inertial confinement fusion

The weapon related research at the five energy research Laboratories—Ames Laboratory at the Iowa State University; Argonne National Laboratory (ANL) near Chicago, Illinois; Brookhaven National Laboratory (BNL) on Long Island, New York; Lawrence Berkeley Laboratory (LBL) at the University of California, Berkeley campus; and the Oak Ridge National Laboratory (ORNL)—represent approximately one to three percent of the total activity at these establishments Their work relates primarily to nuclear waste management, inertial

7 ERDA Environmental Assessment Tonopah Test Range 2nd printing, September 1977 pp 21 22



Source: LLNL Institutional Plan FY 1986-91

Figure 2 3 Organizational chart of Lawrence Livermore National Laboratory and of Defense Systems

confinement fusion, material accounting and control, and weapon effects (see Table 2 4)

There are several organizations that are not government owned but are worthy of mention because they provide major laboratory or R&D support for DOE weapon programs Three of these—the KMF Fusion, Inc of Ann Arbor, Michigan; the Naval Research Laboratory at Washington, D C ; and the University of Rochester in Rochester, New York—are supporting laboratories of the inertial confinement fusion (ICF) program [8] In FY 1984 DOE also began using the Stanford Positron-Electron Accelerator Ring (SPEAR) at the Stanford Synchrotron Radiation Laboratory (SSRL), Stanford University This synchrotron radiation source is used to calibrate X-ray diagnostic equipment in DOE weapon effects research Los Alamos conducts similar activities at Brookhaven's National Synchrotron Light Source

DOD Laboratories

Each military service assists DOE and DOD on nuclear warhead matters Service analyses and evaluations of the specifications and designs of the warheads and their compatibility with the respective delivery systems become an integral part of the overall nuclear weapon research and development process A formal series of nuclear warhead requirements documents (Required Operational Capabilities, Military Characteristics, and Stockpile-to-Target Sequences; see Chapter Four) and joint DOD/DOE Project Officers Groups (POGs) provide the mechanism for coordination between the two departments

Air Force Weapons Laboratory

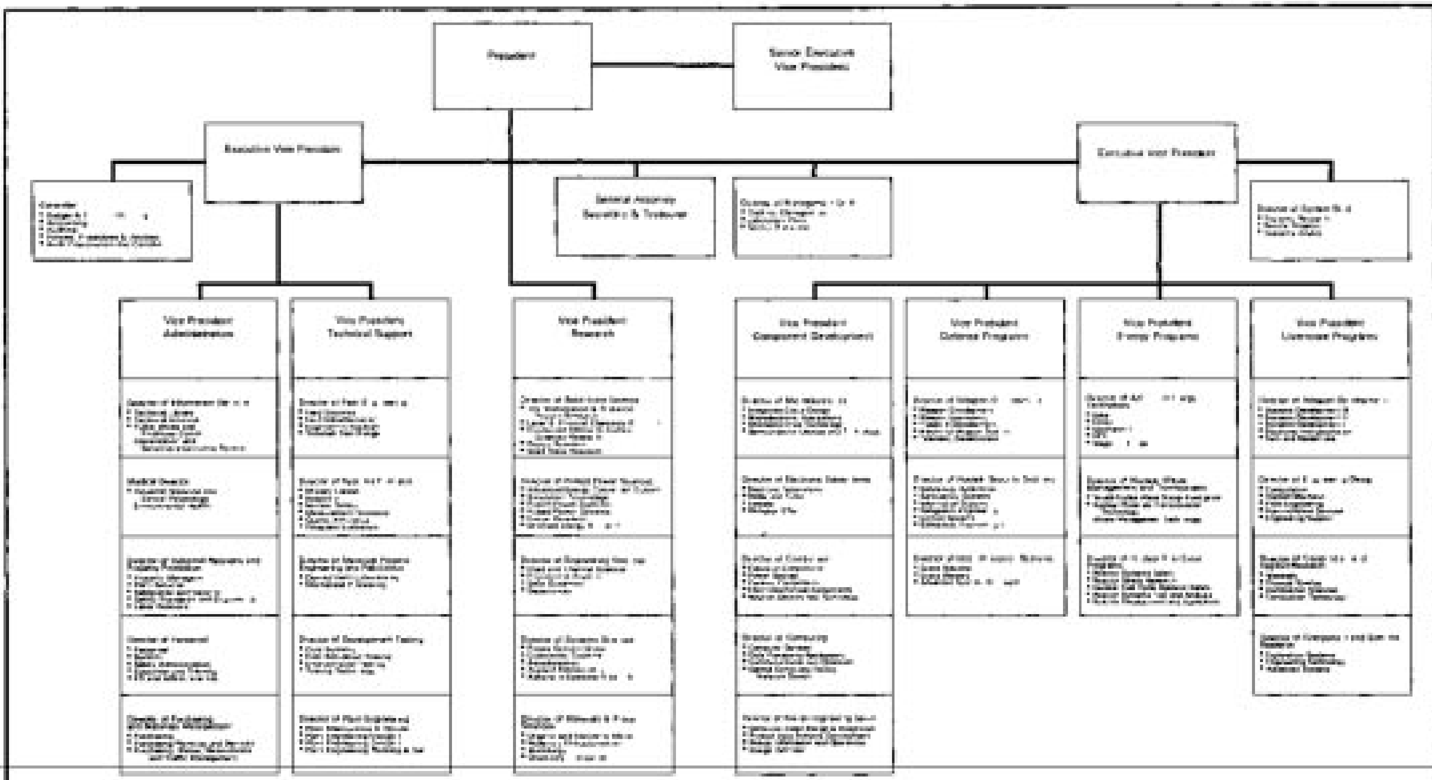
The Air Force Weapons Laboratory (AFWL), located at Kirtland Air Force Base, Albuquerque, New Mexico, conducts the Air Force's "exploratory, advanced, and engineering development programs in nuclear weapons effects, nuclear weapons components, high energy laser systems, advanced weapon concepts and technology, nuclear survivability and vulnerability, conventional high explosive weapon effects on protective structures, and nuclear safety "[9] The laboratory opened officially on 1 May 1963, assuming research and development programs and resources of the Air Force Special Weapons Center at Kirtland Air Force Base Today, the laboratory is subordinate to the Air Force Space Technology Center of the Air Force Systems Command

The AFWL provides technical expertise for Air Force nuclear warheads and bombs The laboratory chairs joint DOE/DOD Phase 1 (conceptual) and Phase 2 (feasibility) studies If an Air Force nuclear warhead proceeds beyond the Phase 2 study point, a joint DOD/DOE Phase 2A study (weapon design definition and cost study) is initiated and an AFWL representative serves as its chairman During Phase 3 (development engineering), the nuclear warhead/bomb design is monitored by AFWL to ensure suitability and compliance with Air Force desired military characteristics

During the advanced engineering and deployment

8 The LLNL LANL and SNLA have lead laboratory responsibilities for the three principal driver (i e beam source) approaches being pursued by the ICF program KMS Fusion Inc uses its Chroma infrared laser (0 6 kilojoule, 1 terawatt) capable of operating at 1 05 0 53, and 0 35 microns, to conduct ICF experiments using both gas filled and cryogenic targets, including classified holraum targets KMS Fusion also manufactures ICF targets and conducts target fabrication research The University of Rochester Laboratory for Laser Energetics uses its 24-beam short wavelength (0 35 micron) Omega laser (4 kJ 12 TW) to conduct ICF direct drive experiments for DOE The Naval Research Laboratory conducts ICF experiments using its Pharo II laser (0 5 kJ, 0 2 TW) and has a small theoretical ICF research program An excellent overview of ICF research is provided by Thomas H Johnson, "Inertial Confinement Fusion: Review and Perspective " Proceedings of the IEEE 72 May 1984 pp 548-94

9 AFWL, Organization and Functions Chart Book 24 October 1983



Effective 1 October 1985 Source: SNL Institutional Plan FY 1986-91 p 43

Figure 2 4 Organizational chart of Sandia National Laboratories

phases of a warhead's development, and throughout stockpile life, nuclear certification and safety issues are continually monitored by AFWL technical personnel AFWL develops criteria and assesses the compatibility of delivery systems and their nuclear stores It recommends nuclear safety certification or decertification of nuclear delivery systems The laboratory develops aircraft monitor and control (AMAC) devices (which are used to prepare aircraft for delivery of nuclear bombs), weapon suspension and release equipment, and AMAC special ground support equipment In the safety field, AFWL determines nuclear warhead loading, aircrew delivery, and transportation airlift procedures AFWL also develops nuclear hardness criteria for Air Force systems To support its research, the laboratory has the largest computation capability within the Department of Defense More than 1100 people are assigned to AFWL, which has an annual budget of about $180 million

Naval Weapons Evaluation Facility

The lead laboratory in the Navy for nuclear weapons research is the Naval Weapons Evaluation Facility (NWEF), colocated at Kirtland Air Force Base, New Mexico with the AFWL The mission of the NWEF is

> "to perform tests, evaluations, and provide technical support for nuclear and designated non-nuclear weapons and weapons systems; maintain direct liaison with all levels of command with the Navy and other government agencies with respect to nuclear weapon safety; advise and assist the Chief of Naval Operations in promoting and monitoring nuclear weapon safety and the prevention of nuclear weapon accidents or incidents; plan and conduct nuclear weapon system safety studies and reviews; [and] plan and coordinate the Navy Nuclear Weapons Safety Program "[10]

The weapons supported by the NWEF include both Navy and Marine Corps nuclear systems NWEF is subordinate to the Naval Space and Warfare Systems Command

Like the AFWL, the NWEF conducts feasibility studies on new concepts and design criteria for future nuclear warheads and delivery systems of the Navy Personnel of the facility participate in Phases 1 to 3 studies for Navy nuclear warheads and prepare the nuclear warhead requirements documents The facility also conducts the Navy's acceptance and vulnerability program for nuclear weapons and recommends improvements of stockpiled nuclear warheads The NWEF has 235 personnel assigned and has an annual budget of $50 million

Army Nuclear and Chemical Agency

The lead laboratory/agency for Army nuclear warheads is the Nuclear and Chemical Agency (ANCA),

10 Navy OPNAVNOTE 5450 serial 2066P09B3 of 3 September 1986

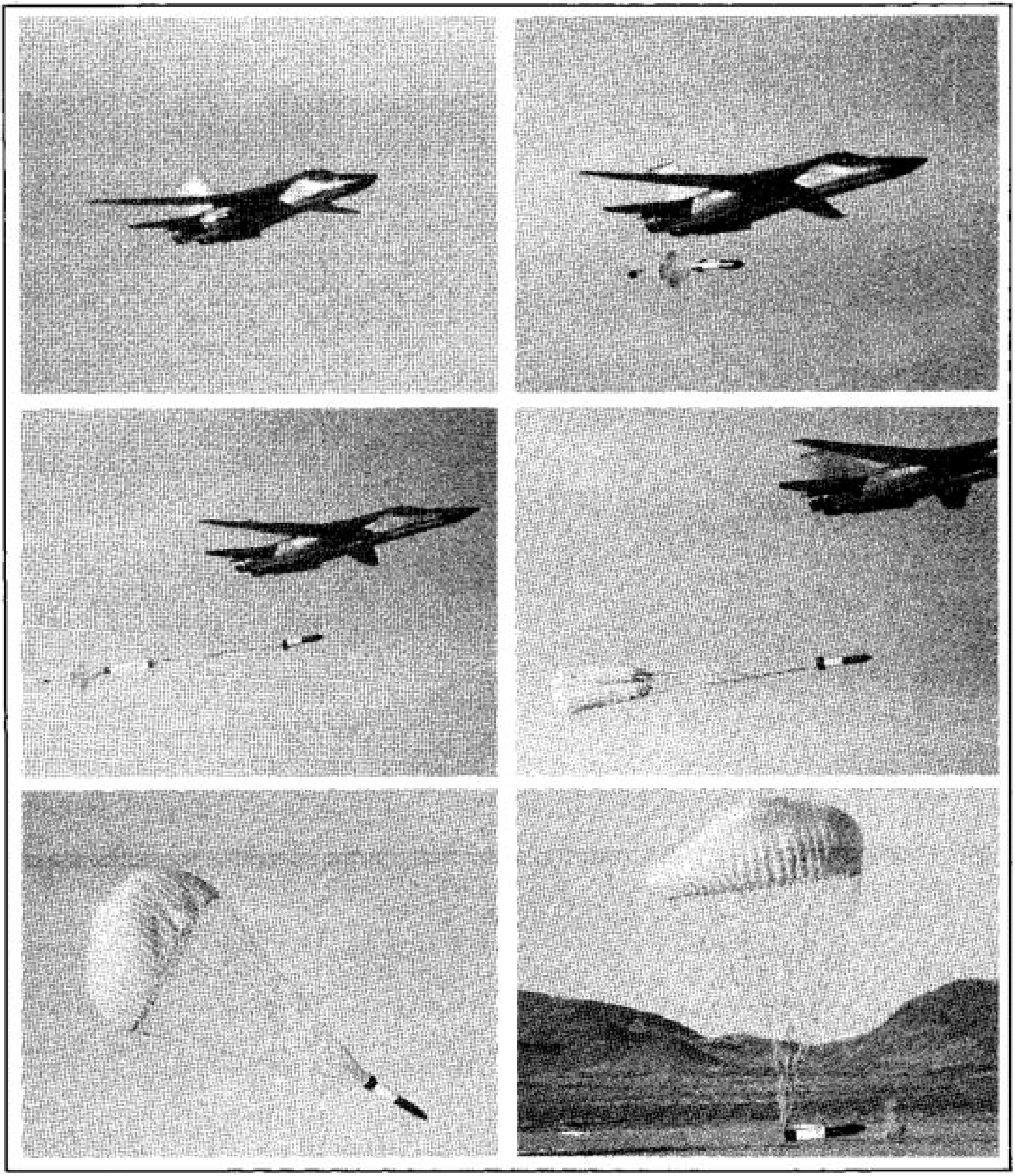


Figure 2.5 FB-111 Bomber dropping B83 bomb on Tonopah Test Range using parachute

Table 2 4

Other DOE Laboratories Engaged in Nuclear Weapons Activities

Facility	Principal Nuclear Weapons Activities	Current Operating Contractor
Weapons Laboratories[a]		
New Brunswick Laboratory Argonne, Illinois	nuclear safeguards, analytical chemistry of nuclear materials	Department of Energy
Savannah River Laboratory* Aiken, South Carolina	nuclear material production and processing support	E I duPont de Nemours and Company
Nuclear Energy Laboratories[b]		
Hanford Engineering Development Laboratory* Richland, Washington	nuclear waste management	Westinghouse Hanford Company
Idaho National Engineering Laboratory* Idaho Falls, Idaho	nuclear fuel processing	EG&G Idaho, Inc /Exxon Nuclear Idaho, Inc
Pacific Northwest Laboratory* Richland, Washington	ICF research and nuclear waste management	Battelle Memorial Institute
Energy Research Laboratories[c]		
Ames Laboratory Ames, Iowa	atomic spectroscopic analysis of spent fuel dissolver tank solutions	Iowa State University
Argonne National Laboratory* Argonne, Illinois	ICF research	University of Chicago
Brookhaven National Laboratory Upton, New York	ICF research; weapons effects	Associated Universities, Inc
Lawrence Berkeley Laboratory Berkeley, California	ICF research	University of California
Oak Ridge National Laboratory* Oak Ridge, Tennessee	U-233 recovery; isotopic analysis for nuclear material security and safeguards	Martin Marietta Energy Systems, Inc

a Responsible to the Assistant Secretary for Defense Programs
b Responsible to the Assistant Secretary for Nuclear Energy
c Responsible to the Director of the Office of Energy Research
* See profile in Volume III for more detail

located in Alexandria, Virginia The mission of the ANCA is to "provide advice and assistance to all elements of the Army and other government agencies on nuclear and chemical matters [and] participate in nuclear weapons research and development programs, and nuclear and chemical weapons effects research, as the representative of the Army in the field "[11] ANCA was formed 1 October 1976 as a consolidation of the Army Nuclear Agency (formerly located at Fort Bliss, Texas), the Army Nuclear and Chemical Surety Group, and the Chairman, Nuclear Weapons Systems Safety Committee (located in Washington, D C) Its roots are in the Office of Special Weapons Development, which was established in December 1952

Like the AFWL and NWEF, the agency prepares nuclear warhead requirements documents, employment manuals and training materials, participates in warhead development groups, develops targeting criteria, defines effects requirements and nuclear survivability criteria, conducts safety studies and operational reviews of nuclear systems and monitors the Army nuclear weapons surety program The agency is organized into four divisions—weapons effects; studies, analysis and literature; material and safety; and surety It is manned by sixty-six personnel and has an annual budget of about $1 million

Materials Production Facilities

There are six principal nuclear materials used in nuclear weapons—uranium-235, uranium-238, plutonium-239, tritium, deuterium, and lithium-6 (see Chapter Three) As shown in Table 2 5 and Figure 2 1, numerous facilities are currently involved in the production of these materials The total budget requested for FY 1986 materials production was $1 98 billion In 1942, the Manhattan Engineer District was made responsible for developing nuclear materials During this time several huge complexes were built at Hanford, Oak Ridge, and various other supporting essaying, processing, and manufacturing facilities (see Figure 2 7) From 1942 to 1946, more than ten prime contractors and several hundred subcontractors operated these facilites for production, research, and development These contractors included industrial concerns, universities, and scientific organizations

11 USANCA Agency Overview Briefing 1979

Table 2 5

Nuclear Materials Production Facilities

Facility	Production Mission
Feed Materials Production Center Fernald, Ohio	slightly enriched uranium feed to metal production for subsequent use as production reactor fuel elements
Ashtabula Plant Ashtabula, Ohio	extrusion of slightly enriched uranium metal into tubes for subsequent use as production reactor fuel elements
Hanford Reservation Richland, Washington	
N-Reactor	plutonium production
PUREX Plant	N-Reactor fuel reprocessing
UO_3 Plant	UO_3 recovery
B-Plant	nuclear waste management
Idaho National Engineering Laboratory Idaho Falls, Idaho	
Idaho Chemical Processing Plant	recovery of highly enriched uranium from spent (naval and research) reactor fuel
Savannah River Plant Aiken, South Carolina	
P,C,K,L, and R-reactors	plutonium and tritium production (P,C,K and L are operating, R remaining on standby)
200-F and H areas	spent fuel and target reprocessing
300-M area	fuel and target element fabrication for SR reactors
200-H area	tritium recovery and weapon-component loading
Heavy Water Plant	production of heavy water (on standby)
Uranium Enrichment Complex	production of enriched uranium
Oak Ridge GDP	placed on standby at the end of FY 1985
Paducah GDP	
Portsmouth GDP	
Y-12 Plant Oak Ridge, Tennessee	lithium enrichment (suspended since 1963); lithium-6 deuteride production; conversion of highly enriched uranium nitrate to metal; conversion of highly enriched UF_6 to uranium metal (suspended since 1964)

The DOE currently operates two large gaseous diffusion plants (GDPs) to enrich uranium—at Paducah, Kentucky and the Portsmouth Plant at Piketon, Ohio A third plant—at Oak Ridge, Tennessee—was placed on standby at the end of FY 1985 Since they operate together as a single integrated facility, the plants are treated together in the facility profile in Volume III under the "Uranium Enrichment Complex "

The uranium enrichment complex was originally constructed to produce highly enriched uranium for nuclear weapons There has been no HEU produced for weapons, however, since early FY 1965 The complex is now used primarily to provide enriched uranium for commercial power, naval propulsion, and some research and test reactors

Plutonium and tritium currently are produced at five DOE production reactors—four heavy water moderated reactors at the Savannah River Plant (SRP) and the graphite moderated N-Reactor at the Hanford Reservation SRP produces and recovers tritium, as well as providing weapon-component loading facilities Two chemical processing plants at SRP and the PUREX Plant at Hanford are used to recover plutonium and uranium from discharged reactor fuel SRP and Hanford complete fuel fabrication for their respective production reactors

The SRP's large heavy water production plant discontinued operation in early 1982 Previously it provided heavy water for the Savannah River production reactors and served as the source of deuterium for lithium-6 deuteride and deuterium used in thermonuclear weapon components Current heavy water requirements are satisfied from the existing inventory

The Y-12 Plant at Oak Ridge has four nuclear material production missions: lithium enrichment (suspended since 1963); the production of lithium-6 deuteride; the conversion of highly enriched uranium nitrate to uranium metal for subsequent use as fuel for production reactors at SRP;[12] and the conversion of highly enriched UF_6 to uranium metal (suspended since 1964) [13]

12 This HEU nitrate to metal conversion process will be transferred to SRP in the late 1980s

13 As discussed in Chapter Three DOE plans to reactivate this facility beginning in FY 1988

Table 2 6
Current Nuclear Warhead Production Facilities

Facility	Production
Rocky Flats Plant Golden, Colorado	plutonium and uranium cores (pits), beryllium fabrication, disassembly of pits from retired weapons
Y-12 Plant Oak Ridge, Tennessee	fabrication of uranium and lithium deuteride components
Savannah River Tritium Facility Aiken, South Carolina	tritium extraction and purification and loading of tritium components
Mound Facility Miamisburg, Ohio	explosive detonators and timers; tritium recovery from retired weapons
Pinellas Plant St Petersburg, Florida	neutron generators, capacitors, and switches
Kansas City Plant Kansas City, Missouri	mechanical and electrical components, rubber, plastics, foams, adhesives
Pantex Plant Amarillo, Texas	high explosive, final assembly of new weapons, maintenance of existing weapons, disassembly of retired weapons

Figure 2 6 W86 PERSHING Earth Penetration Warhead designed by LANL but cancelled in September 1980

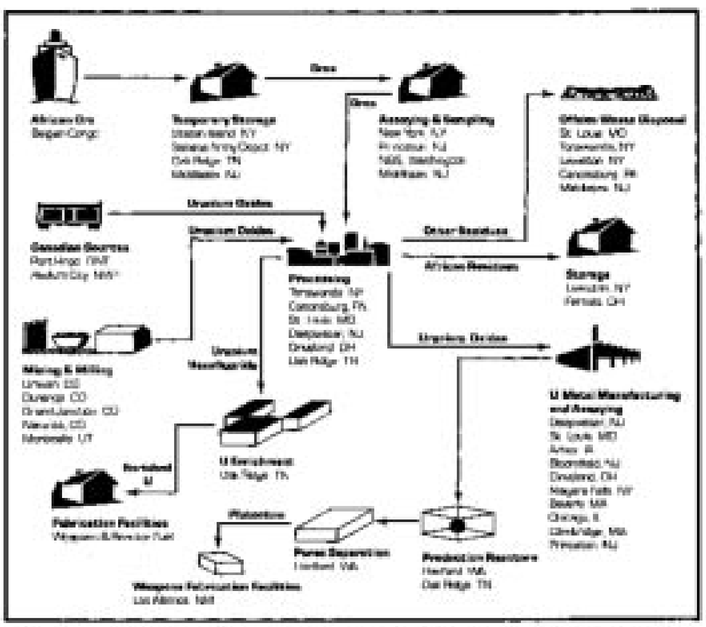


Figure 2 7 Paths for uranium material production during the Manhattan Project

The Feed Materials Production Center (FMPC) near Fernald, Ohio, and the Ashtabula Plant in Ashtabula, Ohio, each play a significant role in the supply of fuel for the production reactors at the SRP and Hanford The FMPC is a large scale integrated facility that converts a variety of low enriched or depleted feed materials into uranium metal used as fuel (and target) cores The Ashtabula Plant—owned by Reactive Metals, Inc —operates under contract with DOE to extrude the uranium metal produced at FMPC into fuel and target tubes

The Idaho Chemical Processing Plant at the Idaho National Engineering Laboratory recovers highly enriched uranium from the spent fuel of naval propulsion reactors and research and test reactors In recent years this has been a primary source of driver fuel for SRP production reactors, supplemented by the HEU recovered in the H Canyon at Savannah River, from the reactors themselves, and from research reactor fuel Lawrence Livermore and Los Alamos National Laboratories conduct minor nuclear materials production activities Los Alamos presently converts to metal weapon-grade plutonium oxide from the Hanford PUREX plant

Warhead Production Facilities

A modern nuclear warhead is made of many nuclear and non-nuclear components Each component must be specifically designed and fabricated for a particular type of warhead, bomb, or artillery shell DOE currently oper-

Table 2 7

Former Government-owned Nuclear Warhead Facilities

FACILITY	OPERATING CONTRACTOR	DATES IN OPERATION	PURPOSE
Weapons Production			
Iowa Army Ordnance Plant Burlington, Iowa	Ordnance Corps, U S Army, later Mason & Hanger-Silas Mason Co	1947-75	Warhead fabrication, final assembly, functions transferred to Pantex
Medina Modification Center Medina, Texas	Mason & Hanger-Silas Mason Company	1958-66	Warhead component tests and modification; weapon repairs and retirements
Clarksville Modification Center Clarksville, Tennessee	Mason & Hanger-Silas Mason Company	1958-65	Warhead component tests and modification; functions transferred to Pantex
Buffalo Works	ACF Industries, Inc	1945-52	Production, research, development engineering; moved to Albuquerque in 1952
Hanford Works Richland, Washington	General Electric Co	1949-65	Fabrication of weapon components from plutonium metal
South Albuquerque Works Albuquerque, New Mexico	ACF Industries, Inc Albuquerque Division	1952-67	Production, research, development engineering and fabricating services
Material Production			
Destrehan Street Plant St Louis, Missouri	Mallinckrodt Chemical Company	1943-58	Supplied uranium feed to facilities producing fissionable materials
Weldon Spring Plant Weldon Spring, Missouri	Mallinckrodt Chemical Company	1958-67	Supplied uranium feed to facilities producing fissionable materials Consolidated at Fernald
Test Sites			
Enewetak Proving Grounds	Holmes & Narver	1948-58 on standby to 1960	Nuclear weapon testing

ates seven facilities for the production of these components and their assembly into completed warheads [14] These facilities and their missions are identified in Table 2 6 All fall under the responsibility of DOE's Office of Military Application (OMA) and are referred to as the "Integrated Production Complex" The complex employed at mid FY 1985 over 28,000 people (see Table 2 8) Since 1975 employment has increased by 68 percent

Warhead Fabrication

Each facility in the production complex provides specific components that are assembled into finished warheads at the Pantex Plant These facilities manufacture some of the parts and rely on corporate suppliers for others [15] Figure 2 8 provides a breakdown of the approximately 1800 component parts of a B61 bomb into the number of items and suppliers for each facility [16]

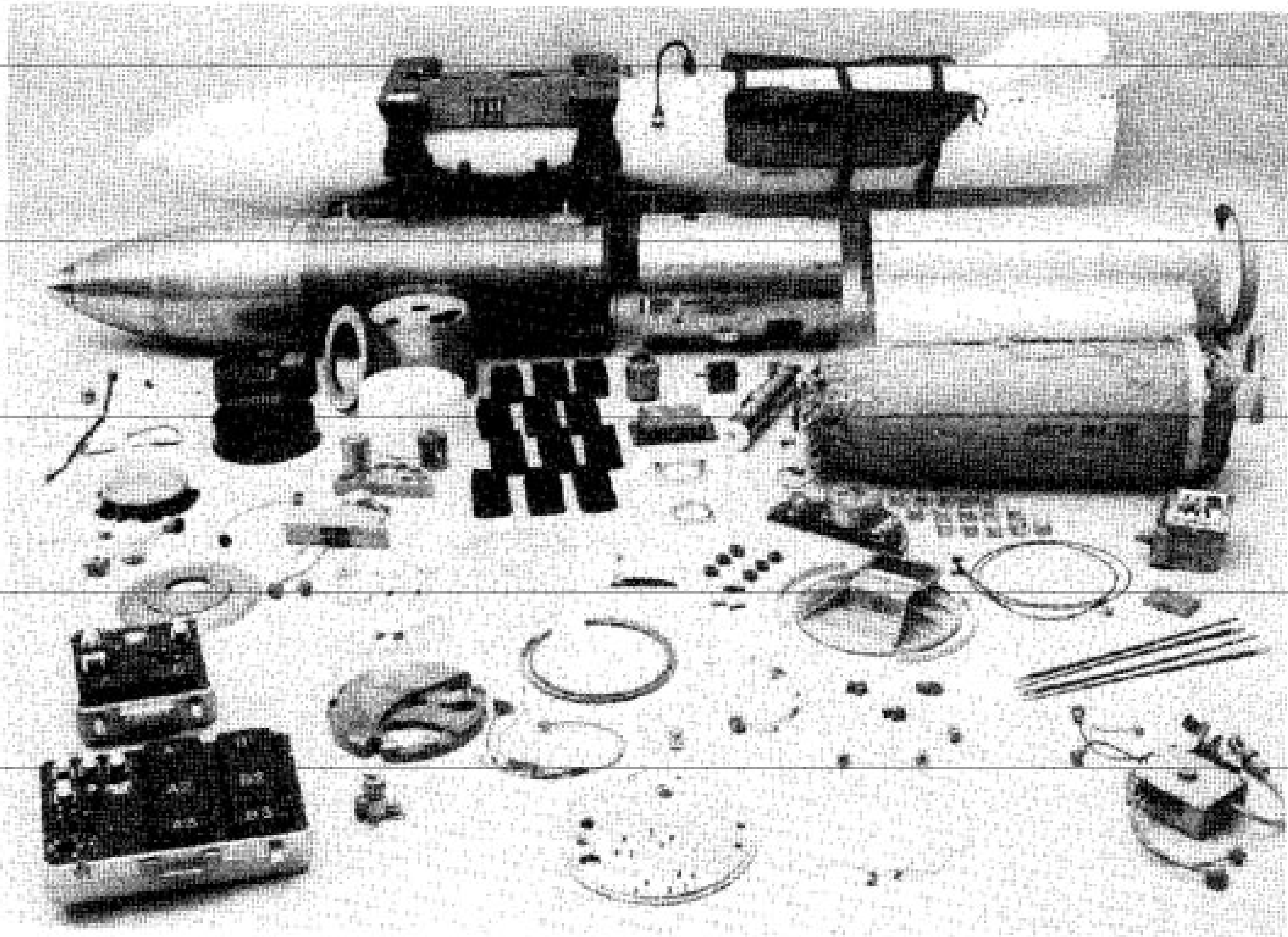
Nuclear materials are fabricated at the Rocky Flats and Y-12 Plants Rocky Flats assembles the "pits" of fission implosion weapons and the fission primaries of thermonuclear weapons The pit is that part of the warhead inside the chemical high explosive, and it contains the fissile core and its surrounding tamper Cores are fabricated from composites of uranium and plutonium while the tampers/reflectors are made of beryllium and natural or depleted uranium Rocky Flats processes and manufactures the plutonium, beryllium and depleted uranium components Y-12 houses a uranium foundry that casts enriched and depleted uranium components

14 In the late 1950s to early 1960s when the rate of production of nuclear weapons was at its highest there were as many as thirteen production facilities (see Table 2 7) As warhead production rates began to taper off in the mid-1960s the AEC consolidated and reduced the production complex to achieve efficiencies and economies Two weapon modification facilities the Clarksville AEC Facility at Fort Campbell (Clarksville), Tennessee and the Medina AEC Facility near San Antonio Texas were closed on 27 September 1965 and 8 April 1966 respectively and their functions transferred to the AEC Pantex Plant at Amarillo Texas and the Iowa Ordnance Plant at Burlington Iowa In 1975 activities at the Burlington Plant were consolidated at the Pantex Plant

In 1965 uranium fabrication work was transferred from the Rocky Flats Plant north west of Denver Colorado to the Y-12 Plant at Oak Ridge Tennessee and fabrication of certain plutonium parts previously assigned to the Hanford works at Richland Washington were transferred to the Rocky Flats Plant Further realignment included reducing machining activities at the AEC plant in Kansas City Missouri operated by the Bendix Corporation and in 1967 the phasing out of ACF Industries Inc production work at the South Albuquerque (New Mexico) Works

15 In addition to commercial suppliers Sandia and Los Alamos Laboratories provide a small number of parts

16 HASC FY 1984 DOE pp 40 185 294



Key: Ship Entities

Contractor	Products	Ship Entities	Items	Suppliers
Bendix	Fuzing & Firing Components; Radar/Hardware; Mech & Elect Subassemblies; Cases/Light Machining	101	1555	387
Rockwell	Nuclear Components	6	16	22
General Electric	Neutron Generators	1	108	80
Mason & Hanger	Final Assembly	1	10	6
Sandia	Weapons Ordnance Design; Thermal Fire	1	1	1
DuPont	Nuclear Materials	2	4	3
Monsanto	Spin Rocket; Detonators; Gas Generator	3	26	26
LANL	Nuclear Design; Nitrogen Valve and Squib	2	2	1
Oak Ridge Y-12	Inner Cap/Ex Threaded Ring; Ctr Case Subassembly Cover & Ret Plates/SS Mtl/Sus Lugs	6	46	43

Source: HASC FY 1984 DOE pp 41 304

Figure 2 8 DOE contractor-manufacturer relationships

Table 2 8

Warhead Production Facilities Employment

Facility	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	03/85
Rocky Flats Plant	2937	2783	2735	2879	3209	3222	3596	4095	4898	5335	5867	5991
Y-12 Plant	5423	4718	4759	5054	5242	5456	5716	6257	6725	6943	7155	7213
Tritium Facility (SRP)	300	300	310	310	320	320	325	329	359	365	360	360
Mound Facility	1731	1575	1567	1675	1690	1714	1811	1910	2060	2161	2302	2364
Pinellas Plant	1220	1109	1123	1202	1260	1435	1520	1786	1762	1841	1918	1926
Kansas City Plant	5362	4602	4552	5400	5935	6200	6449	7030	7138	7505	7838	7853
Pantex	1817	1896	1792	1820	1889	2100	2225	2306	2517	2603	2732	2749
TOTALS	18,790	16,983	16,838	18,340	19,545	20,447	21,642	23,713	25,459	26,753	28,172	28,456

Source DOE GOCO Employment Computer printout for Office of Industrial Relations R-5528308-012 29 August 1985 End FY

Machining of the uranium tampers and beryllium parts occurs at Rocky Flats while the enriched uranium cores are machined at Y-12 prior to shipment to Rocky Flats [17] Y-12 is also responsible for the lithium deuteride and uranium components used in secondaries of thermonuclear weapons Tritium is recovered, purified and loaded into reservoirs at the Tritium Facility of the Savannah River Plant Loaded reservoirs are shipped directly to Pantex for insertion into new warheads Reservoirs are also sent to Army Depots, Navy Installations, and Air Force Bases to replace reservoirs whose tritium has decayed to unacceptable levels

The non-nuclear components of nuclear weapons—among them various fuzes, timers, detonators, mechanical, electrical, rubber, plastic, and foam products—are produced at other facilities The Mound facility makes the detonators that set off chemical high explosive in the primary The Pinellas Plant makes neutron generators which initiate the nuclear chain reaction in the fissile material in the fission primaries The Kansas City Plant manufactures integrated arming, fuzing, and firing systems and other mechanical, rubber, foam, and plastic products Sandia provides the Kansas City Plant with electronic integrated circuit components At Pantex, chemical high explosive components are fabricated from high explosive materials obtained either from commercial suppliers or manufactured on-site [18]

All nuclear and non-nuclear components and subassemblies are sent to the Pantex Plant where final assembly of the warhead occurs Here the high explosives are mixed, heated, and pressed into various solid shapes and machined to final dimensions in special earth-covered, concrete rooms called subassembly bays

Three operations at Pantex represent a microcosm of the combined efforts of the entire DOE complex These operations are the final assembly of new nuclear warheads; the maintenance, modification, and reliability testing of existing warheads; and the complete disassembly of retired warheads withdrawn from the military stockpile These operations go on simultaneously, each requiring almost equal time, space, and labor

Schedules must be carefully planned to coordinate warhead production, maintenance/modification, and retirement rates Otherwise, for example, lack of materials from insufficient or lagging retirements could slow new production

New Production

The first step in the final assembly of a warhead is to mate or join the high explosive (HE) components with the pit assemblies obtained from Rocky Flats This unit is then encased in a protective shell or liner, generally stainless steel, aluminum, or titanium The entire encased unit is referred to as the "physics package" Because the high explosive may accidentally detonate before being encased, this work is done in "assembly cells" An assembly cell, also known as a "Gravel Gertie,"

> consists basically of a vertical cylinder of reinforced concrete covered with a network of steel cables which supports a top covering of washed gravel having a thickness which varies from 14 to 21 feet There is a single access opening into the side of the vertical cylinder which connects with the outside via a blast-absorbing corridor and blast-proof outer doors Personnel entry is through a two-ton rotating blast-proof door leading to the personnel passageway A convex blast door is located at each end of the material passageway, and the two blast doors are interlocked so that only one of the blast doors can be open at a time The principle of this construction is to force the venting from an accidental HE detonation through the gravel and earth overburden The gravel will filter out

17 Although this activity is currently performed at Y-12 Rocky Flats has the capability for machining and assembly of enriched uranium parts DOE is considering providing a backup plutonium pit fabrication facility at another site; HASC FY 1986 DOE, pp 106-7

18 When detonated in an implosion weapon these high explosives compress fissile cores, causing them to become supercritical See Thomas B Cochran William M Arkin and Milton M Hoenig Nuclear Weapons Databook, *Volume I* (Cambridge Massachusetts Ballinger Publishing Company 1984) Chapter Two

and entrap plutonium, reducing the amount of plutonium which might otherwise be spread beyond the confines of the structure in the event of an explosion [19]

The next step in assembling the weapon is to add the non-nuclear components from the weapons laboratories and the Kansas City, Pinellas, and Mound plants; the tritium from the Savannah River Plant; and thermonuclear components from Y-12 to the "physics package" This work is done in the weapon "assembly bay" Like cells, assembly bays are intended to mitigate the consequences from accidental detonation of high explosives, should one occur The completed unit is then placed into a bomb case, missile warhead, or projectile and stored in a nuclear warhead "igloo" awaiting delivery to DOD Nine types of warheads will be in production during FY 1986 (see Table 1 8)

Maintenance, Modification, Reliability

A second operation at Pantex is modifying certain existing warheads and conducting tests on a statistically representative sample of the stockpile to ensure they are reliable and meet design standards Maintaining and modifying weapons requires replacement of components In bays and cells, warheads are partially dismantled Disassembly is more than undoing a few nuts and bolts Since many parts of the warhead are brazed, welded, or soldered together, taking it apart may entail considerable work It may also end up destroying perfectly good components, which will need to be replaced in reassembly To correct some problems, it may be necessary to add further nuclear material to a warhead type

Modifications at Pantex have increased with the Stockpile Improvement Program begun in FY 1982 After review and study in the late 1970s, the DOD and DOE decided on a nine-year (FY 1982-90) $400 million effort to apply hardware improvements to certain types of warheads These improvements include insensitive high explosives, new command and control, and enhanced safety features [20] Four warheads were reported to be part of the program: the B28 bomb, the W31 NIKE HERCULES warhead, and the B61-0,1 bomb [21] In 1978, there were also extensive plans to modernize the B43 bomb The plans included installing a Category D PAL, strong link/weak link switches, a modern radar, a new fuzing and firing set, a Kevlar parachute, and energy absorbing nose for improved laydown delivery capability [22]

In addition to modifying warheads, each year a set number are temporarily withdrawn from the stockpile to test the reliability of specific components Warhead components may have been subjected to corrosion, deterioration, or decomposition, or may not work at all (see below, Stockpile Reliability) Some testing is done in laboratories where components of a disassembled weapon are subjected to tests and inspections with advanced instruments If there are no problems, the warhead is reassembled and returned to the stockpile

A second method of evaluating reliability is through the preparation of flight test units The warhead is partially disassembled, the actual nuclear components are replaced by simulated components and instrumentation, and the warhead is reassembled This device, called a Joint Test Assembly, is delivered to the DOD for flight and environmental tests at military ranges

Final Disassembly

The third operation at Pantex is the complete disassembly of a weapon permanently withdrawn from the military stockpile The procedures followed to assemble the weapon are reversed The non-nuclear components are removed and returned to the manufacturers for refurbishment, salvage, or disposal The high explosive components are separated from other components and then disposed of at Pantex by burning The nuclear components are returned to other DOE facilities for reclamation or recycling

The following warheads were probably being dismantled at Pantex during FY 1985: the W25 (GENIE), the W53 (TITAN), the W50 (PERSHING 1a), W45 (MADM), W68 (POSEIDON), and perhaps the W62 (MINUTEMAN III)

Components of warheads, materials, and finished warheads are transported within the production complex and delivered to "Military First Destination" sites in special DOE vehicles called "Safe Secure Trailers" or "Safe Secure Railcars" (see Figures 2 9 and 2 10) [23] The Department of Energy does not ship nuclear warheads by air [24] All weapon-grade plutonium and highly enriched uranium are moved by truck The percentage of weapons transported by DOE by truck has been increasing The trailers and railcars are the responsibility of the Transportation Safeguards Division based in Albuquerque, New Mexico

Testing Nuclear Weapons[25]

The first test of a nuclear weapon occurred on 16 July 1945, on a 100-foot tower at the White Sands Bombing Range, fifty-five miles northwest of Alamogordo, New Mexico [26] From 16 July 1945 to 31 December 1985,

19 ERDA Environmental Assessment Pantex Plant Amarillo Texas June 1976 p 2 10
20 HAC FY 1982 EWDA, Part 7 pp 179-80
21 Ibid pp 278 79; HASC FY 1985 DOE p 294; SASC FY 1985 DOE p 120 The B61 1 upon modification will become the B61 7 The first delivery took place in October 1985 HASC Report 99 81, p 372 In FY 1986 only the B28 and the B61-1 were mentioned; HASC FY 1986 DOE p 95
22 HASC, FY 1979 DOE pp 230-31 It is not known whether these modifications were completed SASC FY 1985 DOE, p 120
23 For more information on trailer shipments see Carl Gilman, "Trucks: The Nuclear Connection Commercial Car Journal (June 1975): 64-78; Ron Wolf, On the Road with Plutonium APF Reporter (June/July 1981): 9-12; Colonel Richard A Stephens USA (Ret) and Lieutenant Commander Mahlon E Register USN Nuclear Stockpile Management, Army Logistician (May-June 1982): 2 5; John Frook Why They're Called Suicide Jockeys Parade Magazine (3 July 1983): 10 For the trains see HAC FY 1985 EWDA Part 6 pp 65-66, 68
24 DOE FEIS Pantex Plant Site Oct 1983, p 4-53 Nuclear weapons components, though, are transported by air Ross Aviation, Inc has provided air service since 1970 HASC FY 1979 DOE p 299 HAC FY 1986 EWDA Part 6 p 263
25 Nevada Operations Office *Announced United States Nuclear Tests: July 1945 through December 1984* NVO 209 (Rev 5) January 1985; DOE's Nevada Operations Office: What It Does and Why n d ; Bob Campbell *et al* , *Field Testing: The Physical Proof of Design Principles*, *Los Alamos Science* (Winter/Spring 1983): 164-79; ERDA FEIS *Nevada Test Site*, ERDA-1551 September 1977
26 Trinity Site is latitude 33°28' 33°50'N and longitude 106°22' 106°41'W Ferenc Morton Szasz *The Day the Sun Rose Twice: The Story of the Trinity Site Nuclear Explosion July 16 1945* (Albuquerque: University of New Mexico Press 1984) See also Defense Nuclear Agency Project Trinity 1945 1946, DNA 6028F

2

Nuclear Weapons Testing

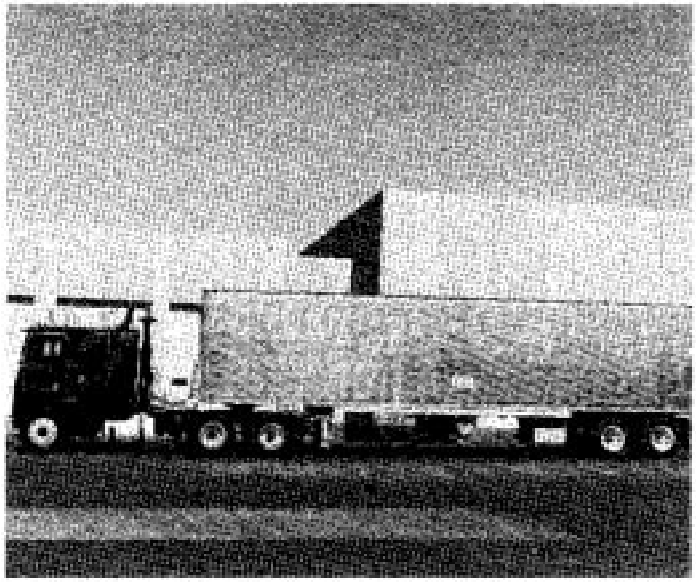


Figure 2 9 Safe Secure Tractor-trailer used to transport nuclear warheads to and from the Pantex Plant near Amarillo, Texas

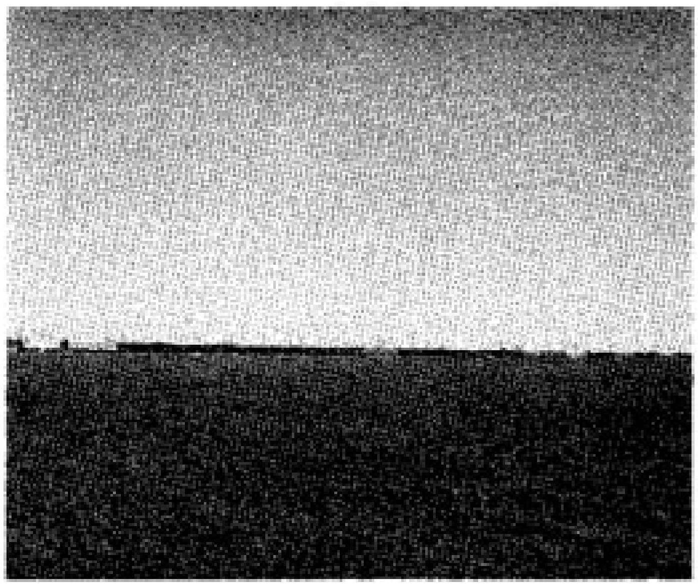


Figure 2 10 Safe Secure Railcars used to transport large shipments of nuclear warheads to and from the Pantex Plant near Amarillo, Texas

the United States has conducted 817 known nuclear tests [27] Of these, 108 took place in the Pacific, 3 over the South Atlantic, 689 at the Nevada Test Site, and 17 others in various states and Alaska Of the 212 atmospheric tests conducted from 1945 through 1962, approximately 220,000 DOD participants, both military and civilian, were present in the Pacific, Atlantic, and continental tests

Tests have occurred atop towers, on barges, suspended from balloons, dropped from aircraft, lifted by rockets, on the earth's surface, underwater, and underground (see Figure 2 11) [28] The most tests in one year was ninety-eight in 1962 This large number (and twenty-nine through June 1963) was in anticipation of a halt in atmospheric, underwater, and outer space testing, which occurred as a result of the Limited Test Ban Treaty, signed on 5 August 1963 The annual average of known tests in the 1950s was 19; in the 1960s, 35; in the 1970s, 17; for the years 1980-85, 17, 17, 19, 18, 19, and 16, respectively

The largest nuclear test conducted by the United States was shot *Bravo*, a 15 Mt device tested at Bikini Atoll, Marshall Islands, in the Pacific on 28 February 1954 Very low yield tests down to less than a ton and a few failures have also occurred

The U S government has had several different policies over the years in announcing and specifying the yield or yield ranges of tests At present, there is still no yield data on forty-three announced tests For all tests the combined yield is estimated to be 173 Mt,[29] the equivalent of 13,000 Hiroshima bombs Approximately 137 Mt of the total was detonated in the atmosphere, almost all between 1952 and 1962 Tests are now limited to a maximum yield of 150 kilotons (Kt) under terms of the Threshold Test Ban Treaty, signed by President Nixon in Moscow on 3 July 1974 The ban did not take effect until 31 March 1976 In the years since, the annual average of known tests has been seventeen (see Appendix B) Figure 2 12 shows the distribution of explosive yields at NTS from 1980 through 1984 Beginning on 9 November 1962, eleven months before the Limited Test Ban Treaty entered into force, every U S test has been underground, all but fourteen at the Nevada Test Site (NTS) [30]

In the weeks following the dropping of atomic bombs on Hiroshima and Nagasaki, American military and political leaders began planning nuclear weapon experiments to test weapon effects and new designs A pair of tests, code-named *Operation Crossroads*, was initially planned to test the effects of atomic weapons against naval vessels, and in November 1945, a search for a test site began In late January 1946, the U S Navy announced that Bikini Atoll in the Marshall Islands met all their requiremnts, including: "a site within the control of the USA, uninhabited or subject to evacuation without unnecessary hardship on large numbers of inhabitants,   offering a protected anchorage at least six miles in diameter "[31] The two tests were conducted in June and July 1946 using the FAT MAN type warhead

In July 1947, the United States announced that it was establishing a proving ground in the Pacific for routine testing of atomic weapons Enewetak Atoll, consisting of some forty-six islands (2 75 square miles of dry land) surrounding a 388 square mile lagoon, was selected Bikini

27 See Appendix B Includes two detonations in warfare—Hiroshima and Nagasaki—and eighteen joint U S -U K tests

28 See Table 2 in Appendix B for a breakdown

29 See Table 5 in Appendix B

30 The last U S atmospheric test was shot Tightrope held on 4 November 1962 The first underground test was Pascal-A on 27 July 1957 It was in a 3 foot diameter hole at a depth of 485 feet

31 DOE Enewetak Radiological Support Project, Final Report NVO 213 September 1982 p 3

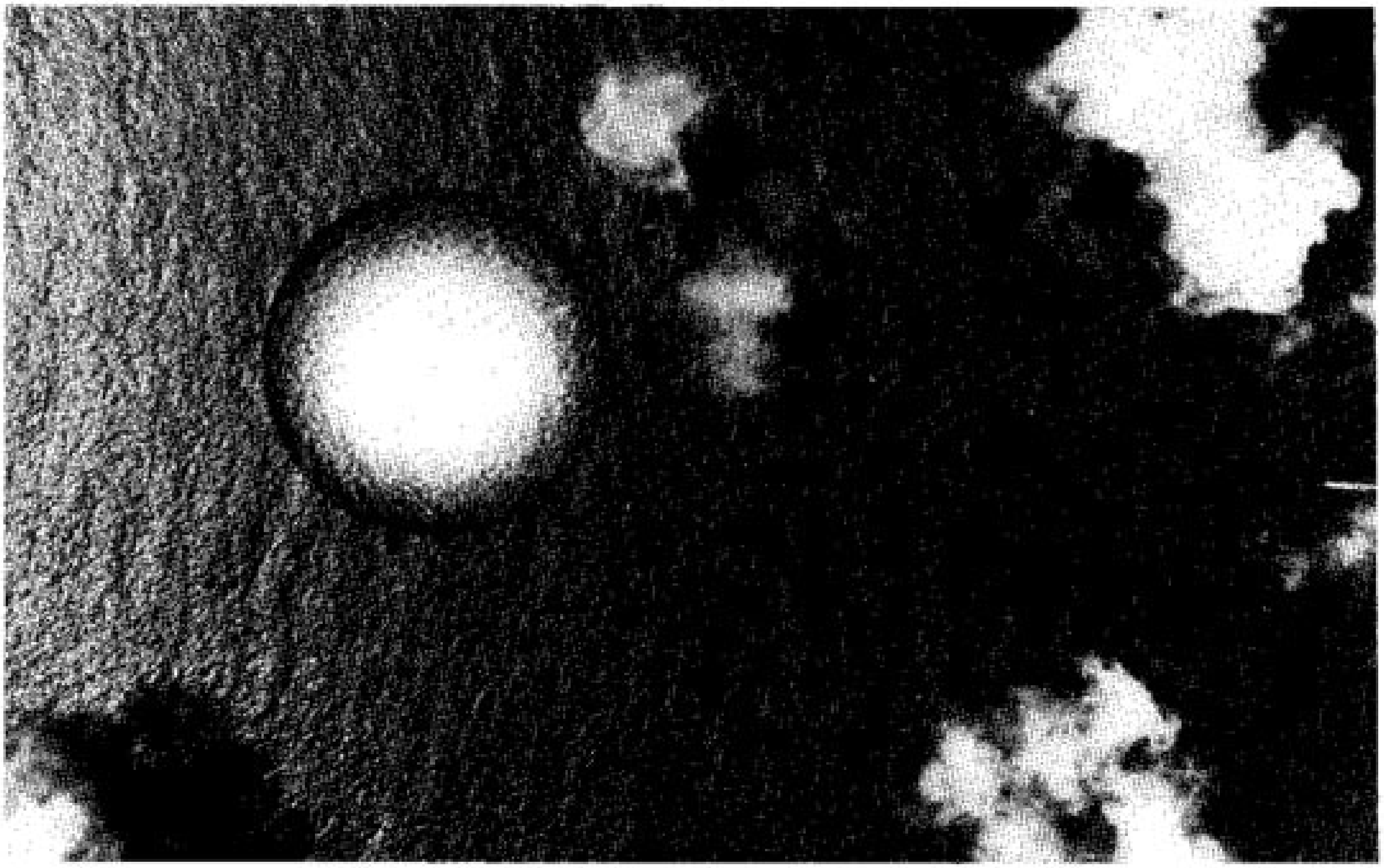
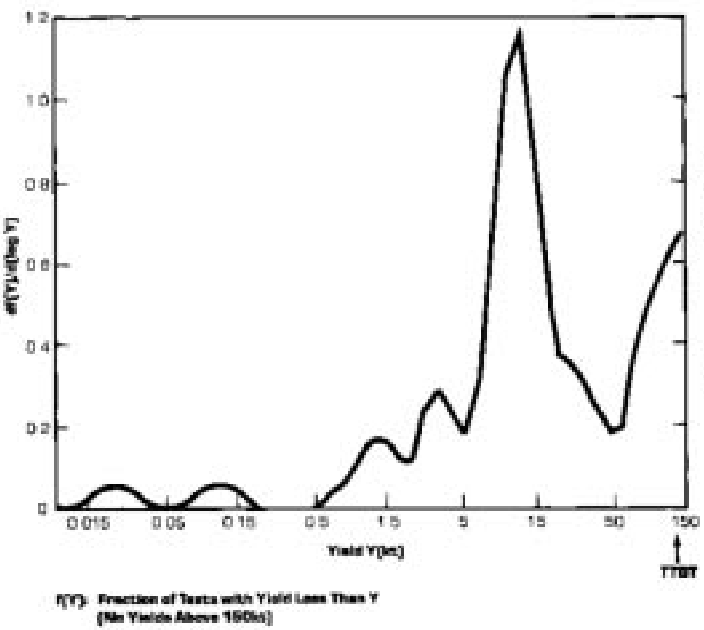


Figure 2 11 *Shot Swordfish*—an aerial view of the underwater detonation of the W44 ASROC missile warhead fired from a destroyer off the coast of San Diego on 11 May 1962



The probability-density distribution shows the relative frequency with yield Y versus that yield for all tests at NTS from 1980 through 1984 The vertical scale is designed to produce an area under the curve of one so that the relative probability of a test being of a given yield Y can be seen immediately

F(Y) = fraction of tests with yield less than Y

The table below lists values of the cumulative distribution function P (i e , the percentage of tests conducted with yield less than Y) versus Y

Percentage P of Tests Conducted with Yield Less than Y

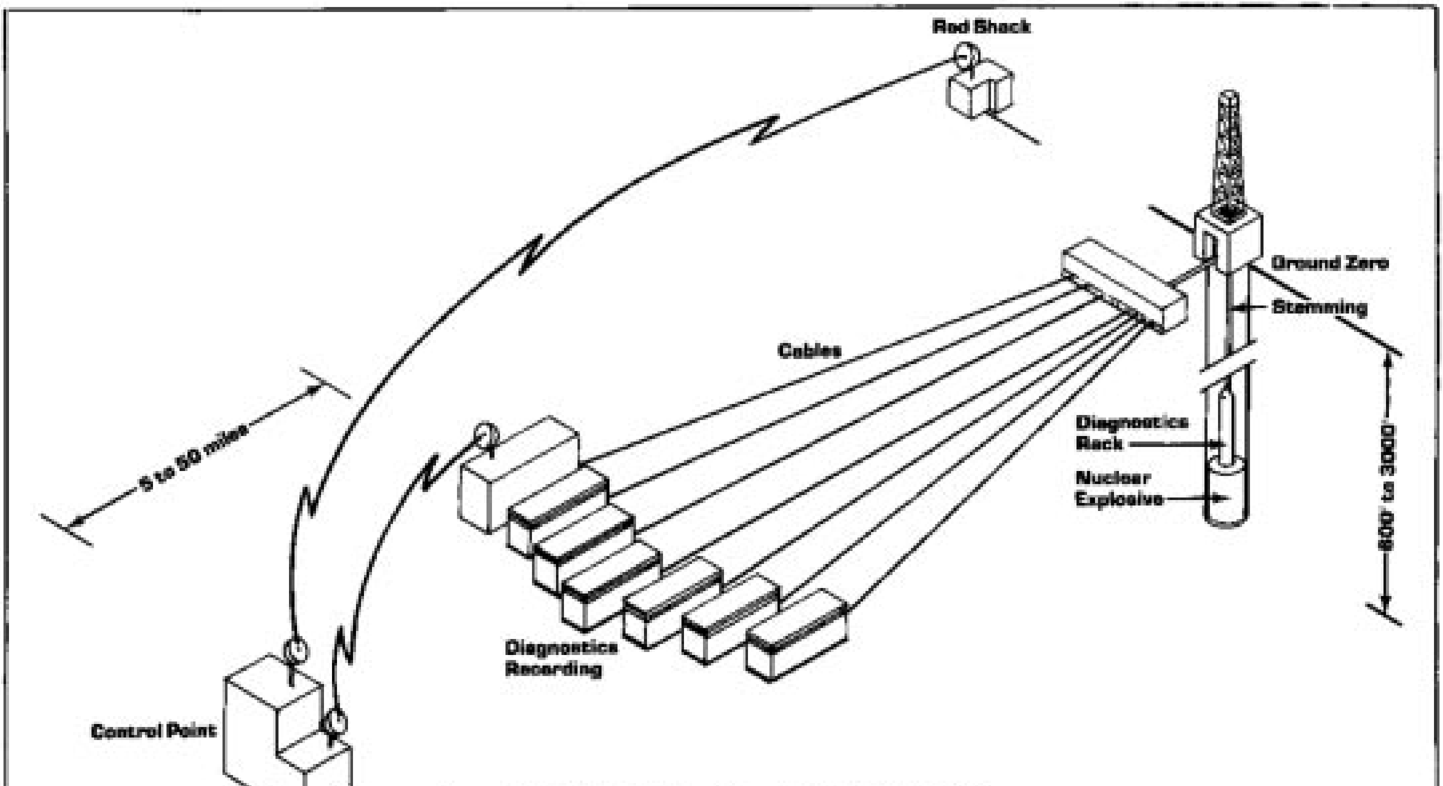
Y(Kt)	**1**	**5**	**20**	**50**	**150**
P(%)	**5**	**18**	**62**	**74**	**100**

a No tests were conducted with yields in excess of 150 kilotons in compliance with the unratified Threshold Test Ban Treaty (TTBT); Ray E Kidder Militarily Significant Nuclear Explosive Yields *F.A.S. Public Interest Report* 38 (September 1985): 1-3

Figure 2 12 Distribution of explosive yields at NTS: 1980 through 1984[a]

2

Types of Tests



Source: Adapted from *Los Alamos Science* (Winter/Spring 1983): 169

Figure 2 13 Typical weapon development test

was not considered acceptable at the time since it lacked sufficient land area for necessary instrumentation In fact, following the first two post-war nuclear tests in 1946 (*Operation Crossroads*), Bikini was not to be used again for nuclear testing until 1954

Nevada Test Site

The need for a continental test site arose with plans to increase the size of the arsenal in the 1950s Land based testing also reduced the expense and logistic problems of testing in the Pacific A number of sites were considered on the basis of low population density, geology, favorable year-round weather conditions, safety, and security

It was decided to use a portion of an Air Force bombing and gunnery range in Nevada Construction of the Nevada Test Site (NTS) facilities began on 1 January 1951 *Operation Ranger* was the first series of tests for which the site was utilized The first test occurred 27 January 1951, when an Air Force plane dropped a 1 Kt device onto Frenchman Flat Figure 30 in Volume III shows the NTS within the state of Nevada, and Figure 31 shows different regions of the site Originally 680 square miles were withdrawn Additional land withdrawals led to its present size of 1350 square miles At Mercury, in the southeast corner of the NTS, centralized facilities support most of the NTS activities Atmospheric testing was conducted at the Frenchman Flat area The area is now used for experimental projects Most tests now take place in or near Yucca Flat Rainier Mesa is the location for the DNA's weapons effects tests Pahute Mesa is an area for higher yield tests Currently it takes from one to two years to prepare a test Depending upon its complexity, the cost of a test ranges between $6 million and $70 million

Types of Tests

There are two principal categories of nuclear weapons tests: weapons related and weapons effects Weapons related tests are tests of nuclear devices intended for specific types of weapon systems or to understand the basic physics of nuclear explosives The former may be for developmental, proof, or confidence purposes During the research and development phases detonating a device will verify the theoretical concepts that underlie its design and operation In later phases, occasional proof tests are conducted of a warhead, to verify its yield, before or just after entry into the stockpile Only occasionally are confidence tests conducted on warheads withdrawn from the stockpile [32] Approximately 79 percent of U S tests have been weapons related Almost

32 HFAC *Proposals to Ban Nuclear Testing* 1985 p 78 Farooq Hussain says only a dozen or so have been conducted over the past thirty-five years The Impact of Weapons Test Restrictions *Adelphi Paper* No 165 (London IISS): 10