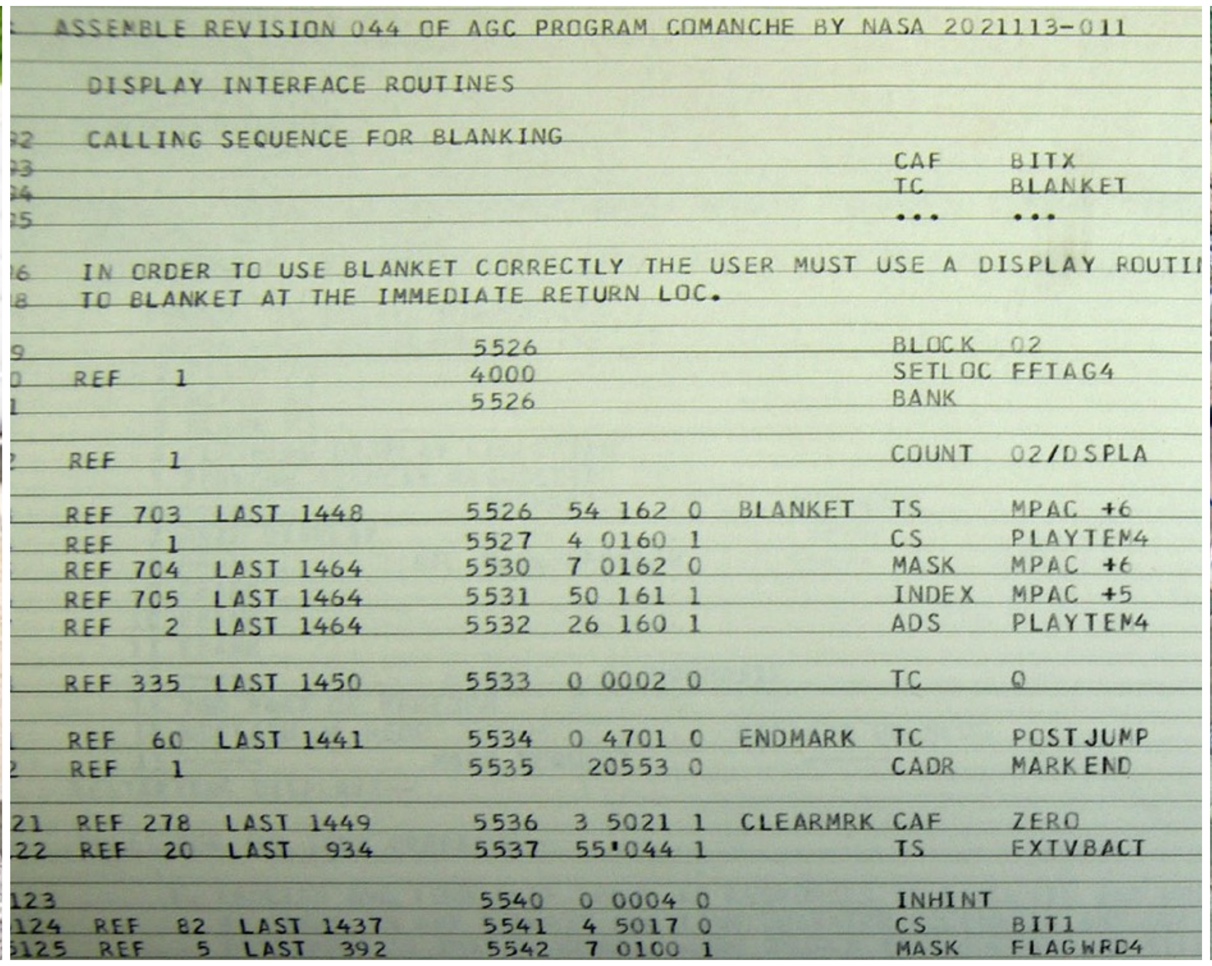


```
ASSEMBLE REVISION 044 OF AGC PROGRAM COMANCHE BY NASA 2021113-011

DISPLAY INTERFACE ROUTINES

CALLING SEQUENCE FOR BLANKING
                                                    CAF     BITX
                                                    TC      BLANKET
                                                    ...     ...

IN ORDER TO USE BLANKET CORRECTLY THE USER MUST USE A DISPLAY ROUTI
TO BLANKET AT THE IMMEDIATE RETURN LOC.

                                5526                BLOCK   02
REF   1                         4000                SETLOC  FFTAG4
                                5526                BANK

REF   1                                             COUNT   02/DSPLA

REF 703  LAST 1448        5526  54 162 0  BLANKET   TS      MPAC +6
REF   1                   5527   4 0160 1           CS      PLAYTEM4
REF 704  LAST 1464        5530   7 0162 0           MASK    MPAC +6
REF 705  LAST 1464        5531  50 161 1            INDEX   MPAC +5
REF   2  LAST 1464        5532  26 160 1            ADS     PLAYTEM4

REF 335  LAST 1450        5533   0 0002 0           TC      Q

REF  60  LAST 1441        5534   0 4701 0  ENDMARK  TC      POSTJUMP
REF   1                   5535   20553 0            CADR    MARKEND

REF 278  LAST 1449        5536   3 5021 1  CLEARMRK CAF     ZERO
REF  20  LAST  934        5537  55'044 1            TS      EXTVBACT

                          5540   0 0004 0           INHINT
REF  82  LAST 1437        5541   4 5017 0           CS      BIT1
REF   5  LAST  392        5542   7 0100 1           MASK    FLAGWRD4
```

RECONSTRUCTING THE HISTORY OF NUCLEAR PROGRAMS

THE ROLE OF COMPUTATIONAL TOOLS & OPERATING RECORDS FOR NUCLEAR ARCHAEOLOGY

Alex Glaser
Program on Science and Global Security
Princeton University

MTV Fuel Cycle Facility Modeling Workshop
October 7–8, Madison, WI, 2019

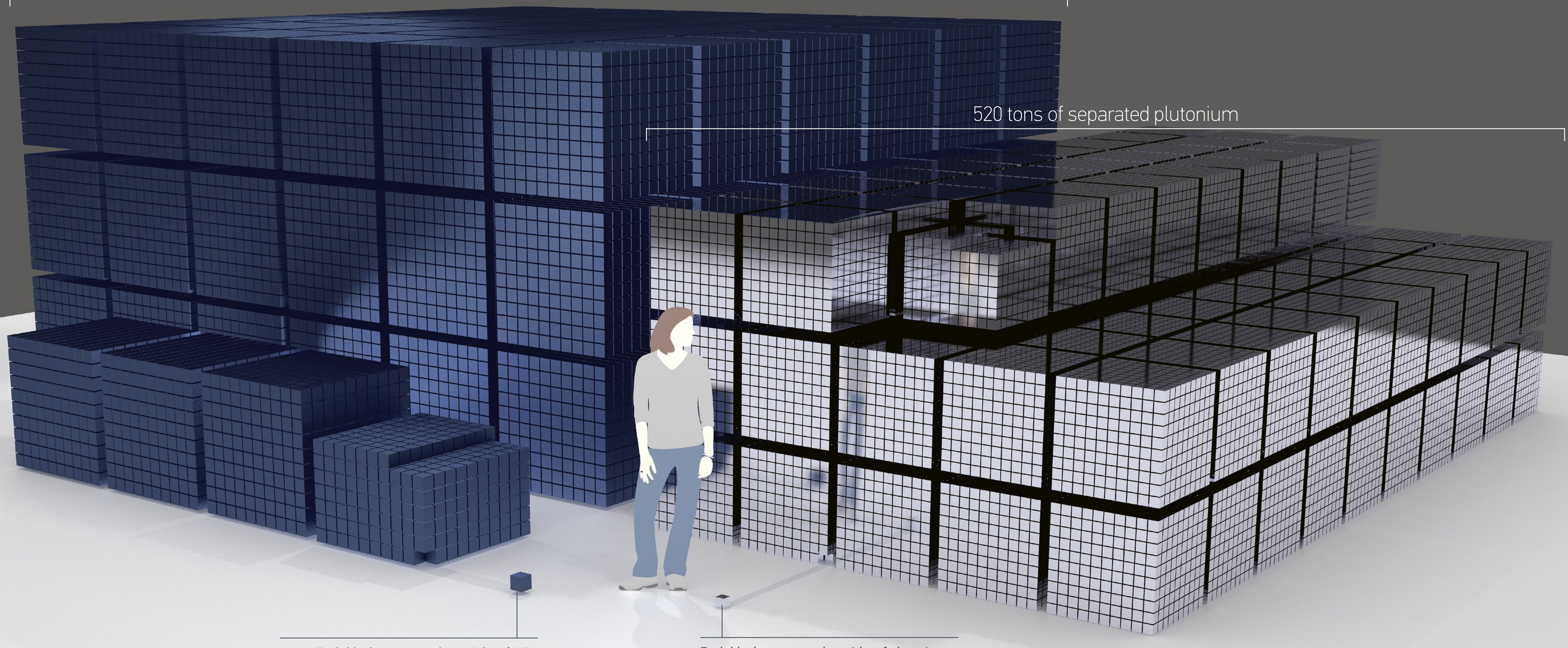
Revision 1

BACKGROUND

There is enough nuclear explosive material worldwide to make over 200,000 nuclear weapons

Graphic/concept by Alex Wellerstein and Tamara Patton
Status as of end of 2016

1340 tons of highly enriched uranium (HEU)

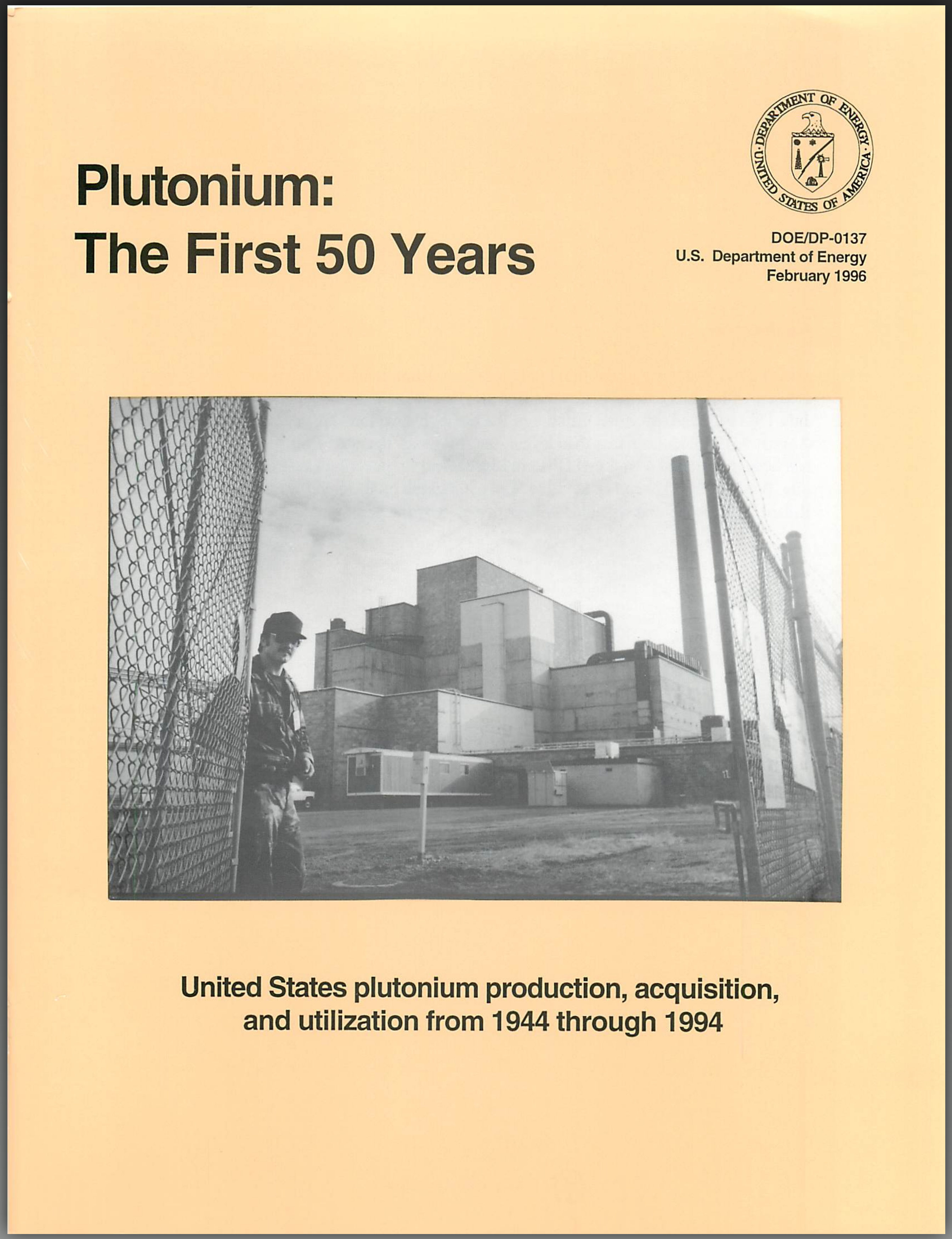


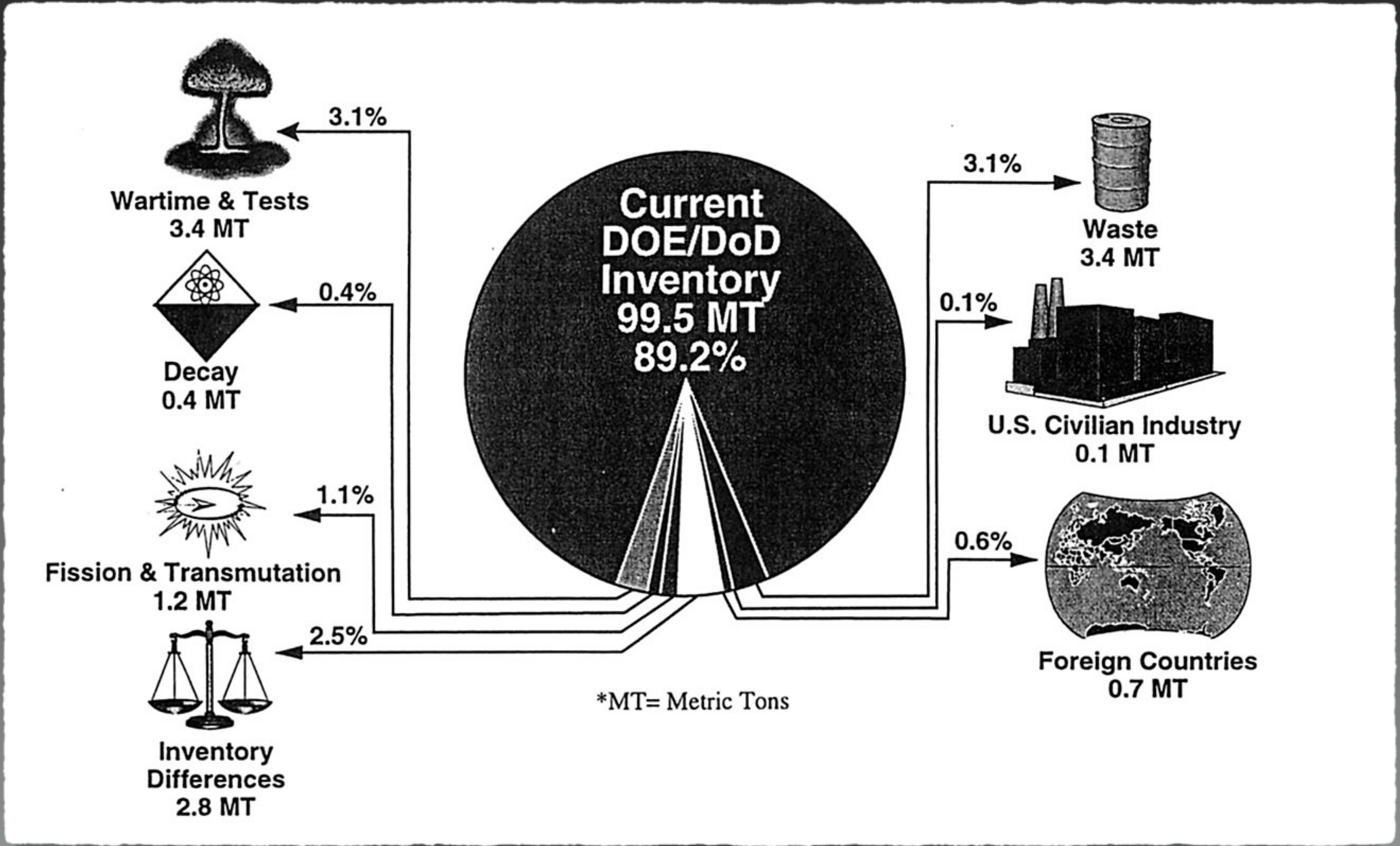
Each block corresponds to 12 kg of HEU, the amount necessary to make a fission bomb; about 111,670 bombs-worth total

Each block corresponds to 4 kg of plutonium, the amount necessary to make a fission bomb; about 130,000 bombs-worth total

ESTIMATING INVENTORIES CAN BE HARD

(AN EXAMPLE FROM THE 1996 U.S. PLUTONIUM DECLARATION)





Plutonium: The First 50 Years, DOE/DP-0137, U.S. Department of Energy, Washington, DC, February 1996, www.ipfmlibrary.org/doe96.pdf

K Reactor, Savannah River Site, i.imgur.com/CPrBoCK.jpg

DEVELOPING THE TOOLS FOR POSSIBLE NUCLEAR ARCHAEOLOGY IN NORTH KOREA

Uranium mine at Pyongsan
Credit: Google Earth

Inside North Korea's Yongbyon Reactor
Credit: CNN/Brian Rokus, 2008

Operating records shared in 2008
Credit: Chung Sung-Jun

MONITORING, TECHNOLOGY, VERIFICATION

Our topic area seeks to develop "new tools and methods for monitoring past and present fuel cycle activities."

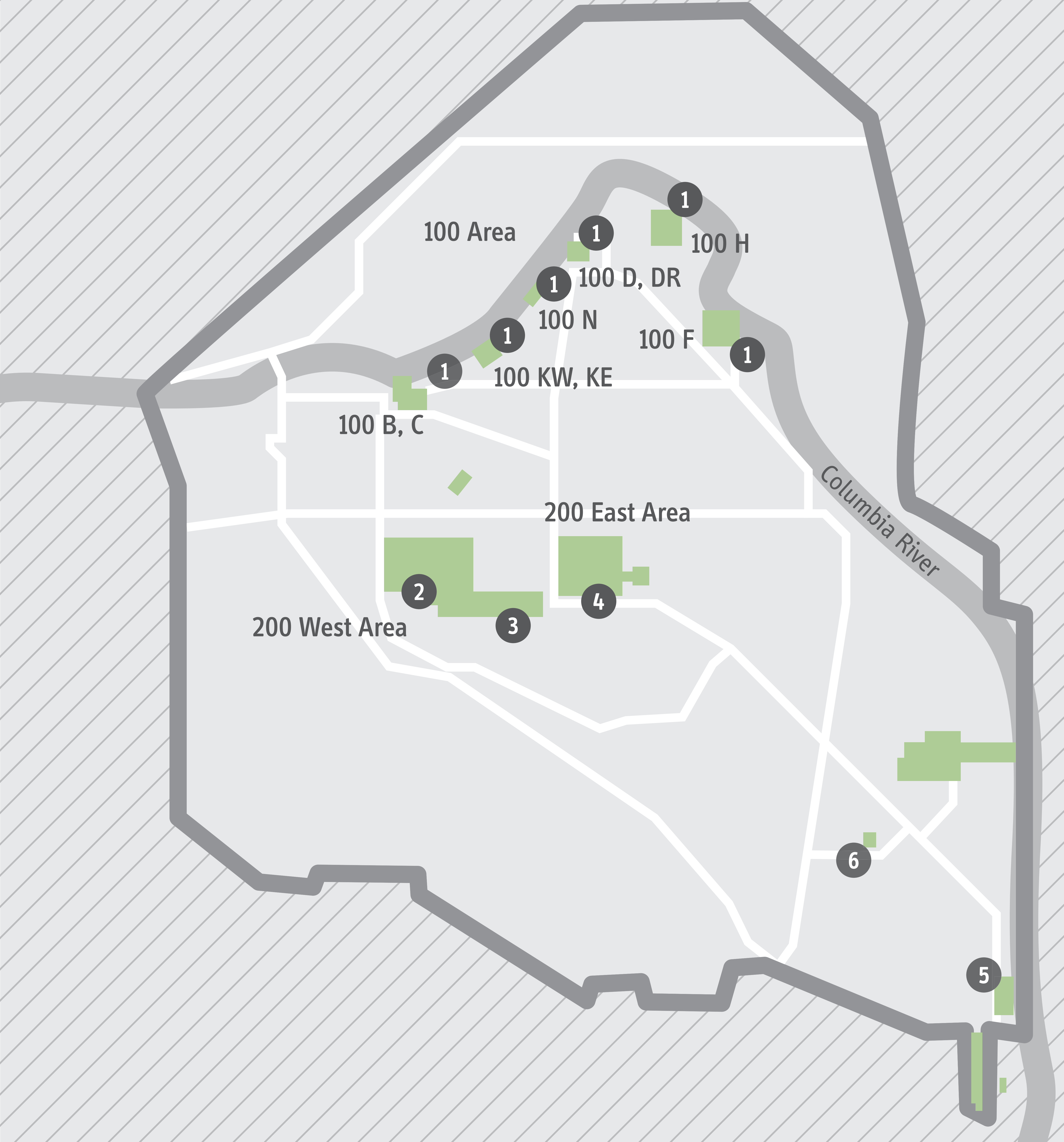
Verified elimination of a nuclear weapons program may require robust methods to reconstruct past activities in order to enable comprehensive, verifiable, and irreversible disarmament.

We envision a framework that allows reconstruction of a state's fissile-material production history by examining the role of state-of-the-art modeling tools, operating records, and other available data.

The framework would complement "traditional" nuclear archaeology techniques.

CASE STUDY

Hanford, WA – West Valley, NY
February 1969



Hanford Site, United States

Coordinates: 46.7 N, 119.5 E

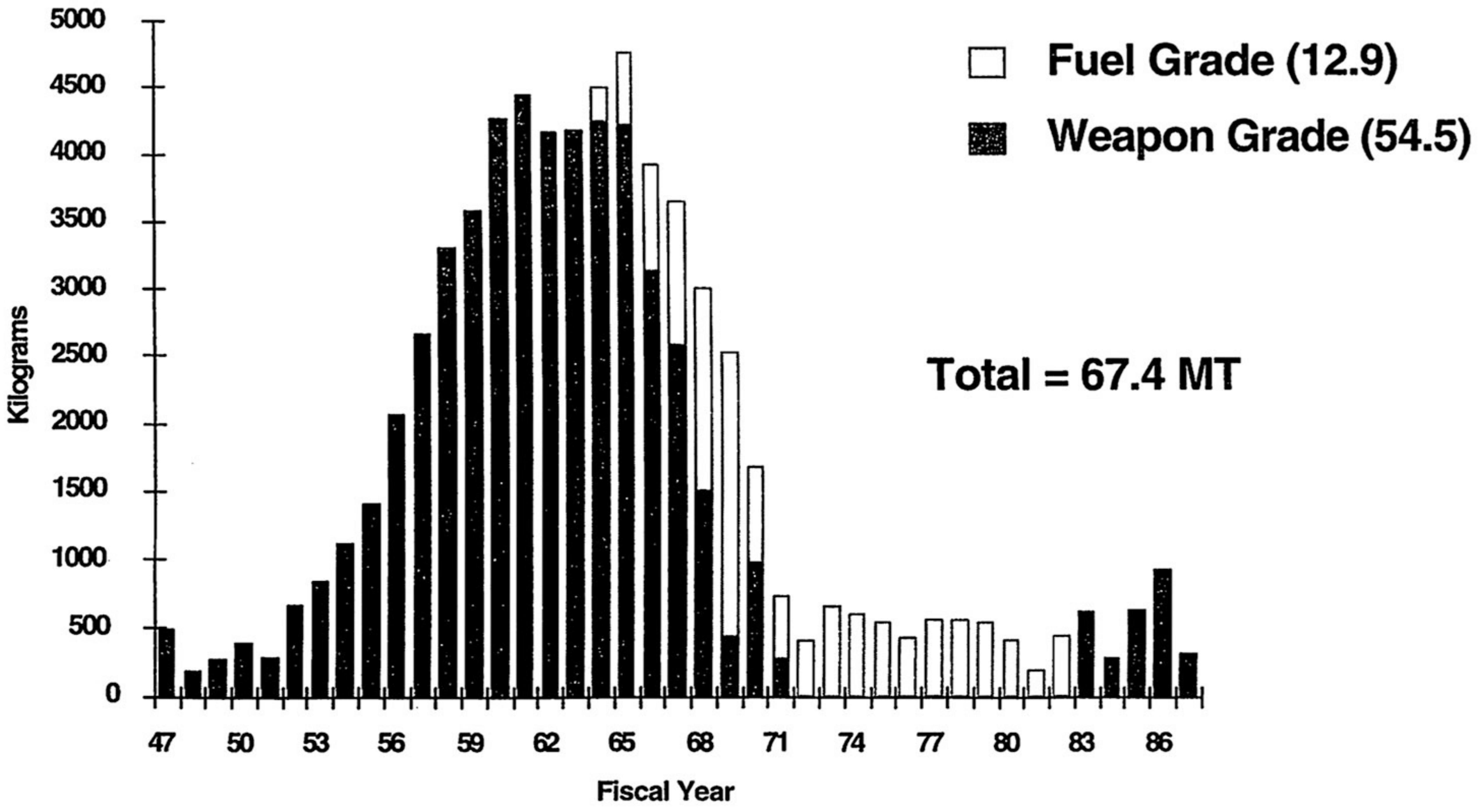
1. Production Reactors
2. Plutonium Finishing Plant
3. Reprocessing plants (T-Plant and REDOX)
4. Reprocessing plants (B-Plant and PUREX)
5. Reactor fuel fabrication
6. Fast Flux Test Facility (FFTF)

N W E S

5 kilometers

5 miles

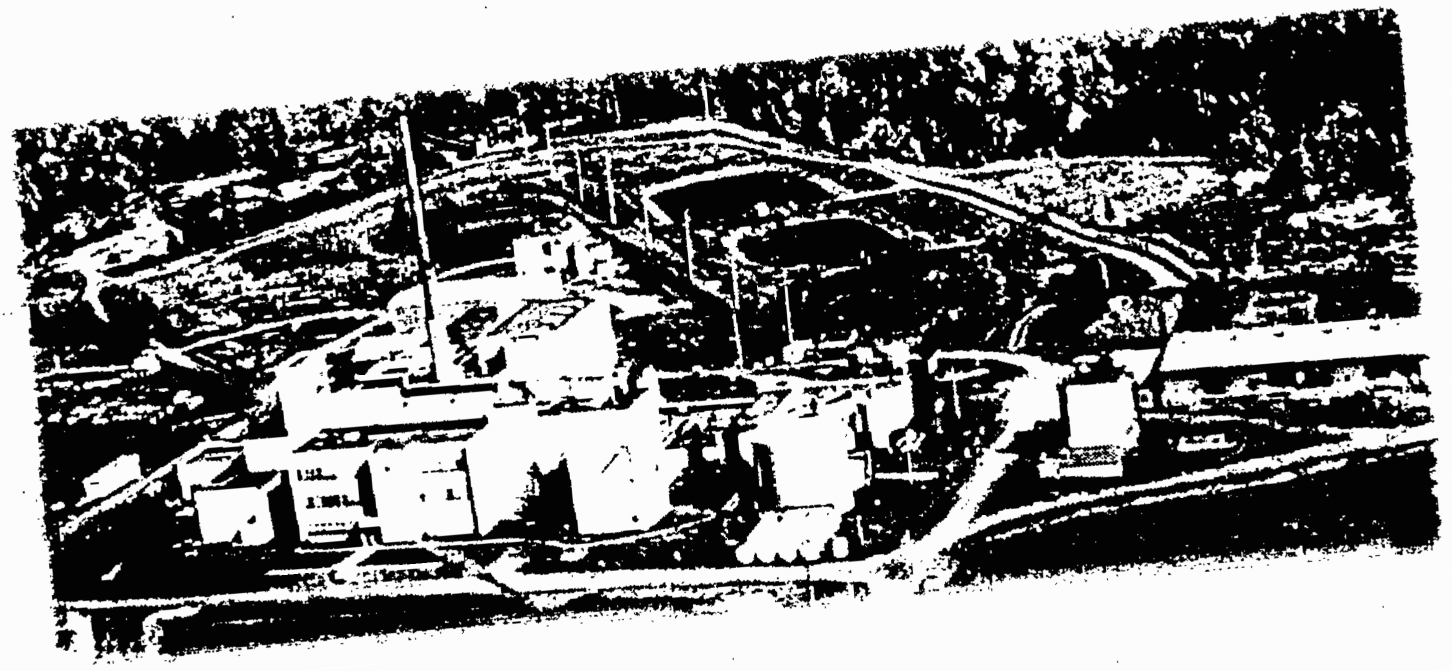
DECLARED PLUTONIUM PRODUCTION AT HANFORD



Fiscal Year	Weapon Grade	Fuel[13] Grade	Annual Total	Cumulative Total	Fiscal Year	Weapon Grade	Fuel[14] Grade	Annual Total	Cumulative Total
1947[15]	493	-	493	493	1969	430	2,109	2,539	56,763
1948	183	-	183	676	1970	977	707	1,684	58,447
1949	270	-	270	946	1971	270	467	737	59,184
1950	392	-	392	1,338	1972	-	414	414	59,598
1951	288	-	288	1,626	1973	-	673	673	60,271
1952	662	-	662	2,288	1974	-	607	607	60,878
1953	838	-	838	3,126	1975	-	557	557	61,435
1954	1,113	-	1,113	4,239	1976	-	429	429	61,864
1955	1,413	-	1,413	5,652	1977	-	560	560	62,424
1956	2,074	-	2,074	7,726	1978	-	559	559	62,983
1957	2,662	-	2,662	10,388	1979	-	544	544	63,527
1958	3,303	-	3,303	13,691	1980	-	413	413	63,940
1959	3,581	-	3,581	17,272	1981	-	196	196	64,136
1960	4,266	-	4,266	21,538	1982	-	449	449	64,585
1961	4,449	-	4,449	25,987	1983	624	-	624	65,209
1962	4,169	-	4,169	30,156	1984	294	-	294	65,503
1963	4,187	-	4,187	34,343	1985	633	-	633	66,136
1964	4,247	256	4,503	38,846	1986	934	-	934	67,070
1965	4,208	562	4,770	43,616	1987	312	-	312	67,382
1966	3,130	800	3,930	47,546	1988[16]	-21	-	-21	67,361
1967	2,586	1,069	3,655	51,201	1989[17]	2	-	2	67,363
1968	1,494	1,530	3,023	54,224					

Plutonium: The First 50 Years, DOE/DP-0137, U.S. Department of Energy, Washington, DC, February 1996, www.ipfmlibrary.org/doe96.pdf

Plutonium & Uranium Recovery from Spent Fuel Reprocessing by Nuclear Fuel Services at West Valley, New York from 1966 to 1972



Revised
November 1999

U.S. Department of Energy
Office of Defense Programs

Table 1. Fuel Reprocessed and Plutonium Recovered at NFS West Valley

Lot No	Fuel Source	Reactor Name	Process Date	Received[b] MTU[d]	Received[b] kg Pu	Recovered[c] kg Pu
2	Atomic Energy Commission	N-Reactor	4-22-66	19.7	1.7	1.2
1			5-20-66	28.8	2.3	2.5
3			7-15-66	46.7	50.9	50.2
4	Commonwealth Edison	Dresden-1	11-12-66	50.0	191.0	182.2
5	Yankee Atomic Electric	Yankee Rowe	6-7-67	49.8	285.1[e]	278.6
6	Atomic Energy Commission	N-Reactor	9-2-67	26.6	52.6	50.4
7			12-2-67	26.1	47.4	46.9
8			1-6-68	42.4	75.4	77.0
9			5-5-68	38.8	79.1	78.0
10			6-29-68	55.3	115.7	114.4
11	Consolidated Edison[f]	Indian Point-1	11-15-68	1.1	-	-
12	Atomic Energy Commission	N-Reactor	2-13-69	48.9	102.5	90.2
13	Yankee Atomic Electric	Yankee Rowe	5-14-69	19.6	176.0	171.6
14	Atomic Energy Commission[g]	N-Reactor	8-16-69	30.3	-	-
15	Commonwealth Edison	Dresden-1	10-1-69	21.5	104.6	102.3
16	Consolidated Edison	Indian Point-1	11-23-69	15.6	107.6	104.2
17	Yankee Atomic Electric	Yankee Rowe	6-2-70	9.3	95.6	91.5
18	Northern States Power	Pathfinder	8-14-70	9.6	7.1	7.0
19	Consumers Power	Big Rock Point	11-26-70	18.4	72.8	72.7
20	Consolidated Edison	Indian Point-1	1-11-71	7.6	68.1	63.0
21	Atomic Energy Commission	N-Reactor	2-25-71	15.8	25.4	22.8
22	Puerto Rico Water Resources Authority	Bonus Superheater[h] Bonus Boiler[i]	4-15-71 4-18-71	1.7 2.4	0.9 4.0	6.5
23	Pacific Gas and Electric	Humbolt Bay	5-20-71	20.8	87.2	86.0
24	Yankee Atomic Electric	Yankee Rowe	7-16-71	9.5	95.7	91.0
25	Carolinas-Virginia Nuclear Power Associates	CVTR-PARR	10-4-71	3.5	11.6	11.8
26	Consumers Power	Big Rock Point	11-30-71	5.8	27.9	28.4
27	Nuclear Fuels Services, Erwin, Tennessee[j]	SEFOR	12-12-71	0.1	95.5	95.2
	Total			**625.7**	**1,983.7**	**1,925.6**

Note: Footnotes for Table 1 can be found on the page 12.

UNDERSTANDING "LOT 12"

(FUEL FROM HANFORD N-REACTOR, PROCESSED IN FEBRUARY 1969)

<u>HANFORD N-REACTOR</u> (+46.6744, –119.5695)

48,900 kg of uranium in spent fuel containing an estimated 102.5 kg of plutonium

About 2.1 g of plutonium per kilogram of fuel

Approximate average burnup: ~ 3000 MWd/t (with about 85% Pu-239)

<u>NUCLEAR FUEL SERVICES, WEST VALLEY, NY</u> (+42.4506, –78.6547)

Recovered 90.2 kg of plutonium

Inventory difference of (102.5 – 90.2) kg = 12.3 kg

Corresponds to 12300 g / (2.1 g/kg) ≈ 5800 kg of spent fuel equivalent

Source: U.S. Department of Energy (top) and Antepenultimate/Wikipedia Commons

CREATING SYNTHETIC NUCLEAR FUEL CYCLE HISTORIES

Creating Synthetic Histories of a Notional Nuclear Weapons Program

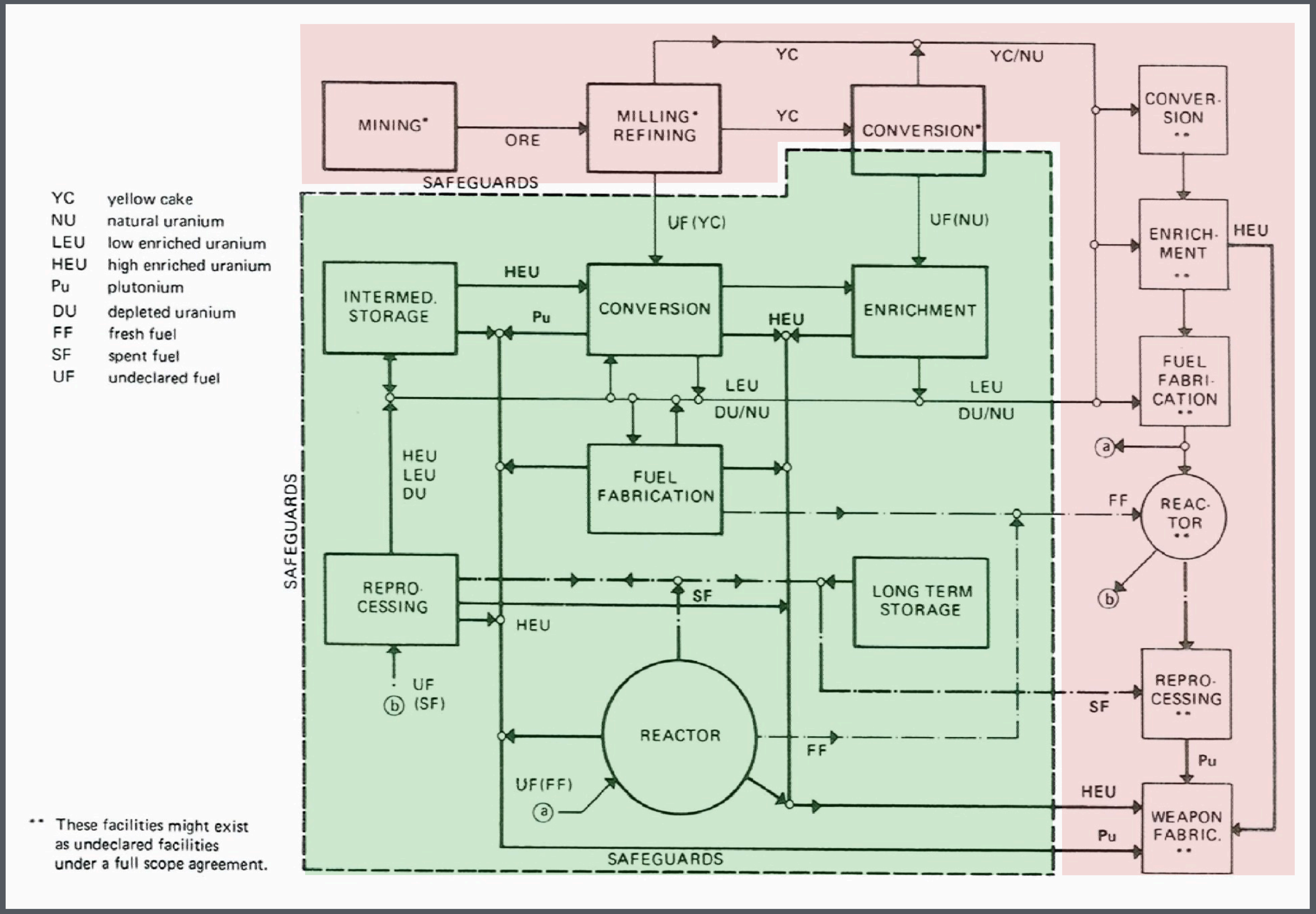
A Tabletop Exercise

Princeton, NJ
September 6, 2018

The plan for this tabletop exercise will be to create synthetic histories for a nuclear weapons program using *Cyclus* and other modeling tools. The exercise will develop a timeline of events and the required infrastructure associated with a notional nuclear weapons program that has produced fissile material and nuclear weapons over a 20–30-year time period (approx. 200 weapons, both fission and boosted fusion). This will be the basis for alternative synthetic histories (generated with *Cyclus*) of fissile material and waste inventories, annual warhead production and dismantlement, and notional production records for these activities. These histories will permit an exploration of the scope for concealing warheads and materials, and the role the documentation of a nuclear program's history could play in verifying a nuclear disarmament plan and establishing confidence in the completeness of a related declaration by a weapon state.

NOTIONAL NUCLEAR FUEL CYCLE

WITH (UNDECLARED) MILITARY DIMENSION



Source: John Kinney, IAEA

BASIC CYCLUS CONCEPTS

Cyclus uses a time-step approach to march through time and determine what actions are taken by each agent at each point in time.

- New agents may enter the system (deployment)
- Each agent prepares for exchange of material
- Agents engage in material trades
- Each agent acts after the exchange of material
- Agents may leave the system (decommissioning)

Source: fuelcycle.org

SCIENCE AND GLOBAL SECURITY

PRINCETON UNIVERSITY