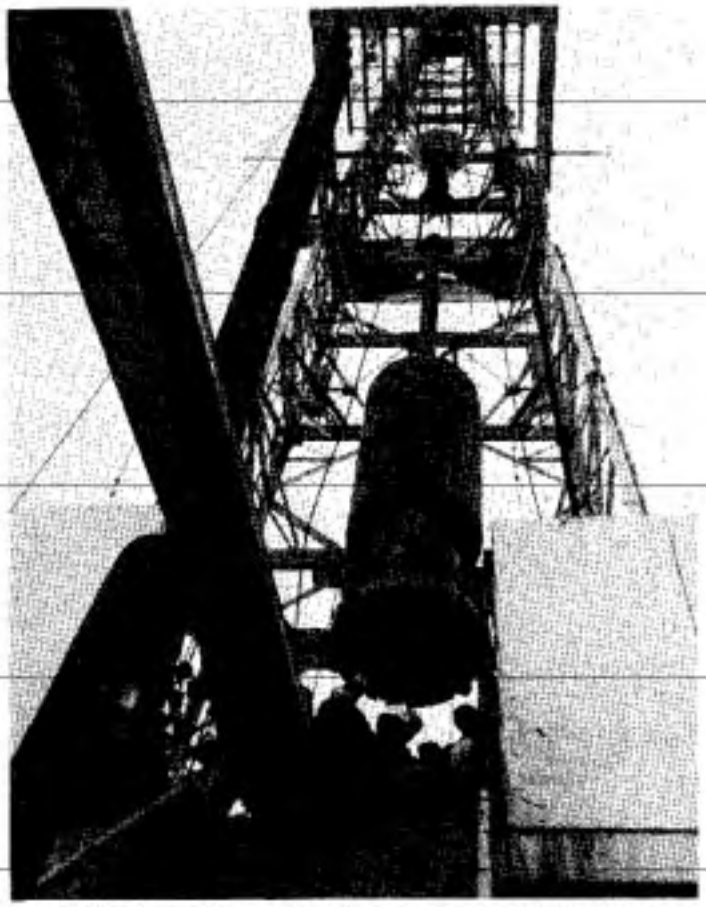

Figure 2 14 Large Diameter Drill Bits are used to drill "Big Holes" at the Nevada Test Site Big holes measure from 36 to 144 inches in diameter with depths from a few hundred to five thousand feet Above the bit are massive steel collars measuring just a few inches less than the bit and weighing up to 450,000 lbs These collars concentrate weight on the bottom of the hole for faster cutting

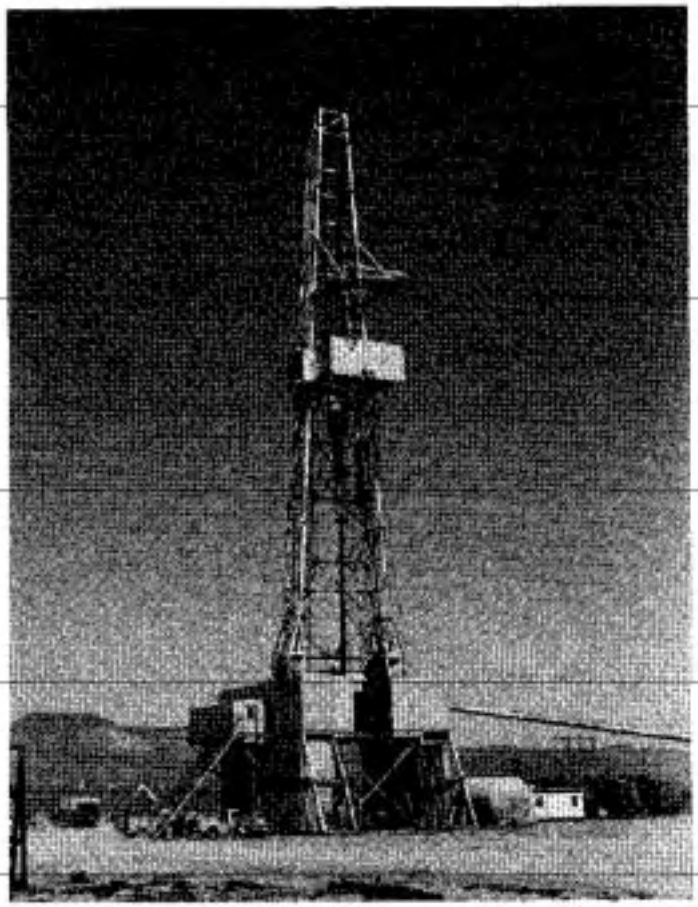

Figure 2 15 The IDECO 2500 Drill Rig This 2,000 horsepower diesel eletric rig is capable of drilling holes 72 to 140 inches in diameter to depths of 4,000 feet The rated capacity of its 158 foot Pyramid Mast is 1,400,000 pounds

without exception, it is not publicly known which test is for which weapon system, though there is information on a few (see Appendix B, Table B 1)

Most weapons related tests are conducted in vertical shafts (see Figure 2 13) Huge drill bits bore holes from 600 to 5000 feet in depth and from 3 to 12 feet in diameter (see Figure 2 14 and Figure 2 15)

The nuclear warhead, or device, is placed at the lower end of a long (up to 200 feet) cylindrical capsule or canister (see Figure 2 16) Diagnostic systems are usually contained within the same canister and normally make up the greater part of its length Canisters have increased to an average weight of over 100,000 lbs in 1981 (up from an average 65,000 lbs in 1978) [33]

A considerable bundle of electrical cables connects the firing and diagnostic systems to the surface recording stations (Figure 2 17) As the degree of complexity has increased, so too have the number and length of cables used per event In 1984, 115 cables totalling over 33 miles (on average) were used per event, up from 71 cables totalling 17 miles five years earlier [34]

After the canister containing the device and diagnostic equipment is lowered,[35] the hole is closed by backfilling with sand and gravel (called "stemming") and from one to three coal tar epoxy plugs Currently "stemming" takes about two weeks The stemming and plugs are meant to contain the explosion, preventing radiation from escaping [36]

When everything is in place, the test device is fired by sending a specific sequence of signals from the control point to the "Red Shack" near Ground Zero The Red Shack houses the arming and firing equipment The diagnostic equipment in the canister detects the explosion and information is sent uphole through the cables

33 HASC FY 1983 DOE p 409 In 1981 the cost of a canister was over $600,000 with some costing over $1 million

34 HASC FY 1985 DOE p 338

35 A new system when fully operational will allow only two days to lower the device instead of from eight to ten days previously

36 This has been successful less than two thirds of the time Of the 530 announced tests at NTS through December 1984 radioactivity was detected on site in 93 (15 percent) and off site in 130 (22 percent) The amount of radioactivity and how far it travels can sometimes be extensive Shot Baneberry (18 December 1970) vented an enormous amount of radioactivity some of which reached Canada

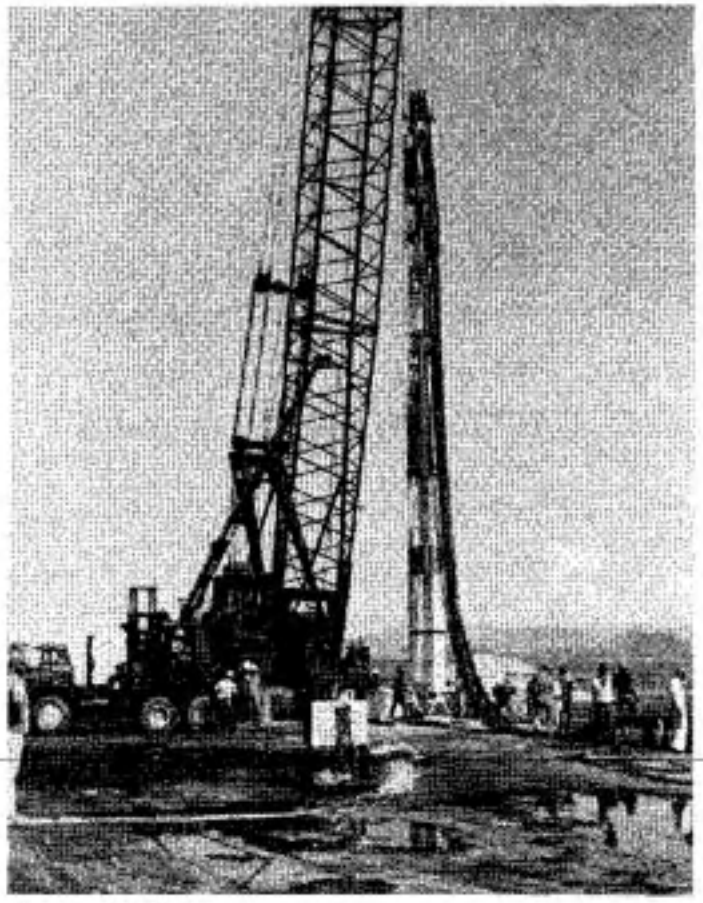

Figure 2 16 Canister

Within a fraction of a millisecond following the detonation, the sensors and cables are destroyed, but by that time the data has been transmitted to the recording stations or to the control point This technique, known as prompt diagnostics, measures whether the nuclear device performed to design specifications

When the device detonates, it creates a large underground cavity, the bottom of which quickly fills with molten rock material and debris As the heat and pressure subside, material begins to fall into the cavity, creating a void that progressively works its way up (see Figure 2 18) If the void reaches the surface, the overlying rock collapses under its own weight, producing a large subsidence crater (see Figure 2 19) The size of the underground cavity and the surface crater (if it forms) depends upon the yield of the explosion, the depth of burial, and the physical properties of the medium in which it is detonated

A second technique used to measure whether the device performed to design specifications is nuclear chemistry diagnostics, where laboratory analyses are made of radioactive materials produced by the explosion The material samples, either solids or gases, are taken from the cavity as soon as possible after the detonation and returned to either LANL or LLNL for analysis From the samples nuclear chemists can learn about explosive yield and burn efficiency (how much nuclear fuel was used) New approaches are being developed that will retrieve gases from a test hole within minutes after the detonation

The NTS is pockmarked with several hundred craters of various sizes from 200 to 2000 feet in diameter and up to 200 feet deep (see Figure 2 20 and 2 21) Astronauts have used the test site for training missions prior to their journeys to the moon

The cost of a weapon development test is between $6 million and $20 million [37]

The purpose of a weapons effects test is to research the range of nuclear effects—airblast, ground and water shock, heat, electromagnetic pulse, neutrons, gamma and x-rays—and to apply that knowledge to military systems, plans, and policy More specifically, the test program assesses the survivability of U S military systems in a nuclear environment and predicts lethality levels for destruction of enemy forces and equipment [38] The Defense Nuclear Agency (DNA) is responsible for research in this area In recent years it has conducted from two to four tests a year at the NTS Overall they have accounted for 11 percent of the tests (see Table B 4 in Appendix B)

Most weapons effects tests are conducted within a horizontally mined tunnel drilled into a mesa Figure 2 22 shows a typical DNA effects test arrangement A laboratory supplied device is located in the Zero Room, which is connected to a long, horizontal line of sight (HLOS) pipe approximately 1000 feet long containing several test chambers The pipe is usually about 1300 feet below ground and is tapered Various pieces of military hardware such as missile reentry vehicles, communication equipment, or other components are placed in the test chambers The HLOS pipe may be vacuum pumped to less than one micron (one millionth of a meter) of pressure to simulate conditions in space Various rapid closure mechanisms in the HLOS allow radiation generated by the nuclear device to reach test chambers but prevent the escape of debris and radioactive gases Following the test military hardware is retrieved from the test chambers and the effects of the explosion are evaluated at laboratories Because of the more extensive tunnelling needed for a horizontal effects test (see Figure 2 23), costs are higher than for development tests, ranging betwen $40 million and $70 million per test [39]

Stockpile Reliability

Periodically design flaws common to certain types of strategic and tactical warheads have been discovered

37 Ronald L Soble Secrecy Cloaks Testing of Awesome Nuclear Arms Los Angeles Times (27 November 1984): 23

38 SAC FY 1986 DOD Part 3 p 535 Soviet and East European military equipment is also subjected to U S weapons effects tests

39 Soble Secrecy Cloaks Testing p 23 Rick Atkinson Underground Events Test Mettle of U S Atomic Arsenal Washington Post (29 May 1984): A6

Table 2 9

Recent Weapons Effects Tests

Date	Event	Purpose
06/24/80	**Huron King**	Part of an Air Force and National Security Agency program to improve the database on nuclear hardening design techniques for satellites A vertical line of sight test using a small DSCS III prototype (see Figure 2 24)
10/31/80	**Miners Iron**	A test to evaluate the nuclear hardness of candidate materials for MX components such as motor cases, ablative nozzle, propellant and external booster parts The test used 2000 channels of data
09/23/82	**Huron Landing**	A horizontal line of sight test on MX components It was one of the largest, most complex tests DNA ever did, using 3000 channels of data to assess 400 separate experiments
09/23/82	**Diamond Ace**	The first event in the **Distant Arbor** series A joint DNA/DOE test to provide detailed diagnostic data of the radiation output of a low-yield nuclear device
05/26/83	**Mini Jade**	A test to obtain data to predict ground motion and cratering prediction The test was conducted in a hemispherical cavity having an eleven meter radius
09/21/83	**Midnight Zephyr**	The second event in the **Distant Arbor** series A joint DNA/DOE test to provide data for a low yield test bed
02/15/84	**Midas Myth**	The first test in a series of three to validate hardness specifications for major elements of the triad This 800 foot line of sight test provided data on the nuclear hardness of strategic reentry systems, specifically the MX's Mark 21 First use of glass strand fiber optics cables, which provide clearer reception of data and are secure from "tapping," thus improving the level of security
04/6/85	**Misty Rain**	The second in a series to validate hardness specifications A 900 foot line of sight test in support of the MX system, specifically the MK21 reentry vehicle Also included was a satellite vulnerability experiment to test its electronics in a radiation environment Some X-ray laser lethality testing was also conducted
10/09/85	**Mill Yard**	A second cavity experiment, similar to **Mini Jade**, obtained data on cratering phenomenology and airblast phenomena Also addressed issues on superhardening silos and the basing of the small ICBM The shot used a very low yield device detonated at ground level in a 22 meter diameter hemispherical cavity
10/09/85	**Diamond Beech**	Third and final proof test for low yield test bed
04/10/86	**Mighty Oak**	The final test to validate hardness specifications for the Mark-21 reentry vehicle for the MX missile and the first validation test for the TRIDENT II (D-5) reentry system X-ray laser lethality experiments were also conducted Test malfunctioned Yield was 1 3 Kt Former tests in the series were **Midas Myth** and **Misty Rain**
Scheduled		
Dec 1986	**Middle Note**	Second validation test for TRIDENT II Mk5 reentry system and SICBM program
Sep 1987	**Mission Cyber**	Large scale event to support validation of D-5 systems and SICBM program
FY 1987	**Mineral Quarry**	Large scale event to support validation of D-5 systems and SICBM program
FY 1987	**Misty Echo**	Third of a series of three events executed in underground cavities to measure the phenomenology of nuclear craters The event is planned to evaluate the contribution of nuclear radiation to the formation of a crater
?	**Distant Drum**	
Sep 1989	**Diske Elm**	
Apr 1991	**Diagonal Light**	
?	**Huron Forest**	

Sources: SAC, FY 1985 DOD, Part 3, pp 530 532-33; HAC, FY 1985 DOD Part 5 pp 552-53; HASC, FY 1985 DOD, Part 4, pp 992; HAC FY 1984 DOD Part 4 pp 395 404; HASC, FY 1984 DOD Part 5 pp 978-79; SAC FY 1984 DOD Part 2 p 803; HASC FY 1983 DOD Part 5 pp 1202 1212; HASC FY 1982 DOD Part 4 p 1156

through inspection, testing, and accidents The most frequent problems appear to be associated with corrosion of fissile material, inoperability of mechanical arming systems, and sensitivity or deterioration of the chemical high explosives These design failures have rendered numbers of stockpiled warheads inoperable and have increased the workload of the production complex in order to rework or replace the defective warheads or components In some instances test explosions were conducted to confirm that the problems were resolved Examples of the problems that have been identified in the open literature include:[40]

W47/POLARIS SLBM. Several problems developed with the Lawrence Livermore designed W47 warhead for the POLARIS A1 and A2 SLBM In December 1961, during scheduled surveillance, weapon engineers discovered that significant corrosion had occurred in the fissile

40 See principally Jack W Roesgen Some Little Publicized Difficulties with a Nuclear Freeze Study sponsored by Office of International Security Affairs DOE, October 1983

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Stockpile Reliability

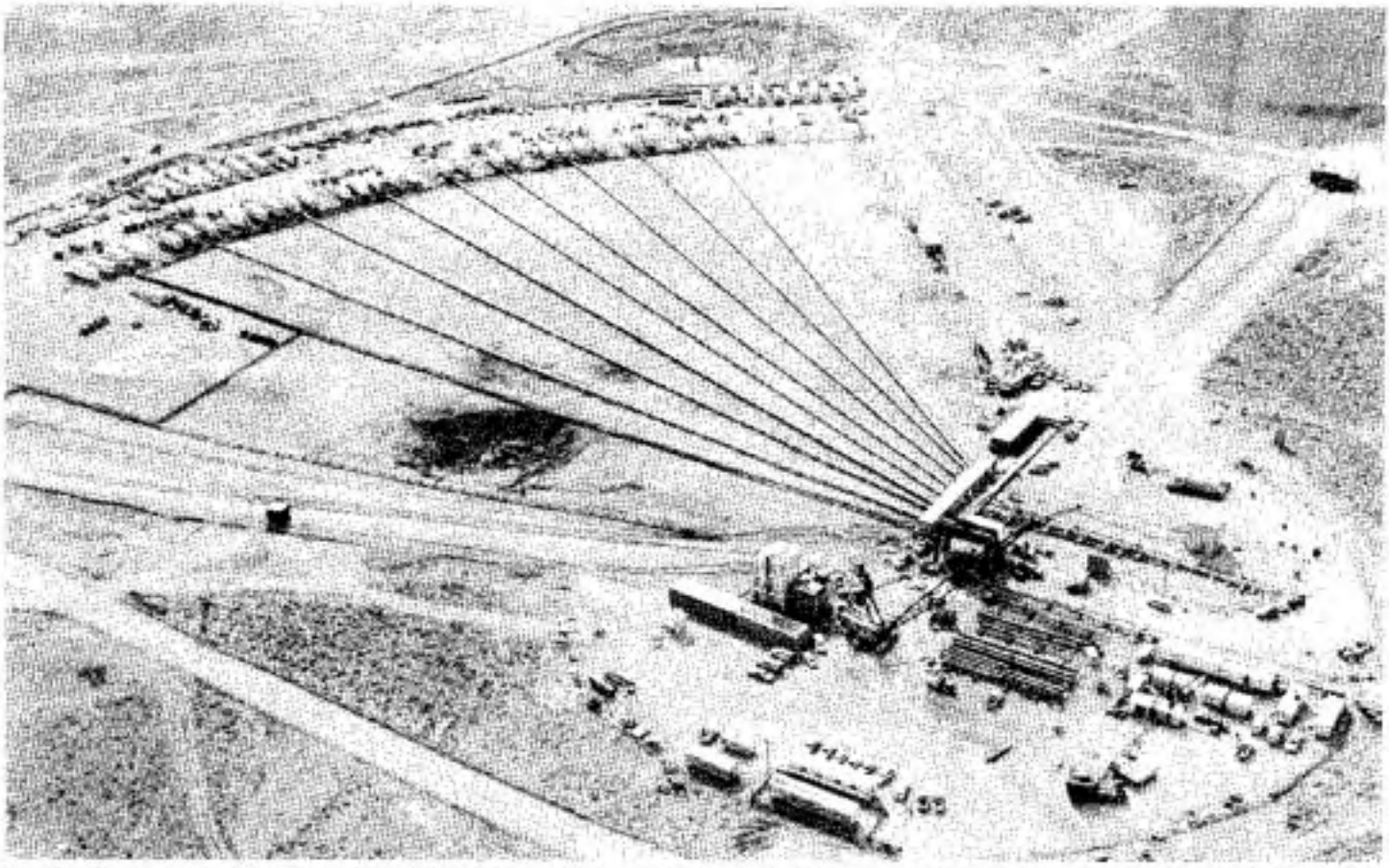


Figure 2-17 Array of diagnostic and recording trailers. Tests are increasing in complexity, yielding more data through use of more diagnostic cables and recording trailers.

material of the 600 Kt W47Y1 Mod 1 warhead. The engineers suspected that the corrosion would have resulted in either a dud or a much reduced yield. Observations of additional warheads yielded evidence of similar corrosion. To see if the engineers' supposition was correct, a test explosion was conducted at NTS using an extremely corroded W47. Though the yield was low it was still within the acceptable range. Nevertheless during the retrofit period that followed, 20 percent of the W47Y1 Mod 1 warheads in the stockpile were replaced with new ones and a slight design change, W47Y1 Mod 2, prevented similar corrosion.[41]

Tests of the W47Y1 warhead had been conducted prior to the start of the test moratorium in October 1958. One, held earlier that year, was a safety test of the W47 designed to determine whether it was "one-point safe."[42] The resulting yield was about one hundred tons, instead of the negligible amount required. To overcome this safety defect the warhead design was modified to incorporate a mechanical safing system. This W47Y1 Mod 1 was used for the production warheads first delivered in April 1960 (on an emergency basis) with normal production commencing in June 1960.

During 1963, two years after weapon testing resumed, engineers discovered that the W47Y1 mechanical one-point-safety system would not fully complete its arming operation, rendering the warhead a dud. Apparently, the arming system motor was too weak to overcome friction, thus preventing full arming. The engineers believed they could correct this problem with a stronger motor.

This modified design was also incorporated into the W47Y2, a higher yield (800 Kt) version of the W47 which entered the stockpile in February 1963. During a nonnuclear test, in August 1965, the mechanical safing system in this higher yield version operated only half way and thus would have produced a dud.[43] At the time of the August 1965 test about three out of four of the higher yield W47s (some 108 of the 144 then deployed) had this problem.[44]

41 A corrosion problem also occurred with the Lawrence Livermore designed 200 Kt W58 warhead for the POLARIS A3 SLBM during the 1970s. It was countered by certain minor changes without further nuclear tests being required or any major rebuilding.

42 One point safe means that the probability of achieving a nuclear yield greater than four pounds of TNT equivalent shall not exceed one in one million in the event of a detonation initiated at the single most sensitive point in the high explosive system.

43 Walter Pincus, "Dud 1960s Polaris Warheads Surface in Test Ban Debate," *Washington Post* (2 December 1978): 4.

44 It is estimated that the overall failure rate for all W47 warheads would have been about 50 percent.

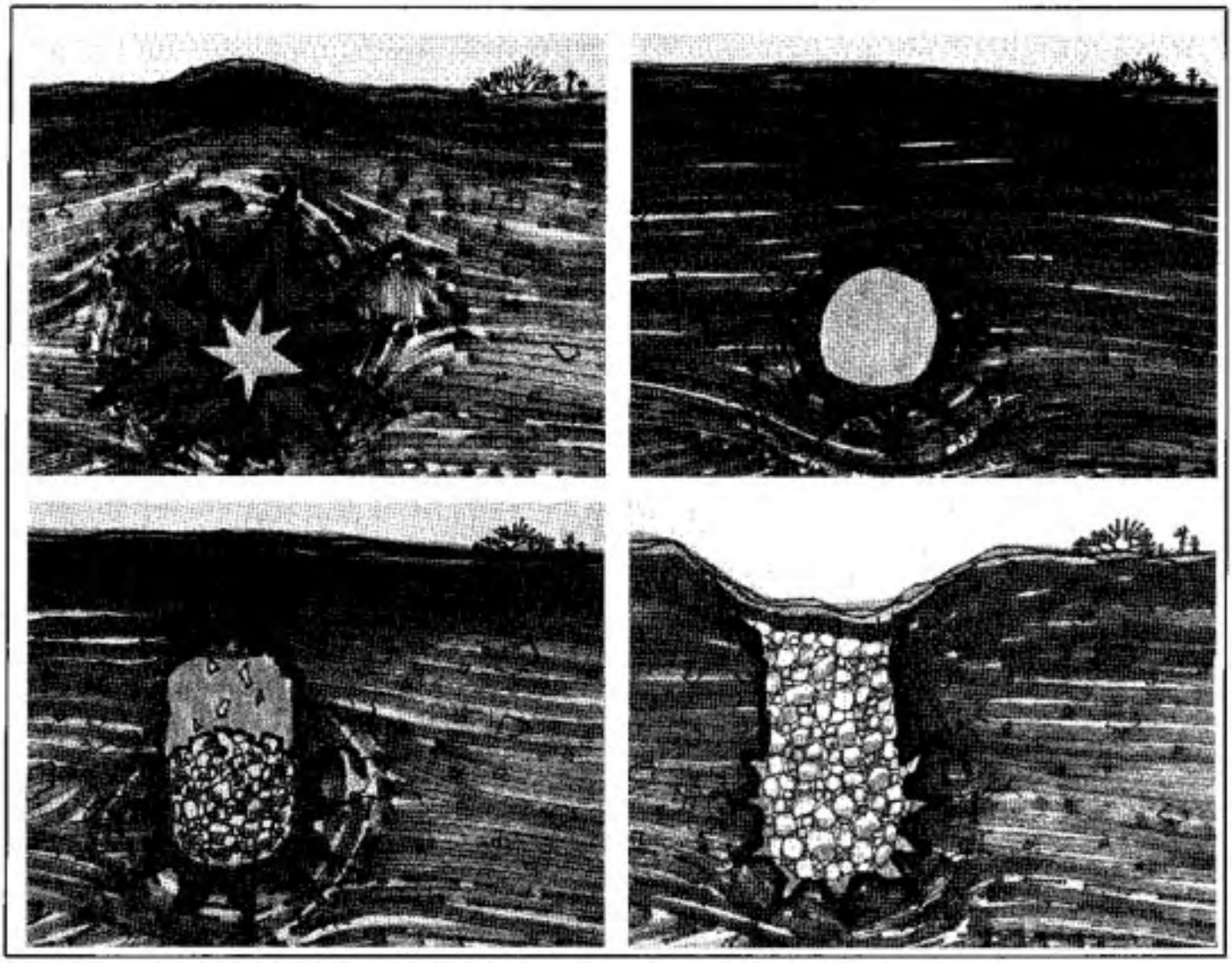


Figure 2 18 Subsidence crater formation Susidence craters may form minutes, days, or weeks after the explosion

After further tests of the W47 Livermore engineers incorporated new features (some borrowed from a similar warhead) The redesigned W47Y2 Mod 3 was without mechanical safing but was both one-point-safe and capable of a full yield By late 1967 the Atomic Energy Commission proceeded to rebuild the entire W47 stockpile—estimated to be enough for thirteen SSBNs (208) plus spares—converting all warheads to the revised version, W47Y2 Mod 3 The redesigned version also required the addition of more weapon-grade plutonium

W56/MINUTEMAN ICBM. Flaws in the mechanical arming system was also found in the Lawrence Livermore designed 1 2 Mt W56 warhead for MINUTEMAN I and II ICBMs Production of the W56 began in March 1963 After about one hundred warheads were produced, weapon engineers discovered that the arming mechanism did not fully complete its operation, again possibly leading to a dud While production continued through 1963 a minor design change was devised to correct the problem It was concluded that it could be confidently incorporated into the new warheads without requiring a test explosion In late 1963 all 160 W56 warheads thus far produced were returned from stockpile to be rebuilt Eventually about 850 were produced until May 1969, 450 of which are still deployed on MINUTEMAN II ICBMs

W45/ TERRIER, MADM, LITTLE JOHN. The W45 is the warhead for the Navy's surface-to-air TERRIER air defense missile Until quite recently it was also the warhead for the Army and Marine Corps' Medium Atomic Demolition Munition (MADM) and during the 1960s the warhead for the Army's LITTLE JOHN short-range surface-to-surface missile Yields of the W45 ranged from 1 to 15 Kt depending upon its application The W45 was produced between January 1962 and June 1966

The Lawrence Livermore-designed W45 warhead

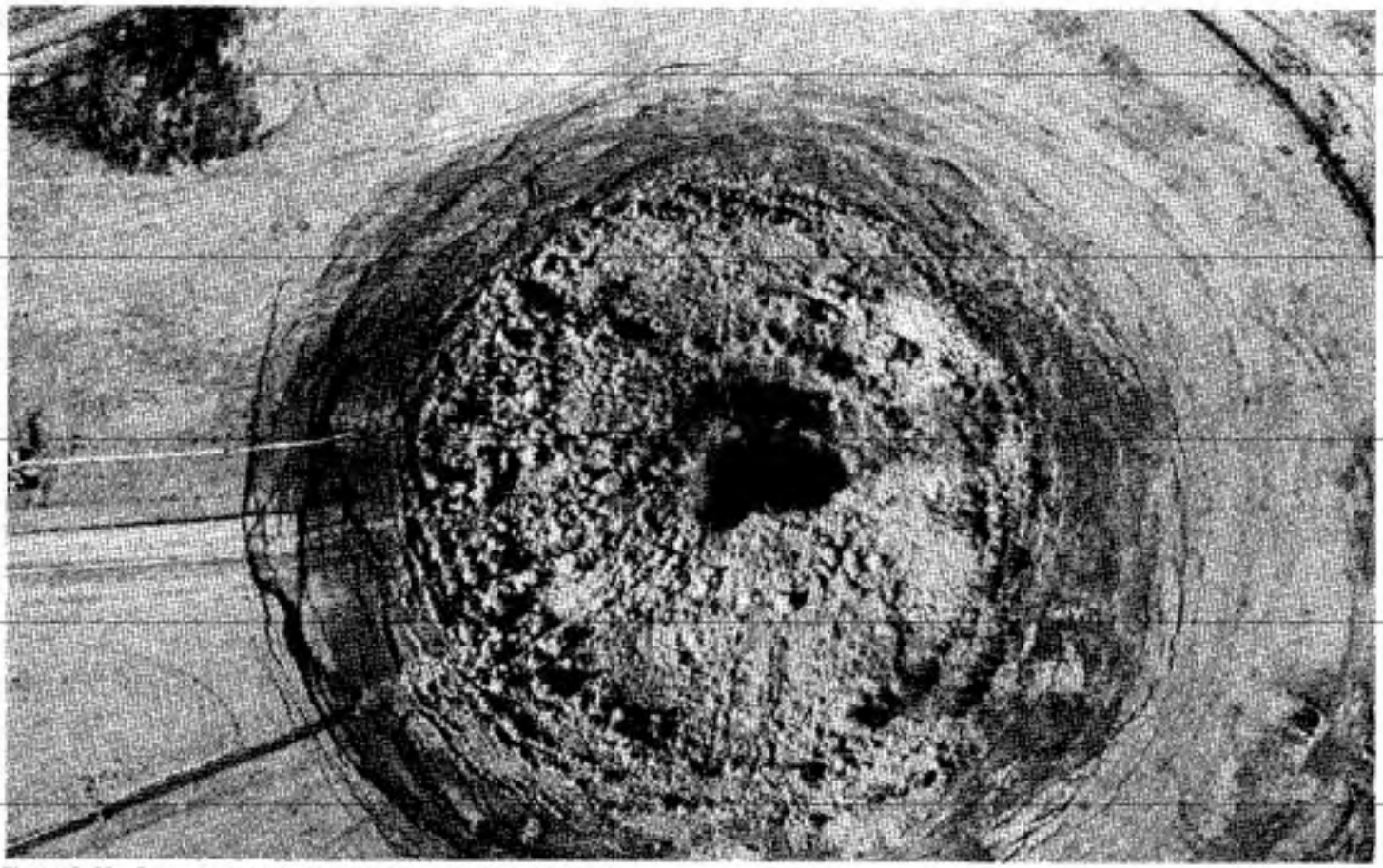


Figure 2 19 Post shot subsidence crater at moment of collapse

has had problems associated with corrosion of its fissile material and with its chemical high explosive After it entered the stockpile, weapon engineers discovered that serious corrosion of the fissile material was altering the geometry of the warhead Each W45 in the stockpile was inspected, and many of the corroded ones were eliminated For those remaining, and for new units, a design change proved adequate to protect against similar corrosion At about the same time a problem with the high explosive was discovered, which led to the rebuilding of every W45

Because of the design changes, the multiple yield options, and because a test device had exploded with only half its rated yield, LLNL tested the W45 in a series of five underground explosions in the mid-1960s

W52/SERGEANT. The W52 was a Los Alamos designed 200 Kt warhead for the Army's now retired SERGEANT, a 75-mile-range surface-to-surface ballistic missile In 1959 two accidents occurred at Los Alamos, killing four people Both accidents involved large pieces of high explosive (HE) of the type planned for the W52 Given the potential hazards of this volatile high explosive, it was decided to change the HE system to one less sensitive Though not able to test during the 30-month moratorium (November 1958-August 1961) the scientists had confidence in the new design, and the first units were produced in May 1962

After more than a year of exploding other test devices that had higher priority, Los Alamos tested a partial yield version of the W52 in early 1963 The test device exploded with only about 1 percent of its expected yield This indicated that those deployed in the field were useless Los Alamos scientists quickly redesigned the warhead, adding substanially to the content of special nuclear material Within three months of the first test a revised design device was exploded as a partial yield version, this time with success The Atomic Energy Commmission replaced the W52 with the new design and completed production in April 1966

W68/POSEIDON SLBM. More recently there has been a problem with the high explosive in the Lawrence Livermore designed W68 50 Kt warhead for the POSEIDON SLBM Between May 1970 and June 1975 approximately 5250 W68 warheads were produced for 496 SLBMs on thirty-one submarines (including spares) During the development period in the 1960s there were two candidate high explosives, LX-09 and LX-10 Though LLNL fired two successful W68 development tests with LX-10, they adopted LX-09

Over a seven-year period in the 1970s Livermore

Figure 2-20 *Sedan* Crater, Yucca Flat, Nevada Test Site, (view is to the north-northeast) Crater diameter is 370 m, depth 98 m, and volume 5.0×10^6 m^3. Crater formed in 1962 by a 100 ± 15 kiloton nuclear device detonated at a depth of 190 m in valley fill. Water table is about 580 m below land surface. Vehicles, left side of photo, provide scale.

scientists dismantled and evaluated portions of about one hundred W68 warheads. They found that the mechanical properties of LX-09 degraded with time and that it began to give off a distinct odor, indicating some chemical change. Effluents from the LX-09 interacted with three other materials in the warhead: the mechanical properties of a plastic component near the high explosive changed, a uranium-alloy component close to the high explosive produced corrosion spots, and the adiprene adhesive in the detonators softened. The last interaction was the most serious problem, for scientists feared that the products from this reaction could interact with the detonator bridgewire and eventually cause the detonator to fail.

During 1977-78 Livermore, the ERDA (later DOE) and the Navy evaluated the problem and considered possible remedies. They finally agreed to undertake a five-year program to replace LX-09 with LX-10 in all W68 warheads. The first retrofitted warhead was delivered in November 1978.[45] Because of a program to retrofit twelve submarines with TRIDENT I SLBMs carrying one hundred Kt W76 warheads, it was necessary to change the high explosive in only 3200 W68s.

Even though Livermore was confident of the LX-10 because of prior tests in the 1960s, a retrofitted W68 was exploded sometime between mid-1980 and mid-1981 to confirm that it would work.[46]

Weapons Effects Simulation

Since the passage of the Limited Test Ban Treaty of 1963, certain kinds of nuclear weapons effects can only be simulated, and a large number of DOD and DOE facilities have been established to conduct effects research. Some of the simulations use underground nuclear tests (effects tests) conducted by DOD, while others use radiation simulators (for X-rays and gamma rays), shock tubes, high explosives, and natural disturbances. Some nuclear weapons effects are also simulated using computers.

The Defense Nuclear Agency (DNA) is the main agency in the effects simulation field, and it manages the

45 Energy and Technology Review (July 1979): 11.

46 Energy and Technology Review (July 1981): 11.

2

Weapon Effects Simulation

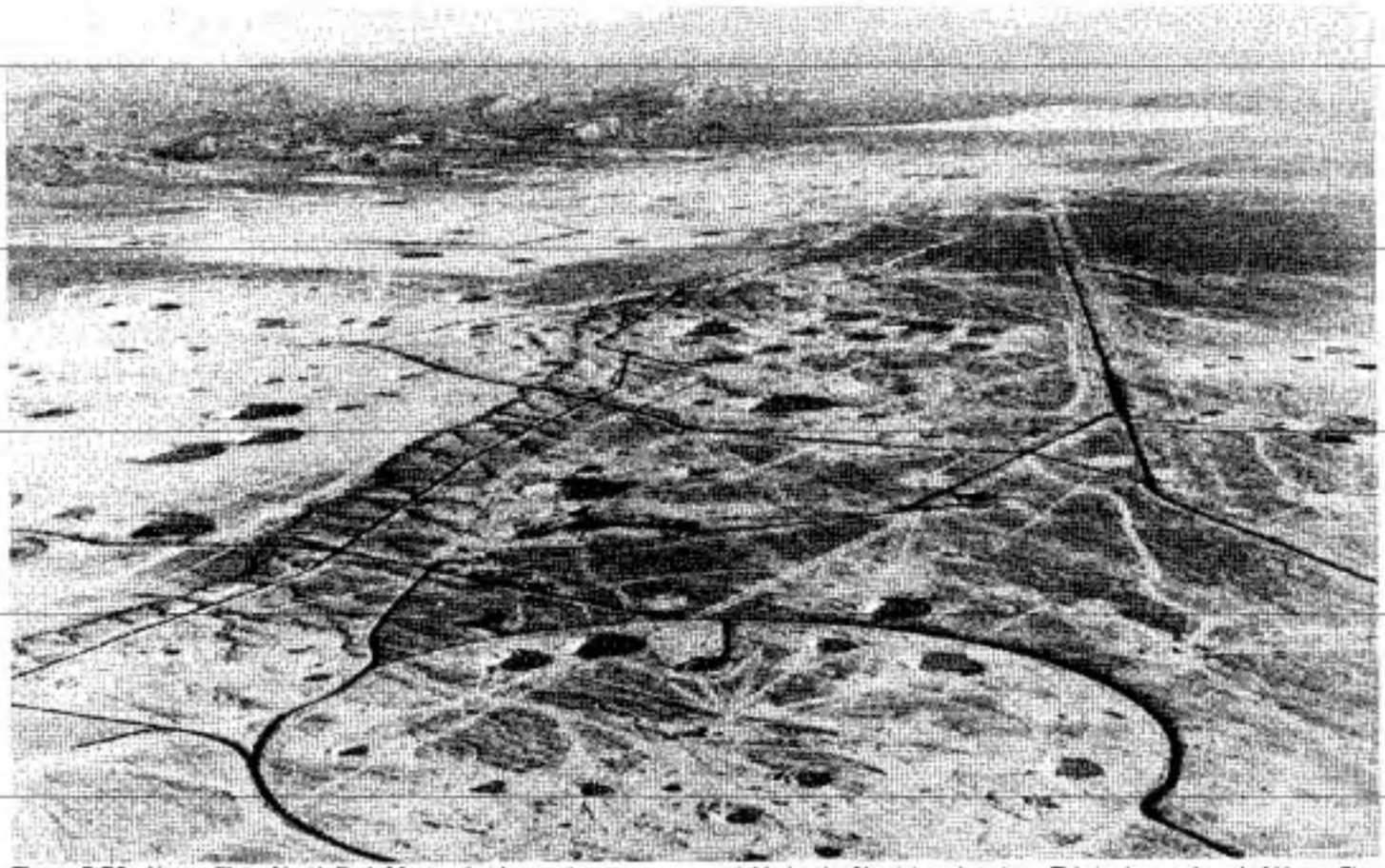


Figure 2-21 Yucca Flat—North End Most subsidences leave saucer-shaped craters varying in diameter and depth, depending upon the yield, depth of burial, and geology This is the north end of Yucca Flat Most tests are now conducted in this valley

entire DOD Nuclear Weapon Effects Program The purpose of the program is to assess the ability of aircraft, missiles, and electronics to withstand nuclear explosion effects The tests also probe how military personnel and equipment respond and could be protected against the effects of nuclear detonations—including blast, thermal shockwaves, neutron flux, X-rays, gamma rays, and electromagnetic pulse (EMP) Also investigated are the indirect environmental effects of nuclear detonations, such as the formation of ice clouds, fallout, and rain-out on military operations Ice clouds, for instance, could hinder the flight of ballistic missiles

To conduct its research on the effects of nuclear weapons upon humans, the DNA operates the Armed Forces Radiobiology Research Institute (AFRRI) in Bethesda, Maryland It uses animal experimentation to determine the response of cells, tissues, blood systems, nervous systems, and so forth to high levels of ionizing radiation AFRRI is the only DNA-operated facility; most of its other research simulation work is done by the military services or private companies

The Air Force Weapons Laboratory (AFWL), Kirtland Air Force Base, New Mexico, is the lead Air Force laboratory for nuclear weapon effects simulation It is also the lead laboratory in the simulation of EMP AFWL conducts all DNA-sponsored Air Force research on nuclear weapons effects and has managed the DNA program since 1973 AFWL operates the world's largest glue-laminated wood structure, called "Trestle EMP" at Kirtland AFB, as a test facility to verify the protection of airborne electronics against EMP Trestle, which cost nearly $60 million to build, can support the largest Air Force aircraft in simulated flight while subjecting it to EMP effects of a very high altitude nuclear detonation

Other major EMP simulators capable of testing aircraft and missiles are the Advanced Research EMP Simulator (ARES) owned by the Defense Nuclear Agency; the joint AFWL/Los Angeles Electromagnetic Calibration and Instrumentation System (ALECS); and Horizontal Polarized Dipole (HPD), and Vertically Polarized Dipole (VPD II) facilities, both located at Kirtland AFB

The Navy also operates EMP simulators to test ships and aircraft The Naval Surface Weapons Center in Dahlgren, Virginia, operates the EMP Radiation Environment Simulator for Ships (EMPRESS I) at Solomons Island, Maryland, and the EMP Simulator for Aircraft (EMPSAC)

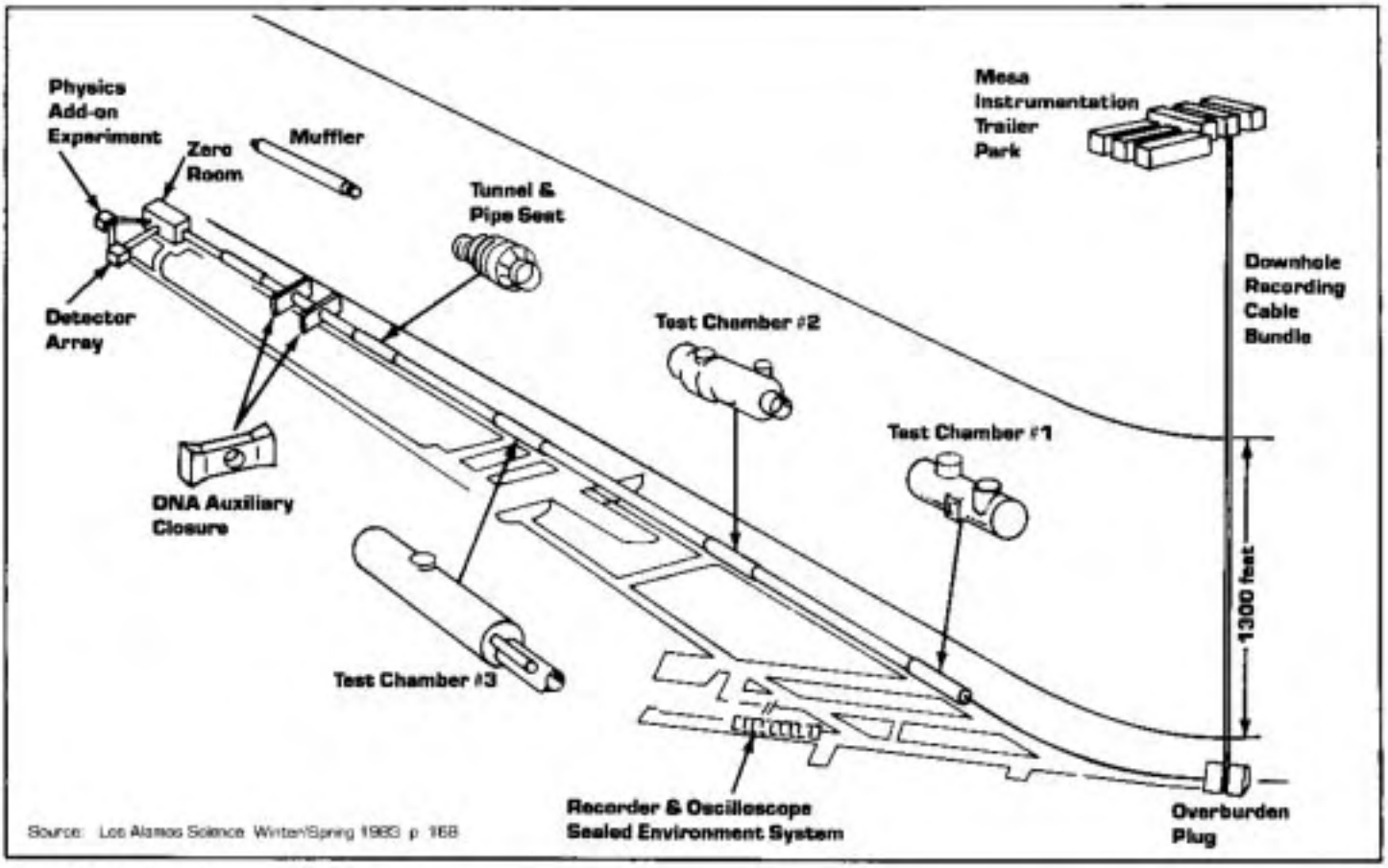


Figure 2 22 Typical weapons effects test

facility at Patuxent River, Maryland The Navy is planning to upgrade the EMPRESS I facility, operational since 1973, with EMPRESS II, to be based at Bloodsworth Island, Maryland during the winter and Elizabeth City, North Carolina during the summer EMPRESS II would consist of a mobile barge 120 feet long and 105 feet wide carrying a cone-shaped antenna 130 feet high and 200 feet wide It could emit a 7 million volt pulse (MVP)—compared to 2 6 million volts for EMPRESS I—directed at nearby ships to determine hardness of electronics against EMP

Army EMP simulation for testing ground-based systems is conducted by the Harry Diamond Laboratories (HDL), the lead laboratory for the Army for nuclear weapons effects, and headquartered in Adelphi, Maryland HDL operates the AESOPS or TEMPS simulators, 1,000 foot long horizontal antennae driven by a 7-MeV pulsar at its center The antennae generate a freely radiated signal AESOP is a fixed system located in Woodbridge, Virginia while TEMPS is transportable system that is taken to the field to test fixed facilities, such as AUTOVON communications switches

Other nuclear effects than EMP are also the subject of research The AFWL, for example, simulates radiation, blast, and shock effects of nuclear explosions and is involved in testing models of possible future ballistic missile protective shelters to determine their ability to withstand a nuclear attack It "performs theoretical modeling and exploits expertise in high explosive technology in simulating and verifying nuclear blast and shock environments to investigate the survivability of deep based shallow buried surface flush or aboveground hardened systems "[47]

To research X-ray effects, simulation of X-rays is performed by the Naval Surface Weapons Center at White Oak, Maryland, which operates the CASINO facility for DNA Harry Diamond Laboratories also operates the AURORA facility at White Oak, Maryland for DNA There, it simulates certain nuclear effects, particularly X-rays to study ionization The 7,500 ton AURORA machine is the largest single power source in the world It produces, for very brief time periods, about twenty terawatts (twenty trillion watts), roughly equal to the total peak electrical power output of the United States

47 AFWL Air Force Weapons Laboratory R&D Program 1984 n p

2

Weapon Effects Simulation

Figure 2-23 Tunnel for weapons effects test. Huge tunnels are drilled into Rainier Mesa at the Nevada Test Site, the primary area for weapons effects tests. Sections of pipe are joined together to encase test chambers, meterials, and components. The biggest pipe used to date was for shot *Diamond Sculls* on 20 July 1972. The pipe was 1,400 feet long, and 27½ feet in diameter at the wide end. An entire *Spartan ABM* missile was put in the pipe.

The Army Pulse Radiation Facility at the Ballistic Research Laboratory, Aberdeen Proving Ground, Maryland also "provides a radiative environment simulating a portion of the nuclear weapons ground environment to determine the nuclear vulnerability of Army equipment and systems."[48] At the White Sands Missile Range, New Mexico, the Army operates the White Sands Solar Furnace, one of the largest furnaces in the world. Capable of generating up to 5,000 degrees Fahrenheit on a 4-inch spot, the furnace simulates the extreme heat of a nuclear explosion. High explosive nuclear effects testing is also conducted by DNA at White Sands. In 1985, DNA completed development of a tri-Service Thermal Facility at Wright Patterson Air Force Base, Ohio, which will use flash lamps to simulate thermal effects. Other laboratories involved in nuclear weapons effects research include the Rome Air Development Center at Griffiss Air Force Base, New York; the David W. Taylor Naval Ships Research and Development Center, Carderock, Maryland, which studies the nuclear survivability of ships and submarines; and the Army Waterways Experiment Station in Vicksburg, Mississippi.

In addition to using man-made simulators, natural disturbances can simulate certain nuclear effects. The main laboratory involved in this work is the Air Force Geophysics Laboratory, at Hanscom Air Force Base, Massachusetts. It conducts much of its research for DNA. The DNA/AFGL program use "natural and artificial phenomena such as aurora and metal releases in the atomsphere to simulate important aspects of atmospheric conditions following nuclear detonations."[49] Their research employs rockets, satellites, the space shuttle, and ground-based instruments. One study seeks to improve understanding of radio signal propagation through an ionosphere disturbed by nuclear weapons. AFGL/DNA researches conduct high altitude barium releases directly between satellites and ground-based receivers.

48 DOD Directive 3200.11(1) p. 22

49 DNA FY 1986 RDT&E Descriptive Summary p. 339

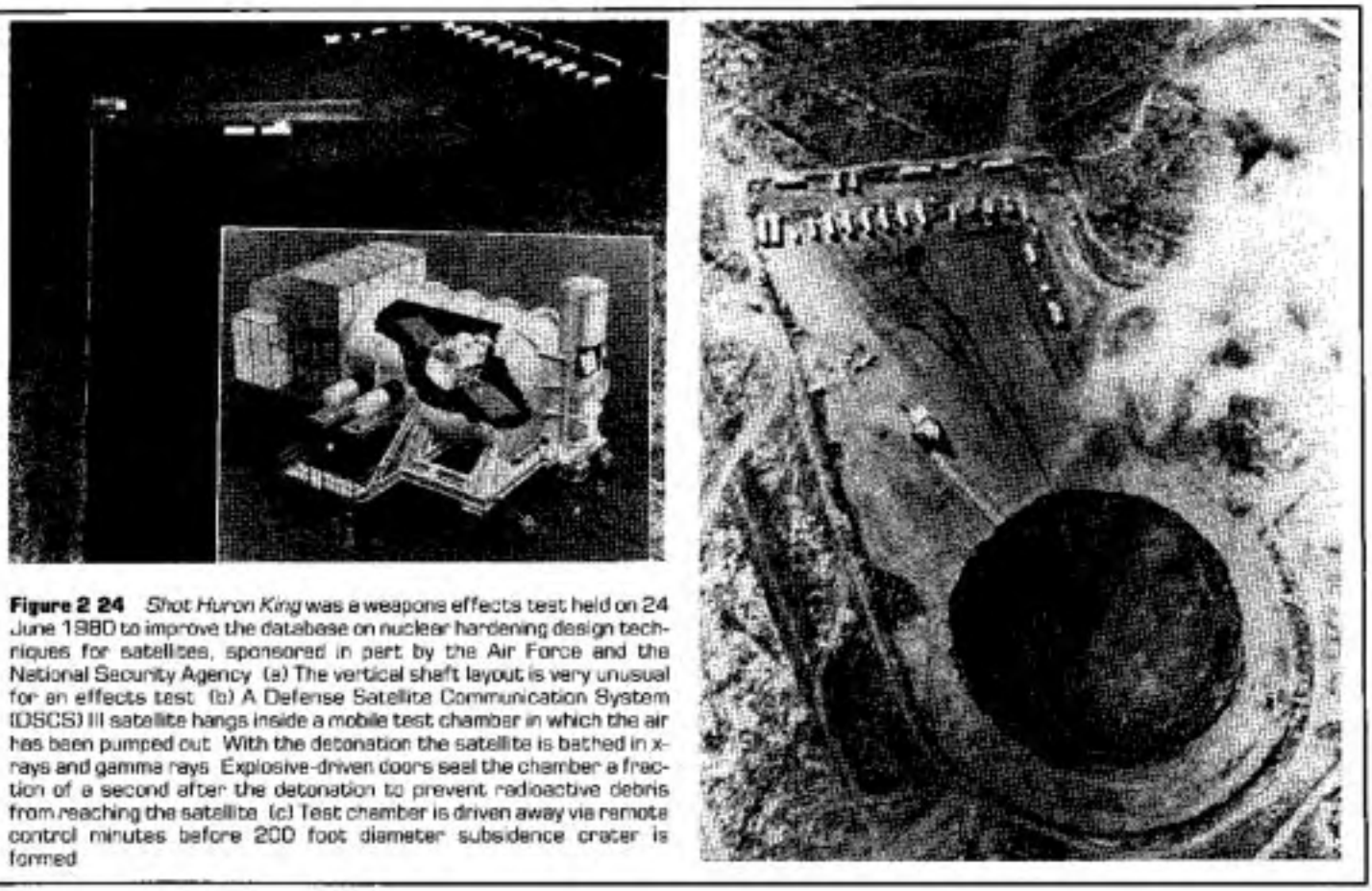


Figure 2-24 *Shot Huron King* was a weapons effects test held on 24 June 1980 to improve the database on nuclear hardening design techniques for satellites, sponsored in part by the Air Force and the National Security Agency. (a) The vertical shaft layout is very unusual for an effects test. (b) A Defense Satellite Communication System (DSCS) III satellite hangs inside a mobile test chamber in which the air has been pumped out. With the detonation the satellite is bathed in x-rays and gamma rays. Explosive-driven doors seal the chamber a fraction of a second after the detonation to prevent radioactive debris from reaching the satellite. (c) Test chamber is driven away via remote control minutes before 200 foot diameter subsidence crater is formed.

Military Test Ranges

Military centers and ranges provide development, test, and evaluation facilities for nuclear warhead delivery systems and components. The ranges have such specialized facilities such as rocket test stands, wind tunnels and simulators, sled test tracks, and electronic and other test facilities. The two national ranges have all the needed capabilities to form a single global tracking network for ballistic missiles, satellites, launch vehicles, and space probes.

The Air Force Eastern Test Range (ETR), with its launch site at Cape Canaveral, Florida, stretches through the Atlantic Ocean into the Indian Ocean. At Cape Canaveral and Eastern Range headquarters at Patrick Air Force Base, fifteen miles to the south, DOD and NASA personnel are engaged in launching and testing missiles, satellites, and manned space systems. Current systems undergoing test and evaluation at the ETR include POSEIDON and TRIDENT SLBMs, the PERSHING II, British SLBMs (including TRIDENT and CHEVALINE), SRAM, and Small ICBM.

The Western Space and Missile Center, Vandenberg Air Force Base, California operates and maintains the Western Test Range (WTR) with its launch sites at Vandenberg Air Force Base in southern California. Current test and evaluation launches include MINUTEMAN I, II, and III ICBMs, MX, SLBMs, air-launched cruise missiles, and bombers. The range extends through the Pacific Ocean into the Indian Ocean where it meets the Eastern Test Range. Range support is also given to the operational training launches of SAC ICBMs.

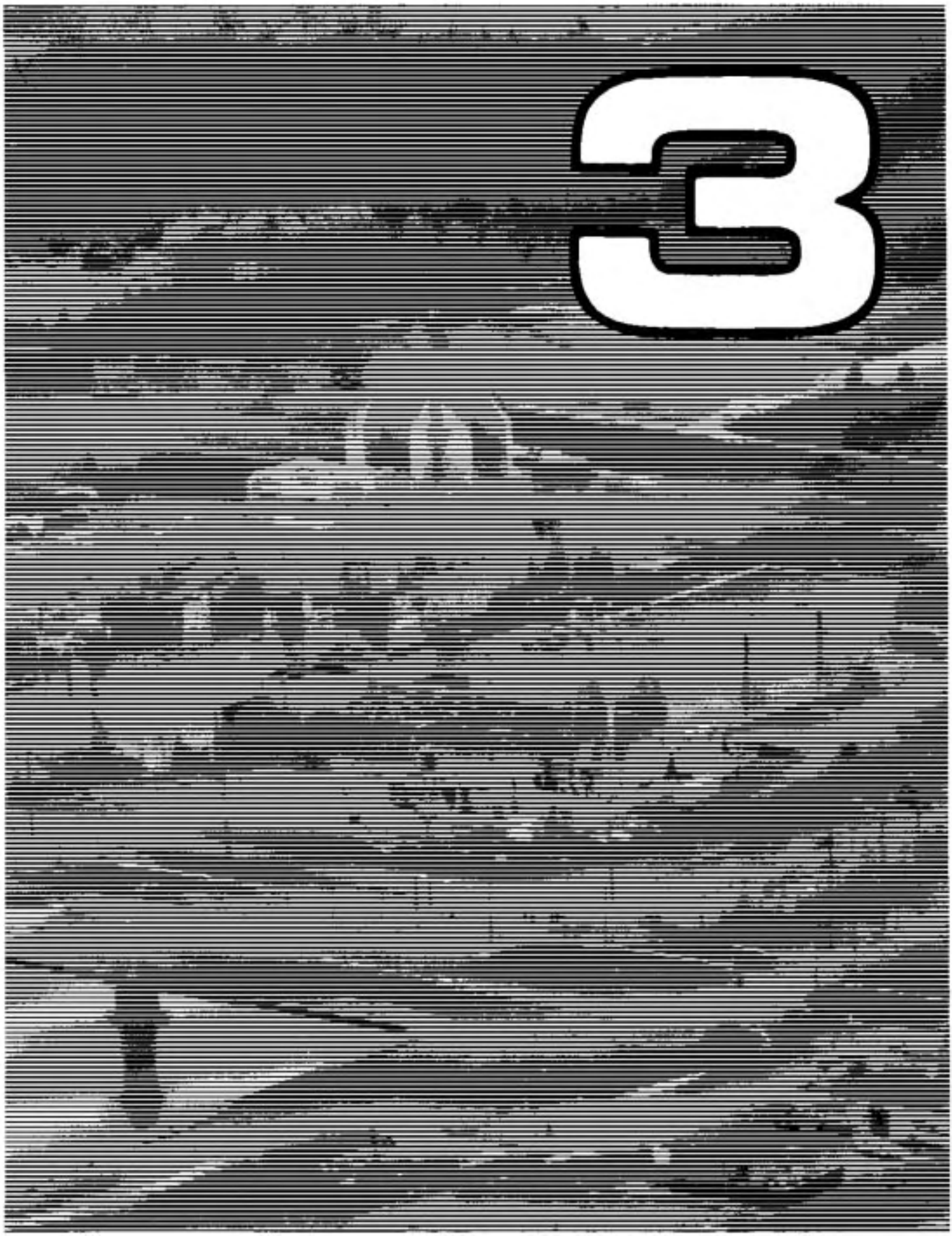
The terminal point of much of the testing of the WTR is the Kwajalein Missile Range (KMR), a national range operated by the Army. Located in the Marshall Islands 4,300 miles from the California coast, KMR supports ballistic missile defense research and development and strategic offensive weapon system developmental and operational testing. It is currently used as a target area for ICBM and SLBM tests, as well as the main DOD site for research on reentry phenomena and ballistic missile defense systems.

In addition to the two major national ranges for missile testing, a number of additional ranges test other aspects of nuclear delivery systems and unarmed warheads:

- Yuma Proving Ground, Yuma, Arizona: Army-operated desert testing range for nuclear artillery, short-range missiles (LANCE), and air-delivered weapons.

- Naval Weapons Center, China Lake, California: test and evaluation of air- and surface-launched weapons and missiles; also operates a nuclear bombing practice range and supports Navy SLBM testing
- Air Force Flight Test Center, Edwards Air Force Base, California: Air Force-operated development, test, and evaluation center for evaluating nuclear capable aircraft and bombers, drop testing of nuclear bombs, and parachute flight testing of nuclear missiles and reentry vehicles
- Pacific Missile Test Center, Point Mugu, California: Air Force-operated development, test, evaluation and follow-on engineering support for naval and Air Force nuclear weapons, including TRIDENT, MINUTEMAN, and MX ICBMs, SM-2 surface-to-air missile, cruise missiles (air-, ground-, and sea-launched), and bombers
- Aberdeen Proving Ground, Aberdeen, Maryland: Army-operated test and evaluation of nuclear artillery and the ground-launch cruise missile
- White Sands Missile Range, White Sands, New Mexico: Army-operated range that provides research and development testing of surface-to-air, surface-to-surface, air-to-surface missiles, reentry vehicles, and anti-ballistic missiles for DOD Currently supported systems include PERSHING 1a and II, SPRINT/LoADS anti-ballistic missiles, and SRAM Also located within the range is the Radar Target Backscatter Facility Division of the Armament Division of Holloman Air Force Base, New Mexico, which provides full- and subscale radar cross-section measurements of rockets, missiles, and reentry vehicles (warheads and decoys, aircraft, and bombs)
- Arnold Engineering Development Center, Manchester, Tennessee: Air Force-operated test facility specializing in simulation of aerodynamic, propulsion, and space flight environments The wind tunnels, heat test units, impact ranges, engine and rocket test cells, and space chambers support testing of the B-1, air-launched cruise missile, MX, MINUTEMAN, reentry vehicles, TRIDENT, and PERSHING
- Dugway Proving Ground, Dugway, Utah: Army-operated range used for mobility testing of the ground-launched cruise missile

Overseas, the Atlantic Undersea Test and Evaluation Center in the Bahamas also supports testing of Navy ASW and undersea research and development programs, including TRIDENT and nuclear attack submarine certification, and submarine sonar operations and silencing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Chapter Three
Nuclear Materials: Production, Inventories, Initiatives

Production of Nuclear Materials

Energy equivalent to thousands or even millions of tons of TNT is released in a nuclear weapon explosion by the fission and fusion of atomic nuclei [1] Six nuclear materials are used in nuclear weapons They are the fissionable materials, uranium-235, plutonium-239, and uranium-238, and the thermonuclear materials, tritium, deuterium, and lithium-6 [2] Except for U-238, which is abundant in nature, all of these materials must be produced or concentrated in special facilities This chapter discusses the production of these nuclear materials, provides estimates of inventories and production rates, and surveys the initiatives planned to increase materials production

The different materials require different production facilities Plutonium and tritium are manufactured in production reactors Uranium-235 is separated out of natural uranium (which is 99 3 percent U-238) in enrichment plants Deuterium, in the form of heavy water, is produced in heavy water production plants Lithium-6 is separated from compounds of naturally occurring lithium (which is 92 4 percent lithium-7) in special enrichment facilities All these materials except for tritium (because of its short half-life) can be stockpiled for extended periods

A production reactor depends on several facilities to support its operations Other plants are required to manufacture the fuel; to separate the plutonium, tritium, and uranium from the spent fuel; and to dispose of the waste products All these facilities, together with their transportation links, constitute the reactor "fuel cycle "

Often, the same facilities support production reactors as well as supplying materials for warheads The uranium enrichment complex, for example, is an integral part of the fuel cycle for some production reactors and also produces U-235 for weapons Similarly, heavy water, the source of deuterium for weapons, is also used as reactor moderator and coolant in heavy water production reactors Complicating these matters, the fuel used in some U S production reactors is obtained, in part, from uranium recovered from the spent fuel of naval, research, and test reactors

Of the four kinds of production facilities, only the production reactors add new materials (plutonium and tritium) to existing U S inventories at this time U S production of highly enriched uranium (HEU) for weapons was terminated in 1964 Highly enriched uranium, however, is currently produced in U S enrichment plants to fuel naval propulsion, research and test reactors, and commercial reactors The United States plans to resume HEU production for weapon use near the end of the decade U S heavy water and lithium enrichment facilities are not now operating Supplies of these materials come from weapons that have been retired and dismantled and from other existing stockpiles

In the United States, in fact, most nuclear materials for new weapons comes from retired weapons These materials must first be recovered, purified, and processed before re-use

Later in this chapter there is a discussion of several reasons for a number of initiatives that have led to the current plans to expand materials production [3]

Plutonium and Tritium Production

The U S Department of Energy (DOE) currently produces plutonium and tritium for the weapon program in five operating production reactors [4] Four of these—the P, K, L, and C-Reactors—are at the Savannah River Plant (SRP) in Aiken, South Carolina The fifth, the N-Reactor, is on the Hanford Reservation, near Richland, Washington The L-Reactor at Savannah River, placed on standby in 1968, was restarted on 31 October 1985, following a two year delay to correct environmental problems

Since 1944, the United States has operated a total of fourteen plutonium production reactors: the eight original graphite-moderated water-cooled reactors and the dual-purpose N-reactor at Hanford and five heavy water-moderated reactors at Savannah River The number of reactors producing plutonium or tritium for weapons grew from three during World War II to fourteen by 1964, then dropped to three by 1971

1 Thomas B Cochran William M Arkin and Milton M Hoenig Nuclear Weapons Databook Volume I, *U S Nuclear Forces and Capabilities* (Cambridge Massachusetts: Ballinger Publishing Company, 1984) Chapter Two Nuclear Weapons Primer for an explanation Hereafter cited as *Nuclear Weapons Databook Volume I*

2 Thorium 232 and uranium-233 are weapon usable fissionable materials but without significant application in weapons programs Plutonium isotopes Pu-240 241 and 242 are fissionable and present in small amounts with Pu-239 in weapon usable plutonium Lithium-6 may be diluted with the more abundant isotope lithium-7 at the cost of efficiency

3 Requirements for nuclear weapon materials are set forth in the annual Nuclear Weapons Stockpile Memorandum (NWSM) Production workloads for specific facilities are detailed in the annual DOE Materials Management Plan Chapter Four discusses in more detail these and other nuclear weapon planning documents

4 Other isotopes (namely Pu-238 Am-241, U-233, Cf-252) used for defense research medical and commercial applications have also been produced in these reactors

5 For a fuller discussion see John R Lamarsh, *Introduction to Nuclear Engineering* (Reading, Massachusetts: Addison-Wesley Publishing Company 1975) p 75

Measuring Production

The production of plutonium and tritium in reactors occurs by means of neutron capture in respective target materials, U-238 and lithium-6 Consequently, the production rates of plutonium and tritium depend on two factors: the rate at which neutrons are produced, by fissions of the fuel materials, and the probability of neutron capture in the targets Both depend on the design of the reactor Fissioning each atom of U-235 (or Pu-239) not only results in the release of two to three neutrons but is also accompanied by the release of about 200 MeV of energy, mainly in the form of kinetic energy of the fission products Most of this energy is ultimately converted into heat [5] Thus, for a given reactor type, the reactor power, the rate at which uranium fuel is consumed, and the rate at which plutonium (or tritium) is produced are all closely coupled

As a practical rule of thumb, in a reactor designed for the production of weapon-grade plutonium (or tritium), one gram of plutonium (or 1/72 gram of tritium) is produced for each gram of U-235 fissioned, which is accompanied by the release of one megawatt-day of thermal energy (1 Mwd) (see Chapter Five, Production Reactors) The actual design-dependent production rates are within about 20 percent of these values The maximum rates of plutonium and tritium production thus can be readily estimated from knowledge of the reactor type and its rated power, measured in megawatts thermal (Mw_t) The actual amounts produced depend on operating power levels and the period of time the reactor is on line [6]

A Brief History of Reactor Operations

Nuclear reactors for the production of plutonium date back to the Manhattan Project during World War II Enrico Fermi produced the first self-sustaining chain reaction in the Chicago Pile (CP-I) on 2 December 1942 This original reactor (or pile) was fueled with lumps of natural uranium oxide embedded in a lattice of graphite moderator

The design had no cooling and required dismantling to recover the plutonium It required modification to make it suitable for a production reactor The deficiencies were corrected in the 1 Mw Clinton Pile (later designated X-10) near Clinton, Tennessee (now Oak Ridge) On 4 November 1943, the Clinton Pile began operations as a pilot production plant for urgently needed plutonium The air-cooled Clinton Pile consisted of a block of graphite with horizontal channels through which aluminum clad cylinders of uranium could be pushed from front to back for discharge

In September 1943, before the Clinton Pile's completion, construction began at the Hanford Reservation on the B-Reactor, the first of three full-scale, graphite-moderated production reactors The B-Reactor began operation a year later in September 1944 It was graphite-moderated and water-cooled and was fueled with natural uranium—the first of eight such reactors built at Hanford between 1943 and 1952 [7] Two others (D, F) also began operation during World War II By the end of the war, serious deterioration of the B, D, and F-Reactors resulted from intensive operation They all required major overhaul and reconditioning at Hanford The B-Reactor was shut down in March 1946 to assure some production capability should the other two reactors fail Repairs to the reactor, started at the end of 1947, were scheduled during periods of normal shutdown so as to not interrupt plutonium production This work was finished by mid-1948, when the B-Reactor was also restarted Late in 1948 the production rates of the B, D, and F-Reactors surpassed any achieved in wartime [8]

The eight original Hanford reactors operated between 1944 and 1971 for a total of 139 reactor-years Table 3 1 shows their operating histories All eight reactors have now been retired and are being dismantled They are not considered to have any restart capability [9]

The first four reactors (B, D, DR, F) were originally powered at 250 Mw_t These and the next two reactors (H, C) were extensively modernized and uprated in the 1950s and early 1960s They eventually operated with power limits of 2090 to 2310 Mw_t [10] The last two of the original graphite reactors (KE, KW) began operating in 1955, each with a design power level of 1850 Mw_t Both were upgraded to 4400 Mw_t before being shut down in 1970 and 1971, respectively The eight reactors had an average lifetime power of 1120 Mw_t per reactor Additional characteristics of the Hanford graphite reactors are described in Volume III, Hanford Reservation

The 4000 Mw_t N-Reactor—the ninth production reactor to be constructed on the Hanford Reservation—has been in operation since 31 December 1963 In the late 1960s and 1970s, it continued to operate during a slump in demand for materials, because it was a source of electrical power [11] During this period it mainly produced fuel-grade plutonium for the research program It was not used to produce significant quantities of weapon-grade plutonium until 1982

The life of the N-Reactor will extend until about 1998, when irreversible damage to the blocks of graphite moderator will make operation increasingly difficult DOE has begun studies on extending N-Reactor's useful lifetime [12]

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6 The period of time on line depends on such factors as length of a production cycle the refueling interval and the downtime for maintenance U S production reactors are typically on line 50 percent (N-Reactor) to 80 percent (SRP reactors) of the time In commercial reactors performance is expressed as a capacity factor defined as the electrical output as a percentage of the plant design capability In recent years the average capacity factor of U S power plants has been about 65 percent

7 While water was chosen prior to 1943 helium gas had been thought to be the only acceptable coolant

8 AEC Report to Congress January 1949 p 25

9 HAC FY 1980 EWDA Part 7 p 2536; HASC FY 1980 DOE p 250

10 Early consideration had also been given to the use of fast reactors to breed plutonium The experimental breeder reactor (EBR I) went into operation in Idaho in 1951 demonstrating breeding in 1953 However the use of breeder technology for the U S weapon program was not pursued, the program favoring more certain thermal reactors

11 DOE, Report of the New Production Reactor Concept and Site Selection Advisory Panel Q-DO-82 07 15 November 1982 p 28

12 HAC FY 1983 EWDA Part 4 p 428

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Savannah River Production

Operation of production reactors, moderated and cooled by heavy water, at Savannah River commenced in December 1953 with the R-Reactor It was followed by the P, L, and K-Reactors in 1954 and the C-Reactor in 1955 (see Table 3 1) The R- and L-Reactors were placed on standby and shut down in June 1964 (R) and February 1968 (L), while the P, K, and C-Reactors have continued operation Through 1985, the Savannah River reactors compiled a total of 114 9 reactor-years of operation

Planning for construction of the Savannah River heavy water reactors began in earnest following President Truman's 31 January 1950 decision to authorize the development of thermonuclear weapons Truman approved the AEC construction program for the Savannah River Plant on 8 June 1950 Although the feasibility of thermonuclear weapons was still problematical at that time, the motivation was to ensure tritium production, still thought to be necessary in large quantities for use in high yield thermonuclear weapons [13]

Meanwhile, tritium had to be supplied for the thermonuclear research program without seriously curtailing the plutonium production at Hanford for the existing fission weapons program Personnel at Hanford successfully attacked the technical problems of making tritium Using 10 percent of the capacity of one of the production reactors, they provided Los Alamos with enough of the element for research [14]

The anticipated heavy demand for tritium subsided as weapon design moved to favor using lithium-6 deuteride in the fusion stage of thermonuclear weapons [15] But the flexibility of the heavy water reactors for the production of either tritium, plutonium, or uranium-233 had been one of their selling points The Savannah River project was initiated in an environment of increasing demand for all nuclear materials From the start its cost was said to be almost entirely justified by new plutonium production capacity alone, should thermonuclear weapons not prove feasible This view held sway especially since the existence of sizeable domestic deposits of uranium ore was still unproven, but also because of plutonium's utility in small diameter tactical nuclear weapons The Savannah River reactors were also justified as insurance against the failure of Hanford and as a replacement for the older Hanford reactors [16]

Savannah River Production

The production history for the Savannah River reactors from FY 1955 to FY 1983 is shown in Figure 3 1 The annual plutonium and tritium production, including projections to FY 1999, are given in Table 3 2 With three reactors on line, SRP was producing (FY 1985) about 1 0 MT of supergrade plutonium and 11 kg of tritium annually With the restart of the L-Reactor the rate of plutonium production increased to about 1 6 MT (see Table 3 2)

Selected documents and reports give additional information on the operation of the P, K, and C-Reactors since the early 1970s The highest power achieved in any reactor prior to 1977 was 2915 Mw_t,[17] but the typical nominal reactor power for plutonium production, up to the mid-1970s, was about 2150 Mw_t (2000 to 2200 Mw_t) and 2400 Mw_t for a reactor producing tritium [18] During FY 1977-79 the three reactors were at times operated at a power of about 1850 Mw_t each, and none of the reactors were dedicated to tritium production alone Production cycles for weapon-grade plutonium lasted an average of 60 days A minimum three-day shutdown followed, to allow fuel-changing machines to remove and replace irradiated target assemblies [19]

A contrast between operations in the middle and late 1970s is provided by the following report of activities The Savannah River reactors completed ten production cycles during a six-month period in FY 1976 [20] During FY 1977-79, at a reduced level of production, forty-two cycles were completed while one of the three reactors was shut down for a period of six months Eight cycles were finished during an eight-month period in 1980 [21] These activities are reflected in the 20 percent drop in the rate of production in FY 1977-80 compared to the rate in FY 1976 (See Table 3 2)

There was only one dedicated tritium campaign, for an eight-month period, in the decade prior to 1981 [22] A tritium production run in 1972 is reported[23] and another was scheduled for late 1981 [24] Subsequently, one of the production reactors (C-Reactor) has been dedicated solely to the production of tritium [25] To meet the tritium requirement projected in the 1984 Nuclear Weapons Stockpile Memorandum, an average of 1 2 reactors will have to be dedicated to tritium production through FY 2000 [26]

13 Lee Bowen The United States Air Force Historical Division *A History of the Air Force Atomic Energy Program 1943-1953, Volume IV, The Development of Weapons* [Washington D C : U S Air Force Historical Division History 1955 declassified with deletions June 1981] pp 31 33

14 Ibid

15 By 1953 there was a large-scale program for the production of lithium-6 at the Oak Ridge Reservation in preparation for the 1954 thermonuclear weapons tests The first two shots of the Castle series *Bravo* and *Romeo* confirmed the practicality of stockpiling lithium deuteride (dry) bombs and as a result of the Castle tests the requirements for tritium production was significantly reduced

16 Bowen *Development of Weapons* pp 33 36

17 J A Smith et al "Safety Analysis of Savannah River Production Reactor Operation E I duPont de Nemours & Co , Savannah River Laboratory DPASTA 180-1 Rev 12/76 Issued September 1975, revised December 1976 p VI-43

18 Ibid pp V-36 V 38 VI-43 Documented operating powers are for 18 19 August 1959 (observed), 2256 Mw_t (C-Reactor), 1494 Mw_t (K), and 2062 Mw_t (L); for 25-26 August 1959 (calculated), 2250 Mw_t (C) 2100 Mw_t (K) 2100 Mw_t (L) J S Neill and D F Babcock "The Dissipation of Reactor Heat at the Savannah River Plant " DP 1274 Savannah River Laboratory Aiken SC October 1971 p 62

19 Joseph Albright, Cox News Service, 14 May 1981; R Cochran Acting Director of Nuclear Production DOE Briefing Session before the Subcommittee on Nuclear Regulation of the Senate Committee on Environment and Public Works 6 December 1981 p 7 [see Savannah River Plant, Volume III] Smith indicates an exposure of 440 000 Mwd for Savannah River Mark 16 HEU driver assemblies over three plutonium production cycles; this averages to fifty-five days at 2130 Mw_t or sixty three days at 1850 Mw_t for each cycle; Smith Safety Analysis p V 31

20 Albright Cox News Service

21 Ibid

22 Ibid

23 Smith Safety Analysis p V-35 This is consistent with SRP atmospheric release data for tritium (see Table C 1 in Appendix C)

24 Albright Cox News Service

25 HAC FY 1985 EWDA Part 4 p 428

26 J S Alleader and I M Macafee *Economic Analysis of the Fuel Production Facility* DPST 84 420 Savannah River Laboratory Technical Division 6 April 1984 pp 5 24 See also HASC Rept 98 124 Part 1 13 May 1983 p 19

Table 3.1

A. Operating Histories of U.S. Production Reactors
Original Eight Hanford Graphite Reactors

Reactor	Construction Began	Operation Startup	Operation Shutdown	Years of Operation
B	09/1943	09/1944	03/19/1946[a]	
		07/02/1948[a]	02/12/1968	21.1
D	11/1943	12/1944	06/26/1967	22.5
F	12/1943	02/1945	06/25/1965	20.3
H	03/1948	10/1949	04/1965	15.5
DR	12/1947	10/1950	12/30/1964	14.2
C	06/1951	11/1952	04/25/1969	14.4
KW[b]	11/1952	01/1955	02/01/1970	15.1
KE[c]	01/1953	04/1955	01/28/1971	15.7
			TOTAL	138.6

B. Hanford Graphite Reactor Power Level Limits, Megawatts

	Original Design Level	Effective Date of Limits[d]						
		01/31/58	01/16/59	01/09/61	12/02/63	02/18/64	03/04/64	09/01/68
B	250	1440	1900	2090	1940	2090	e	f
D	250	1440	1900	2090	2005	2090	e	f
DR	250	1440	1900	2090	1925	2090	e	f
F	250	1440	1900	2090	1935	2090	e	f
H	400	1440	1900	2090	1955	2090	e	f
C	650	1740	2100	2310	2310	2310	e	e
KE	1950	3140	4000	4400	4400	4400	4400	g
KW	1950	3140	4000	4400	4400	4400	4400	g
TOTAL		15,220	19,600	21,560	20,870	21,560		

C. Hanford N-Reactor

Reactor	Construction Began	Operation Startup	Operation Shutdown	Years of Operation through 1985
N	1958	12/31/1963	operating	22.0

D. Savannah River Heavy Water Reactors

Reactor	Construction Began	Operation Startup	Operation Shutdown	Years of Operation through 1985
R	6/1951	12/1953	6/15/1964[h]	10.5
P	7/1951	2/1954	operating	30.9
L	10/1951	7/1954	2/18/1968[h]	13.6
		10/31/1985[i]	operating	0.2
K	10/1951	11/1954	operating	30.1
C	2/1952	3/1955	operating	29.7
			TOTAL	114.9

a. B was shut down on 19 March 1946 and restarted on 2 July 1948, letter John L. Mellinhardt, Director, Office of Nuclear Materials Production, 4 June 1985, to Thomas B. Cochran; see also Richard G. Hewlett and Francis Duncan, *Atomic Shield, A History of the United States Atomic Energy Commission*, Volume II, 1947/1952 (U.S. Atomic Energy Commission, 1972), pp. 174-75, 669.

b. K West.

c. K East.

d. Reactors limited to the maximum power level that had previously been achieved.

e. Effective 4 March 1964, the power level limits of 2090 and 2310 Mw were removed and a bulk outlet water temperature limit of 95.0 Celsius was established. Maximum power levels were in the 2000 to 2100 Mw range for B-Reactor, D-Reactor, DR-Reactor, F-Reactor, and H-Reactor, and 2300 Mw range for C-Reactor.

f. Reactors were shut down prior to 1 September 1968.

g. Effective 1 September 1968, top-of-riser pressure and process tube power limitations were imposed at both K-Reactors. Maximum power levels were in the 4000 to 4200 Mw range. An administrative maximum level of 4000 Mw was imposed late in 1968.

h. Placed on standby.

i. The L-Reactor scheduled restart in October 1983 was delayed until 31 October 1985 to correct environmental problems.

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Reactor Operating Histories

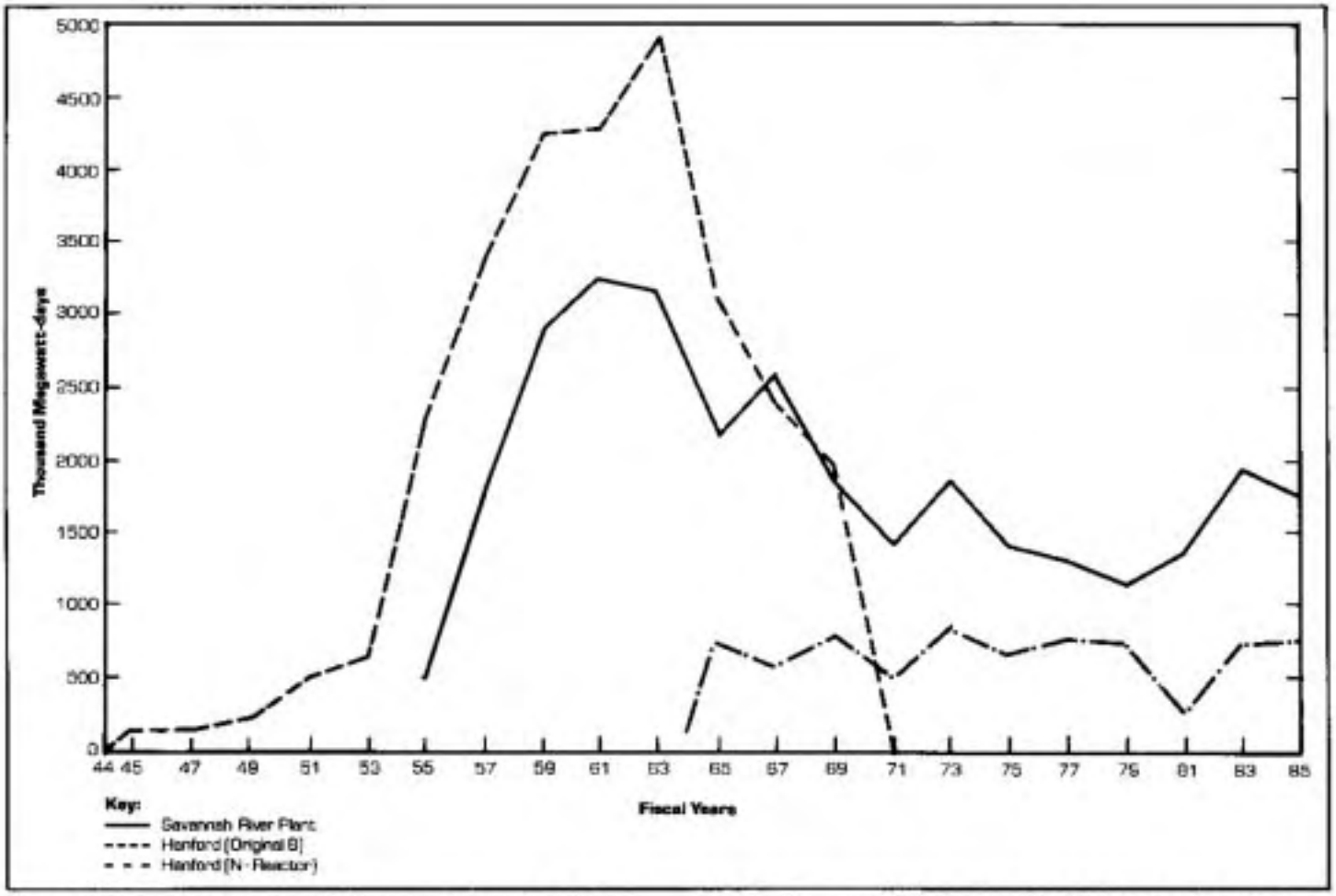


Figure 3 1 Operating histories of U S production reactors Annual thermal energy output (in thousands of megawatt-days) for the U S production reactors The outputs of the original eight graphite reactors, the N-reactor at Hanford, and the five heavy water reactors at the Savannah River Plant are shown separately

Even in the reactors dedicated to plutonium production, tritium is generated in enriched lithium control rods, used to absorb excess neutrons, and in lithium targets Annual production rates of plutonium vary because the first priority is to satisfy the tritium requirement, which varies from year to year The remaining SRP capacity is devoted to plutonium [27] The highly enriched uranium driver assemblies used for plutonium production (Mark 16B) have the option to contain a separately dischargeable lithium-aluminum target inside the inner fuel tube [28] In addition, the reactor cores are now blanketed with a ring of lithium targets to shield the stainless steel reactor tank walls from neutron irradiation [29]

The combined production of tritium from secondary sources is estimated at 0 002 g/Mwd, of which one half is assumed to be generated in control rods [30] This was clearly the chief mode of tritium production from the mid-1970s through 1981 During this period the three operating SRP reactors would have produced between 2 4 and 2 9 kg of tritium annually, enough to maintain a steady state tritium inventory of some 46 kg against radioactive decay (see Appendix C)

The three operating Savannah River reactors (P, K, C) were scheduled to run at full capacity in FY 1981 and FY 1982 [31] The goal was fully achieved in FY 1982 when the "innage" (or percentage of clock time of reactor operation) rose to 80 percent as reported by DOE By then the restoration and upgrade program was improving the efficiency of operation Reactor operating power for plutonium production was back up to a nominal 2150 Mw_t The innage since January 1981 was reported, in August 1982, to be more than 80 percent [32] During the first quar-

27 *Ibid*

28 Smith *Safety Analysis*, p V 6

29 D A Ward, et al , Extended Service Life of Savannah River Plant Reactors DPST 80-539 Savannah River Laboratory Aiken S C October 1980 p 8; E D Dukes and R W Benjamin Savannah River Plant Airborne Emissions and Controls, DPST-82-1054 Savannah River Laboratory Aiken S C 1982 p 4-4

30 The estimate for control rods is based on published data for the reactivity worth of the control rods during exposure See Savannah River Production Reactors Chapter Four

31 HASC FY 1982 DOE p 128

32 Memorandum of Herman E Roser to the Secretary of Energy Major Accomplishments at the Savannah River Plant Since January 1981 DP-3 2 28 July 1982

Table 3 2

Estimated Nuclear Materials Production in Savannah River Reactors

FY	Number Reactors Operating[a]	Annual Thermal Output[b] (1000 Mwd)	Cumulative Thermal Output (1000 Mwd)	Annual Plutonium Equivalent[c] (kg)	Cumulative Plutonium Equivalent[c] (kg)	Annual Plutonium[c] (kg)	Annual Tritium[d] (kg)	Unit Costs[e] ($ per Mwd)
1955	5	500	500	485	0 5			
1956	5	1225	1725	1190	1 7			
1957	5	1825	3550	1770	3 4			
1958	5	2100	5650	2040	5 5			
1959	5	2900	8550	2815	8 3			
1960	5	3125	11,675	3030	11 3			
1961	5	3225	14,900	3130	14 5			
1962	5	3175	18,075	3080	17 5			
1963	5	3150	21,225	3055	20 6			
1964	5.4[f]	3225	24,450	3130	23 7			
1965	4	2125	26,575	2060	25 8			
1966	4	2200	28,775	2135	27 9			
1967	4	2600	31,375	2520	30 4			
1968	4.3[g]	2475	33,850	2575	33 0			
1969	3	1750	35,600	1820	34 8			
1970	3	1500	37,100	1560	36 4			
1971	3	1425	38,525	1480	37 9			
1972	2 2(W)&0 8(T)	1750	40,275	1820	39 7	1150	10 7	
1973	3(W)	1865	42,160	1960	41 6	1695	3 8	
1974	3(W)	1910	44,070	1985	43 6	1720	3 8	
1975	3(W)	1410	45,480	1465	45 1	1270	2 8	
1976[h]	3(W)	2025	47,505	2105	47 2	1820	4 0	
1977	3(W)	1310	48,815	1360	48 6	1180	2 6	
1978	3(W)	1210	50,025	1260	49 6	1090	2 4	86
1979	3(W)	1190	51,215	1240	51 1	1070	2 4	85
1980	3(W)	1450	52,665	1510	52 6	1305	2 9	74
1981	3(W,S)	1380	54,045	1435	54 0	1240	2 8	80
1982	2(W,S)&1(T)	1850	55,895	1925	55 9	1075	11 3	67
1983	2(S)&1(T)	1850	57,745	1925	57 9	1070	10 7	
1984	2(S)&1(T)	1900	59,645	1975	59 8	1100	10 7	
1985	2(S)&1(T)	1750	61,395	1820	61 7	1010	10 7	
1986	3 3(S)&0 7(T)	2310	63,705	2400	64 1	1680	9 7	
1987	3 1(S)&0 9(T)	2330	66,035	2425	66 5	1590	11 0	
1988	3(S)&1(T)	2330	68,365	2425	68 9	1545	11 6	
1989	3(S)&1(T)	2340	70,705	2435	71 3	1505	12 2	
1990	2 7(S)&1 3(T)	2360	73,065	2455	73 8	1370	14 2	
1991	2 1(S)&1 9(T)	2410	75,475	2505	76 3	1060	18 7	
1992	2 3(S)&1 7(T)	2390	77,865	2485	78 8	1150	17 4	
1993	2 6(S)&1 4(T)	2370	80,235	2465	81 3	1325	14 8	
1994	2 5(S)&1 5(T)	2370	82,605	2465	83 7	1280	15 5	
1995	2 7(S)&1 7(T)	2390	84,995	2485	86 2	1150	17 4	
1996	2 6(S)&1 4(T)	2370	87,365	2465	88 7	1325	14 8	
1997	3 2(S)&0 8(T)	2320	89,685	2415	91 1	1635	10 3	
1998	3 3(S)&0 7(T)	2310	91,995	2400	93 5	1680	9 7	
1999	3 2(S)&0 8(T)	2320	94,315	2415	95 9	1635	10 3	

a W = weapon-grade plutonium; S = supergrade plutonium; T = tritium. For FY 1986-89 the number of reactors dedicated to tritium production is given in J. S. Allender and I. M. Macafee, *Economic Analysis of the Fuel Production Facility*, DPST-84-420, pp. 5-24 and based upon the projected tritium requirements given in the 1984 Nuclear Weapons Stockpile Memorandum.

b Values for FY 1955-71 from graph in HASC, FY 1985 DOE, p. 333. Values for FY 1972-82 from graph in HASC, FY 1984 DOE, p. 272. Values for FY 1983-84 from graph in HASC, FY 1986 DOE, p. 240. Data for FY 1985-99 are authors' estimates.

c Based on 0.97 gram (1955-57) and 1.04 gram (1958-) plutonium equivalent per megawatt-day of thermal energy output.

d Assumes 1 gram of tritium output is equivalent to 72 grams weapon-grade plutonium; HASC, FY 1982 DOE, p. 172. Includes 0.002 g of tritium per Mwd produced in plutonium producing reactors in control rods, blankets, and targets.

e Constant FY 1982 dollars; from graph in HASC, FY 1984 DOE, p. 272.

f R-Reactor shutdown in June 1964.

g L-Reactor shutdown in February 1968.

h A 15 month fiscal year.

i L-Reactor restarted 31 October 1985.

Table 3.3

Estimated Plutonium Production in the Eight Original Hanford Graphite Reactors

Calendar Year	Number Reactors Operating	Annual Th Output[a] (1000 Mwd)	Average Reactor Power (Mw_t)	Annual Pu Prod.[b] (kg)	Cumulative Pu Prod. (MT)
1944	0.3	21	175	18	0.02
1945	1.9	120	175	103	0.12
1946	2.1	141	175	121	0.24
1947	2.0	128	175	110	0.35
1948	2.5	160	175	138	0.49
1949	3.2	213	181	183	0.67
1950	4.2	307	200	264	1.94
1951	5.0	500	273	430	1.37
1952	5.1	1000	534	860	2.23
1953	6.0	1250	570	1075	3.30
1954	6.0	1500	684	1290	4.59
1955	7.5	2250	812	1935	6.53
1956	8.0	2500	856	2150	8.69
1957	9.0	3400	1164	2924	11.60
1958	9.0	2900	993	2494	14.09
1959	9.0	4250	1455	3655	17.75
1960	8.0	4750	1626	4085	21.73
1961	8.0	4300	1472	3698	25.53
1962	8.0	4500	1541	3870	29.40
1963	8.0	4900	1678	4214	33.62
1964	8.0	4016	1371	3454	37.07
1965	5.7	3140	1496	2700	39.77
1966	5.0	3550	1945	3053	42.82
1967	4.4	2400	1474	2064	44.89
1968	3.1	2200	1928	1892	46.78
1969	2.2	1950	2331	1677	48.46
1970	1.1	750	1826	645	49.10
1971	0.04	0	0	0	49.10
TOTALS	138.8	57,170		49,167	

a. Values for years 1951-1971 are from DOE. See Letter from John L. Meinhardt, Director, Office of Nuclear Materials Production, DOE to Thomas B. Cochran which includes N Reactor production. Values for 1944-1950 are based on the assumption that the reactors operated at 70 percent capacity.

b. Assumes 0.86 grams plutonium produced per megawatt-day of thermal energy output. See ACDA, Criticality Studies of Graphite Moderated Production Reactors, Contract No. ACSN/0707, January 1980. No correction has been made here for the small quantities of non-defense plutonium: U-233, Pu-238, Co-60 and C-14 known to have been produced. These corrections are made as Table 3.13.

ter of FY 1982 the reactors operated at an 85 percent innage.[33] Reports indicated that "Savannah River reactors have operated 38% more efficiently than planned during the first 9 months of FY 1982,"[34] and "FY [19]82 materials production is the highest since 1974, and is 143 percent of the program milestone."[35] Furthermore, reactor power levels "exceeded records" with the K reactor operating at higher power than ever before.[36] The result was that the "plutonium and tritium production goals have exceeded the forecasts,"[37] and "at levels substantially exceeding our fiscal year 1982 plan."[38] In FY 1983, the innage was 75 percent with operation again at higher power levels.[39]

This expanding production environment has continued for FY 1984 and FY 1985, although meanwhile the plutonium output was converted (by FY 1983) entirely to supergrade (high-purity) production, for blending.[40] Making supergrade plutonium requires halving target

33. HASC FY 1983 DOE, p. 415.
34. Memorandum of Herman E. Roser, op. cit.
35. DOE, Major Accomplishments at the Savannah River Plant Since January 1981, August 1982. The milestone was probably 60 to 65 percent.
36. HASC FY 1984 DOE, p. 273.
37. Ibid.
38. Ibid, p. 151.
39. HASC FY 1985 DOE, p. 332.
40. We have been exceeding our production goals. In FY 1983 C, K, and P-Reactors obtained more than 1.65 million Mwd of production while operating at an on-line availability (innage) of 75 percent. C-Reactor has already (since March 1984) achieved its highest power level since March 1969 and has set monthly production records this year. December and January ... and we have set a new calendar year production record [1983] for three-reactor operations; HASC FY 1985 DOE, pp. 331-33. "Our production reactors are operating at the highest capacity ever."; HASC FY 1986 DOE, p. 27.

Table 3 4

Production History of the Hanford N-Reactor

Calendar/ Fiscal Year	Annual Production[a] (1000 Mwtd)	Thermal Capacity Factor[b]	Cumulative Production (1000 Mwd)	Annual Pu Prod.[c] (kg)	Plutonium Mode[d]	Cumulative Pu Prod (MT)[e]	Cumulative Weapon-Grade Pu Production (6% Pu-240)	Annual Electricity Production[f] (million Kwh)	Cumulative Electricity Production (million Kwh)
Cal 1964	234	0 16	234	201 24	W(6)	0 201	0 20	0	0
1965	660	0 45	894	567 60	W(6)	0 768	0 76	0	0
1966	750	0 51	1644	592 50	F(9)	1 361	0 76	1012	1012
1967	600	0 41	2244	474 00	F(9)	1 835	0 76	2056	3067
1968	850	0 58	3094	671 50	F(9)	2 506	0 76	3963	7030
1969	800	0 55	3894	632 00	F(9)	3 138	0 76	3924	10,954
1970	550	0 38	4444	434 50	F(9)	3 573	0 76	2702	13,656
1971	500	0 34	4944	395 00	F(9)	3 968	0 76	2622	16,278
1972	700	0 48	5644	553 00	F(9)	4 521	0 76	3016	19,294
1973	845	0 58	6489	667 55	F(9)	5 188	0 76	4580	23,874
1974	799	0 55	7288	575 28	F(12)	5 764	0 76	4033	27,907
1975	679	0 47	7967	468 88	F(12)	6 253	0 76	3425	31,332
1-9 1976	294	0 27	8261	211 59	F(12)	6 464	0 76	1436	32,768
FY 1977	792	0 54	9053	570 24	F(12)	7 034	0 76	4262	37,030
1978	768	0 53	9821	552 96	F(12)	7 587	0 76	4175	41,205
1979	751	0 51	10,572	540 72	F(12)	8 128	0 76	4062	45,267
1980	575	0 39	11,147	414 00	F(12)	8 542	0 76	3182	48,399
1981	257	0 18	11,404	185 04	F(12)	8 72	0 76	1411	49,810
1982	581	0 40	11,985	443 73	F(12)W(6)	9 17	0 86	3134	52,944
1983	727	0 50	12,712	625 22	W(6)	9 79	1 49	3849	56,793
1984	682	0 47	13,394	586 52	W(6)	10 38	2 08	3659	60,452
1985	783	0 54	14,178	674 05	W(6)	11 05	2 75	4044	64,497

a Values for 1964-72 from John L Meinhardt, Director of Nuclear Material Production DOE 10 January 1985 private communication Values for 1973-84 are based on the assumption that the electric capacity factor is the same as the thermal capacity factor

b Based on design rating of 4000 Mw$_t$

c Assumes 0 66 g Pu (6 percent Pu-240)/Mw$_t$d 0 79 g Pu (9 percent Pu-240)/Mw$_t$d and 0 72 g Pu (12 percent Pu-240)/Mw$_t$d

d Indicates the mode of reactor operation which depends on the refueling interval W = weapon-grade F = fuel-grade Number in parenthesis indicates the nominal percentage of Pu-240

e Actual values may differ because during fuel-grade mode of operation plutonium ranging in Pu-240 content from 5 percent to 19 percent is produced In FY 1984-85 following the restart of PUREX 6 percent Pu-240 fuel was outed from N-Reactor spent fuel in storage and processed

f Figures taken from back issues of *Nucleonics Week*

exposure time, thus doubling the rate at which targets pass in and out of the reactors This doubles the annual target (Mark 31) fabrication effort at Savannah River and similarly increases activities at the Fernald and Ashtabula feed plants

Hanford Production

The production history of the original eight Hanford graphite-moderated reactors from 1944 to 1971 is shown in Figure 3 1 The amount of plutonium produced by the reactors is estimated in Table 3 3

Only one reactor at Hanford, the N-Reactor, now produces plutonium for weapons It is supported by fuel cycle facilities that include the PUREX chemical separation plant and fuel fabrication facilities

The dual purpose, graphite-moderated and water-cooled N-Reactor also produces steam for commercial electricity generation (see Hanford Reservation, Volume III)

Table 3 4 documents the production history of the N-Reactor The most significant weapons production initiatives implemented at Hanford in recent years have been the conversion of the N-Reactor from the production of fuel-grade plutonium (12 percent Pu-240) to weapon-grade (6 percent Pu-240) and the restart of the PUREX processing plant The N-Reactor underwent repairs and upgrading to state-of-the-art technology in 1981 and 1982 The conversion to weapon-grade production began in February 1982 and was completed by October, approximately five months ahead of schedule [41] No tritium is produced in the N-Reactor nor is production contemplated [42]

41 HAC FY 1984 ERDA Part 4, p 389

42 The N Reactor operated in a plutonium/tritium coproduction mode of operation in 1966 and 1967; DOE, PEIS, L Reactor Operation EIS 0108 Savannah River Plant May 1984 Vol 1 p 2 4 Because the N Reactor is fueled with slightly enriched uranium tritium production is limited to a coproduction mode of operation Consequently the maximum tritium output of the N-Reactor per Mwd of operation is significantly less than the output of a Savannah River reactor dedicated to tritium production

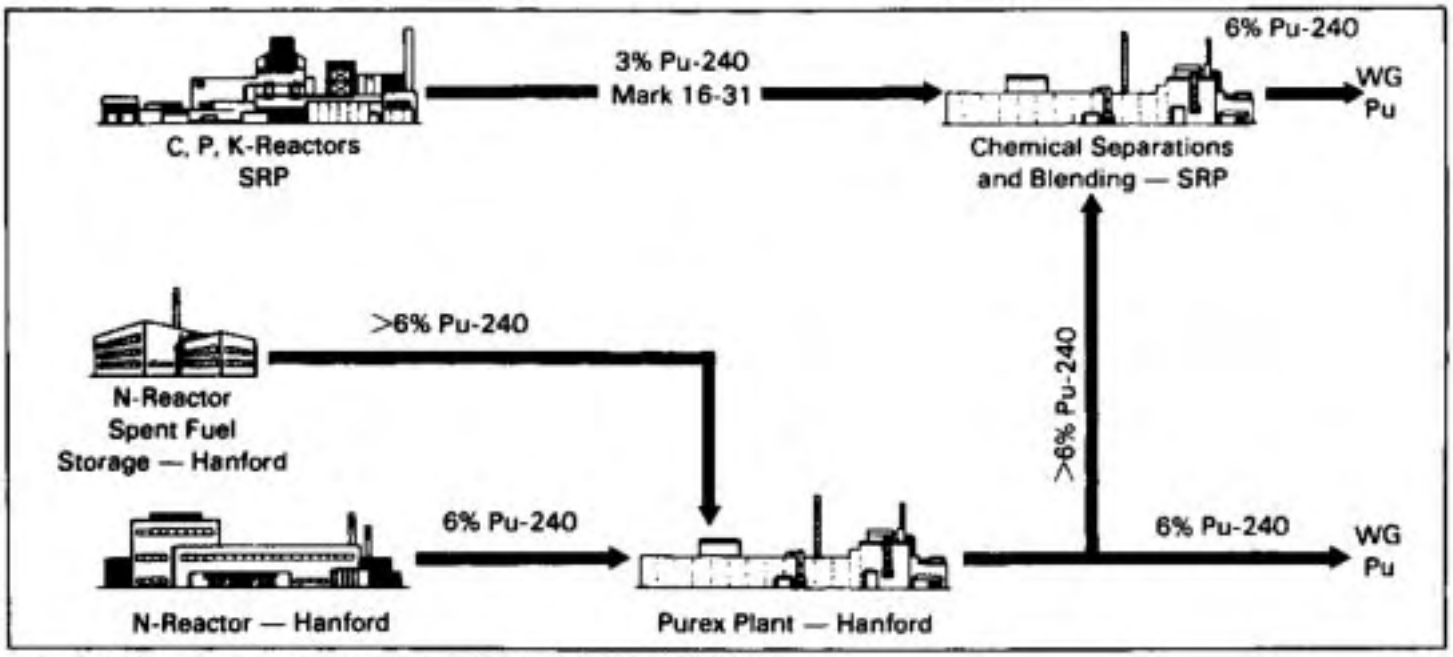


Figure 3 2 Current methods for producing weapon-grade plutonium (1984)

The N-Reactor has generally operated at a power of 3800 to 4000 Mw_t, producing both plutonium and by-product steam for electricity [43] The N-Reactor produces about 600 kg of weapon-grade plutonium annually, for operation at an expected 50 percent capacity factor In the 6 percent Pu-240 production mode, reactor operation requires the shutdown and discharge of approximately one fourth of the core of slightly enriched fuel (average 1 0 percent U-235) eight times a year [44] Some two-and-one-half times the fuel throughput is required for weapon-grade (6 percent Pu-240) versus fuel-grade (12 percent Pu-240) plutonium production at the same capacity factor

From the beginning of operations in December 1963, until 1973, the N-Reactor produced 9 percent Pu-240 fuel-grade plutonium part of the time The rest of the time it produced weapon-grade (6 percent Pu-240) plutonium [45] From 1973 to 1982, the reactor produced plutonium with a Pu-240 content of approximately 12-percent [46] By December 1980 the N-Reactor had produced in all about 7 8 MT of fuel-grade plutonium, intended for research and development in the breeder program and other civilian activities [47] Of this amount, about 3 6 MT had been processed at the Hanford PUREX plant before it shut down in 1972 The remaining 4 2 MT of unprocessed spent fuel was placed in storage awaiting restart of the PUREX plant [48] By the end of FY 1984 the N-Reactor had produced in all about 8 3 MT of fuel-grade plutonium

In FY 1981, DOE instituted its plan for blending fuel-grade plutonium at Savannah River with supergrade plutonium to increase the supply of weapon-grade material The unseparated fuel-grade plutonium, in stored N-Reactor spent fuel, is designated for blending [49] When PUREX was restarted, discharged N-Reactor fuel with the lowest Pu-240 content was processed first This maximized the amount of weapon-grade plutonium available for military activities, directly or through blending [50] In FY 1984 1046 MT of low burnup fuel was processed, producing approximately 1 0 MT of weapon-grade (6 percent Pu-240) plutonium FY 1985 plans called for processing an additional 1200 MT of low burnup fuel for recovery of 1 2 MT of weapon-grade plutonium (6 percent Pu-240) Little, if any, of the newly recovered fuel-grade plutonium is scheduled to go into R&D "All of the plutonium, both fuel-grade and weapon-grade, is required to meet defense program requirements "[51]

The electrical power output of the N-Reactor is 860 Mw_e Through FY 1984 the N-Reactor has delivered about 60 billion kilowatt hours of electricity to the Pacific Northwest since 1966 The income to the Federal government from electricity sales was about $37 million

43 The N Reactor first reached its full design power of 4000 Mw_t in December 1965; AEC, Report to Congress January 1966 p 76 Power was about 3850 Mw_t in FY 1982; HASC, FY 1983 DOE, p 243 At conversion the power is 4000 Mw_t In 1966 and 1967 while coproducing plutonium and tritium it operated as high as 4600 Mw_t for one day (18 June 1967); DOE FEIS L-Reactor, Vol 1 p 2-4

44 DOE FEIS L-Reactor Vol 1 p 1-4

45 Ibid

46 Ibid

47 F C Gilbert DOE, in letter to Thomas B Cochran 24 March 1981

48 Ibid

49 [A] significant portion of the plutonium in the N Reactor spent fuel is reserved for defense programs it is designated for blending Ibid

50 HAC FY 1984 EWDA, Part 4 p 305; DOE, FEIS L-Reactor p 1-4 As of the end of FY 1983 about 3600 MT of N-Reactor spent fuel were in storage at the Hanford Reservation The average Pu-240 assay of this material was around 11 percent; letter from John L Mann hardt Director Office of Nuclear Materials Production Department of Energy to Thomas B Cochran 30 August 1985

51 HAC FY 1984 EWDA Part 4 p 305

52 DOE Memorandum, Defense Programs Accomplishments Since January 1981 DP-3 2, 28 July 1982

Table 3 5

Weapon-Grade Plutonium from Reactor Production and Blending

FY	Hanford Weapon-Grade Separated[a] (kg)	Savannah River Weapon-Grade Separated[a] (kg)	Savannah River Supergrade Separated[a] (kg)	Fuel-Grade Required[c] (kg)		Weapon-Grade by Blending (kg)	Total Weapon-Grade (kg)
				Annual	Cumulative		
1982		700[d]	360[d]	180	180	540	1240
1983		240[d]	700[d]	350	530	1050	1290
1984	910[b]	0	1085	540	1070	1590	2500
1985	1050[b]	0	1055	530	1600	1585	2635
1986	650[c]	0	1345	670	2270	2015	2665
1987	650[c]	0	1635	820	3090	2455	3105
1988	650[c]	0	1570	785	3875	2355	3005
1989	650[c]	0	1525	760	4635	2285	2935
1990	650[c]	0	1435	720	5355	2155	2805

a Allows for 6-month cooling period of discharged fuel before processing
b PUREX separated only 6 percent Pu-240 plutonium in FY 1984 (from 1046 MT uranium) and in FY 1985 (from 1200 MT uranium) culling out all of the 6 percent Pu-240 plutonium in storage and processing fuel from current production
c Assumes N-Reactor operation at 4000 MW, and 52 percent capacity factor
d Assumes 20 percent of the plutonium production in FY 1981 and 50 percent of the production in FY 1982 is supergrade
e This assumes blending with 12 percent (average) Pu-240 plutonium and gives an upper bound to fuel-grade requirements (Blending with 9 percent Pu-240 plutonium for example requires 50 percent less fuel-grade plutonium

in 1982-83 and was expected to rise by 69 percent, to more than $60 million in 1983-84, as a result of the ten-year extension to 1993 of the contractual agreement between DOE and the Washington Public Power Supply System (WPPSS) signed in June of 1982 [52]

Figure 3 2 shows the pathways leading to the production of weapon-grade plutonium An estimate of the net annual production of weapon-grade plutonium projected into the late 1980s is provided in Table 3 5 This table combines weapon-grade production at the N-Reactor and supergrade production plus blending at Savannah River

The Fuel Cycles

Figure 3 3 depicts the fuel cycles for the production of plutonium and tritium at Savannah River and Hanford and the operation of the naval nuclear reactors Shown are the basic steps in a fuel cycle: uranium ore mining and milling, uranium enrichment, uranium conversion, fuel and target fabrication, reactor operation, chemical processing, and waste storage The fuel cycle for the Naval Nuclear Propulsion Program is included because the uranium recovered from processing of naval reactor fuel is recycled into the Savannah River production reactors

The Savannah River Fuel Cycle. As noted previously, the Savannah River reactors are currently producing tritium in the C-Reactor and supergrade (3 percent plutonium-240) plutonium in the P, K, and L reactors Before the transition to supergrade production began in 1981, the plutonium output was entirely weapon-grade (6 percent Pu-240) [53]

The flow of materials through the Savannah River fuel cycle depends in part on whether the reactors are producing plutonium or tritium For supergrade plutonium production, the Savannah River reactors have operated primarily with a mixed-lattice core—that is, a core with a 50-50 mixture of HEU driver fuel assemblies (about 60 percent enriched in uranium-235) and separate depleted uranium target assemblies in which plutonium is bred [54]

The HEU for the Savannah River fuel assemblies (Mark 16B and Mark 22) comes from four sources In order of priority, based on the cost of recovery from spent fuel or oralloy production, these are: HEU recovered at SRP and ICPP from research reactor fuel (about 80 percent enriched), HEU recovered at ICPP from naval reactor fuel (about 78 percent enriched), HEU recovered from production reactor fuel recycled at SRP (currently about 40 percent enriched), and oralloy or its equivalent at 90 percent enrichment [55]

52 For a discussion of physical processes for the production of plutonium and tritium see Chapter Five The plutonium grades are based on the content of the isotope plutonium-240 Grade Percentage of Pu-240: Supergrade 2 to 3; Weapon-grade less than 7; Fuel grade 7 to less than 19; Reactor-grade 19 or greater

54 In time the reactors may change to a uniform core (one type of assembly serving as both fuel and target) of natural or slightly enriched assemblies giving as much as 25 percent increased plutonium productivity

55 HASC, FY 1983 DOE p 269; HAC, FY 1984 EWDA Part 6 p 520; Memorandum from J S Alleader and J M Macelee to R L Cook and P L Roggenkamp Savannah River Laboratory DPST-84-420, 6 April 1984 p 5

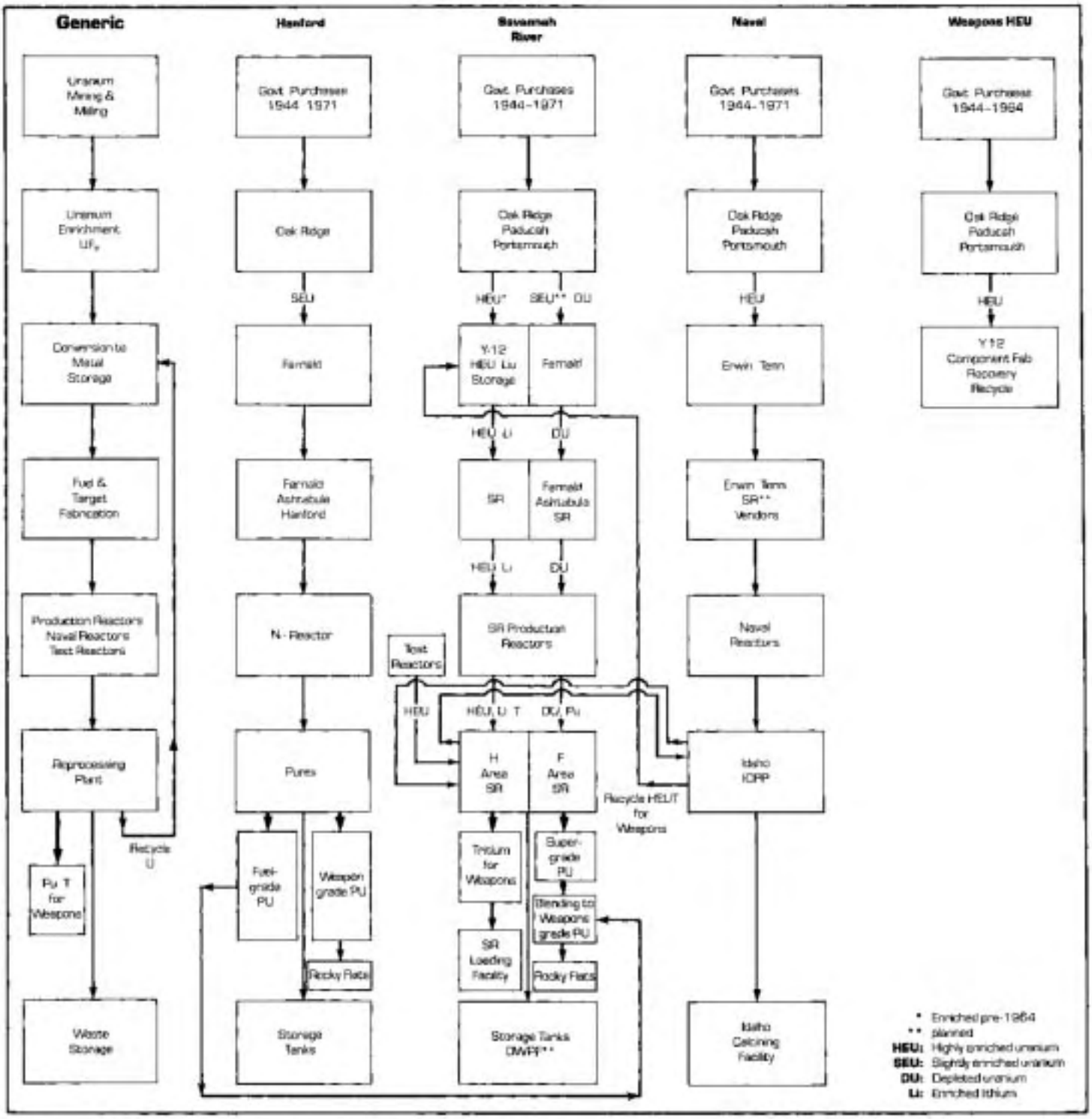


Figure 3-3 Nuclear weapons production and naval propulsion fuel cycles

The U-235 consumed in the fuel of the SRP reactors must be made up by shipments from other sources to augment SRP recycle For the operation of four production reactors, the "make up" is about 3 MT of U-235 per year This results from a thermal energy production of about 2350 thousand Mwd annually, and a total core loading of some 6 to 7 MT of U-235 Currently about 1 MT comes from research reactor fuel and naval reactor returns, and another 2 MT comes from the diminishing stockpile of virgin oralloy at the Oak Ridge Y-12 Plant Beginning

Table 3 6

HEU Requirements for SRP Reactor Operation[a]

(kilograms)

Fiscal Year	SRP: Recycle + Research Reactor[b]	ICPP	Oralloy	Total
1988	9691	947	820	11,458
1989	10,046	947	1462	12,455
1990	10,970	947	2047	13,964
1991	10,957	947	1672	13,576
1992	11,194	947	1774	13,915
1993	12,435	1874	1089	15,398
1994	12,659	1874	640	15,523
1995	12,812	1874	990	15,676
1996	13,903	1874	942	16,719
1997	14,223	1874	284	16,381
1998	15,027	1874	683	17,584
1999	15,649	2859	412	18,920
2000[c]	15,649	2859	412	18,920

a For Mark 16-31/Mark 22 fuel assemblies: J S Allender and I M Macafee, Economic Analysis of the Fuel Production Facility, DPST-84-420, Savannah River Laboratory Technical Division, 5 April 1984, p 30

b Not including uranium recovered from reject fuel tubes

c Assumed equal to FY 1999 throughput

about 1988, SRP will draw oralloy from UF_6 newly enriched at the Portsmouth gaseous diffusion plant [56] The quantities of HEU needed annually at SRP for the fabrication of fuel to support reactor operations during FY 1988-2000 are shown in Table 3 6

The driver fuel assemblies are made of uranium-aluminum alloy at the Savannah River fuel fabrication facility Uranium metal is shipped there from the Oak Ridge Y-12 Plant At Savannah River it is alloyed with aluminum and extruded into aluminum-clad fuel tubes for Mark 16 assemblies After discharge from the production reactors, the spent driver fuel elements are processed in the H-canyon, one of Savannah River's two chemical reprocessing plants, to recover HEU for recycle [57] The HEU is shipped as uranyl nitrate by tanker trucks from the H-canyon separation plant to the Oak Ridge Y-12 plant for further processing and conversion to metal As noted above, the metal is recycled to SRP to be made into new driver fuel elements This happens after the recycle stream has been supplemented with virgin oralloy drawn from Y-12 stocks and HEU recovered from spent naval reactor fuel processed at the Idaho Chemical Reprocessing Plant (ICPP) at the Idaho National Engineering Laboratory (INEL); and research and test reactor fuel processed at INEL and at Savannah River DOE is constructing a facility for producing HEU driver fuel from a mixture of highly enriched uranium oxide (U_3O_8) and aluminum using techniques of powder metallurgy [58]

The depleted uranium targets used at Savannah River (Mark 31 assemblies) are fabricated from metal slugs prepared at the Feed Materials Production Center (FMPC) in Fernald, Ohio and the Ashtabula (Ohio) Extrusion Plant They are bonded into tubular metal cans at Savannah River for reactor loading Irradiated targets are processed in the F-canyon, the second Savannah River chemical processing plant, for recovery of plutonium going into weapons, as well as recovery of depleted uranium, which is stored as oxide (UO_3) on-site

Tritium is produced at Savannah River by irradiating lithium-6 targets The enriched lithium is recovered at Y-12 from components of retired warheads and is alloyed with aluminum at Savannah River Reactors are loaded with a uniform core of Mark 22 assemblies composed of alternating concentric tubes of enriched lithium-aluminum alloy and HEU aluminum alloy (75 to 90% U-235) Tritium is extracted from irradiated lithium-aluminum targets in H-area separation facilities and transferred to the Savannah River Tritium facility There it is loaded into reservoirs for subsequent insertion into weapons (see Fuel and Target Fabrication Facilities, Tritium Facility, under Savannah River Plant, Volume III)

An important byproduct of plutonium production

56 HASC FY 1983 DOE, p 289

57 Recovered uranyl nitrate liquid is shipped to the Y-12 plant for conversion to oxide DOE is planning to close the Y-12 facility and centralize conversion operations in a new facility at Savannah River HAC FY 1985 EWDA Part 4, pp 486-492

58 HASC FY 1985 DOE, pp 337-337

activities is the production and recovery of neptunium-237 After several recycles the concentration of U-236 in the fuel builds up Under further irradiation the U-236 is converted to Np-237, which is recovered and fabricated into targets for Pu-238 production activities Pu-238 is used as a heat source for the generation of electricity in reactors used in space and for other purposes In 1968 the SR reactors changed from natural uranium fuel for plutonium production to highly enriched drivers This increased production of U-236 and Np-237 and accelerated the Pu-238 program [59]

Inventories of radioactive wastes at the SRP through 1983 include 111 thousand cubic meters (776 million curies) of high-level waste (HLW) stored in fifty-one large steel tanks,[60] 3 4 thousand cubic meters of stored transuranic waste (TRU) (98 5 kg of transuranics; 581 thousand curies), 4520 cubic meters of buried TRU (9 4 kg of transuranics; 54 thousand curies), and 414 4 thousand cubic meters of buried low-level waste (LLW) (9 57 million curies as buried) [61]

The Hanford Fuel Cycle. Fuel for plutonium production operations at the N-Reactor is fabricated from slightly enriched uranium, concentrated to an average of about 1 percent in in U-235 The principal assemblies, called Mark 1-A, are composed of an outer cylinder enriched to 1 25 percent and an inner cylinder enriched to 0 95 percent The enriched material is now supplied directly from the gaseous diffusion plants, although in the years prior to FY 1984 it came from existing stocks at Fernald [62] DOE Defense Programs are now rebuilding their stockpile of slighly enriched uranium hexafluoride This stockpile became severely depleted in FY 1984 [63]

Uranium metal ingots for N-Reactor fuel are prepared at the Feed Materials Production Center (FMPC), extruded into billets at the Ashtabula Plant The billets are simultaneously extruded and clad with zirconium at the Hanford fuel fabrication facilities The final product is finished fuel cylinders

In the weapon-grade (6 percent Pu-240) production mode, the N-Reactor requires about 750 to 800 MT of uranium annually, compared to 315 MT when producing fuel grade (12 percent Pu-240) plutonium The plutonium and unused uranium is recovered from N-Reactor fuel at the PUREX separation plant Technically, PUREX (Plutonium-*U*Ranium-*EX*traction) can process up to 2300 MT of N-Reactor spent fuel However, following restart in November 1983, it processed only 1046 MT of spent fuel in the first year, and 1057 MT in FY 1985

The amount of fuel processed annually is expected to remain in this range due to limitations imposed by bimonthly inventories of the product (PuO_2) stream of the plant [64]

The PUREX plant is also capable of recovering plutonium and uranium from other low burnup, slightly enriched fuel After the PUREX chemical processing plant was placed on standby in 1972, batches of irradiated fuel were stored on-site at Hanford in water-filled concrete basins

The recovered fuel-grade plutonium oxide will be shipped to Savannah River for blending, while the weapon-grade plutonium oxide is sent to the plutonium facility at LANL for conversion to metal

Chemical processing wastes from PUREX, as well as from previous processing operations (Bismuth Phosphate and REDOX, see Hanford Reservation, Volume III) are stored on-site The totals through 1983 include 203 thousand cubic meters of HLW (474 million curies) stored in 169 large steel tanks,[65] 12 8 thousand cubic meters of stored TRU (340 kg of transuranics; 28 4 thousand curies of alpha activity), 92 1 thousand cubic meters of buried TRU (350 kg of transuranics; 29 2 thousand curies of alpha activity), and 317 1 thousand cubic meters of LLW (5 04 million curies as buried) [66]

Naval Reactor and Research Reactor Fuel Cycles. The Naval Nuclear Propulsion Program (NNPP) is a joint program of the Department of Energy and the Department of the Navy It oversees all aspects of naval nuclear reactors including research, procurement, disposal, and supplying reactor fuel The naval fuel cycle interacts with the cycle that produces material for weapons Highly enriched uranium recovered from spent fuel of naval reactors is recycled to supply a part of fuel used in the Savannah River production reactors

In the more than thirty years of the NNPP 161 nuclear-powered ships have served in the active fleet [67] These ships were propelled by a total of 182 reactors The current fleet (as of March 1986), numbering 149, uses 169 reactors [68] The program also operates nine reactors at eight land prototype nuclear propulsion plants These land prototypes are used to test reactor designs and train crews

Since the *Nautilus* first went to sea more than thirty years ago, U S naval nuclear-powered ships have steamed over 65 million miles and have accumulated 2900 reactor years of operation [69] Currently the nuclear fleet travels approximately 2 5 million miles a year

59 AEC Report to Congress, January 1959 p 39

60 Savannah River has 29 million gallons of HLW including 3 million gallons of sludge 9 million gallons of saltcake and 17 million gallons of liquid; HASC FY 1985 DOE p 536

61 DOE Spent Fuel and Radioactive Waste Inventories Projections and Characteristics DOE/NE-0017/3, September 1984 pp 66 118-19 154

62 HAC FY 1984 EWDA Part 6 p 530

63 HAC FY 1985 EWDA Part 4 p 435

64 These measures were put into effect at the beginning of FY 1985 to improve material accounting safeguards

65 There are 149 single shell and 20 double shell tanks Eight additional double shell tanks are under construction (1984)

66 DOE Spent Fuel and Radioactive Waste Inventories Projections and Characteristics DOE/NE 0017/3 September 1984 pp 66 118-19 154; HAC FY 1985 EWDA Part 6 p 874

67 Commissioned to 30 September 1985 Includes NR-1 Deep submergence research vehicle

68 See NRDC Nuclear Weapons Databook Working Paper "Naval Reactors May 1986

69 HAC FY 1987 EWDA Part 6 p 1072; DOE/DOD *A Review of the United States Naval Nuclear Propulsion Program* June 1984 p 1 For a history see Richard G Hewlett and Francis Duncan *Nuclear Navy 1946-1962* (Chicago The University of Chicago Press, 1974) and Norman Polmar and Thomas B Allen *Rickover* (New York Simon and Schuster 1982)

Approximately 600 fresh reactor cores have been procured through FY 1984 In 1974 there were 409 and by 1979, 508 cores procured Refuelings have become less frequent as longer-lived cores have been developed There were fifty-eight refuelings between 5 May 1969 and 25 February 1974, forty-two between 25 February 1974 and 24 April 1979, and five a year between 1979 and 1982 [70] The total number to December 1985 was 203

The first core for the *Nautilus* propelled the submarine for more than two years and 62,562 miles Modern cores last 10 to 15 years and over 400,000 miles Refuelings are done at Portsmouth Naval Shipyard at Kittery, Maine; Mare Island Naval Shipyard at Vallejo, California; and Newport News Shipbuilding and Dry Dock Company at Newport News, Virginia

In recent times, naval reactors have required approximately 5 MT of HEU each year [71] Twelve percent of this goes to research [72] Assuming approximately twenty new fuel cores procured per year, modern cores average about 200 kg of HEU each HEU (97 3 percent U-235) is enriched at the Portsmouth plant from slightly enriched feed supplied from the Paducah plant The HEU is shipped from Portsmouth as UF_6 to Nuclear Fuel Services (NFS) at Erwin, Tennessee There it is converted to the chemical and physical form used in naval fuel elements Since 1978 NFS has been the sole contractor performing this work [73] A second facility, this one government-owned, is being built at the Savannah River Plant Known as the Fuel Materials Facility, it is scheduled to start to make fuel in 1986 and be on line in FY 1988 [74] The amount of HEU procured for the naval program will double—to about 9 6 MT in FY 1986—to meet the needs of NFS (Erwin) and the new facility and establish a three-month working inventory for the program

After conversion at NFS the reactor fuel is sent to either Babcock and Wilcox in Lynchburg, Virginia or UNC Naval Products in Uncasville, Connecticut for fabrication into reactor cores Typically, it takes five to seven years between the delivery of NFS fuel to these two fabricators, and the delivery of the cores to the Navy

Naval reactors are built by either Westinghouse or General Electric Westinghouse supplied virtually all the reactors until the 1970s, producing 123 to date (to 30 September 1985) General Electric produces reactors for LOS ANGELES class and OHIO class submarines, and its current total is 57

Two government-owned contractor-operated laboratories conduct research on improved nuclear propulsion plants The DOE's Bettis Atomic Power Laboratory, Pittsburgh, Pennsylvania is operated by Westinghouse Electric Corporation, while the General Electric Company operates the Knolls Atomic Power Laboratory, Schenectady, New York

Spent fuel cores removed from naval reactors are sent to the Idaho Chemical Processing Plant (ICPP) for HEU recovery Over its lifetime, ICPP has recovered on average 0 28 MT of U-235 per year from naval reactor spent fuel This amounts to about 47 kg of U-235 per reactor core, at an estimated enrichment of 78 percent U-235 [75] DOE, however, has "firm commitments" for substantially increased quantities of spent fuel from the Navy in the early 1990s [76] A recently-started restoration project at the Idaho Chemical Processing Plant will increase the chemical processing capacity for HEU recovery from spent naval reactor fuel

The spent fuel returns from the Navy are scheduled to double 1984 rates by 1992 and nearly double again by the year 2000 (see Table 3 6) [77] Uranium recovered at INEL is shipped to the Oak Ridge Y-12 plant to be stored or converted into metal "for reuse as fuels in the Savannah River production reactors and for use in the weapons program "[78] Alternatively, in the future naval reactor spent fuel may be disposed of directly without processing to recover uranium for reuse [79]

The DOE processes spent fuel from U S and foreign research and test reactors at Idaho and Savannah River Currently the DOE accepts only HEU fuel, with an after-irradiation U-235 content of about 70 percent [80] Through February 1985 an estimated 19 MT of U-235 has been recovered from civilian, domestic, and foreign reactor HEU fuel (see Table 3 7) Overall, an estimated 0 5 to 0 6 MT of HEU is recovered from research and test reactors annually [81]

The recovered uranium is shipped to Y-12 and, like the naval fuel, is recycled into driver fuel for the Savannah River production reactors

Prior to 1982 most spent fuel returned to the United States from foreign countries was sent to Savannah River

70 See NRDC Naval Reactors

71 Each year the Director of the NNPP prepares a twelve-year forecast of HEU requirements; HAC FY 1983 EWDA Part 6 p 174 The charge to government agencies for enrichment services is $80 per SWU (FY 1982) $93 per SWU (FY 1984) and $96 per SWU (FY 1985); Gene Schmitt DOE private communication Thus the HEU (97 3 percent U-235) purchases for naval reactors were 4 64 MT (FY 1983) 5 10 MT (FY 1984) and 4 63 MT (FY 1985) using 261 SWU/kg of HEU (97 3 percent U 235)

72 In the matter of Nuclear Fuel Service Inc Erwin Tennessee NRC Docket No 70-143 SNM License No 124 1 March 1983

73 Prior to 1978 the following companies also provided fuel for the NNPP Nuclear Materials and Equipment Corporation (NUMEC) Apollo Pennsylvania 1961-1971; United Nuclear Corporation Hematite Missouri 1961-1972; Babcock and Wilcox Apollo Pennsylvania 1973-1978

74 HAC FY 1987 EWDA Part 6 p 1074; In the Matter of Nuclear Fuel Services, Inc Erwin, Tennessee NRC Docket No 70 143 SNM License No 124 1 March 1983 The Enriched Uranium Conversion Facility undergoing renovation at the Oak Ridge Y-12 plant will probably be used to supply the SRP Fuel Materials Facility with uranium metal for naval fuel; HAC FY 1986 EWDA Part 7 p 740

75 J S Allender and J M Matalee Economic Analysis of the Fuel Production Facility Savannah River Laboratory Technical Division DPST-84 420, 6 April 1984, p 5 There were 25 76 MT of U-235 recovered at INEL between FY 1953 and FY 1984 Of this approximately 13 75 MT were recovered (through February 1985) from civilian HEU fuel (Volume II Table 6) There were 180 naval reactor refuelings to 1982 and an average of five refuelings a year between 1970 and 1982

76 HASC FY 1986 DOE p 149

77 ibid pp 149 165

78 HAC FY 1984 EWDA Part 4 p 301

79 J S Allender and J M Matalee p 5

80 Plans are in preparation to accept low enriched research reactor fuel (less than 20 percent U-235) at Savannah River

81 In FY 1980 SRP recovered 0 6 MT HEU from research and test reactor fuels (nonproduction DOE fuels and fuels from industry); HASC FY 1980 DOE p 782

Table 3 7

Uranium-235 Recovered through February 1985 from HEU Fuel of Civilian, Domestic, and Foreign Reactors

Reprocessing Facility	Amount U-235 Recovered (kg)
SRP	
Domestic	3200[a]
Foreign	circa 1250[b]
Subtotal	4450
INEL	
Research, Test, and Power Reactors	
Fuel Originally Enriched more than 90% U-235	7530[c, d]
EBR 2 Fuel (60% U-235)	3400[e]
Project Rover Space Propulsion	2820[d]
Subtotal	13,750
West Valley, NY	800[e]
TOTAL	19,000

a This information is derived from Tables D 2, D 3, D 5, and D 6 in Appendix D that detail the amount of U-235 required by domestic reactors. The amount of U-235 recovered is computed by assuming that about 30 percent of the U-235 was consumed in the reactors.

b Estimated from Table 3 10.

c Letter from John E. Meinhardt, Director, Office of Nuclear Materials Production, Department of Energy to David Albright, 6 May 1985. It includes a small amount of foreign HEU.

d Using the information in Tables D 2, D 3, D 5, and D 6 in Appendix D and assuming a burnup of 30 percent, an estimated 6900 to 7650 kg of U-235 was recovered at INEL from domestic research and power reactors whose fuel was originally enriched over 90 percent U-235.

e Meinhardt, *op. cit.*, and corrections to the amount listed in the letter as recovered from EBR 2 spent fuel, INEL, personal communication, 21 May 1985.

Source: Table compiled by David Albright.

Table 3 8

Receipts of Spent Fuel from Research Reactors

Savannah River

	Domestic[a, b]		Foreign[b]	
Year	HEU (kg)	U-235 (kg)	HEU (kg)	U-235 (kg)
1976	?	?	71	46
1977	?	?	43	32
1978	176	?	379	283
1979	136	110	185	150
1980	108	70	224	160
1981	165	130	201	160
1982	159	120	200	150
1983	111	?	25	20
1984	146	?	67	?

Idaho Chemical Processing Plant

	Foreign[c]		Total[d]	
Year	HEU (kg)	U-235 (kg)	HEU (kg)	U-235 (kg)
1973			913 8	598 8
1974			623 3	357 5
1975			1237 7	1031 1
1976	?	?	3024 9	2570 1
1976T	?	?	184 8	125 4
1977	?	?	535 4	414 9
1978	2 5	0 6	288 9	200 4
1979	0	0	317 1	201 0
1980	0	0	479 3	325 7
1981	0	0	254 5	177 6
1982	82	57	766 3	541 2
1983	95	72	141 8	91 3
1984	?	?	345 4	246 5

a For 1976-79, C E. Behrens, Questions Concerning Spent Nuclear Fuel Entering the U S. from Abroad, Congressional Research Service, 27 November 1979. For 1979-81, letter with attachments to T. Harris, Public Research Foundation, Columbia, SC, from R C. Webb, Deputy Director, Office of External Affairs, DOE, Savannah River Operations Office, 22 July 1983. For 1982 and 1983, *DOE News* Fact Sheet on Foreign/Domestic Research Spent Fuel Shipments, Savannah River Operations Office, June 1983 and February 1984.

b Domestic fuel is also received at Idaho.

c DOE, Nuclear Materials Management and Safeguards System.

d Values in these two columns are given for Fiscal Years.

for processing. Beginning in 1982 increased amounts of returned spent fuel were also routed to Idaho because of the reprocessing plant's unique capability to recover krypton, then in short supply. (Radioactive krypton is used commercially as a leak detector.) This arrangement will probably continue until 1986 when the Idaho plant will have been modified to collect krypton from the processing of naval fuel. Spent fuel from domestic research reactors is processed regularly at both Idaho and Savannah River. Table 3 8 shows receipts of foreign and domestic spent fuel at the reprocessing plants in recent years.

In the United States there are twenty-two DOE-owned research and test reactors in addition to fifty-nine research and test reactors licensed by the Nuclear Regulatory Commission (operated mainly by universities), all with DOE-owned fuel. Approximately ninety-three foreign research and test reactors operate with uranium of U.S. origin. Annually, about 1 MT of HEU (90 percent enriched) is either used domestically (about 600 kg) or exported (about 300 to 500 kg).[82]

Exported HEU comes from three sources: the Y-12 inventory, the Portsmouth gaseous plant, and the United Nuclear Corporation Recovery System. In the years

82 Memorandum from James R. Shea, NRC, to NRC Commissioners, 1 December 1981. In the years 1978-82 an average of 438 kg of HEU enriched to an average of 46.7 percent was exported annually for research purposes; see Table 3 9.

Table 3 9

U.S. HEU Exports and Returns by Country[a]

Year	Exports (kg)[b]		Returns (kg)[c]			
			Spent Fuel[d]		Total[e]	
	HEU	U-235	HEU	U-235	HEU	U-235
Argentina	94 11	59 15			0 06	0 02
Austria	9 75	7 32			7 05	4 57
Australia	10 19	9 16	3 4	2 3	0 06	0 05
Belgium	186 55	159 17	86 6	63 2	494 30	385 70
Brazil	7 70	7 15				
Canada	1861 49	1723 64	408 2	268 9	509 02	355 12
Colombia	3 11	2 82				
Denmark	26 21	23 55	37 9	25 9	37 86	26 70
Finland	3 86	0 77				
France	6268 41	4655 46	408 2	324 8	2411 05	1738 65
Greece	8 61	6 15				
IAEA	0 31	0 25				
India	0 10	0 08				
Indonesia	0 02	0 01				
Iran	5 55	5 16				
Israel	18 73	17 09				
Italy	382 07	306 80	12 0	9 6	45 76	36 63
Japan	2015 52	964 61	69 8	61 8	167 51	146 41
Mexico	29 63	12 32	0 6	0 4	0 57	0 40
Netherlands	63 22	56 52	105 5	80 4	149 77	115 77
Pakistan	5 76	5 18				
Philippines	3 29	3 07				
Portugal	7 66	7 14				
Romania	39 25	36 56				
South Africa	32 70	30 21	19 0	14 3	33 50	25 75
South Korea	29 61	18 47				
Switzerland	8 79	7 96			6 46	4 36
Spain	9 41	8 30				
Sweden	148 07	133 34	204 1	153 8	225 48	170 42
Taiwan	9 91	9 21				
Thailand	5 30	4 77				
Turkey	5 32	4 78				
U K	2301 02	2141 35	0 4	0 3	107 95	82 97
Venezuela	0 01	0 01				
Vietnam	0 39	0 08				
W Germany	9993 85	6612 51	131 5	93 5	890 05	325 23
Yugoslavia	17 05	5 91			0 22	0 05
Zaire	1 35	0 28				

a Does not include HEU exported for military purposes

b For 1 January 1954 through 28 February 1983 Excludes countries receiving a cumulative shipment of 0 005 kg U-235 or less DOE Nuclear Materials Management and Safeguards System NMMSS Report TJ-25 28 March 1983

c U S origin HEU returned In some cases returns from a country exceed exports (q v) because data to not reflect retransfers between foreign countries for fabrication or reprocessing of fuel

d Data for 1954-81 U S GAO, Obstacles to U S Ability to Control and Track Weapons-Grade Uranium Supplied Abroad GAO/ID-82-21 2 August 1982, p 15

e DOE Nuclear Materials Management and Safeguards System NMMSS Report U S Origin Imports 26 November 1984 enclosure in letter to Thomas B Cochran from Robert A O'Brien Jr DOE 13 December 1984

1980-1983 about 40 percent was uranium metal taken from the DOE inventory at Y-12 Most of the remainder was enriched on order at Portsmouth and shipped overseas as UF_6 A small amount (about 2 percent) was material recovered by United Nuclear [83]

From 1954 through 1983 the United States shipped abroad approximately 17 MT of U-235 as HEU for research purposes (It is estimated that 11 MT of the U-235 was HEU-enriched to 90 percent or better) As shown in Tables 3 9 and 3 10, about 1 5 MT was returned as spent fuel, and about 3 6 MT of U-235 was returned

83 DOE Nuclear Materials Management and Safeguards System

Table 3 10

U.S. HEU Exports and Returns by Year

Year	Exports (kg)[a]		Returns (kg)[b]			
			Spent Fuel[c]		Total[d]	
	HEU	U-235	HEU	U-235	HEU	U-235
1954-1956	0	0	0	0	0	0
1957	26 43	24 59	0	0	0	0
1958	13 75	12 33	1 67	1 32	1 67	1 32
1959	17 74	16 18	0	0	0	0
1960	52 87	47 53	2 76	2 24	4 32	3 22
1961	264 94	212 32	2 29	1 81	3 94	2 17
1962	328 55	296 04	1 93	1 47	2 32	1 74
1963	360 88	296 20	16 18	13 49	22 08	18 92
1964	806 30	675 18	46 70	37 96	63 10	52 92
1965	2518 55	1346 92	18 86	15 59	35 50	29 51
1966	1505 22	927 71	46 23	29 42	109 77	74 81
1967	2682 06	1260 61	115 15	83 69	226 91	168 68
1968	905 27	806 72	6 02	5 09	89 89	73 52
1969	1961 78	1450 28	4 02	3 34	14 01	12 60
1970	1274 52	962 09	37 12	26 48	63 49	43 64
1971	2220 02	1358 91	49 46	38 61	441 80	340 22
1972	885 07	795 73	42 79	31 82	738 22	216 13
1973	887 75	823 03	9 07	7 90	434 87	316 85
1974	1550 67	1221 62	10 50	7 65	344 81	255 52
1975	686 14	618 72	14 59	10 94	174 37	135 57
1976	601 10	556 85	87 38	44 14	384 50	296 70
1977	1961 80	1367 99	82 32	61 80	149 00	103 56
1978	404 46	346 81	372 91	276 37	874 28	593 06
1979	361 33	336 43	168 00	128 17	217 53	167 35
1980	491 48	424 24	273 23	198 39	210 84	151 40
1981	535 03	485 51	212 30	164 70	251 42	195 74
1982	397 05	349 04	268 70[e]	207 00[f]	?	?
1983	125 00[g]	116 00[h]	120 00[h]	92 00[h]	?	?
TOTAL	23705 76	17135 58	2010 18	1493 39	ca 5300	ca 3600

a Data except for 1983 from DOE Nuclear Materials Management and Safeguards System NMMSS Report TJ-25 28 March 1983
b Returns of U S origin HEU
c DOE Nuclear Materials Management and Safeguards System 28 March 1983
d DOE Nuclear Materials Management and Safeguards System, NMMSS Report U S Origin Imports 28 November 1984, enclosure in letter to Thomas B Cochran from Robert A O Brien Jr DOE 13 December 1984
e GAO Report to Richard L Ottinger Return of Spent Nuclear Fuel from Foreign Research Reactors to the United States GAO/RCED-85-47 13 December 1984
f Estimated
g DOE Nuclear Materials Management and Safeguards System, 28 November 1984
h DOE News Fact Sheet on Foreign/Domestic Research Fuel Shipments Savannah River Operations Office June 1983 and February 1984

overall Additional uranium was sent back to the United States following separation from DOE-owned fuel at reprocessing plants in Belgium and France, during the 1970s, and in Japan Recently, annual returns from abroad (average 240 kg contained U-235 per year for 1978-82) have paralleled supply (assuming a fuel burnup of about 50 percent and a process loss of about 20 percent) [84]

Plutonium and Tritium Inventories

In the public domain government data is not available on the inventories of weapon-grade plutonium, tritium, highly enriched uranium, or lithium-6 The Department of Energy's inventory of fuel-grade plutonium is unclassified, and there is data on heavy water production Nonetheless reliable estimates of the inventories of nuclear weapon materials can be made (see Table 3 11) [85]

These inventories include the materials actually in the weapons themselves as well as material allocated to the weapons program In the case of plutonium and tritium it is believed that only a small fraction is currently available as a reserve

84 Letter from Ralph E Caudle DOE to Milton M Hoenig 23 December 1982

85 An early estimate of the U S inventory of nuclear materials is given by Marvin I Kalkstein and Winthrop Smith, An Estimate of the Nuclear Stockpile from Unclassified Sources in Arms Reduction Program & Issues David H Frisch ed (New York The Twentieth Century Fund Inc , 1961)

Table 3 11
Nuclear Materials Inventories and Production
(End FY 1984)

Material	Inventory	Annual Production
Plutonium		
Weapon-Grade	93 ± 7 MT	2 5 MT[a]
Fuel-Grade	15 5 MT	None[b]
Tritium	70 ± 25 kg	10 7 kg[c]
Uranium		
HEU metal	approx 500-530 MT	None[d]
Lithium-6	greater than 390 MT	None
Deuterium	740 ± 20 MT as heavy water[e]	None

a With startup of the L-Reactor this increases to some 3 MT by FY 1987: see Table 3 5
b The inventory is decreasing by 0 5 MT per year (FY 1985); 0 6 (FY 1986); 0 8 (FY 1987-90); see Table 3 5
c Tritium production is projected to increase to about 19 kg by FY 1991 and then decrease to about 10 kg annually by the late 1990s; see Table 3 2
d New production planned for FY 1988-90
e 3700 MT heavy water (D2O) Of this, 525 MT is in storage 1100 is in four Savannah River reactors and 2075 MT is allocated for weapons and other purposes (including losses)

Table 3 12
U.S. Weapon-grade Plutonium Inventory
(End FY 1984)

8 Hanford Reactors	49 1 ± 2 0 MT[a]
5 Savannah River Reactors	
Total Pu (equivalent)	59 8 ± 5 9[b]
Tritium (Pu equivalent)	-13 7 ± 2 9[c]
Other Isotopes (Pu equivalent)	-1.4 ± 1.0[d]
Subtotal SRP Production	44 7 ± 6 6
N-Reactor (since October 1982)	1 7 ± 0 2[e]
Additions through Blending	1.0 ± 0.2[f]
Subtotal Production	96 5 ± 6 9 MT
Losses	
Reprocessing (0 5%)	-0 5 ± 0 5
Weapon Tests (3 0%)	-2 9 ± 1 0
Subtotal Losses	-3.4 ± 1.1
TOTAL INVENTORY	93 1 ± 7 0 MT[g]

a From Table 3 3
b From Table 3 2 Assumes 6-month cooling period
c Based on cumulative production of 180 kg tritium of which 70 kg was produced in control rods (see Table C 1 in Appendix C) One kg of tritium production equivalent to 72 kg of plutonium production
d Assume to be 1 percent of total production plus approximately three years of small core operation based on authors' calculations
e From Tables 3 4 and 3 5
f From Table 3 4
g Excludes weapon-grade plutonium that may have been received from the United Kingdom under the Mutual Defense Agreement of 1958 It is conjectured that 0 78 MT weapon-grade plutonium may have been received from UK military reactors See R V Hesketh "Nuclear Power UK Nuclear Weapons USA " Evidence on behalf of CND in the Sizewell B Inquiry, September 1984 pp 42 85) and 0 36 MT from civil reactors; see K W J Barnham D Hart, J Nelson and R A Stevens, "The Production and Destiny of British Civil Plutonium" *Nature* 317 (19 September 1985) 213-17

Weapon-grade Plutonium. The stockpile of weapon-grade plutonium accumulated from the Savannah River and Hanford production reactors is estimated to be 93 ± 7 MT as of the end of FY 1984 (see Table 3 12) The principal sources are the 49 ± 2 MT from the original eight Hanford reactors (see Table 3 3) and 45 ± 7 MT from the Savannah River reactors (see Table 3 2 and Table 3 12) Some losses have occurred during reprocessing and tests By the end of FY 1990 the weapon grade plutonium inventory is expected to reach 110 MT [86]

Fuel- and Reactor-grade Inventories. In addition to the stockpile of weapon-grade plutonium produced specifically for weapons, DOE's Defense Program also has jurisdiction over some 16 MT of mainly fuel-grade plutonium (7-19 percent Pu-240) and an additional 0 8 MT of reactor-grade plutonium (>19 percent Pu-240) that has been accumulated over several decades

The stocks of these materials might be legitimately referred to as "military" and "civil" inventories, depending on their original or intended use Traditionally the fuel-grade inventory has been the source of plutonium for the U S breeder research reactor program and other non-defense activities [87] Some of this material is in unseparated spent fuel The remainder has been either unallocated or loaned to DOE civilian research and development programs Since 1981, weapons program demands have diverted fuel-grade plutonium from potential civilian use to blending for weapons use Plans also call for the eventual purification of the remainder in a plutonium isotope separation plant starting in the early 1990s

The single largest source of fuel-grade plutonium is the N-Reactor at Hanford From the start of operation in 1963 until conversion to weapon-grade production in October 1982, it produced about 8 MT of fuel-grade plutonium [88] About half of this was separated prior to 1972, when the PUREX plant was placed on standby The rest was processed after the recent restart of the PUREX facility The remainder of the fuel-grade inventory was built

86 See Table 3 5
87 See Cochran Briefing Session
88 As of December 1980 the N-Reactor is estimated to have produced about 7 8 MT of fuel grade plutonium since operation began in 1963 : letter from P C Gilbert Acting Deputy Assistant Secretary for Nuclear Materials DOE to Thomas B Cochran 29 March 1981 At the end of FY 1990 4 2 MT of fuel-grade plutonium resided in unprocessed N Reactor spent fuel: DOE Materials Management Plan FY 1981-1992 Table D 2

Table 3 13
Inventory of Fuel-grade and Reactor-grade Plutonium
Metric Tons of Plutonium

	30 Sept 1980[a]	30 Sept 1981[b]	
	Fuel-grade	Fuel-grade	Reactor-grade
Product (separated)	4 0	3 5	0 2
N-Reactor Fuel (unseparated)		4 7	
Nonproduction Reactor Fuel (unseparated)	5 5	0 6	0 2
Scrap (separated)[c]		0 6	
R&D Programs (separated)[d]	7.6[e]	7.6	0.4
TOTAL	17 1[f]	17 0	0 8

a Letter from F C Gilbert, DOE Acting Deputy Assistant Secretary for Nuclear Materials to Thomas B Cochran 24 March 1981 Does not include any plutonium that has been exported to other countries Inventory values for 31 December 1978 are found in HAC FY 1980 EWDA Part 7 p 2638

b Letter from John J Jicha Jr Director, Production Operations Division, Office of Nuclear Materials Production DOE to Thomas B Cochran 19 April 1982

c In addition DOE expects to recover all fuel-grade plutonium scrap expected to be available through FY 1992, letter from F C Gilbert DOE, 24 March 1981

d An estimated 0 3 MT of weapon-grade plutonium was in DOE nondefense R&D programs in February 1981 ibid

e Another reported value for end-of-year FY 1980 is 7 15 MT fuel grade plutonium DOE Materials Management Plan FY 1981-92 Table D 3

f As of 30 September 1980 the fuel-grade plutonium had the following status The separated product was not yet allocated but was reserved for authorized activities in both defense and non-defense programs and a significant portion of the unseparated plutonium in N-Reactor spent fuel was reserved for defense programs through blending in the future after PUREX processing ibid

up "from the acquisition of material from many sources over the last forty years—for example, from commercial reactor fuel reprocessing operations (West Valley, New York), the accumulation of material from other U S government reactor operations, material obtained by barter, and donations from firms and foreign governments "[89]

Tables 3 13 and 3 14 give several accountings of the quantity of plutonium in the fuel-grade inventory and its status, whether "separated" in a processing plant from the irradiated fuel in which it was produced or still "unseparated " As of 30 September 1981, the inventory consisted of 17 0 MT of fuel-grade and 0 8 MT of reactor-grade plutonium; in addition, there were some 0 3 MT of weapon-grade plutonium in DOE non-defense R&D programs [90] In the year and a half before 31 March 1983, the fuel-grade inventory dropped 870 kg to a total of 16,130 kg This resulted from withdrawals for blending at Savannah River and additions of fuel-grade plutonium inventory from further production at the N-Reactor and scrap recovery While the N-Reactor underwent conversion to a full weapon-grade plutonium production (October 1982), both weapon-grade and fuel-grade plutonium were discharged [91] The fuel-grade plutonium produced was a few hundred kilograms at most

The DOE plutonium in non-defense R&D, 7 6 MT of fuel-grade and 0 8 MT of reactor-grade plutonium, is used principally by the breeder reactor program in fuel research and development; in the mixed-oxide fuel of the Fast Flux Test Facility (FFTF) at Hanford; and in the fuel plates or "coupons" for the Zero Power Plutonium Reactor (ZPPR), a critical facility at INEL FFTF fuel contains just over 2 9 MT of fuel-grade plutonium (nominal 12 percent Pu-240) in approximately four core loadings[92] fabricated in the 1970s by the Kerr McGee Corporation This should cover operation through most of the 1980s Plans are to fabricate additional fuel in the late 1980s (at the Los Alamos plutonium facility), withdrawing the needed plutonium from the stockpile The ZPPR Project contains a total of 3 8 MT of plutonium, consisting of 3 4 MT fuel-grade, 0 2 MT weapon-grade, and 0 2 MT reactor-grade [93]

In early 1983, the schedule for converting fuel-grade plutonium for weapons use was tentatively set at blending 4 MT through the end of the decade and then enriching the remaining 11 MT by laser isotope separation in a Hanford plant [94]

Some 4 MT of the fuel-grade plutonium now in DOE R&D facilities, mainly in the fuel of ZPPR and FFTF, was obtained in the 1960s by barter from the United Kingdom under the Mutual Defense Agreement of 1958, the United States received the material in return for highly enriched uranium and tritium The potential use of the bartered plutonium in weapons has brought attention to some aspects of the exchange;[95] because of its origin in civil

89 Ibid During West Valley operation (April 1966 to December 1971), 1684 kg of plutonium were recovered including 533 kg from N Reactor irradiated fuel; Gene I Rochlin et al, Bulletin of the Atomic Scientists (January 1978) 23

90 Letter from F C Gilbert DOE to Thomas B Cochran 24 March 1981

91 Letter from John J Jicha DOE to Milton M Hoenig 11 August 1982 The inventory of weapon-grade plutonium in N-Reactor spent fuel is about 160 kg ibid ; or 400 kg, letter from Donald Paul Hodel Secretary of Energy to Richard L Ottinger 30 August 1983

92 Letter from Donald Paul Hodel, Secretary of Energy to Richard L Ottinger 30 August 1983 Encl p 5

93 Letter from Donald Paul Hodel to Richard L Ottinger 5 March 1984 Encl 1 p 3

94 HAC, FY 1984 EWDA, Part 6 p 350 p 364; HASC FY 1984 DOE p 180

95 Milton R Benjamin, International Herald Tribune (19 March 1984) 1

Table 3 14

Inventory of DOE Fuel- and Reactor-grade Plutonium

(31 March 1983)

Fuel-grade Plutonium[a]			
Separated	9760 0 kg	Defense Uses	285 0 kg
Unseperated	6350.0 kg	Nondefense Uses	7115 0 kg
Total	16,130 0 kg	Not Allocated[b]	8730.0 kg
		Total	16,130 0 kg
Reactor-grade Plutonium[c]			
Separated	505 0 kg	Defense Uses	0 0
Unseparated	205.0 kg	Nondefense Uses	400 0 kg
Total	710 0 kg	Not Allocated[d]	310.0 kg
		Total	710 0 kg

a Locations: Los Alamos National Laboratory, Mound Laboratory, Argonne National Laboratory, Brookhaven National Laboratory, Savannah River Plant, Oak Ridge National Laboratory, Hanford Site, Idaho National Engineering Laboratory, Lawrence Livermore National Laboratory, *ibid*

b Not allocated for immediate use but planned for use pending clarification of definitive requirements *ibid*

c Locations: Los Alamos National Laboratory, Battelle Memorial Institute, Argonne National Laboratory, Savannah River Plant, Oak Ridge National Laboratory, Hanford Site, Idaho National Engineering Laboratory, Nevada Test Site, *ibid*

d Not allocated for immediate use but planned for use pending clarification of definitive requirements *ibid*

Source: Letter from Donald Paul Hodel, Secretary of Energy, to Richard L. Ottinger, 5 March 1984

reactors[96] assurances were given in 1964 by the United States that it would not be used for weapons purposes.[97]

Table 3 5 shows the quantities of fuel-grade plutonium estimated to be required for blending to produce weapon-grade material. Four metric tons will probably be used by about 1989. The table is based on projections for the annual production of supergrade plutonium at Savannah River, an activity that will be in competition with the production of tritium. After 1989 the remaining inventory of fuel-grade plutonium will be converted to weapon-grade either by blending or laser isotope enrichment, contingent on the latter program's progress.

Tritium Inventory. The best estimate of the tritium inventory as of the end of FY 1984 is 70 kg with an uncertainty of ± 25 kg (see Appendix C). Based in part on an analysis of atmospheric releases of tritium from SRP, some 140 to 200 kg of tritium has been produced (with an uncertainty of ± 60 kg) since production began in the mid-1950s. Much of this has been lost through radioactive decay (tritium decays at a rate of 5 5 percent per year). In addition, very small quantities have been sold commercially and used in research (see below), and the supply in weapons must be replenished periodically.

During the period from 1973 through 1981, tritium was produced in control rods, targets, and blankets as an adjunct to plutonium production. If this production was intended solely to offset radioactive decay, thereby maintaining the inventory at a constant level, that inventory would have been 40 kg (see Appendix C). With the subsequent increase in production it would have grown to approximately 63 kg.

Estimates of the growth of the tritium inventory are based on the projected requirements for tritium production in the 1984 Nuclear Weapons Stockpile Memorandum. Table 3 15, assuming that the FY 1984 inventory is 70 kg, shows subsequent tritium inventory estimates.

Nonweapon Uses and Sources of Tritium

Tritium produced at Savannah River is also both made available for commercial use and used by DOE's fusion R&D programs. Distributed by the Oak Ridge National Laboratory, some 0 5 kg per year is supplied for self-illuminating signs and other commercial purposes. The present tritium requirement of the magnetic fusion program is on the order of tens of grams annually.[98]

In the Magnetic Fusion Engineering Act of 1980, Congress called for the construction of a demonstration fusion power reactor by the year 2000.[99] Subsequently, the program was slowed by budget cuts and its goal made less ambitious.[100] Two competing magnetic confinement concepts, the Tokamak and the magnetic mirror, were under development. The Tokamak Fusion Test Reactor (TFTR) at Princeton University, was completed in

96 Harward Written Answers, 27 July 1982, c 438

97 ACDA, Documents on Disarmament 1964, p 171

98 The Tritium Systems Test Assembly at LANL was first tested in June 1984 using 10 5 grams of tritium; LANL, Los Alamos Newsbulletin, 27 July 1984, p 1. The on-site inventory has been estimated at 150 grams; Physics Today (November 1982): 18

99 Heat would be produced by the fusion of D-T fuel in a high temperature plasma of ionized atoms confined to the reactor's interior by a magnetic field

100 Science (2 November 1984): 525

Table 3 15
Inventory of Tritium
(FY 1984-99)

FY	Tritium Inventory (kg)[a]
1984	70
1985	78
1986	81
1987	86
1988	92
1989	99
1990	108
1991	120
1992	130
1993	137
1994	145
1995	154
1996	160
1997	161
1998	162
1999	163

a Assumes tritium inventory at the end of FY 1984 is 70 kg (see Appendix C) Annual tritium production to meet requirements projected in the 1984 Nuclear Weapons Stockpile Memorandum are calculated in Table 3 9 based upon data presented in J S Allender and I M Macafee *Economic Analysis of the Fuel Production Facility*, DPST-84-420 Savannah River Laboratory Technical Division 9 April 1984 pp 5 24

1983 [101] The first D-T burn was scheduled for 1986[102] but has now been delayed a few years due to budgetary constraints The Mirror Fusion Test Facility-B (MFTF-B) at LLNL is to be completed in FY 1986, but funding to operate the project may be deferred [103] Should the program proceed to the development of commercial prototype machines the future tritium requirement is not expected to exceed one kilogram annually or about 25 kg total [104]

Tritium may be available commercially from Canada by the late 1980s when it could be recovered in quantity from the heavy water of CANDU power reactors Canada's Ontario Hydro is considering building a tritium recovery plant at Darlington [105] The $150 million plant, scheduled for operation in April 1987, is designed to process 350 kg/hour of tritiated heavy water,[106] producing up to 2 5 kg of tritium annually [107] The commercial demand in the West is between 0 5 and 1 0 kg annually

The Production of Uranium

Uranium is a slightly radioactive metallic element (atomic number 92; atomic weight 238 07), discovered by the German chemist H M Klaproth in 1789 As found in nature uranium is a mixture of three isotopes: U-234 (0 01 percent), U-235 (0 711 percent), and U-238 (99 288 percent) [108] Only in the last forty years has uranium developed from a commodity of minor commercial use to one vital for both nuclear weapons and nuclear power

In the peak weapon production years 1955-1967, the United States manufactured some 30,000 nuclear warheads To meet material requirements for these warheads, the AEC fostered the growth of a commercial uranium mining and milling industry by buying uranium ore and concentrate (U_3O_8), and by building three huge uranium enrichment plants based on the gaseous diffusion technology By the end of FY 1964 the AEC had produced on the order of 700 MT of highly enriched uranium (HEU), most of which was converted to metal, or oralloy, for use in weapons [109] While most of this oralloy was indeed used in weapons, the AEC also had unused stocks when production of HEU metal was halted [110]

Since 1967, the number of weapons and their yields have decreased, and the AEC (now DOE) has been able to meet its requirements for HEU metal from existing supplies During this period all HEU for new weapons came from material recovered from retired weapons, and it was unnecessary to draw down the oralloy stocks at the Y-12 plant [111] Some of the oralloy inventory, however, has been used to supply a portion of the fuel for the SRP production reactors, as well as fuel for some DOE and foreign research and test reactors

Demand for HEU is increasing The U S weapon stockpile is growing once again, newer warheads have a

101 The TFTR system had its first test at 3:06 a m 24 December 1982 successfully heating hydrogen gas and generating a plasma lasting 80 thousandths of a second

102 Walter Sullivan *New York Times* 29 December 1982 p 1 The first D T fusion tests are scheduled for 1986 and the tritium inventory would be only five grams LANL *Los Alamos Newsbulletin* 27 July 1984 p 1

103 *Science* (2 November 1984): 525

104 STARFIRE a 1200 MWe (3010 MW heat) Tokamak power plant designed by Argonne National Laboratory would have an inventory of about 12 kg of tritium; Argonne National Laboratory STARFIRE—A Commercial Tokamak Fusion Power Plant Study ANL/FPP 80-1 September 1980 Subsequent designs that suggest significant reductions in the inventory are possible Reactors after the initial tritium loading could produce all the tritium needed by neutron absorption in surrounding lithium blankets

105 *Nuclear Engineering International* (June 1983): 32-33 Plans for a second plant at Pickering have been canceled The Darlington plant is being designed by Sulzer Brothers of Winterthur Switzerland The Canadian plant will be essentially a scaled-up version of the tritium removal system supplied by Sulzer for the high flux reactor operated by the Laue Langevin Institute at Grenoble, France

106 Ontario Hydro has over 8 GW, installed nuclear capacity and another 8 GW, planned all based on heavy water-moderated CANDU reactor technology During normal operation the heavy water moderator becomes tritiated by neutron absorption

107 *Nucleonics Week* (8 November 1984): 11 See also *Nuclear Engineering International* (June 1983): 32 and *Nucleonics Week* (31 March 1983): 9

108 John F Hogerton The Atomic Energy Deskbook (New York: Reinhold Publishing Corporation 1963) p 578 The concentrations are given in weight percent

109 Oralloy is the name used for U-235 or highly enriched uranium (93 5 percent U-235) metal for weapons The name which derives from Oak Ridge Alloy was a code word used during the Manhattan Project

110 Long Range Nuclear Weapons Planning Analysis for the Final Report of the DOE/DOE Long Range Resource Planning Group 15 July 1980, p 73 The Enriched Uranium Conversion Facility at the Oak Ridge Y 12 plant used to convert enriched UF_6 to UF_4 was placed on standby in FY 1964; HAC FY 1985 EWDA Part 4, p 506 On 20 April 1964 President Johnson announced that he had ordered further reductions in the production of enriched uranium to be carried out over a period of four years Added to previous reductions it meant a decrease of 40 percent On the same day Premier Khrushchev announced that the Soviet Union would stop construction of two plutonium production reactors reduce the production of U-235 for weapons and allocate more fissionable materials for peaceful uses; ACDA *Documents on Disarmament 1964* pp 168-69

111 HASC FY 1985 DOE p 115-16; by FY 1982 for example 100 percent of the HEU recovered from retired weapons was recycled for new weapons; HASC FY 1982 DOE pp 55 172; HAC FY 1983 EWDA Part 5 p 939 The projected supply of highly enriched uranium shown in the FY 1984-89 Nuclear Weapons Stockpile Memorandum includes material from weapons scheduled for retirement plus the existing Y-12 Plant inventory *Ibid*, p 860

Table 3 16
AEC Domestic Uranium Ore Purchases
(FY 1949-62)

	At Buying Stations		Under Special Arrangements		Total	
FY	Tons of Ore	Pounds U_3O_8	Tons of Ore	Pounds U_3O_8	Tons of Ore	Pounds U_3O_8
1949	28,742	126,302	-	-	28,742	126,302
1950	65,602	351,152	-	-	65,602	351,152
1951	55,904	383,663	-	-	55,904	263,663
1952	87,191	445,725	1,300	4,713	33,491	450,438
1953	121,015	707,581	48,960	232,181	169,975	939,772
1954	287,510	1,601,241	110,515	698,248	378,025	2,299,489
1955	480,232	2,922,826	126,853	982,490	607,085	3,885,316
1956	753,595	4,347,485	52,303	280,677	805,898	4,628,142
1957	587,495	3,778,372	17,016	97,921	604,511	3,876,293
1958	220,649	1,163,049	1,507	5,934	222,156	1,168,983
1959	138,596	1,531,374	734	3,806	139,330	1,535,180
1960	113,345	1,099,826	31,634	148,236	144,979	1,248,164
1961	41,465	453,773	179,966	922,201	221,431	1,375,974
1962	30,408	265,601	60,351	332,210	90,759	597,811
Totals	2,991,749	19,058,052	631,139	3,688,827	3,622,888	22,746,679

The second and third columns represent ore purchased at eleven different ore-buying stations operated for varying lengths of time in the western United States by AEC between 1948 and 1962. The fourth and fifth columns show ore bought under special arrangements with mills and the AEC ore-buying agent to purchase ore in certain areas for a limited time and usually while mills were under construction. All of the 3,622,888 tons of ore bought during this period was gradually sold to the mills. By the end of 1960 there were 1.3 millions tons of ore held in government stockpiles; at the end of December 1966, the AEC had no ore stockpiles. The eleven AEC ore-buying stations were at Globe and Tube City, Arizona; Edgemont, South Dakota; Grants and Shiprock, New Mexico; Marysvale, Moab, Monticello, and White Canyon, Utah; and Crooks Gap and Riverton, Wyoming. The last AEC station, at Monticello, Utah, was closed on 31 March 1962, with the termination of the Domestic Uranium Program Circular 5, Revised.

Source: DOE, Statistical Data of the Uranium Industry, Grand Junction Area Office, GJO-100(83), 1 January 1983, p. 71.

higher yield to volume, and production reactors continue to draw on the oralloy inventory for part of their fuel requirements. As a consequence, DOE plans to call for the resumption of oralloy production in FY 1988-90 with "a potential for a substantial increased requirement for highly enriched uranium."[112]

Uranium Mining and Milling

To meet military needs in the early 1940s, the Manhattan Engineer District obtained uranium ore from the rich pitchblendes (greater than 10 percent equivalent in the uranium oxide U_3O_8) of the Belgian Congo and the Great Bear Lake, Canada. These deposits were supplemented by production from a few small mines in the Colorado Plateau area. These high-grade ores and concentrates were refined by an ether extraction technique adapted from analytical chemistry procedures. The processes used for low-grade ores were relatively crude and reflected little change from methods used at the turn of the century. Milling costs were high and uranium recovery was relatively inefficient.

After the Atomic Energy Act of 1946 went into effect, the AEC placed strong emphasis on the discovery and development of new sources of uranium in the United States. It also encouraged development of improved processing techniques to satisfy renewed military demands.[113] Major domestic sources of uranium were found in flat-lying deposits in sedimentary rock—principally sandstone—in the western states. In April 1948 the AEC initiated a program of incentives that included price guarantees and bonuses for discovery and delivery in order to spur exploration and production. The response was so great that the government was able to terminate domestic ore purchases in 1962 and slow concentrate purchases until terminating them in 1970. Between 1949 and 1962 the AEC purchased some 3.6 million short tons of uranium ore, containing 11,373 tons of U_3O_8 (see Table 3.16).

Contracts to process the ore were negotiated with private industrial concerns. The end product of this activity was uranium concentrate, mainly uranium oxide

112 HASC, FY 1985 DOE, pp. 315-16; Renovation of the Enriched Uranium Conversion Facility at the Y-12 plant facility is scheduled for completion in the spring of 1988; HAC, FY 1985 EWDA, Part 4, p. 505; quote from HAC, EWDA, FY 1986, Part 7, p. 664.

113 Wartime control over uranium exercised by the War Production Board was continued by the Office of Temporary Controls until AEC took control of source material on 31 March 1947; AEC, Report to Congress, July 1947, p. 2.

Table 3 17

AEC Uranium Concentrate Purchases

(FY 1942-71)

FY	Domestic Tons U_3O_8	Canada Tons U_3O_8	Overseas Tons U_3O_8	Total Tons U_3O_8	Cumulative Tons U_3O_8
1942-44	710	400	3700	4810	4810
1945	-	50*	450*	500	5310
1946	-	400*	3700*	4100	9410
1947	-	216	1440	1656	11,066
1948	116	206	1689	2011	13,077
1949	115	217	1909	2241	15,318
1950	323	235	2505	3063	18,381
1951	639	255	2792	3686	22,067
1952	824	210	2623	3657	25,724
1953	982	225	1680	2887	28,611
1954	1455	688	2550	4693	33,304
1955	2141	828	2971	5940	39,244
1956	4202	1587	4645	10,434	49,678
1957	7582	3371	5205	16,158	65,836
1958	10,243	9475	6657	26,375	92,211
1959	15,162	13,506	4659	33,327	125,538
1960	16,566	13,443	4572	34,561	160,119
1961	17,758	10,251	4251	32,260	192,379
1962	17,255	7728	4379	29,362	221,741
1963	15,760	7017	4205	26,982	248,723
1964	12,607	2240	3830	18,677	267,400
1965	11,240	1190	2805	15,235	282,635
1966	10,178	720	1600	12,498	295,133
1967	8902	260	625	9787	304,920
1968	7937	-	-	7937	312,857
1969	7124	-	-	7124	319,981
1970	4010	-	-	4010	323,991
1971	1295	-	-	1295	325,286
	175,126	74,718*	75,442*		

Note: All resources are expressed in short tons U_3O_8 (one short ton U_3O_8 contains 0 7693 metric tons of uranium (tonnes U)

* Approximate numbers

Sources: FY 1964 and after: DOE Statistical Data of the Uranium Industry GJO-100(83 Grand Junction Area Office 1 January 1983, pp 72 74; These data exclude uranium recovered as byproduct from the processing of phosphates FY 1947-FY 1963: JCAE Private Ownership of Special Nuclear Materials 1964 Hearings June 1964, p 162 Values are slightly higher than values reported in GJO-100(83 These differences are presumed to represent byproduct recovery Mid FY 1947-FY 1952: Richard G Hewlett and Francis Duncan *Atomic Shield 1947/1952* A History of the United States Atomic Energy Commission U S Atomic Energy Commission 1972 Vol II Appendix 5 p 674 FY 1945-FY 1946: unpublished report of Robert Pitman (DOE) Mike Lopez and Kirk Smith (see Frank von Hippel and Barbara Levi, Controlling the Source, Verification of a Cutoff in the Production of Plutonium and High-Enriched Uranium for Nuclear Weapons Princeton University Report PU/CEES 167, October 1984; FY 1944: Richard G Hewlett and Oscar E Anderson Jr *The New World 1939/1946 A History of the United States Atomic Energy Commission* (University Park: Pennsylvania State University Press 1962) Vol I pp 291-92

Purchases prior to 1947, which predate the AEC were by Manhattan Engineer District

A total of 31 738 tons of concentrate were purchased from foreign sources prior to FY 1956 (201 tons less than indicated by the table above): Robert Pitman DOE private communication 11 February 1991

(U_3O_8), known as "yellowcake" (See Uranium Mining and Milling, Chapter Five) While domestic ore purchases ceased in 1962, the AEC continued to buy U_3O_8 from both domestic and foreign sources (primarily, Canada and the Belgian Congo) until the end of calendar year 1970 By that time the AEC had purchased some 325,286 short tons of U_3O_8, 55 percent from domestic sources (see Table 3 17 and Figure 3 4)

Between 1943 and 1964, when production of oralloy ceased, the United States had accumulated some 205,000 MT of uranium (containing 1458 MT U-235) One third of this U-235 is found in the nuclear weapons stockpile

Table 3 18 documents the record of concentrate (U_3O_8) production from U S uranium mills About 398,000 short tons of U_3O_8 had been produced by the end of 1984, resulting in over 200 million short tons of mill tailings

Between 1960 and 1962, up to twenty-six mills operated in the United States (excluding plants producing byproduct uranium from phosphates) Their annual production exceeded 15,000 short tons of U_3O_8 from seven million short tons of ore (average grade of 0 21 percent)

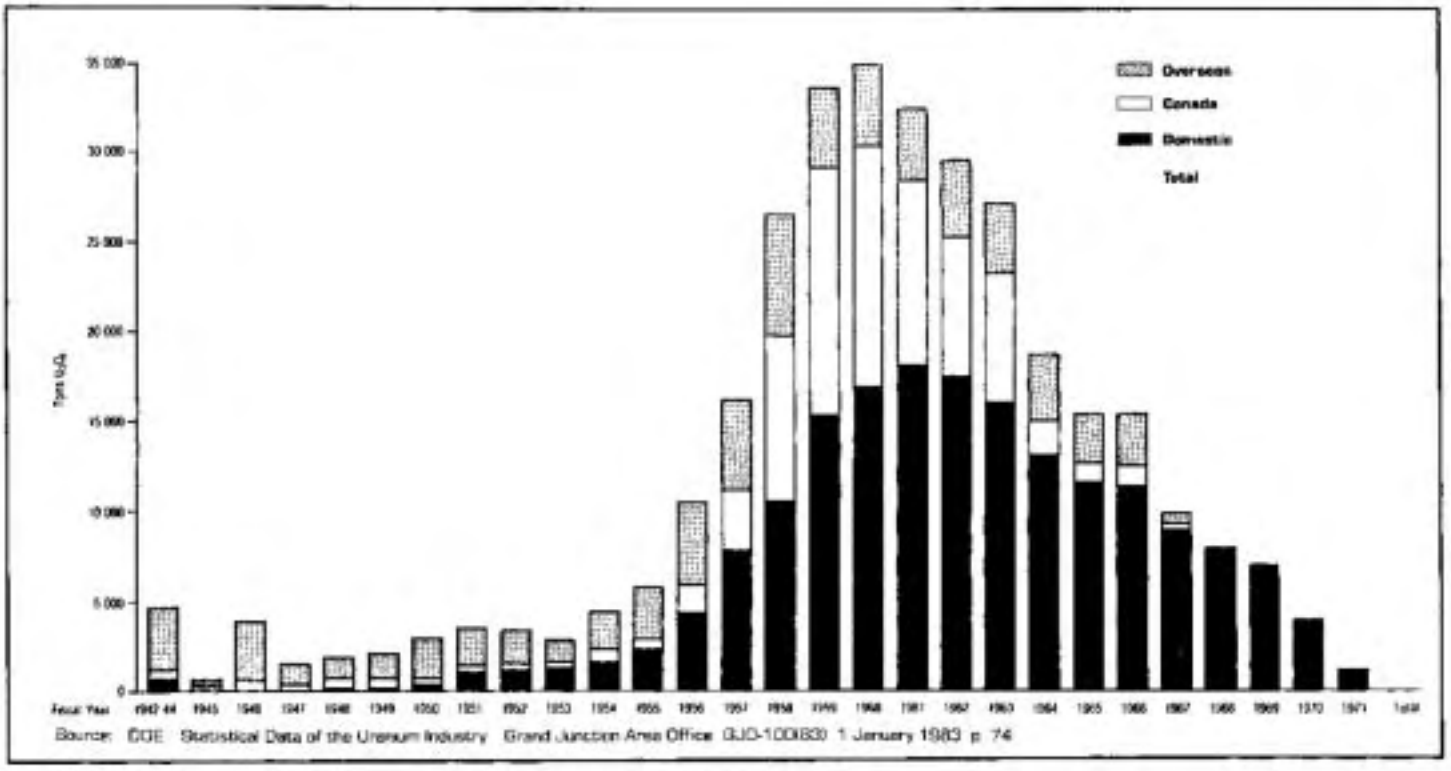


Figure 3 4 AEC uranium purchases (Tons of U_3O_8 and millions of dollars)

Reduced military requirements and the slow development of commercial nuclear power resulted in fewer operating mills and lower uranium production between 1963 and 1970 Since the mid-1970s, a curtailment in commercial reactor sales, cancellations of reactors planned and under construction, and foreign competition from high-grade ores have all contributed to a substantial drop in the demand and price of U_3O_8 and a sharp reduction in U_3O_8 production The number of operating uranium mines in the United States has decreased steadily since 1979, when there were 362 underground and open-pit mines By 1983 the number was down to 110 [114]

Between December 1981 and February 1984 the number of operating mills dropped from twenty to ten (with an average capacity of 2800 short tons per day) (see Tables 3 19 and 3 20) Mill capacities in 1984 ranged from 750 to 7000 short tons of ore per day

As of January 1983, U S uranium ore reserves in the ground contained a total of 889,000 short tons of U_3O_8 (average grade 0 06 percent) recoverable at a forward cost of $100 per pound or less [115] Of this, 576,000 short tons (average grade 0 10 percent) were recoverable at $50 per pound or less, including 180,000 short tons of U_3O_8 (high-grade, 0 21 percent) recoverable at $30 per pound or less

Uranium Enrichment

In U S nuclear warheads, fissile components made of uranium are enriched to a concentration of 93 5 percent U-235 Thus the concentration of U-235 must be increased 130 times from its value in naturally occurring uranium The separation of uranium isotopes to obtain U-235-enriched product is an important step in the production of uranium weapon components

The development of uranium enrichment and the U S enrichment enterprise was begun under the Manhattan Project during World War II Four processes were developed during the war and brought into the large demonstration or production stages The electromagnetic process, using the Calutron isotope separator developed by E O Lawrence, was set up in the Y-12 plant at Oak Ridge It produced the first gram quantities of HEU in 1944 This process was abandoned after 1946 because it proved more costly than gaseous diffusion The thermal diffusion process operated in the S-50 plant at Oak Ridge provided slightly enriched feed to the Y-12 plant until

114 DOE Domestic Uranium Mining and Milling Industry DOE/S-0033 December 1984 p 19 In 1983 there were also ten solution (in situ) mining operations eight byproduct (phosphate and copper) mining operations and seven nonconventional processes (heap leaching mine water mill tailing and low-grade stockpiles

115 DOE, Domestic Uranium Mining and Milling Industry, DOE/S-0033 December 1984 p 115 Forward costs are the operating and capital costs incurred in the production of the uranium

3

Uranium Enrichment

Table 3 18
U.S. Uranium Concentrate Production

Calendar Year	Short Tons of U_3O_8[a] Annual	Short Tons of U_3O_8[a] Cumulative	Grade of Ore (% U_3O_8)
1947-1965		139,706	
1966	10,589	150,295	0 229
1967	11,253	161,548	0 203
1968	12,368	173,916	0 195
1969	11,609	185,525	0 208
1970	12,905	198,430	0 202
1971	12,273	210,703	0 205
1972	12,900	223,603	0 213
1973	13,235	236,838	0 208
1974	11,528	248,366	0 176
1975	11,600	259,998	0 170
1976	12,747	272,713	0 157
1977	14,939	287,652	0 154
1978	18,486	306,138	0 131
1979	18,736	324,874	0 105
1980	21,852	346,726	0 119
1981	19,237	365,963	0 114
1982	13,434	379,397	0 119
1983[b]	10,579	389,976	0 128
1984 (est)[b]	8,000	397,976	

a One short ton (2000 pounds) U_3O_8 contains 0 7693 metric tons of uranium
b DOE Energy Information Administration private communication to Milton M Hoenig March 1985

Source: DOE Statistical Data of Uranium Industry 1 January 1983 p 45
Includes U_3O_8 production obtained from mine water heap-leaching solution mining or as a byproduct of another activity

1945 At that time the S-50 was shut down in favor of gaseous diffusion, with its lower cost and greater energy efficiency

The first sections of the Oak Ridge K-25 gaseous diffusion plant were completed and became operational in 1945 [116] The K-27 Building was added and went into operation in early 1946 [117] By the late 1950s, gaseous diffusion plants had been constructed at three U S locations: Oak Ridge; Paducah, Kentucky; and Portsmouth, Ohio By 1977 all of the Manhattan Project stages at Oak Ridge had been retired from operation and replaced by gaseous diffusion stages of the K-29, K-31, and K-33 sections (see Uranium Enrichment, Chapter Five)

Gas centrifuges for uranium enrichment, the fourth wartime process, were operated in 1944 at the Bayway, New Jersey, refinery of the Standard Oil Company Work was suspended at that time because of mechanical difficulties The process was based on Beams' work on isotope separation at the University of Virginia It was resumed again in the United States in the late 1950s [118] The government then began a program to develop large, high capacity machines of the type constructed for the now-cancelled Portsmouth gas centrifuge enrichment plant

After 1946, all enriched uranium was produced in the three gaseous diffusion plants—at Oak Ridge, Paducah, and Portsmouth Construction and expansion of these plants occurred from 1943 to late 1955 On completion, as HEU requirements for weapons increased, production of enriched uranium rose sharply and reached a peak of about 16 5 million SWU in FY 1961 [119] This was close to the overall capacity of 17 2 million SWU The plants maintained output rates into 1964, when the production of HEU for weapons was terminated Separative work production then dropped to a low of about 6 million SWU in 1970[120] (see Figure 3 5) After that production began to rise again in anticipation of demand by civilian nuclear power plants for low-enriched uranium Consequently, plans were made and implemented to increase the capacity to its present level of 27 3 million SWU New reactor construction and enrichment sales did not meet expectations, however Only about 40 percent of the capacity was in use when the Oak Ridge plant was placed on standby at the end of FY 1985 Construction of the Gas Centrifuge Enrichment Plant (GCEP) at Portsmouth was cancelled in 1985, after spending $2 6 billion New capacity was not needed so soon, and Atomic Vapor Laser Isotope Separation (AVLIS) technology was being developed for the future

The main enrichment activity is to produce low-enriched uranium at Paducah and Portsmouth for the commercial nuclear industry The gaseous diffusion complex produced about 10 4 million SWU in FY 1985 and expects to produce about 7 6 million SWU in FY 1986 (see Table 3 21) Highly enriched uranium is produced at the Portsmouth plant, which alone has a capacity of 8 3 million SWU per year Just over one million SWU of enrichment are utilized annually for defense related purposes, almost all of it going to HEU for the naval reactor program [121] Based on current DOE estimates, future annual requirements for military programs range from about one to five million SWU [122]

Uranium oxide from the mills (yellowcake) or oxides of uranium recovered from fuel processing and metal from storage must be converted into UF_6 before introduction into the enrichment cascade There, a UF_6 feed under pressure encounters a series of micropore barriers that selectively pass molecules containing U-235 more frequently than molecules containing U-238 (See Ura-

116 Hewlett and Anderson The New World, 1, pp 302 624
117 Ibid p 638.
118 DOE United States Gas Centrifuge Program, UCC ND 1877 Rev 2 6/81
119 A SWU is a measure of the effort expended to enrich uranium in the isotope U-235 For a more extensive discussion, see Uranium Enrichment, Chapter Five
120 James H Hill Uranium Enrichment in the United States ERDA CONF 750324-7 5 March 1975
121 HAC FY 1984 EWDA Part 4 p 502
122 HAC FY 1985 EWDA Part 6 p 997

Table 3 19

Status of U.S. Conventional Uranium Mills

Mill	Location	Rated Capacity (Short Tons of Ore per Day) Dec 1981	Dec 1982	Dec 1983	Feb 1984
Anaconda	Bluewater, NM	6000	[a]	[a]	[a]
Atlas Minerals	Moab, UT	1400	1400	1400	[a]
Bear Creek	Powder River Basin, WY	2000	2000	2000	2000
Chevron	Hobson, TX	2500	2500	2500	2500
Conoco/Pioneer Nuclear	Falls City, TX	3400	[a]	[b]	[b]
Cotter	Canon City, CO	1200	2000	[a]	[a]
Dawn Mining	Ford, WA	450	[a]	[a]	[a]
Energy Fuels Nuclear	Blanding, UT	2000	2000	[a]	[a]
Exxon Minerals	Powder River, WY	3200	3200	3200	3200
Federal/American	Gas Hills, WY	[a]	[a]	[a]	[a]
Kerr McGee	Grants, NM	7000	7000	7000	7000
Minerals Exploration	Red Desert, WY	3000	3000	[a]	[a]
Pathfinder Mines	Gas Hills, WY	2500	2500	2500	2500
Pathfiner Mines	Shirley Basin, WY	1800	1800	1800	1800
Petrotomics	Shirley Basin, WY	1500	1500	1500	1500
Plateau Resources	Ticaboo, UT	[c]	[a]	[a]	[a]
Rio Algom	La Sal, UT	750	750	750	750
Sohio/Reserve	Ceboletta, NM	[a]	[a]	[a]	[a]
Union Carbide	Uravan, CO	1300	[a]	[a]	[a]
Union Carbide	Natrona, WY	1400	1400	[a]	[a]
United Nuclear	Church Rock, NM	3000	[a]	[a]	[a]
United Nuc /Homestake	Grants, NM	3400	3400	3400	3400
Western Nuclear	Jeffrey City, WY	[a]	[a]	[a]	[a]
Western Nuclear	Wellpinit, WA	2000	[a]	2000	2000
TOTAL		49,800	33,650	29,250	27,850

a Inactive
b Dismantled
c Mill under construction

Source: DOE, Domestic Uranium Mining and Milling Industry, DOE/S-0033, December 1984, p. 21

nium Enrichment, Chapter Five.) The enriched UF_6 product that emerges from the cascade is converted to the desired form—e.g., uranium metal for production reactors or uranium oxide (UO_2) for power plants—prior to fuel fabrication.

Enriched uranium to fuel the naval propulsion reactors comes only from enrichment plants. Uranium recovered from spent naval fuel is not recycled to the naval reactors. As already stated, the production reactors at Savannah River and Hanford obtain enriched uranium for fuel directly from four sources: HEU recovered from spent naval and research reactor fuels; slightly enriched uranium (SEU) and HEU recovered from the irradiated production reactor fuel; HEU stockpiled at the Oak Ridge Y-12 Plant; and SEU from the gaseous diffusion plants.[123] Prior to FY 1984, SEU for the N-reactor came from existing inventories, but in FY 1984 the proper assays (0.95 percent and 1.25 percent U-235) were no longer available. DOE began to acquire them again from the enrichment complex.[124]

Table 3.22 illustrates separative work requirements for various uranium enrichments required in defense programs. For example, the production of a kilogram of oralloy for weapons, starting from natural uranium feed, requires the expenditure of 236.9 SWUs, while the production of a kilogram of 1.1 percent enriched U-235 requires only 0.53 SWUs, all at 0.2 percent U-235 in the tails.

Uranium Inventories

HEU for Weapons (Oralloy). The DOE has allocated a fixed quantity of HEU metal for weapons.[125] The best estimate of this inventory (in weapons and reserved for weapons) is about 500 MT (see Appendix D). In addition, the DOE has a dwindling stock of HEU metal, perhaps as much as 30 MT, stored at Y-12, which is allocated to meet fuel requirements for Savannah River reactors and

123 HAC, FY 1984 EWDA, Part 6, p. 526.

124 Ibid., p. 530. The FY 1984 request was $20 million for separative work for N-Reactor fuel; HAC, FY 1984 EWDA, Part 4, p. 310. This would provide 580 MT uranium at an average enrichment of 1.0 percent, tails of 0.2 percent and cost of $90 per SWU.

125 "[T]here is a constant inventory ... most of it is in weapons. Others are in reserve for use in weapons." HASC, FY 1979 DOE, p. 264.

Table 3 20

Capacity of U.S. Conventional Uranium Production Facilities

	Dec 1981	Dec 1982	Dec 1983	Feb 1984
Number of mills operating	20	14	12	11
Number of mills not operating	3	10	11	12
Total number of mills	23	24	23	23
Total rated mill capacity (tons of ore per day)				
Operating	49,900	33,650	29,250	27,850
Not operating	4,250	21,400	22,400	23,800
TOTAL	54,050	55,050	51,650	51,650
Annualized utilization of operating mills[a] (tons of ore per day)	41,570	21,510	16,930	-
Utilization level of operating mills				
% of operating capacity	83	64	58	-
% of total rated U S capacity	77	39	33	-

a Annualized to 350 work days

Source: DOE Domestic Uranium Mining and Milling Industry DOE/S-0033 December 1984 p 20

DOE and foreign research and test reactors through FY 1988-90 The HEU inventory for weapons is expected to rise to as much as 650 MT by the mid-1990s (see below, Production of Additional HEU for Weapons)

At Enrichment Plants. The uranium inventory at the DOE enrichment plants consists of enriched uranium, tails, and natural uranium feed As of the end of FY 1984 DOE has 6824 MT of enriched uranium at an average of 1 9 percent U-235 (see Table 3 23) The enrichment tails inventory totaled 275,813 MTU in the chemical forms UF_4 and UF_6 [126] The assay of these tails ranged from 0 2 percent to 0 3 percent U-235, with more than one half 0 2 percent Most of the tails, 183,485 MTU, was at the Paducah GDP There were 37 8 MTU of uranium feed (natural uranium in the chemical form UF_6), 21 8 MT of which was also at the Paducah plant

The DOE separative work inventory at the end of FY 1984 was 19 125 million SWU[127] (see Table 3 21)

At Other Sites. As of the end of FY 1984 the inventory of unclassified DOE-owned uranium spread among thirty-five locations (other than enrichment plants) included 5076 MT of enriched uranium, mostly at UNC Nuclear Industries, which operated the N-Reactor and its fuel fabrication facility at Hanford; 335 MT of depleted uranium, over half of which is also at Hanford; and 47 7 MT of natural uranium (see Table 3 24)

Production of Additional HEU for Weapons

The enrichment of uranium for weapons is planned to resume in FY 1987 and take place over several years New oralloy production is projected to increase the inventory by as much as 150 MT, approximately 30 percent of the current inventory The new HEU is desired for weapon production and later for reactor operation "We now see a potential for a substantial increased requirement for highly enriched uranium the total cost, if this all materializes, for that increase will be approximately $4 billion over several years "[128]

Initially DOE gave consideration to purchasing additional uranium ore It has since decided otherwise since it "has sufficient uranium resources in its enriched, natural, and depleted inventories to economically meet currently projected defense needs for uranium through at least 2000 "[129]

The enrichment complex has sufficient operating capacity to meet schedules for new HEU, but production would be costly The annual production of 15 MT of oralloy (e g , to supply 150 MT over a period of ten years) would take 3 5 million SWU of separative work and cost $365 million (FY 1985 dollars)

The FY 1984 supplemental budget requested $4 9 million to begin renovation of the Enriched Uranium

126 P T Marquess, DOE, Oak Ridge Operations Letter to Thomas B Cochran 18 March 1985 The tails inventory as of October 1978 was: 140,000 MTU at 0 20 percent U-235 78,000 MTU at 0 25 percent U-235 35 600 MTU at 0 35 percent U 235

127 DOE, Enclosure to letter from J W Parks to Thomas B Cochran 6 January 1986

128 HAC FY 1986 EWDA Part 7, p 664-65 The cost of oralloy is assumed to be $24 33/g U-235 (1985 dollars) and feed costs are excluded

129 *Nuclear Fuel* (20 May 1985): 2-3; HAC FY 1986 EWDA Part 7 p 746

Table 3 21

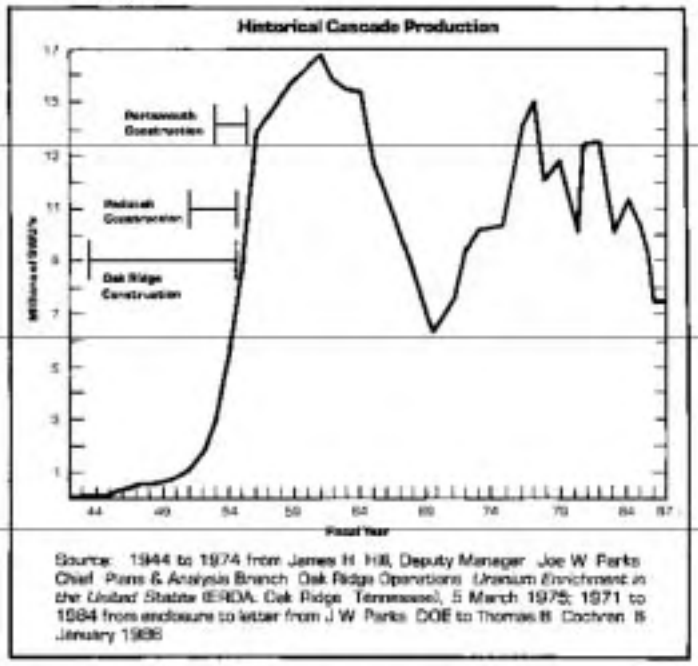
DOE Uranium Enrichment Production, Sales, and Inventories

(FY 1971-84)

Thousands SWU at Production Tails Assay

		Sales			Ending Inventories		
FY	Production	Civilian Lease/Sale	Government	Total Sales	Work In Process	Finished Product	Total
1971	9640	6991	1945	8836	434	13,232	13,666
1972	8353	5166	253	5419	897	15,713	16,600
1973	10,355	7657	521	8178	1398	17,379	18,777
1974	10,415	12,203	238	12,441	1500	15,251	16,751
1975	11,627	6558	422	6980	1927	19,471	21,398
1976	14,263	7378	613	7991	2224	24,545	26,769
TQ	3751	2069	89	2158	2453	25,675	28,128
1977	15,090	9099	1422	10,521	2292	29,459	31,751
1978	12,550	11,234	1174	12,408	1620	30,029	31,649
1979	13,670	13,922	871	14,793	356	32,325	32,681
1980	10,817	9995	820	10,815	274	32,409	32,683
1981	9620	10,480	1360	11,840	623	29,940	30,463
1982	9777	13,698	1538	15,236	460	24,544	25,004
1983	10,177	13,799	1277	15,076	151	19,964	20,115
1984	11,348	10,779	1559	12,338	1043	19,082	19,125
1985	10,400						
1986	7600	9300	1700				
1987	7600	9400	2100				

Sources: For 1971-84: DOE, Enclosure to letter from J W Parks to Thomas B Cochran, 8 January 1988; estimates for FY 1985-87: HAC, FY 1987 EWDA, Part 4, p 1797



Source: 1944 to 1974 from James H Hill, Deputy Manager, Joe W Parks, Chief, Plans & Analysis Branch, Oak Ridge Operations, *Uranium Enrichment in the United States* (ERDA, Oak Ridge, Tennessee), 5 March 1975; 1971 to 1984 from enclosure to letter from J W Parks, DOE to Thomas B Cochran, 8 January 1988

Figure 3 5 Historical separative work production. Annual separative work (in millions of Kg SWU) performed by the three U S gaseous diffusion enrichment plants. The enriched uranium product has been used for weapons and as reactor fuel

Conversion Facility at the Y-12 plant [130] This facility, last used in 1964, converts UF_6 from the enrichment plants to UF_4, an intermediate step subsequent to conversion to metal [131] The deteriorated facility will require extensive refurbishment and restoration over a four-year period (FY 1985-88) at an estimated cost of $20 6 million [132]

Resumed production of HEU for weapons is planned for FY 1988 This early date was set to meet the demand from new weapon designs with different mixes of materials, to expand the stockpile, to rebuild the reserve, and to offset retirement bottlenecks

A drop in the stockpile size and total yield suggests that HEU weapon requirements have been reduced since 1965 The historical trend has been to use less HEU in the fission cores of smaller and lighter weapons that rely more heavily on plutonium Some new warheads entering the stockpile are altering this trend Greater amounts of HEU are used to achieve higher yields and higher yield-to-volume ratios Higher yields are achieved by substitution of HEU for depleted uranium as, for exam-

130 HAC FY 1985 EWDA, Part 6, pp 555-56
131 HAC FY 1985 EWDA Part 4 pp 385 88
132 Ibid

3

Deuterium and Heavy Water Production

Table 3 22
Enrichment Requirements for One Kilogram of Product

Product Use	Product Assay (%U-235)	Uranium Feed Required (kg)	Feed Assay (%U-235)	Enrichment Tails Assay (%U-235)	Separative Work Required (kilogram SWU)
Naval Fuel	97 3	190 0	0 711[a]	0 2	261 0
Naval Fuel	97 3	55 5	1 95	0 2	132 0
Weapons	93 5	182 6	0 711[a]	0 2	236 9
Weapons	93 5	42 4	2 4[b]	0 2	108 9
SRP Driver Fuel	60 0	116 0	0 711[a]	0 2	147 0
Power Reactors	3 0	5 48	0 711	0 2	4 3
Mark 15 Fuel	1 1	1 76	0 711[a]	0 2	0 53

a Natural uranium feed

b Assumes HEU production from existing LEU stockpile

Table 3 23
Uranium Inventories at the Enrichment Plants
(As of 30 September 1984, in kilograms)

	Normal	Enriched	Depleted
Oak Ridge GDP			
Element	7,241,764	4,155,672	38,931,917
Isotope	51,499	101,930	86,250
Paducah GDP			
Element	21,791,217	2,334,770	193,485,003
Isotope	154,936	19,673	426,525
Portsmouth GDP			
Element	8,730,548	333,932	53,395,618
Isotope	62,074	9,741	123,392
Total Element	37,763,529	6,824,374	275,812,538
Total Isotope	268,499	131,244	636,167

Source: P T Marquess, DOE Oak Ridge Operations Letter to Thomas B Cochran 18 March 1985

ple, in the PEACEKEEPER/MX W87 warhead [133] Higher yield-to-volume ratios are achieved by substituting HEU for lithium deuteride

Since HEU is supplied for new warhead production mostly from retirements, disruption of a planned retirement schedule can also affect the availability of HEU

The 1000 W33 8-inch artillery-fired atomic projectiles, for example, contain some 60 to 70 MT of HEU, or roughly 10 percent of the entire HEU inventory [134] Retirement of these artillery shells, planned for the late 1970s, was held up due to several factors Delays were caused by controversy over production and deployment of the original "neutron bomb" replacement, subsequent production problems with the replacement, and military reluctance to remove W33s from Europe without replacements

Deuterium and Heavy Water Production

Deuterium (symbol D), the stable isotope of hydrogen with one proton and one neutron in the atomic nucleus, occurs in ordinary water with a natural abundance of approximately one part in 6500 (0 015 mole percent) of the element hydrogen [135] The isotope was discovered by Urey in 1932 as a component of liquid hydrogen in which deuterium had been concentrated by evaporation [136]

Deuterium in high concentrations is produced in the form of heavy water (D_2O) through processes that increase the proportion of deuterium to hydrogen atoms in water (H_2O); far beyond natural occurrance Heavy water with a (D_2O) purity of 99 75 percent or higher is produced routinely

In practice, slight differences in the chemical properties of heavy water and natural water are exploited, through processes of distillation and chemical exchange, to bring about the separation of the heavy water from natural water Various isotope separation processes have been developed and engineered for concentrating heavy water (and deuterium) (see Chapter Five, Heavy Water Production) In the United States, Canada, and other countries it has been the practice to utilize several processes as the concentration increases from 0 015

133 SASC, FY 1983 DOD, Part 7 p 4966

134 The W33 is a gun assembly oralloy fission weapon LITTLE BOY the bomb dropped on Hiroshima, was a gun assembly weapon containing 60 kg of oralloy (see Nuclear Weapons Databook Volume 1 Chapters One to Three)

135 This is for rivers and lakes in eastern North America where most of the world's heavy water has been produced Benedict op cit p 710 In the atmosphere of Venus the concentration is 100 times greater Science (7 May 1982) 630

136 H C Urey F G Brickedde and G M Murphy Physical Review 40 1(1932)

Table 3 24

Uranium Inventories at Other Sites

(As of 30 September 1984, in kilograms)

Organization	Natural	Enriched	Depleted
AiResearch			
Element	15	0	0
Isotope		0	0
Ames Laboratory			
Element	63	1	18
Isotope		*	*
Argonne National Laboratory - Plutonium Holding Area			
Element	59	1	952
Isotope		1	2
Babcock & Wilcox, Lynchburg			
Element	0	1629	13
Isotope		62	*
Battelle, Pacific Northwest Lab			
Element	911	3322	22,391
Isotope		127	42
Chicago Operations Office			
Element	20	0	0
DOE Environmental Measurements Laboratory			
Element	2	0	0
EG&G Idaho, Inc			
Element	0	5794	2718
Isotope		935	5
Fast Flux Test Facility			
Element	2506	39	1860
Isotope		13	3
Fermi National Laboratory			
Element	0	0	5373
Isotope		0	9
GA Technologies, Inc., San Diego			
Element	0	0	1000
Isotope		0	1
General Electric, Vallecito, CA			
Element	125	1	33
Isotope		*	*
General Electric, San Jose, CA			
Element	33	0	0
Isotope		0	0
Hanford Engineering Development Laboratory			
Element	3062	389	26,936
Isotope		148	50
IRT Corp., San Diego, CA			
Element	0	2	0
Isotope		*	0
LLNL, Mercury, NV			
Element	0	0	2541
Isotope		0	6
MIT			
Element	2512	2275	76
Isotope		55	*
Oak Ridge Assoc Univ			
Element	45	less than 1	76
Isotope		less than 1	
Oak Ridge National Laboratory			
Element	9603	0	43,579
Isotope		0	81
Oak Ridge Operations			
Element	39	1	4
Isotope		less than 1	0
Pennsylvania State Univ			
Element	2500	935	1
Isotope		69	*
Princeton Plasma Laboratory			
Element	0	0	3
Isotope		0	*
Purdue University			
Element	12,740	4069	2
Isotope		114	*
Rockwell Hanford Operations			
Element	1030	404,726	130,259
Isotope		3458	339

Table 3 24
Uranium Inventories at Other Sites (continued)
(As of 30 September 1984, in kilograms)

Organization	Natural	Enriched	Depleted
Rockwell Intl , Santa Susana, CA			
Element	3752	26	14,185
Isotope		10	31
Rockwell Intl , Rocketdyne			
Element	0	0	339
Isotope		0	1
Stanford Linear Accelerator Center			
Element	0	0	69,156
Isotope		0	110
Stanford University			
Element	9	0	0
Savannah River Operations Office			
Element	16	11	29
Isotope		*	*
TRW Systems			
Element	1198	10	59
Isotope		*	*
UNC Nuclear Industries			
Element	5901	4,652,320	10,891
Isotope		40,036	51
University of California Lawrence Berkeley Laboratory			
Element	123	0	2589
Isotope		0	3
University of Puerto Rico			
Element	1413	less than 1	0
Isotope		less than 1	0
University of Virginia			
Element	13	less than 1	11
Isotope		less than 1	0
TOTAL (MT)	47 7	5075	335

* Means less than a reportable quantity

Source P T Marquess DOE Oak Ridge Operations Letter to Thomas B Cochran 18 March 1985, Robert A O'Brien Jr DOE Washington DC Letter to Thomas B Cochran 17 April 1985

percent to the desired reactor-grade concentration of 99 75 percent or higher

Reactor-grade heavy water has been produced in the heavy water production facility (now on standby) at the Savannah River Plant This plant uses a combination of the dual-temperature hydrogen sulfide extraction process and the distillation process (see Savannah River Plant, Heavy Water Plant, Volume III) Between the years 1952 and 1957, heavy water was also produced in the United States at the Dana Plant in Newport, Indiana [137] Heavy water from the Dana and Savannah River Plants has been used for the moderator and coolant in the SRP production reactors Approximately 250 MT of D_2O is required for the initial loading of each SRP reactor [138] Heavy water from the Savannah River facility has also been used in DOE test reactors, privately owned research reactors in the United States, and in foreign reactors

In May 1982, DOE announced the termination of heavy water production at Savannah River (as well as its sale) The plant capacity had already been reduced to 90 MT per year DOE claimed at that time to have an inventory that would last into the 1990s,[139] including requirements for the restart of the L-Reactor [140] The heavy water rework unit remains in operation (this recovery facility consists of four distillation towers) to remove H_2O that has accumulated in the coolant during reactor operation [141] The heavy water production facility, although officially on standby, will probably never be restarted [142]

The second important use of heavy water is as a source of deuterium for the fusion yield warheads of

137 The Dana Plant was constructed on the Army Depot at Newport Indiana (near Dana) and operated for the AEC by E I duPont de Nemours & Co It was placed on standby in 1957, and on 29 July 1959 ownership was transferred from the AEC to the Army Chemical Corps to permit modification of the facilities for other uses [John P Hogerton The Atomic Energy Deskbook (New York Reinhold Publishing Corporation, 1963) p 120

138 E K Dukes and R W Benjamin, Savannah River Plant Airborne Emission Controls DPST 82-1054 Savannah River Laboratory Aiken S C p 6-1

139 Nucleonics Week (3 June 1982)

140 Environmental Information Document L-Reactor Reactivation E I duPont Savannah River Laboratory Aiken South Carolina DPST-81 241 p 5 134

Table 3 25

U.S. Heavy Water Production, Sales and Inventory

FY	Maximum Capacity (MT/yr)	Production (MT)		Sales (MT)		
		Annual	Cumulative	Annual		Cumulative
				Domestic[o]	Total	
Manhattan District Plants						
1942-45	14[a]					
Consolidated Mining and Smelting Co of Canada, Ltd , Trails, BC, Canada						
1945-55	6 9[b]					
Dana Plant, Wabash River Ordnance Works, Newport, IN[c]						
1952-57	410[d]		1500[e]			
Savannah River Plant (first product October 1952)						
1952				0 0	0 0	0 0
1953				0 0	0 0	0 0
1954				0 0	1 81	1 81
1955				0 0	0 0008	1 81
1956	450-480[f]			0 16	84 03	85 84
1957	app 320[f]			0 05	70 65	156 48
1958	app 177[f]			0 45	86 20	242 69
1959				0 41	53 50	296 19
1960				0 45	77 94	374 13
1961				0 95	88 29	463 42
1962				0 91	70 39	533 81
1963				1 72	34 73	568 54
1964				9 43	34 52	603 06
1965				2 95	69 57	672 63
1966		178[g]		3 40	86 83	759 46
1967		207[g]		12 25	382 25	1141 71
1968				10 07	88 55	1230 26
1969				9 84	315 65	1545 91
1970				5 53	562 42	2108 33
1971				2 54	699 26	2807 59
1972				4 54	250 18	3057 71
1973				3 75	386 83	3444 60
1974				4 85	60 12	3504 72
1975				3 08	4 24	3508 96
1976(15mo)[g]			5300 00[p]	5 38	5 38	3514 34
1977				0 14	12 12	3526 46
1978				0 86	1 03	3527 49
1979[n]				3 27	10 09	3537 58
1980[h]		65[h]	5600 00[p]	1 54	10 51	3548 09
1981	90[f]	65[i]		1 91	7 71[k]	3555 80
1982[o]				4 40	4 54[l]	3560 34
1983				0 0	0 00	3560 34
1984				0 0	0 45	3560 79

a Combined production capacity of Manhattan District Plants at Morgantown WV Childersburg AL and Newport IN Donald W Kuhn D_2O-H_2O Separation in *Reactor Handbook*, Vol 1 *Materials* edited by C R Tipton Jr (New York: Interscience Publ 1960) p 50

b In 1955 this plant was still manufacturing heavy water at 6 9 tons per year; *ibid*

c Production began in April 1952 operations were discontinued on 24 May 1957 and the plant was placed in standby on 23 August 1957; AEC Report to Congress July 1957 p 12

d Achieved within five years after startup; letter from F C Gilbert Acting Deputy Asst Sec for Nuclear Materials, DOE to Thomas B Cochran 17 September 1981 Benedict et al , *Nuclear Chemical Engineering* (New York: McGraw Hill 1981) p 711 gives 400 MT/yr as the most recent capacity of the Dana plant

e Gilbert *ibid*

f *Ibid*; see also Volume III Savannah River Heavy Water Plant

g Includes 3-month transition quarter

h HASC FY 1980 DOE p 285

i Projected values

j HASC FY 1982 DOE p 158

k The inventory at Savannah River included 800 MT of heavy water in reactors; SAC FY 1981 EWDA Part 2 p 788

l The inventory at Savannah River included 900 MT of heavy water in reactors; HASC FY 1980 DOE p 239

m The inventory at Savannah River included 916 MT in reactors and 638 MT out of reactors; *ibid*

n In 1978 demand for heavy water was projected to be about 34 MT/yr between FY 1978 and FY 1984 and about 60 MT/yr between FY 1985 and FY 1990; data derived from HASC FY 1980 DOE p 238

o Production of heavy water at Savannah River terminated in 1982; Nucleonics Week 10 June 1982)

p AEC Report to Congress January-December 1967 p 43 Values given are for calendar year

* John L Meinhardt DOE Letter to Thomas B Cochran 29 April 1985

nuclear weapons For this purpose deuterium is either in the form of deuterium gas (D_2) or in compound with lithium as lithium deuteride (see *Nuclear Weapons Databook*, Volume I, Chapter Two) Deuterium gas processing and lithium deuteride production are both carried out at the Oak Ridge Y-12 Plant [143] D_2 is not recovered from heavy water at Savannah River prior to shipment to Y-12 [144] DOE is currently increasing lithium compound production and heavy water requirements at the Y-12 Plant [145]

Heavy water in small quantities was first made available for sale in the United States by the AEC on 1 May 1947 The first exports and large scale domestic sales of heavy water for use in reactors began in FY 1956 [146] Canada has been a major commercial producer of heavy water In 1984 Ontario Hydro of Canada was carrying its heavy water inventory at a book value of (Cdn) $375 per kilogram, while in its annual report Atomic Energy of Canada, Ltd (AECL) valued heavy water at about $270 per kilogram [147]

Data on U S heavy water production, sales, and inventory are presented in Table 3 25 Canadian data for the 1945-55 period are also included since the United States probably purchased heavy water from this source

Estimates place the United States production at approximately 7300 MT of heavy water Approximately 3600 MT were sold through February 1983 (see Tables 3 25 and 3 26) Approximately 1100 MT are in four Savannah River reactors An additional 525 MT is in storage at Savannah River This leaves a balance of approximately 2100 MT, a portion of which has been used or reserved for weapons

Table 3 26
U.S. Heavy Water Exports[a] and Imports[b]
(1 January 1954 through 28 February 1983)[c]

Country	Exports D_2O (MT)	Imports (Returns)
Argentina	198 722	
Australia	24 3615	0 3457
Belgium	0 531	
Canada	2207 453	77 6884
Denmark	16 4458	2 9853
France	203 7866	49 4531
India	32 6312	13 5971
Israel	3 9916	-
Italy	101 3301	22 335
Japan	93 783	-
Netherlands	1 406	1 3540
Norway	28 4868	-
Pakistan	17 4282	-
South Africa	5 4889	5 1834
Spain	4 6266	4 6207
Sweden	216 0753	25 0857
Switzerland	104 3139	-
Taiwan	2 4986	
United Kingdom	95 7826	
West Germany	353.5669	0.8922
TOTAL	3712 7096	203 5406

a Letter from Donald Paul Hodel Secretary of Energy to Richard L Ottinger House of Representatives, 10 May 1983 Enclosure 2
b DOE NMMSS Report U S Origin Imports, enclosure in letter from Robert A O'Brien Jr to Thomas B Cochran 13 December 1984
c There were no imports (returns) of U S origin heavy water prior to 1957 and in the years 1960 1961 1967 and 1975 to mid-1984 (the end of the report period)

Enriched Lithium Production

The metal lithium (symbol Li, atomic number 3, atomic weight 6 939) is found in nature as a mixture of two stable isotopes, lithium-6 (7 42 percent) and lithium-7 (92 58 percent) Lithium-6 has two principal nuclear weapon applications, as a reactor target and control rod material for the production of tritium, and as a thermonuclear weapon material in the chemical form lithium-6 deuteride In both cases tritium is produced by a neutron absorption process:[148] $n + {}_3Li^6 \rightarrow T + {}_2He^4$ Lithium constitutes approximately 0 006 percent of the earth's crust, making it more abundant than lead or tin [149]

Many processes can be used to enrich lithium in the isotope Li-6 In the U S nuclear program enriched lithium had been concentrated by a chemical exchange process in facilities at the Y-12 Plant [150] (See Volume III, Oak Ridge Reservation, Lithium Enrichment Facility) The production venture was begun in 1953 The material was needed for the 1954 thermonuclear weapons test, and it was necessary to build the enrichment plants before the feasibility of using lithium-6 had been verified [151] After a decade of activity, the enrichment plants were placed on standby in the early 1960s and later most were dismantled These plants were also the sole source of high purity lithium-7 (99 7 percent-99 9 percent) for commercial use [152]

Currently at Y-12, metallic lithium-6 is chemically bonded with deuterium from Savannah River to produce lithium-6 deuteride, compacted into a chalk-like solid The pressed powder is then baked and machined to final

141 Environmental Information Document DPST-81-241
142 Dukes and Benjamin, op cit
143 Y 12 activities include the processing of lithium metal and deuterium gas, DOE "DOE Research and Development and Field Facilities June 1979 p V-42
144 Letter from F C Gilbert Acting Deputy Assistant Secretary for Nuclear Materials DOE to Thomas B Cochran, 3 September 1981
145 HAC FY 1984 EWDA Part 4 p 308
146 AEC Report to Congress January 1957 p 360
147 *Nuclear Fuel* (16 July 1984) 4
148 Lithium 7 may also make a significant contribution via neutron absorption in the reaction $n + {}_3Li^7 \rightarrow T + {}_2He^4 + n$
149 John F Hogerton *Atomic Energy Desk Book* (New York: Reinhold Publishing Corp 1963) p 125
150 Little is published in the unclassified literature about this process A brief description is provided in Volume III Processes Lithium Enrichment
151 Lee Bowen Vol IV The Development of Weapons p 33
152 AEC Report to Congress January 1960 p 4

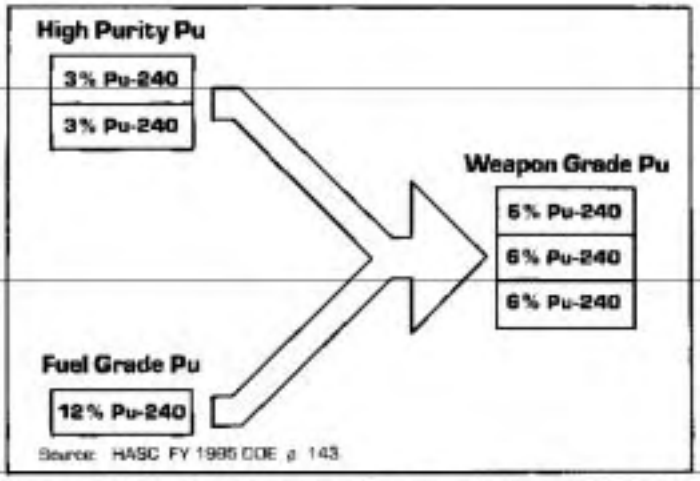


Figure 3 6 Blending Two parts of supergrade plutonium (3% Pu-240) when blended with one part fuel-grade plutonium (12% Pu-240) will produce three parts weapon-grade plutonium (6% Pu-240)

dimensions The result is a ceramic material so chemically unstable in the presence of moisture that it must be assembled in "dry rooms "[153] Dry room workers in the Y-12 Plant wear air-conditioned waterproof body suits with sealed helmets to keep their body moisture from causing the lithium-6 deuteride to decompose [154]

The lithium-6 deuteride components are shipped from Y-12 to the Pantex Plant for the final assembly of weapons Enriched lithium recovered from retired weapons is recycled to the weapon program and is used to make reactor targets for tritium production [155]

In the early 1950s the AEC began purchasing lithium hydroxide in quantities amounting to several million pounds annually Purchases continued into 1959 when they were stopped as abruptly as they started [156] The lithium hydroxide that was acquired by the AEC, presumably for the weapons program, came from three sources: the Lithium Corporation of America (Lithco) in Gastonia, North Carolina (now a subsidiary of Gulf Resources and Chemical Corporation of Houston, Texas); the Foote Chemical Company in Exton, Pennsylvania; and American Potash, which is now absorbed into the Kerr-McGee Corporation Except for some lithium processing carried out on a very small scale under government contract by Lithco, these companies have not, since 1959, supplied or procured lithium for the weapos program

Thus the enriched lithium for weapons and production reactor targets appears to be derived almost solely from government purchases of lithium hydroxide between 1950 and 1959 [157] Existing stocks of enriched lithium are apparently sufficient for the needs of the weapons program A lithium enrichment plant at the Y-12 Plant in Oak Ridge is officially maintained on "standby condition,"[158] but it is probably either dismantled or requires upgrading before it is capable of restart [159]

Approximately 42,000 MT of lithium hydroxide monohyrdate ($LiOH \cdot H_2O$)—from the quantities purchased by the government for the nuclear weapons program between 1950 and 1959—have been transferred to the General Services Administration (GSA) and advertised for sale since about 1968 This represents only a portion of the lithium hydroxide purchased by the government during the 1950s Of the amount transferred, 6450 MT of material depleted in lithium-6 (containing 965 MT of lithium) were sold for commercial purposes from FY 1968 through FY 1978 [160] No further sales were made until FY 1982 The GSA excess stock in 1981 was reported to be 25,850 MT of depleted material (containing 4270 MT lithium) and 10,400 MT of virgin material (containing 1720 MT lithium) [161]

A lower limit to the quantity of enriched lithium metal in the U S defense programs stockpile is estimated to be some 390 MT [162] This estimate is based upon the amount that could have been produced in the enrichment plants leaving 31,700 MT of depleted material A second estimate is 1500 MT This estimate assumes all of the deuterium in the 2500 MT of heavy water available for weapons was combined with enriched lithium to produce lithium deuteride

Non-nuclear Material Production

Beryllium. Beryllium metal (symbol Be, atomic number 4, atomic weight 9 0122) is used in non-nuclear components of nuclear weapons It serves as a neutron reflector and neutron amplifier in nuclear warheads At an earlier stage in the design of nuclear weapons, beryllium was an important component of neutron initiators Neutrons to initiate the fission reaction were produced by the interaction of alpha particles from the radioactive decay of polonium with beryllium [163] Beryllium components are manufactured primarily, if not exclusively, at the Rocky Flats Plant Beryllium is also suitable as a neutron reflector and moderator material in nuclear reactors It is a highly toxic material

Production In the mid-1950s beryllium requirements were met by a government-owned plant at Luckey, Ohio operated by the Brush Beryllium Co In 1955 AEC invited proposals to supply beryllium from private industry Subsequently the material was supplied solely by commercial sources [164]

153 Howard Mucland *The Secret that Exploded* (New York: Random House 1981) p 283
154 Ibid
155 HASC FY 1981 DOE p 572
156 Foote Chemical Company Exton Pennsylvania Brochure for Chemicals and Minerals Division
157 There are no commercial sources of Li-6 A pilot plant for high purity Li 7 for the nuclear power industry operated since 1977 by Eagle Picher Industries in Quapaw Oklahoma produces negligible amounts of Li-6 Currently the principal source of Li 7 for commercial sale is Oak Ridge A full-scale $50 million plant is being designed by Eagle Picher It would be built for DOE on a cost-plus fixed-fee basis The plant will utilize the most advanced laser enrichment techniques instead of a chemical exchange process involving lithium amalgam Plant capacity will be a few hundred kg per month and by-product Li-6 will be sold to the government
158 HAC, FY 1985 FWDA Part 4 p 257
159 As of FY 1982 the General Services Administration had for sale 280 000 flasks of mercury used in the lithium isotope separation process at Y 12
160 Readus Long GSA private communication
161 John K Fessel and James P Searle "Lithium 1981 Bureau of Mines Minerals Yearbook Preprint U S Department of the Interior Only about 9 MT of this stock were sold between FY 1982 and the first quarter of FY 1985 An additional 17 MT of depleted

Currently Brush-Wellman, Inc of Elmore, Ohio (formerly Brush Beryllium) is the only large United States commercial producer of beryllium concentrates Low-grade bertrandite ore mined in Utah is the major commercial source of beryllium ore Imports of beryl, a silicate of beryllium and aluminum ($3BeO \cdot Al_2O_3 \cdot 6SiO_2$) augment the domestic supply of ore concentrates, and there is a small domestic output of beryl

Brush-Wellman converts both beryl and bertrandite ore to beryllium at its plant in Delta, Utah The company has initiated a program to stimulate domestic and foreign beryl mining, to make use of its beryl ore processing capacity Brush-Wellman plans to modify the Delta plant by mid-1983 to process lower grade beryllium ore [165] The company uses the Sawyer-Kjellgren process to produce reactor-grade metal and beryllium oxide (BeO) from beryl Domestic production consists of beryllium metal, beryllium oxide, and beryllium-copper master alloy [166]

The Cabot Berylco Division (formerly Kawecki-Berylco Industries, Inc) of the Cabot Corporation produces beryllium-copper and other beryllium alloys at its plant in Reading, Pennsylvania The plant uses imported and domestic ores that have been converted to beryllium oxide [167]

In 1980 the manager of the Albequerque Operations Office, testified, "Only one company [probably Brush Wellman] in the U S manufactures beryllium to DOE specifications Previously there were two "[168]

The projected weapon requirements for beryllium were set out in 1979 by the Assistant Secretary for Defense Programs: "If we look at the requirements through 1986 which are in the present stockpile paper , our estimate is it will require about 125,000 pounds of beryllium oxide to fulfill the need of that stockpile "[169]

Beryllium is inventoried by the government for the National Defense Stockpile of strategic materials Holdings as of 31 March 1984 are 18 0 tons of beryl ore (11 percent Be), 7 4 tons of beryllium copper master alloy, and 229 tons of beryllium metal [170]

Other Non-nuclear Materials. Gold, a metal used in nuclear weapons, is purchased by the government on the open market In addition to gold and beryllium, other non-nuclear materials that might be incorporated into nuclear warhead components—aluminum, chromium, nickel, tin, titanium, and tungsten—are acquired by the government as part of the National Defense Stockpile inventory of strategic and critical materials

Initiatives to Increase Production

The Carter administration began plans to upgrade the nuclear weapons production complex These plans have given rise to several initiatives to increase the production of nuclear materials, principally plutonium and tritium President Carter bequeathed to President Reagan an accelerated set of warhead production goals These were contained in Carter's last NWSM, signed on 20 October 1980, and in his FY 1982 budget request Upon entering office, Reagan provided an FY 1982 budget of his own, increasing the DOE Defense Programs request by almost $300 million, to just over $5 billion The materials production budget, alone, increased from $837 million to $931 million [171]

The Reagan administration, in addition to taking on Carter administration production accelerations, also added new requirements In August 1981 Reagan announced that enhanced radiation weapons would be produced, reversing the Carter moratorium On 2 October 1981, President Reagan unveiled his five-part strategic weapons modernization program [172] Reagan's first NWSM, signed on 17 March 1982, called for a different mix of weapons that, coupled with certain technological developments, drove materials production requirements even higher Smaller size weapons with higher yield-to-weight ratios required more plutonium per weapon And additional supplies of tritium would be needed for enhanced radiation weapons

Reagan's second Stockpile Memorandum, signed 18 November 1982, reinforced production goals In approving the NWSM, he had declared that, " as a matter of national policy, [a]rbitrary constraints on nuclear materials availability shall not be allowed to jeopardize attainment of the forces required to assure our defense and maintain deterrence "[173] This memorandum included, apparently, a plan to create "sufficient reserves" of special nuclear material (SNM),[174] needed "as insurance against unforseen SNM production interruptions and to allow for surge capacity "[175] The required plutonium "reserve" was set at some 5 MT By the time Reagan's third NWSM was signed on 16 February 1984,[176] plans to build up the inventory of HEU had also been established, signalling a move to increase the yield of new warheads

The size of the U S nuclear weapons stockpile has increased slightly since 1982 As a DOE official stated in March 1983, the number of weapons in the stockpile was expected to increase by 13 percent by the end of FY

material was sold directly from DOE inventories in FY 1982 and FY 1983; Residue Long GSA private communication

162 At 100 percent efficiency this would provide a fusion yield of about 30 000 MT

163 The W33 gun assembly type warhead which has been in the stockpile since 1956 uses a polonium beryllium neutron initiator

164 AEC Report to Congress, January 1956

165 Benjamin Pethof Beryllium, 1981 Bureau of Mines Minerals Yearbook Preprint U S Department of the Interior 1981 p 1

166 Ibid

167 Ibid

168 HASC FY 1981 DOE p 184

169 HASC FY 1980 DOE p 286

170 FEMA Stockpile Report to the Congress October 1980-March 1984 October 1984 p 22

171 Comparison of the Carter Budget Justifications in HAC FY 1982 EWDA Part 6 with Reagan s in HAC FY 1982 EWDA Part 5

172 For an extensive discussion see SASC Strategic Force Modernization Programs Hearings and SASC Modernization of the U S Strategic Deterrent Hearings

173 DOE FEIS L-Reactor Vol 1 p 1 2

174 DOD FY 1984 Annual Report, p 277 There was no mention of a reserve the year before

175 Office of the Assistant to the Secretary of Defense (Atomic Energy) The Nuclear Weapons Production and RD&T Complex—DOE Support of DOE Requirements December 1982, p 2 See also HASC FY 1984 DOE pp 126-27

176 HAC FY 1985 EWDA Part 6 pp 554-55 761

1988 [177] Nonetheless, technical problems in production, funding constraints, and political controversy over certain warheads have held back these projections significantly

Increased production trends are reflected in the budgets for materials production and in the increased employment in the production complex The budget for materials production has gone from $506 million in FY 1980 to $1 741 billion in FY 1985 [178] In just these three years employment has grown at materials facilities from 9700 in FY 1981 to 21,400 in FY 1984 [179]

A number of initiatives designed to increase the amounts of plutonium and tritium, and HEU available for the weapons program are shown below:

- The Facility Restoration Program
- Blending
- N-Reactor Conversion
- PUREX Reactivation
- L-Reactor Upgrade
- High Productivity Cores
- U-236
- New Production Reactor
- Special Isotope Separation (SIS)
- PUREX Modification

The near-term programs have served to expand the productivity of present facilities or revive dormant ones The longer term programs call for building a new production reactor as well as using new technologies to process material more efficiently The total cost of these initiatives is well over $2 billion, plus $3 to $6 billion more if a new reactor is built

Facility Restoration

The *Facility Restoration* program was begun in FY 1981 as a general multiphase effort to improve and restore operations throughout the materials production complex The seven-year program is estimated to cost $462 million (FY 1985)[180] by completion It will have made equipment replacements and system improvements at the production sites, Savannah River and Hanford, and at the feed plants, Fernald, Ashtabula, and Y-12 [181] Idaho National Engineering Laboratory, although excluded from this initiative, has its own restoration program to upgrade and expand the ICPP for receiving increased quantities of spent naval reactor fuel, separating the uranium for recycle, and storing the waste

Blending

At production sites, several initiatives have contributed directly to increasing the output of plutonium for weapons Prior to FY 1981, the Savannah River reactors produced weapon-grade plutonium The *Blending* program initiative, started in FY 1981, converted the reactors to the production of supergrade (3 percent Pu-240) plutonium By mixing supergrade with fuel-grade plutonium from Hanford, about 50 percent more weapon-grade plutonium is produced than with the reactors alone [182]

The first supergrade production occurred in April 1981 [183] By FY 1983 the conversion was complete in two reactors (P, K), and the third (C) was producing tritium Accelerated reactor operations for supergrade production required halving the target irradiation time and doubling the fuel throughput This increased target fabrication activities at Fernald, Ashtabula, and Savannah River and expanded the volume of irradiated targets processed at Savannah River

N-Reactor Conversion and PUREX Reactivation

At Hanford, two initiatives—*N-Reactor Conversion* and *PUREX Reactivation*—brought additional plutonium into the weapons program relatively inexpensively and quickly First conversion of the N-Reactor from the production of fuel-grade plutonium to the production of weapon-grade plutonium began in early 1982 and was completed by October The conversion increased weapon-grade plutonium production by some 600 kg per year Fuel requirements jumped to more than twice those for fuel-grade production The FY 1983 budget included $34 4 million to support increased fabrication requirements at the feed plants, Fernald, Ashtabula, and Hanford In addition, most of the fuel charge-discharge and handling equipment at the N-Reactor had to be overhauled and modified The N-Reactor plutonium could not be recovered, however, without an operating reprocessing plant The PUREX reactivation program was thus funded in the FY 1981 budget In November 1983 it began operations five months ahead of schedule, creating its first product in February 1984 [184] It was needed to process newly irradiated N-Reactor fuel and to recover fuel-grade plutonium (about 4 MT) from spent fuel in storage since 1972 The latter was needed for blending Reactivating the plant cost $195 million Annual operating costs are $71 million with another $21 million for waste management [185] Other options have been suggested to increase N-Reactor production further One was to increase power some 10 to 15 percent [186] The

177 HASC, FY 1984 DOE, p 19

178 HAC FY 1982 EWDA, Part 5, p 226; House Report 98-1080 DOE Authorization Conference Report, 26 September 1984, pp 347-49

179 HASC FY 1982 DOE, p 121; HASC FY 1984 DOE, p 133; Nevertheless as DOE officials told Congress in early 1985 "We have been barely staying above the demand curve HASC, FY 1986 DOE, p 18

180 HASC, FY 1985 DOE, p 144

181 HAC, FY 1982 EWDA, Part 5, p 538; HAC FY 1983 EWDA, Part 4, p 262; HASC FY 1983 DOE, p 377; HASC FY 1983 DOE, p 351; HAC FY 1984 EWDA Part 6, p 532; HAC FY 1985 EWDA Part 6, p 865

182 Blending (see Figure 3 5) combines two parts of supergrade (3 percent Pu-240) plutonium with one part of fuel-grade (12 percent Pu-240) plutonium to obtain three parts of weapon-grade (6 percent Pu-240) plutonium

183 HASC FY 1983 DOE, p 278

184 HASC FY 1985 DOE, p 144 The PUREX fuel processing plant which had operated from 1956 to 1972 was on standby

185 HASC FY 1985 DOE, p 144

186 HASC FY 1983 DOE, p 243

187 Ibid, p 239

188 Senate Report No 97-673 EWDA 1983 6 December 1982, p 93

other suggestions was producing plutonium with 5 percent Pu-240 for blending[187] instead of 6 percent Congress has denied funding, stating that DOE "has proposed several new and expensive initiatives that appear to provide only marginal supply contributions "[188]

L-Reactor Restart

The L-Reactor Restart was another early production initiative proposed by DOE It was to add a fourth operating reactor at Savannah River, thereby increasing production capacity by one third The L-Reactor was placed on standby status in February 1968, during a period of decreased demand for nuclear materials Although the initiative was proposed in late 1980 and funded soon after, the L-Reactor startup was delayed to meet state and federal environmental regulations This occurred despite a Presidential directive to restart the reactor "as soon as possible, but no later than October 1983 "[189] The reactor was restarted on 31 October 1985 and began producing supergrade plutonium for blending [190] The total cost of upgrading the L-Reactor is estimated at $190 million [191]

High Productivity Cores and U-236 Recovery

At Savannah River, two further initiatives, both leading to increased reactor productivity, are High Productivity Cores and U-236 Recovery program The first involves reactor core design changes that would increase plutonium productivity A proposal, first advanced in 1981, was to increase productivity by about 25 percent by replacing the Mark 16/31 cores used in Savannah River reactors with a uniform core of slightly enriched (1 1 percent U-235) Mark 15 fuel assemblies [192] The replacement was considered as early as 1972 [193] A demonstration performed in the K-Reactor in August and September of 1983 verified design and operability [194] But the Mark 15 program has proved controversial Congress cut funding the past several years due to the cost of enrichment In FY 1985, Congress cut $90 5 million, all that had been earmarked for enrichment, out of the $113 5 million budget [195] DOE placed the enrichment costs at $300 million over the next two to three years [196] Thus far, from FY 1983-85, $45 7 million has been authorized exclusive of enrichment In the face of continual Congressional budget cuts DOE is assessing an alternative, the Mark 22S/25 core This core consists of Mark 25 highly enriched uranium drivers and Mark 22S natural uranium targets It would provide about half the productivity increase of the Mark 15 at about 40 percent of the cost [197] The high productivity cores will be tested in 1986

Table 3 27
Typical Isotopic Content of SRP Recycle Uranium

Isotope	Without PSP (percent)	With PSP (percent)
U-234	1 6	1 2
U-235	49 0	68 7
U-236	35 0	25 8
U-238	14.4	4.3
	100 0	100 0

Source: J B Allender and A E Chalk, DPST-83-696 Savannah River Laboratory Technical Division 21 October 1983 p 10

The goal of the U-236 Recovery program at Savannah River is to "purify" the recycled HEU that is fabricated there into driver fuel for the production reactors Since 1983 Savannah River Laboratory (under contract with TRW, Inc) has been developing the Plasma Separation Process (PSP) PSP would recover the isotopes U-236 and, to a lesser extent, U-234 and U-238 All three build up during continued fuel recycle and irradiaton [198] The concentration of U-236 may be as high as 35 percent Left in, these non-fissile isotopes absorb neutrons and result in significant production loss during reactor operation Removed, reactor efficiency increases and the need for additional HEU decreases

Typical isotopic concentrations in SRP recycle uranium, with and without purification, by PSP are shown in Table 3 27 The PSP facility planned by DOE will process approximately 4 2 MT of uranium metal feed into 2 8 MT of product and 1 4 MT of tails [199] DOE estimates that by using PSP some 11 7 MT to 13 1 MT of U-235 can be recovered from the "half-billion dollar" stockpile of enriched uranium at the Savannah River Plant [200] In FY 1984, DOE spent about $20 5 million on the PSP effort In FY 1985, $10 7 million will be used to procure PSP

187 November 1981 approval directive to the FY 1983-1988 NWSM as quoted in affidavit of Herman E Roser Assistant Secretary for Defense Programs, DOE 19 May 1983, in NRDC et al v William A Vaughan et al C A No 83-3173 (D D C) Congress directed the DOE to prepare an EIS thus delaying the restart of the L-Reactor On 15 July 1983 the U S District Court also directed DOE to prepare and publish an EIS as soon as possible NRDC et al v William A Vaughn et al 15 July 1983

188 HAC FY 1984 RWDA Part 4 p 303; DOE FEIS L Reactor Vol 1 p 1-6

189 HASC FY 1985 DOE p 133

190 This would be the heaviest reactor core loading in Savannah River history; DOE Safety Analysis of Savannah River Production Reactor Operations Savannah River Laboratory, DPST-108 1 Rev 12/81 p 4-12 The Mark 15 uniform lattice design would be the most efficient core that can be accommodated at SRP; DOE FEIS L Reactor Vol 1 p 1-6

191 Smith, *Safety Analysis*, p V-25

192 DOE FEIS L Reactor Vol 1 pp 2 7 1-8

193 From the enrichment costs one can estimate the uranium fuel requirements for this program $80 million at $83 per SWU (FY 1984) would have supplied 0 536 million SWU (or about 1000 MTU [1 1 percent U 235]); $90 5 million at $96 per SWU (FY 1985) would have given 0 943 million SWU or some 1750 MTU (1 1 percent U 235) all at 0 2 percent tails

194 DOE FEIS L Reactor Vol 1 pp 2 7 1-8

195 HASC, FY 1985 DOE p 145

196 HAC FY 1984 RWDA Part 6 p 851 HASC FY 1985 DOE p 145

197 PSP was a TRW funded uranium enrichment program prior to FY 1977 when ERDA awarded TRW a contract for the performance of experimental and analytical studies toward development of source, separator, and collector subsystems that would produce samples of enriched uranium Extensive facilities were built to support DOE-sponsored work at TRW By the end of FY 1983 total government expenditures were about $89 million TRW invested some $10 3 million of corporate funds on PSP development through mid 1983

198 L W Gray Closing the High-Enriched Uranium Fuel Cycle at SRP, memorandum to H O Harason Savannah River Laboratory Technical Division DPST 83-554 4 August 1983 revised 18 January 1984

199 According to DOE cost-benefit analyses Based on a $34 20/g value of U-235 in uranium enriched to around 90% the stockpile would have a disposal value of $480 to $450 million by FY 2000 Memorandum from J S Allender et al to M R Beckner et al Savannah River Laboratory 3 June 1983 According to recent testimony once in operation the U-236 will result in annual net savings of $37 6 million per year equivalent to about 1 MT of 90 percent enriched uranium per year

equipment from TRW, Inc [201] A single module PSP plant may start operation at Savannah River in FY 1987 and reach full production the following year The total cost of the PSP plant is an estimated $90 million (FY 1985)

New Production Reactor

Construction of the last U S production reactor was finished in 1963 Since 1980 several government studies have looked at possible designs and locations for a new tritium and plutonium production reactor (NPR) [202] Once authorized by Congress, the NPR would require about ten years to construct and would cost an estimated $3 billion to $6 billion, depending on the design [203] DOE plans were to submit recommendations to the President on a reactor concept and site [204] If approved, the reactor would be operational by the mid- to late-1990s [205]

DOE has given three reasons justifying an NPR:

- "to ensure the availability of tritium to meet long term national security requirements,"[206] because of an "increasing probability over time" that the Savannah River reactors "would become unavailable,"[207]to have an alternate site to Savannah River for the production of tritium and for plutonium once the N-Reactor is shut down, and
- to bolster deterrence, since "without a reactor in our planning, we are going to send a message to the world that we may not have a reliable stockpile "[208]

Most of the reactor technologies conceived or developed over the past forty years have, at some time, been considered for the NPR Three types of reactors at three possible sites were being examined: a heavy water reactor (HWR) at Savannah River, a HWR or a high temperature gas reactor (HTGR) at Idaho National Engineering Laboratory, and a HTGR or a pressurized-water reactor (PWR) at Hanford [209]

One NPR study known as the Glennon Report was issued in November 1982 by DOE's New Production Reactor Concept and Site Selection Advisory Panel The Glennon Report ranked as its first choice for the NPR the zero electric power heavy water reactor (ZEPHWR) at Savannah River It placed Idaho last, after Hanford, in its choice of sites [210] Subsequently, a study on nuclear materials needs written for the Office of Science and Technology Policy emphasized the desirability of an alternate site to Savannah River for tritium and plutonium production An earlier study on materials needs by UNC Nuclear Industries had narrowed the production alternatives to five reactor concepts [211]

Congress, following the lead of the House Armed Services Committee, has been reluctant to support a new production reactor In 1983 the Committee rejected the need for the NPR arguing that up to four Savannah River reactors would be available in the early 1990s due to a slack in demand for plutonium production [212] A year later the committee noted, "It would appear that a political assessment of state and local attitudes toward such a project should be made prior to selection of a site for other reasons "[213]

Originally, studies for the NPR concentrated on large reactors, comparable in power to the largest commercial reactors in the United States By 1985 DOE had broadened its studies to consider smaller reactors of the same type In 1986, DOE decided to defer indefinitely the NPR, pending the completion in mid-1987 of "life cycle" studies of the existing DOE production reactors

Special Isotope Separation (SIS)

Using lasers to separate isotopes was suggested in the United States in 1971 by the Los Alamos National Laboratory [214] Since then, the development of laser isotope separation (LIS) technology has expanded to include major government sponsored LIS efforts for uranium enrichment and plutonium purification

Research to develop a technology for enriching plutonium in the "desirable" isotope plutonium-239 was launched in secret by the AEC in 1975 at LLNL and LANL [215] During the initial years, the program operated

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201 HAC FY 1985 EWDA Part 4 p 440 Installation is to be in Building 305M at Savannah River

202 The recommendation for a new production reactor or reactors was contained in the Starbird Report in mid 1980 p 16 The concept was first known as the NPR or replacement production reactor

203 HAC FY 1985 EWDA Part 6 p 858; higher estimates of $4 to $6 billion are made in House Report 98-124 Part 1 13 May 1983 p 19, and $12 to $16 billion with requirements for earthquake hurricane and tornado standards; ibid

204 HASC FY 1985 DOE pp 150 51; SASC FY 1986 DOE p 62

205 HAC FY 1985 EWDA Part 4 p 433 In early 1982 the target date was 1992; HASC FY 1983 DOE p 235; Inside NRC 2 November 1981 p 4

206 HAC FY 1985 EWDA Part 4 p 433

207 Ibid ; See also HAC FY 1984 EWDA Part 6 p 533 The President s Private Sector Survey on Cost Control noted that there are no identifiable reasons why the Savannah River reactors should not remain operable well past the turn of the century "; Draft Report 15 April 1983, p 23 With regard to when the NPR would be needed studies are underway to reduce the uncertainty in the useful lifetime of the Savannah River and N Reactors; without costly renovations the N Reactor is expected to reach the end of its useful life in the mid-1990s; HAC FY 1985 EWDA Part 6 p 858

208 HASC FY 1985 DOE p 150 However arguments in favor of NPR operation by the early 1990s were necessarily blunted by cancellation of the SENTRY anti ballistic missile (ABM) and other enhanced radiation warheads in the early 1980s thus reducing projected nuclear material requirements

209 The Secretary of Energy s preferred choice in 1983 was the HWR at Idaho Memorandum from Donald Paul Hodel Secretary of Energy to Herman Roser Assistant Secretary for Defense Programs 9 August 1983 As a result of Congressional pressure Savannah River was restored to consideration and environmental impact statements are including all three candidate sites An HTGR of the required size has never been constructed in the United States, and it as well as the PWR and their fuel cycles need further development; HAC FY 1985 EWDA Part 6 p 859

210 Report of the New Production Reactor Concept and Site Selection Advisory Panel (unclassified version) T Keith Glennon Chairman DOE Q-DO 82 97 15 November 1982 The panel evaluated the adequacy of future supplies of strategic nuclear materials and reviewed seven reactor concepts and four sites The second choice if byproduct steam was required was the vertical-pressure tube low temperature heavy water reactor at Savannah River or the Replacement N Reactor at Hanford The latter was favored if an alternate site for tritium production was essential Other sites were INEL judged less suitable because of possible contamination of the aquifer and lack of barge access and local construction labor and without many of the facilities and technologies required for a strategic materials production site; " ibid pp 3 5 9 Other concepts included the light water reactor using highly enriched uranium fuel the liquid metal fast breeder reactor the HTGR and the partially completed Washington Public Power Supply System pressurized water reactor WNP-4 located on the Hanford Reservation; ibid , p 3 Although opposed by the panel on economic grounds the production of byproduct steam was still one of the DOE ground rules; ibid , p 2b; HASC FY 1983 DOE April 1982 p 239; S V Jackson Los Alamos National Laboratory LA 8888-MC June 1981

211 United Engineers and Constructors—United Nuclear Industries APR Feasibility Study Draft Report UE&C-UNC/DOE-810225, circa 1980

212 House Report 98 124 Part 1 13 May 1983 p 19

213 House Report 98-724 26 April 1984 p 28

214 HASC FY 1980 DOE p 159

215 HASC FY 1981 DOE pp 162 174

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Special Isotope Separation

at a low level of effort [215] In FY 1980, the plutonium SIS program was formally initiated [217] In addition to the two plutonium LIS processes, it included, at a much lower level of support, the (non-laser) PSP developed by TRW and LANL [218] This PSP is currently being utilized in the U-236 recovery program [219] These same processes were under development for enriching uranium in U-235 [220]

The purpose and scope of the plutonium SIS program were first publicly revealed in 1981 [221]

At least a half a dozen weapons-related applications of LIS processes for plutonium have been considered One application is enriching reactor-grade plutonium recovered from commercial power reactor spent fuel[222] or fuel-grade plutonium from the N-Reactor for weapons use [223] Plutonium from civil reactors is not directly useful to the nuclear weapons program because of the high Pu-240 and Pu-241 content Another is separating out the Pu-240 and Pu-241 from the existing inventory of weapon-grade plutonium This would reduce radiation exposure to plant and military personnel [224] A third application would provide a source of non-fissile isotopes Pu-240 and Pu-242 for research Plans exist to build an SIS production plant [225]

In 1982 Congress banned the use of plutonium from commercial spent fuel in weapons [226] This legal prohibition eliminated one of the principal justifications for the SIS program and the construction of a plutonium LIS plant Nevertheless, the SIS program continues to receive a high level of funding from Congress at the behest of the authorizing and appropriating committees and despite uncertain support from the Administration DOE continues to emphasize the need for this technology to enrich up to 11 MT of fuel-grade plutonium,[227] as well as an eventual "clean-up" of the existing weapon-grade stockpile [228]

The potential SIS feed includes the plutonium currently being used in continuing civil R&D activities for the breeder program The 6 3 MT of fuel-grade plutonium in the fuel of the two breeder program facilities, the Fast Flux Test Facility (FFTF) and the Zero Power Plutonium Reactor (ZPPR), will become available for other uses in the early 1990s [229] The FFTF and ZPPR facilities are now the depository of most of the fuel-grade plutonium from civil reactors received by the United States in barter from the United Kingdom between 1964 and 1969 under the Mutual Defense Agreement of 1958 Should the United States continue its policy of not using the bartered plutonium for weapons, the SIS plant would have as its primary mission the clean-up of only about 7 MT of fuel-grade plutonium

FY 1981 through FY 1985 funding for the SIS program totaled $295 million Congress has shown more enthusiasm for the program than the Reagan Administration The pattern has been for the Office of Management and Budget (OMB) to cut back on the SIS funding sought by DOE, and for Congress to restore it partially For example, the FY 1985 DOE request for the SIS program was $100 million for operating expenses and capital equipment; OMB cut SIS funding to $39 million and Congress restored it to $69 million

Most funding for SIS over the years has gone to support the LLNL AVLIS process, which has always been recognized as being in the lead for plutonium LIS development In 1982, the Livermore group conducted a successful laser isotope separation experiment, and in December of that year the DOE-sponsored Peer Review of the SIS program (Kintner Report) concluded that the AVLIS process appeared to be significantly far more advanced than the MLIS process for plutonium enrichment Earlier in the year, at the end of April 1982, AVLIS won out against MLIS in the competition for uranium enrichment in the AIS program [230]

In August 1983, the Secretary of Energy announced his selection of DOE's Hanford Reservation in Richland, Washington, as the site of an SIS production plant using the AVLIS process for plutonium enrichment The plans call for a facility costing some $600 million to be in full production at Hanford by 1992, preceded by an AVLIS prototype operating in 1987 to 1988 at LLNL [231] From published information, the design capacity of the plant is estimated at some 3 MT or more of plutonium output annually [232] To recover fuel-grade plutonium to be used as SIS feed, DOE is also planning a *Process Facility Modification* at the Hanford PUREX plant that will enable processing of irradiated FFTF fuel (16 percent Pu-240)

Several issues continue to loom over the SIS issue: the need in the weapons program for an SIS plant, the technical risk involved in an accelerated SIS program, the relative costs of SIS and alternatives for acquiring additional quantities of weapon-grade plutonium, and the merits of the Los Alamos molecular laser (MLIS) process for plutonium enrichment

215 *Ibid* p 162
217 HASC 96-39 March June 1980 p 580
218 PSP for plutonium experienced technical problems and was withdrawn by TRW from the SIS program as of FY 1983; HAC FY 1985 EWDA Part 6, p 650 PSP technology is being developed to recover uranium 235 from the recycled HEU fuel of the Savannah River production reactors
219 HAC, FY 1986 EWDA Part 6 p 715
220 See Chapter Five Uranium Enrichment for a description of the AVLIS MLIS and PSP processes for uranium
221 HASC FY 1982 DOE pp 159-66 174-76 236
222 HASC FY 1982 DOE p 160
223 HASC FY 1983 DOE pp 157 175
224 *Ibid* p 160; testimony of F C Gilbert to the Subcommittee on Oversight and Investigations of the House Committee on Interior and Insular Affairs 1 October 1981
225 HASC FY 1982 DOE pp 146 161 175
226 The Hart Simpson Mitchell amendment to the NRC Authorization Act for FY 1982-83 Public Law 97-415 was passed by the Senate on 30 March 1982 and signed into law on 4 January 1983
227 HAC FY 1984 EWDA Part 6 pp 364-65
228 House Science and Technology Subcommittee on Energy Research and Production [No 121] Vol VI March May 1982, p 684
229 Letter from Donald Paul Hodel Secretary of Energy to Richard L Ottinger 5 March 1984 Enclosures
230 The House Armed Services Committee in its May 1983 report called for a halt to MLIS support and the choice of the AVLIS process for full scale demonstration; HASC Report 98-124 pp 17 18
231 Nucleonics Week (11 August 1983): 4
232 According to testimony of F Charles Gilbert, Deputy Assistant Secretary for Nuclear Materials DOE, the maximum rate at which plutonium can be made available for weapons through blending supergrade and fuel grade plutonium is less than the SIS alternatives HAC FY 1985 EWDA Part 6 p 349

The Administration's FY 1985 DOE budget justification referred to an "uncertainty as to whether a production facility is required" OMB, in the document, attacked any implication that SIS would provide cheap plutonium for weapons:

> The SIS process has the highest cost (in total dollars and in dollars per gram of additional plutonium) of the various methods of increasing productivity The SIS process also requires the most lead time and is the most technologically uncertain [233]

The administration's SIS schedule, proposed in early 1984, called for continued research and development on the plutonium AVLIS process at Livermore—on both separator hardware and laser technology This would lead to an AVLIS process demonstration at Livermore in FY 1987[234] and would leave open the option to begin construction of an SIS plant at Hanford for operation in the early 1990s [235] Design of systems to support a possible SIS plant continues at Hanford [236]

In early 1984, the White House Office of Science and Technology Policy (OSTP), supporting a delay in commitment to an SIS production plant, requested yet another SIS technology review and process selection The OSTP study reconsidered both AVLIS and MLIS technologies for the plutonium enrichment plant [237] As a result of the OSTP study, completed in late 1984, plans for development of the AVLIS prototype were not altered, but a decision on the final choice between AVLIS and MLIS was delayed until completion of yet another review With the AVLIS process, LLNL demonstrated the removal of a single "unwanted" plutonium isotope on a laboratory scale sometime in FY 1984 [238] By early 1985 they tested a module of full-scale plant size equipment Also in 1985, Los Alamos, using the MLIS technology, demonstrated the highest separation factor of any process and was nearing completion of an enrichment facility (SIS-III) intended to meet the Laboratory's needs for special isotopes of plutonium (Pu-240 and Pu-242) for research purposes [239]

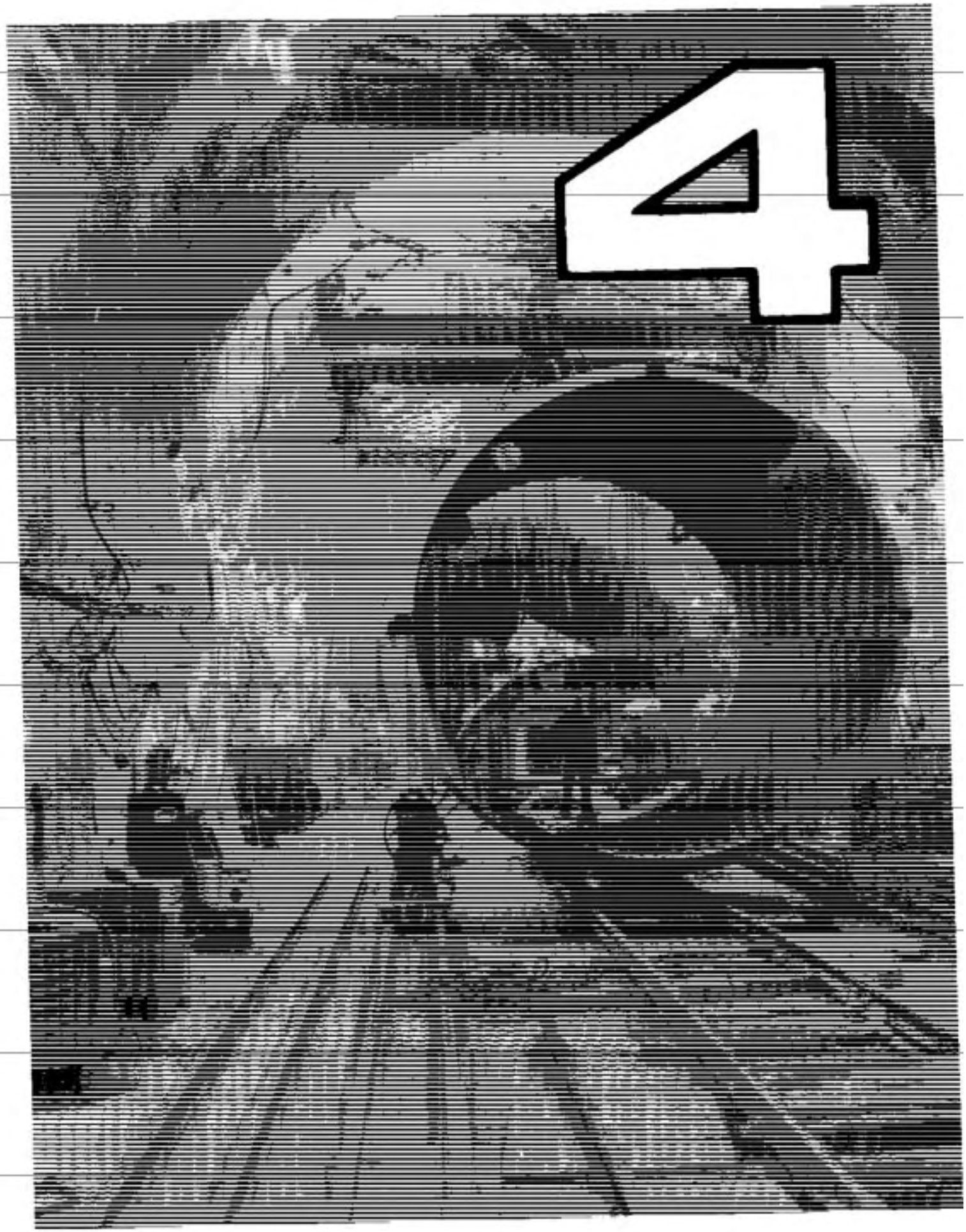
PUREX Process Facility Modification

The Process Facility Modification (PFM) is important for DOE's plans to operate an SIS plant at Hanford in the early 1990s The program will modify the PUREX plant to handle high burnup oxide fuels in stainless steel or zircalloy cladding The necessary modifications will allow the PUREX facility to receive and store the high burnup fuel, chop the stainless steel cladding into short lengths, and dissolve the contained oxide fuel material (these two operations are known as shear/leach), and dilute the dissolved material for further chemical processing [240]

The immediate objective of PFM is to recover fuel-grade plutonium from irradiated FFTF fuel and other DOE-owned research fuels PFM will also give PUREX the capability to process other high burnup fuels DOE claims it has no plans to process commercial light water reactor fuel in the PFM project [241] However, in connection with the design for handling FFTF fuel, "there may be a limited capacity to handle commercial fuel, but it would require major capital additions to handle any substantial quantity "[242] The design capacity calls for a maximum of 10 MT of FFTF fuel per year containing about 2 MT of plutonium (15 percent Pu-240) [243] The expanded plant would possibly have a capacity of up to 5 MT per day of commercial type fuel

Funding for the PFM program began in FY 1983 Construction of facility modifications is estimated at $155 million, and is expected to begin in FY 1986 and end in FY 1990 [244]

233 HAC FY 1985 EWDA Part 6 p 631
234 Ibid
235 FY 1986 EWDA Part 6 pp 762-65
236 Ibid
237 FY 1986 EWDA Part 6 pp 563 577 78 848-49 913; House Report 98-72 26 April 1984 pp 26-27
238 FY 1986 EWDA Part 6, p 714 In the AVLIS SIS separator the unwanted plutonium isotopes are swept out of a beam of plutonium metal vapor leaving plutonium vapor enriched in Pu 239; Ibid p 676
239 SASC, FY 1986 DOE p 152
240 M M Beary et of Functional Design Criteria Process Facility Modification Rockwell Hanford Operations SD-414-PDC 001 January 1983 p 1 1
241 Letter from Hoffel to Ottinger, 5 March 1984 pp cit , Enclosure 1
242 Letter from Donald Paul Hodel to Richard Ottinger 30 August 1983, enclosure The Hart Simpson Mitchell amendment, P.L. 97-415, prohibits use of special nuclear materials produced in NRC licensed facilities for nuclear explosives
243 Letter from Donald Paul Hodel to Richard Ottinger 5 March 1984 Enclosure 1
244 HASC FY 1985 DOE p 146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Chapter Four:
Nuclear Warhead Acquisition Policy

Government officials formulate plans and make policies resulting in the acquisition and production of nuclear warheads This chapter describes their roles, responsibilities, and relationships It identifies the key departments, offices, directorates, divisions, branches, and committees that constitute the nuclear warhead decisionmaking structure and organization of the U S government Also discussed are the major documents that determine requirements for nuclear weapons and assist in planning and budgeting

Two caveats are in order regarding the scope and purpose of this chapter It focuses first on acquisition policy Employment policy (how weapons would be used) and deployment policy (where weapons are based) have their own extensive planning and decisionmaking processes and organizations Aspects of employment and deployment will be mentioned here only as they influence acquisition policy [1] Second, this chapter focuses on warhead acqusition policy, not on delivery vehicles The two are nonetheless intimately connected; new warheads are normally designed and produced to fit new delivery systems

Predecessor Organizations

Manhattan Engineer District

The U S Army's Manhattan Engineer District (MED) or "Manhattan Project" developed the first nuclear bombs Prior to MED's formation in September 1942, research and development was directed first by the National Defense Research Council (NDRC), established 27 June 1940, followed by the Office of Scientific Research and Development (OSRD), established on 28 June 1941 The MED was a highly centralized organization that met its goals with unlimited resources during total wartime mobilization From August 1942 to the end of 1946, MED expenditures totaled $2 2 billion (see Table 1 1)

Even before the war ended officials began preparing for the postwar control of atomic energy In his announcement of the bombing of Hiroshima on 6 August 1945 President Truman recommended that Congress "consider promptly the establishment of an appropriate commission to control the production and use of atomic power " Draft legislation was circulating in the War and State Departments and within hours of Congress' convening in September, legislation was introduced The first effort was an attempt to keep the military in control With help and pressure from the War Department a bill was introduced by Representative Andrew Jackson May (D-Kentucky), Chairman of the House Committee on Military Affairs, and Senator Edwin C Johnson (D-Colorado) The May-Johnson Bill gave a prominant role to the military, sweeping but vague powers to a commission, and a few oversight controls to Congress Throughout the fall of 1945 the bill and issue became enmeshed in political controversy Scientists raised questions about research and security restrictions Concerns were raised regarding military domination of atomic energy After initial support, President Truman withdrew his endorsement of the bill and repudiated many of its key provisions The bill passed the House but died in Senate Committee

In its place Senator Brien McMahon intoduced bill S 1717 on 20 December 1945 In slightly different form it would become the Atomic Energy Act of 1946,[2] also known as the McMahon Act McMahon, a freshman senator from Connecticut, was appointed the first chairman of the Senate Special Committee on Atomic Energy established in October Through the following seven-and-one-half months parts of the McMahon Bill were redrafted and revised but left largely intact The bill passed the Senate unanimously, by voice vote, on 1 June 1946 The House adopted it, 265 to 79 on 20 July During the following week the two chambers worked out their differences, and on 1 August 1946 the President signed into law the Atomic Energy Act of 1946 [3]

During this postwar period the MED remained under the direction of General Leslie R Groves Groves faced severe funding and personnel reductions His goal was to maintain a research and production infrastructure until such time as the question of control could be resolved Several facilities at Oak Ridge and Hanford were put in standby or discontinued Scientists and technicians left Los Alamos to return to their former jobs, contractor companies were anxious to turn to other pursuits, and fund-

1 Employment policy will be treated in Volume VII of the Nuclear Weapons Databook series *Command and Control of Nuclear Weapons and Nuclear Strategy* forthcoming. Deployment policy has been extensively treated in William M Arkin and Richard Fieldhouse, *Nuclear Battlefields: Global Links in the Nuclear Arms Race* (Cambridge, Mass : Ballinger Publishing 1985) and will be covered in the revised edition of Volume I of the Nuclear Weapons Databook series *U S Forces and Capabilities* (forthcoming)

2 The original bill is reproduced in Hewlett and Anderson *The New World* pp 714 22

3 For the details see Hewlett and Anderson *The New World*, Chaps 12-14; and Byron S Miller "A Law Is Passed: The Atomic Energy Act of 1946" *University of Chicago Law Review* XV (Summer 1948) pp 799 821

ing dropped dramatically Expenditures fell from a monthly average of $78 million in 1944 and $50 million in 1945 to $23 million in 1946 On 31 December 1946 the functions of the MED, along with its facilities and the existing stockpile of around ten complete warheads, were transferred to the new Atomic Energy Commission

The Atomic Energy Act of 1946 and the Atomic Energy Commission

The Atomic Energy Act of 1946 established the Atomic Energy Commission (AEC) and gave it control over all aspects of atomic energy The act provided an executive structure to oversee nuclear warhead research, development, testing, and production

The act provided for a five-person, full-time presidentially appointed civilian commission [4] It set up a nine-member General Advisory Committee to counsel the Commission on technical and scientific matters [5] It also established four AEC operating divisions, one of which (Military Application) was to direct all weapons work using the decentralized field offices bequeathed to it by the MED A Military Liaison Committee (MLC), composed of three senior officers from the Army and three from the Navy (later two each from the Army, Navy and Air Force) was created to channel military demands and requirements This basic structure remains largely intact today

The Act prohibited (with few exceptions) the private ownership of fissionable material and the enrichment capability It forbade patenting inventions that related to atomic energy or nuclear explosions The Act also created a new category of information designated "Restricted Data " The 1946 Act defined this new term as covering three broad categories of atomic energy information These were "all data concerning" (1) "design, manufacture, or utilization of atomic weapons;" (2) "the production of special nuclear material;" and (3) "the use of special nuclear material in the production of energy " The Act prescribed a system for controlling access to such information and for declassifying and disseminating information no longer deemed sensitive

Joint Committee on Atomic Energy

To reinforce civilian control, the McMahon Act also established a permament Joint Congressional Committee on Atomic Energy (JCAE) to oversee all atomic energy programs Unlike the wartime situation where the Manhattan Project had no Congressional scrutiny, the AEC was required to keep the JCAE "fully and currently informed with respect to the Commission's activities " The legislation provided for nine members each from the Senate and the House Not more than five from either chamber could belong to the same political party [6]

The JCAE became a power in its own right It energetically encouraged a larger weapons program and the emerging commercial nuclear power industry As one commentator has said,

> Historians of the future who investigate the etiology of the rise of the United States atomic stockpile will no doubt find their richest material in the files of the Joint Committee on Atomic Energy It was this Committee of 18 men—not the AEC itself or even the Department of Defense—that took the lead in expanding the program of weapons-building [7]

The Atomic Energy Act of 1954

On 30 August 1954 Congress passed a new Atomic Energy Act The main purpose of the Act was to promote the peaceful uses of atomic energy through private enterprise and to implement President Eisenhower's Atoms for Peace program The Act allowed the AEC to license private companies to use special nuclear material; to build and operate commerical nuclear power facilities; and to regulate companies to prevent "undue risk to the health and safety of the public "

The Act also created a new classification category for certain kinds of information, known as "Formerly Restricted Data" (FRD) FRD information deals with the "military utilization of atomic weapons " Removing this information from the category of "Resticted Data" allowed for greater dissemination within the Department of Defense and eventually with certain allies The new Act did not change the essential functions of the AEC with regard to nuclear weapons, to any significant degree

ERDA/DOE

Throughout the 1960s and early 1970s controversy arose over the AEC As civilian nuclear energy grew the AEC came under increasing criticism for its dual role in both promoting and regulating commercial nuclear energy development A second concern arose over U S energy self-sufficiency, reinforced by the emergence of the OPEC cartel These concerns led to the Energy Reorganization Act of 1974, which was signed into law on 11 October 1974 and took effect 19 January 1975 [8] The Act abolished the Atomic Energy Commission and tranferred its regulatory functions to the newly created Nuclear Regulatory Commission The weapons activities and

4 The first five were Chairman David E Lilienthal, Sumner T Pike Lewis L Strauss William W Waymack and Dr Robert F Bacher

5 The first members were J Robert Oppenheimer (chairman), James B Conant, Lee A DuBridge, Enrico Fermi Isidor I Rabi, Hartley Rowe Glenn T Seaborg Cyril S Smith and Hood T Worthington Because of their experience in the Manhattan Project they played a key role in defining policy while the new commission was organizing; Hewlett and Duncan The New World pp 18 46

6 For a study of the Committee see Harold P Green and Alan Rosenthal Government of the Atom: The Integration of Powers (New York: Atherton Press 1963)

7 Ralph E Lapp Kill and Overkill (New York: Basic Books 1962) pp 24-25

8 Public Law 93-438 42 U S C 5801 et seq Per a legislative history see 1974 U S Code Cong and Adm News p 5470

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Decisionmaking Documents

R&D functions of the AEC were transferred to the newly created Energy Research and Development Administration(ERDA) During its thirty-two months of existence ERDA expanded research into alternate energy technologies

In the mid-1970s the U S government responded to the continuing worldwide changes in energy production, consumption, and supply by creating the Department of Energy The Department of Energy Organization Act was signed by President Carter on 4 August 1977 [9] The nuclear weapons functions formerly assigned to ERDA were transferred to DOE, where they remain today

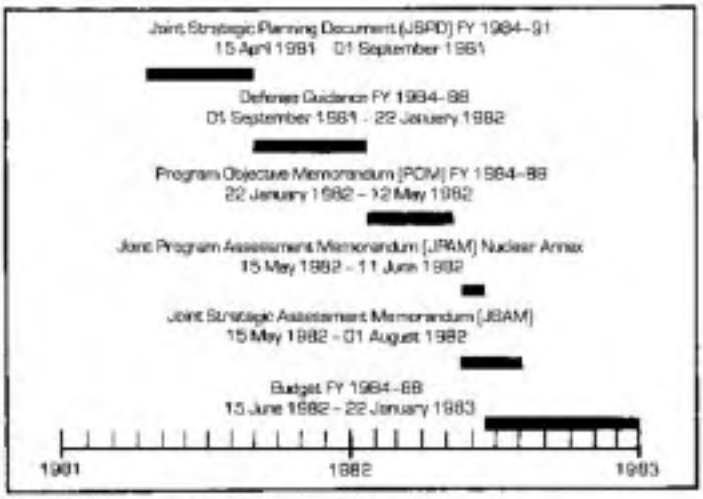

Figure 4 1 Time Line—Planning Documents

Nuclear Weapon Decisionmaking Documents

Decisions to develop and acquire nuclear weapons are a part of a complex military planning process This process translates broad national goals into military objectives, with strategies and forces to attain them A formal annual process coordinates the President's national security guidance with the views of the Secretary of Defense, the military's own view as represented by the Joint Chiefs of Staff (JCS) and the military services, and the Department of Energy

The Joint Strategic Planning System (JSPS) is a series of six documents that create short-range, mid-range, and long-range planning objectives They guide overall military planning including nuclear weapons acquisition [10] Through the JSPS, broad military objectives and more specific desires are reconciled with financial and material resources available and the technological ability of the DOD and DOE to produce nuclear warheads and weapon systems The DOE, whose primary responsibility is the production of nuclear warheads, becomes directly involved in the planning process only at the late stages

The time line (Figure 4 1) shows the two documents from the JSPS that bear directly on nuclear weapons acquisition, and four other documents generated in the planning process This chapter section discusses these planning documents, two key Presidential authorizing documents, and the Nuclear Weapons Development Guidance that coordinates DOD and DOE resources

Joint Strategic Planning Document

The JSPD is an annual study prepared by the Joint Staff of the JCS for approval sixty days prior to publication of the first draft Defense Guidance (see below) of the Secretary of Defense (normally in September) According to the JCS, "The JSPD provides the advice of the Joint Chiefs of Staff to the President, the National Security Council, and the Secretary of Defense on the military strategy and force structure required to support the attainment of the national security objectives of the United States" over a five-year period [11] It provides a military appraisal of the threat to U S interest worldwide and recommends military strategy necessary to attain military objectives "in the mid-range period "[12]

The JSPD includes a "summary of the JCS planning force levels that are required to execute the approved national military strategy with a reasonable assurance of success," including force requirements for strategic and nonstrategic forces [13] It is intended to influence preparation of the Defense Guidance

Annex B (Nuclear) of the JSPD:

1 Provides advice and supporting rationale on the levels of strategic and nonstrategic nuclear warheads necessary to support the planning force levels;
2 Evaluate[s] the total impact of these levels on the stockpile of special nuclear materials (SNM) and the capabilities to produce the additional SNM and warheads required;
3 Compare[s] these levels with currently projected levels identifying shortfalls where they exist; and
4 Provide[s] advice on modernization of the nuclear warhead stockpile [14]

9 42 U S C 7101 *et seq* For legislative history, see 1977 U S Code Cong and Adm News p 854 On 1 October 1977 the Department of Energy formally came into existence Former agencies such as the ERDA Federal Energy Administration Federal Power Commission and other energy programs from other departments were consolidated

10 The six documents are the Intelligence Priorities for Strategic Planning, the Joint Intelligence Estimate for Planning, the Joint Long Range Strategic Appraisal, the Joint Strategic Planning Document, the Joint Program Assessment Memorandum, and the Joint Strategic Capabilities Plan Two of these documents directly bear upon weapon acquisition policy the Joint Strategic Planning Document and the Joint Program Assessment Memorandum

11 JCS Joint Strategic Planning System, JCS MOP 84 1 February 1983 p 18 JCS Joint Program and Budget Procedure JCS MOP 136 6 September 1982

12 JCS MOP 84 p 19

13 Ibid

14 Ibid p 20

Defense Guidance and Consolidated Guidance

The Defense Guidance (DG), is prepared annually by the Under Secretary of Defense for Policy for the Secretary of Defense It "translates broad national goals and objectives into statements of policy and strategy that are sufficiently specific for initiating and developing the Consolidated Guidance [CG] to which it is a fundamental contributor "[15] Focusing on the near- and mid-term, the DG and CG become the Secretary's authoritative statements to the military They cover "policy; military strategic concepts and objectives; planning and programming guidance; force levels; and manpower, support, and fiscal guidance "[16] Within each of these parts specific sections address strategic and nonstrategic nuclear forces and DOD support to DOE Recognizing that force structure "can only be changed marginally" to meet immediate peacetime and crisis goals, the DG and CG attempt to "assure that planners and programmers avoid altering specified goals by implicitly adjusting the ends to suit the means "[17] These two documents highlight specific issues of current political and international importance They guide the military in short-term weapon and resource decisions and contingency planning

Program Objective Memorandum

Each military service develops its own annual Program Object Memorandum (POM) Military force requirements and goals of the JSPD, together with the CG go into each POM The three POMs, issued in May, formally present Army, Navy (including Marine Corps), and Air Force proposals for resource allocations as part of the Five Year Defense Program (FYDP) and the budget submitted to Congress by DOD A series of Issue Papers are prepared on a variety of programs, including strategic nuclear forces, theater nuclear forces, nuclear employment, deployment, acquisition, and the nuclear stockpile The Secretary of Defense then makes budget decisions relating to the POMs and issues these decisions as Program Decision Memoranda (PDMs)

If a military service determines that a PDM decision warrants the personal attention of the Chief of Staff or Secretary, it issues a "reclama,"[18] which results in a "major issues meeting " The Secretary of Defense then issues an Amended PDM that resolves the issue The final PDMs are then issued and form the basis of the budget

Joint Program Assessment Memorandum

About thirty days after the military services publish their POMs, the JCS issues the Joint Program Assessment Memorandum (JPAM) This annual JCS document makes force recommendations to the Secretary of Defense Normally published in mid-June, it provides "the views of the Joint Chiefs of Staff, taking into consideration the views of commanders of unified and specified commands, on the adequacy and capabilities of the total forces contained in the POM to execute the national military strategy and the risks inherent in those force capabilities "[19] The JPAM contains recommendations on the size, composition, and distribution of the nuclear weapons stockpile in its Nuclear Annex

Nuclear Weapons Stockpile Memorandum

The Nuclear Annex of the JPAM establishes military requirements for nuclear weapons It thus forms the basis of the annual Nuclear Weapons Stockpile Memorandum (NWSM) The Stockpile Memorandum is coordinated between the DOD and DOE They work through the Military Liaison Committee (see below) of the Secretaries of Defense and Energy The NWSM is forwarded to the National Security Council staff for approval by the President [20] The NWSM contains four major parts that become the basis for maintaining the size and composition of the nuclear stockpile:

- Stockpile authorization for the current year and following five years The NWSM authorizes procurement of hardware and production of precise numbers and types of weapons specified Nuclear warhead production, retirement schedules, and stockpile adjustments, by warhead type, are specified
- Authorization to plan and commit to long-lead procurements for specific numbers and types of warheads, for delivery in the seventh through eleventh years These plans include gross projections of stockpile size, and contingency requirements for rapid production increases
- Planned weapon stockpile projected through the sixteenth year
- Analysis of the special nuclear material (SNM) requirements in terms of plutonium, uranium, and tritium demand by year, anticipated SNM supply by year, and reserve requirements [21]

15 PPBS Handbook p 2-37
16 *Ibid* p 2-36
17 *Ibid* p 2-37
18 A request to duly constituted authority to reconsider its decision or its proposed action
19 JCS MOP 85 pp 25-26
20 The Department of Energy's authority to produce nuclear weapons lies in Section 91 of the Atomic Energy Act of 1954 as amended (Public Law 83-703, 68 STAT 919 42 U S C 2011 et seq) The Act provides that DOE shall produce weapons to the extent that the express consent and direction of the President of the United States has been obtained which consent and direction shall be obtained at least once each year
21 The Reagan administration extended the planning period from eight to fifteen and then to sixteen years The FY 1981-83 NWSM signed by President Carter on 24 October 1980 was the last memorandum with an eight year planning horizon It authorized warhead production and retirement schedules for FY 1981 through FY 1988 authorized preproduction activities and long lead procurement through FY 1985, and acted for planning purposes the weapon deliveries (production plan) for the years FY 1989 through 1988 HASC FY 1980 DOE p 566; HAC FY 1982 EWDA Part 7 p 105