# NUCLEAR ENERGY BASICS,

# PART 2:
# REACTORS AND NUCLEAR FUEL MAKING

A presentation by
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Executive Director
Nonproliferation Policy Education Center
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# QUESTIONS TO BE ADDRESSED:

1. What are the basic stages of once-through uranium based fuel cycles?

2. What are the most popular methods of enriching uranium?

3. What are the different types of nuclear reactors and how proliferation prone is each?

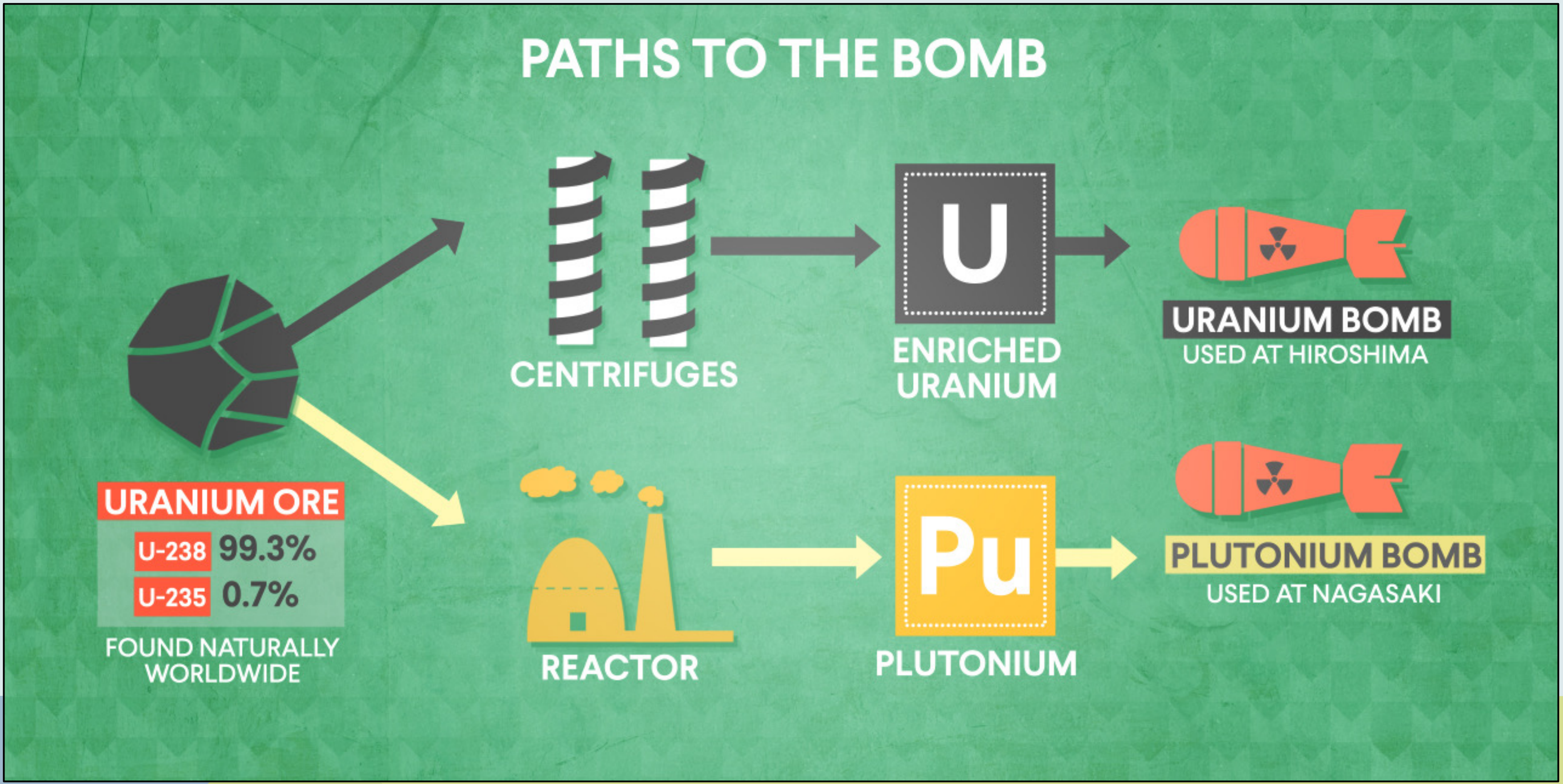
4. What can be done with spent reactor nuclear fuel?

# SHORT ANSWERS

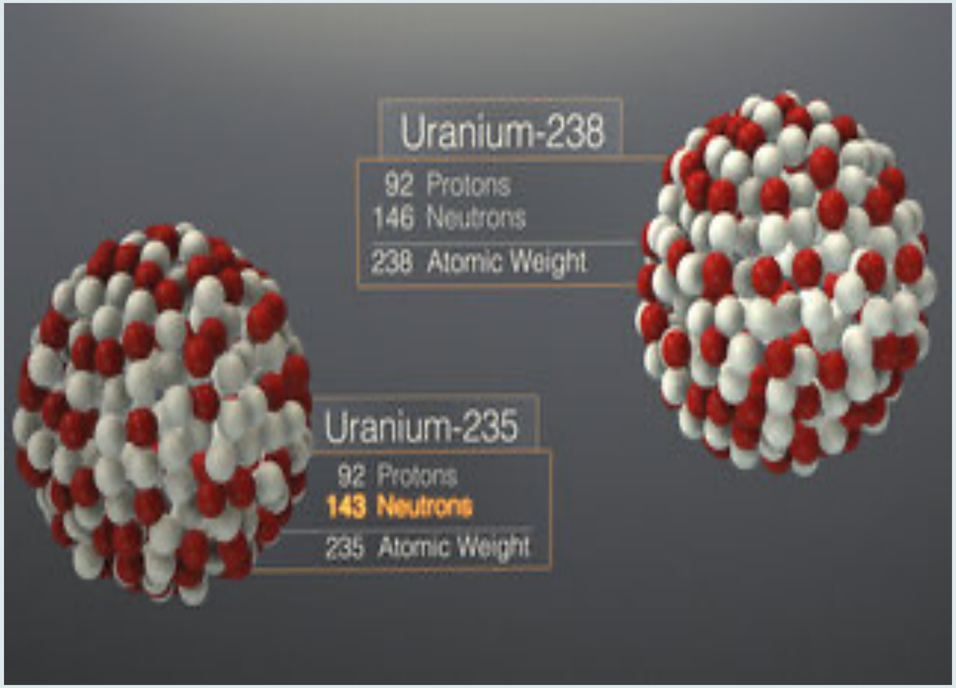
1. There are six stages: Uranium mining and milling, conversion to uranium hexafluoride ($UF_6$), uranium enrichment, fuel fabrication, generating nuclear electricity, spent fuel storage.
2. Centrifuges and gaseous diffusion
3. All types of reactors can make nuclear explosive plutonium– light water and heavy water reactors, gas cooled and graphite reactors, RMBK and fast reactors
4. Spent fuel can be recycled or not. In either case, there will be considerable waste that must be stored above or under ground.

# 0. NUCLEAR FUEL CYCLE BASICS

# THERE ARE TWO MAJOR PATHS TO THE BOMB



# U238 & U235: TWO IMPORTANT URANIUM ISOTOPES



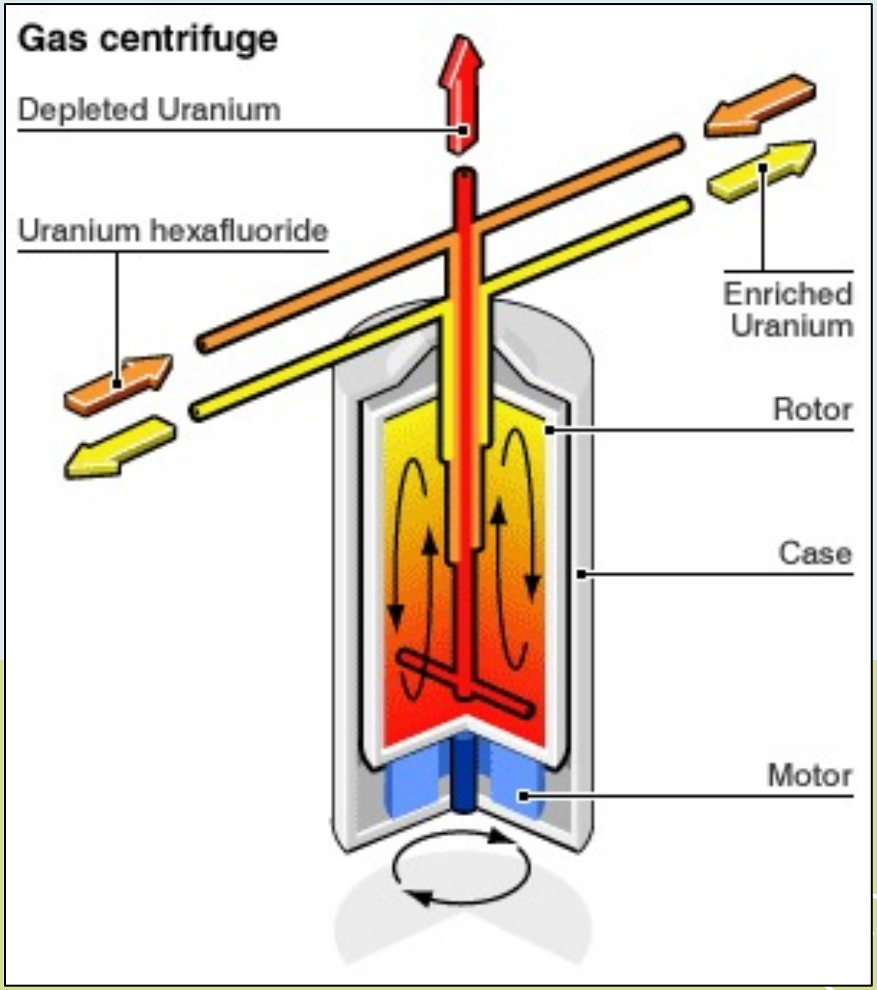

## U238

- Has 146 neutrons
- constitutes 99.3% of uranium in nature
- Is not prone to fission

## U235

- Has 143 neutrons
- Constitutes .7% of uranium found in nature
- Is prone to fission

# URANIUM CENTRIFUGE ENRICHMENT SEPARATES THE HEAVY URANIUM FROM THE LIGHT URANIUM



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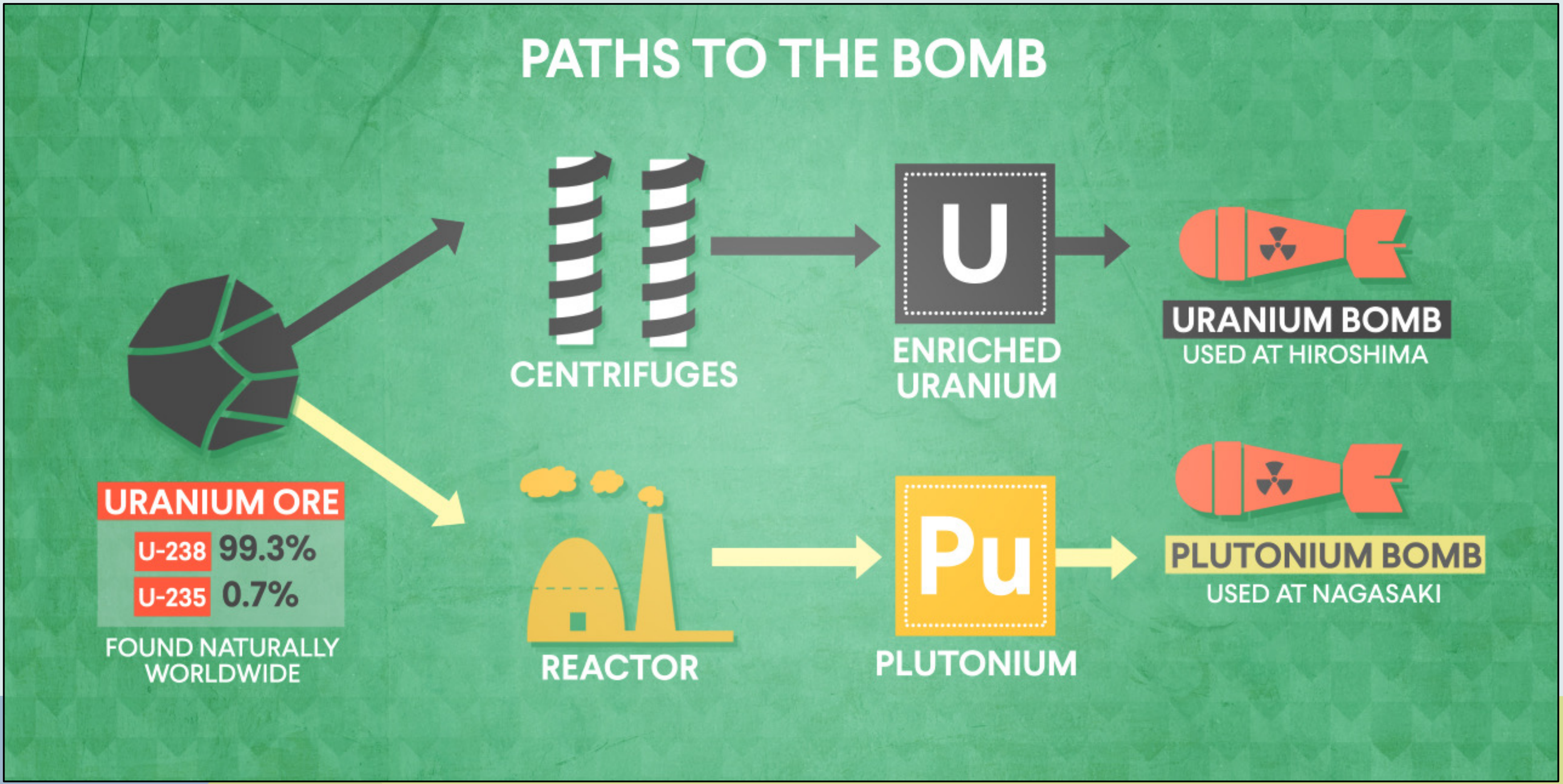
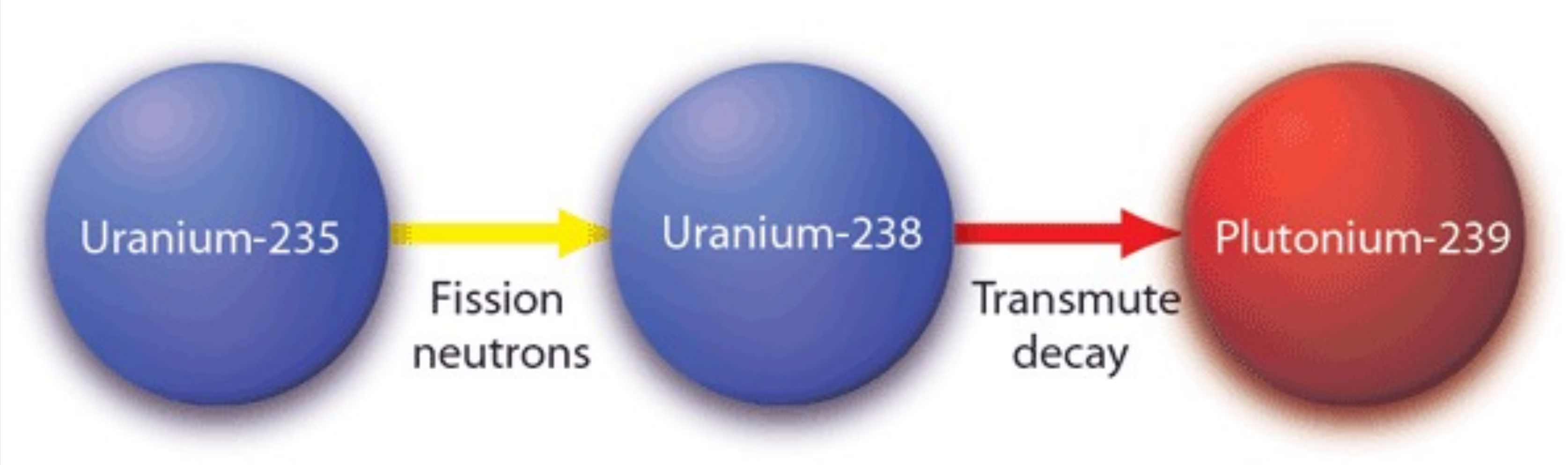
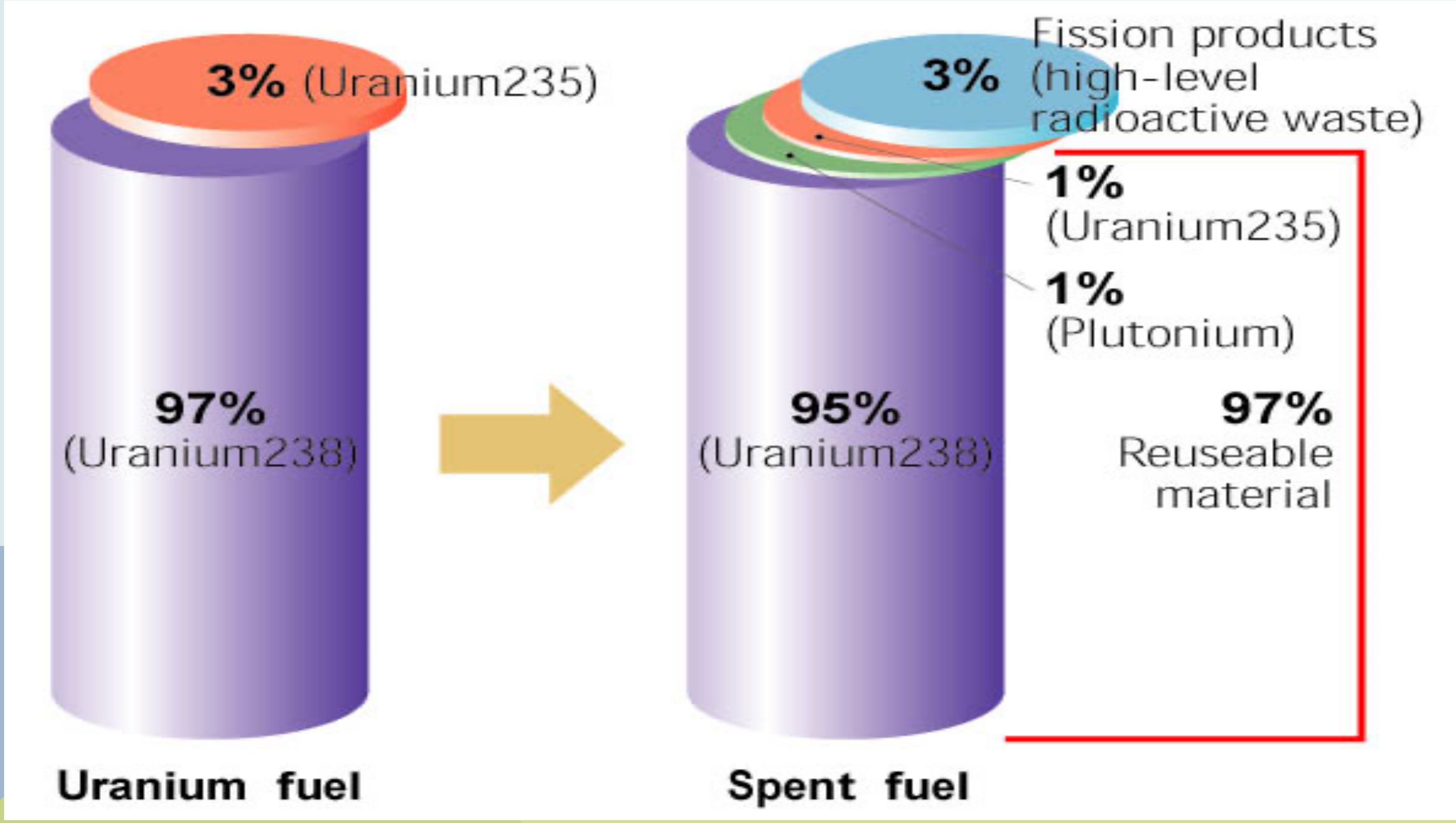


# URANIUM TRANSMUTES TO PLUTONIUM IN A REACTOR



# SPENT REACTOR FUEL CONTAINS PLUTONIUM THAT CAN BE CHEMICALLY STRIPPED OUT (REPROCESSED)



# 1. WHAT ARE THE BASIC STAGES OF ONCE-THROUGH URANIUM BASED FUEL CYCLES?

# ONCE-THROUGH FUEL CYCLE DOESN'T REPROCESS SPENT FUEL

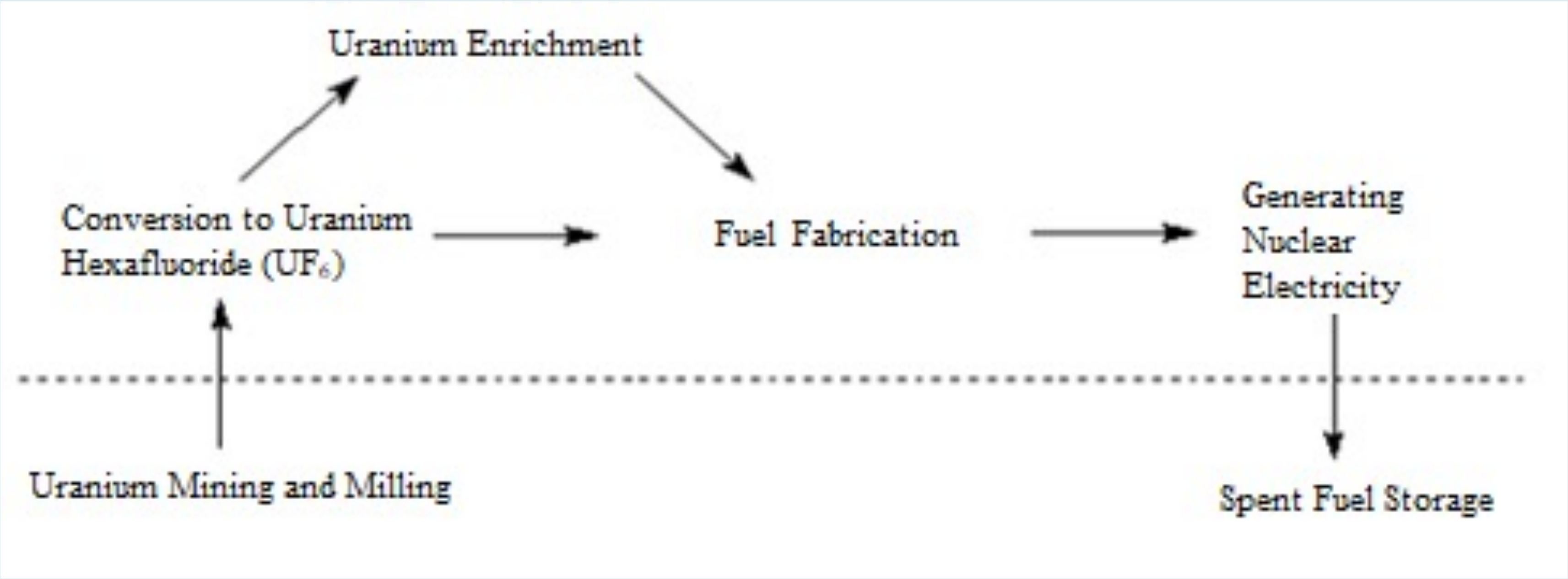



**FIGURE 1**

# CLOSED PLUTONIUM-BASED FUEL CYCLE REQUIRES REPROCESSING

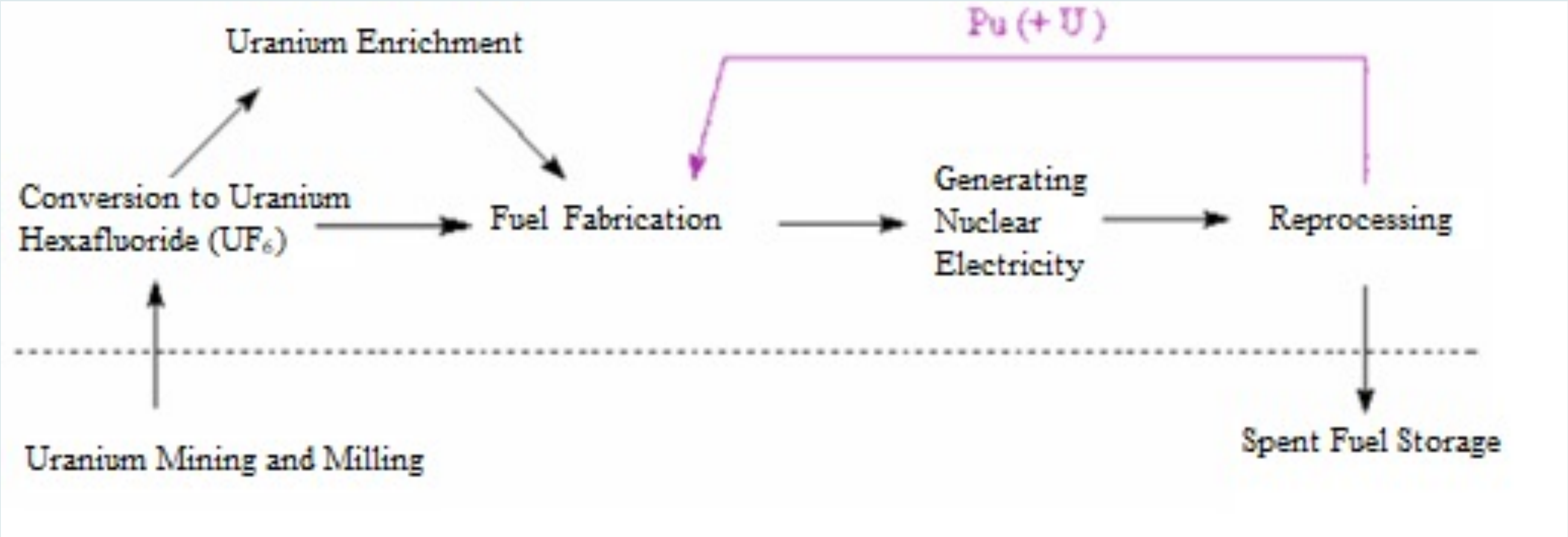



**FIGURE 2**

# BASIC STAGES OF ONCE-THROUGH URANIUM-BASED FUEL CYCLES

1. Uranium Mining and Milling
2. Conversion to Uranium Hexafluoride ($UF_6$)
3. Uranium Enrichment
4. Fuel Fabrication
5. Generating Nuclear Electricity
6. Spent Fuel Storage

# MAJOR URANIUM PRODUCERS 2016

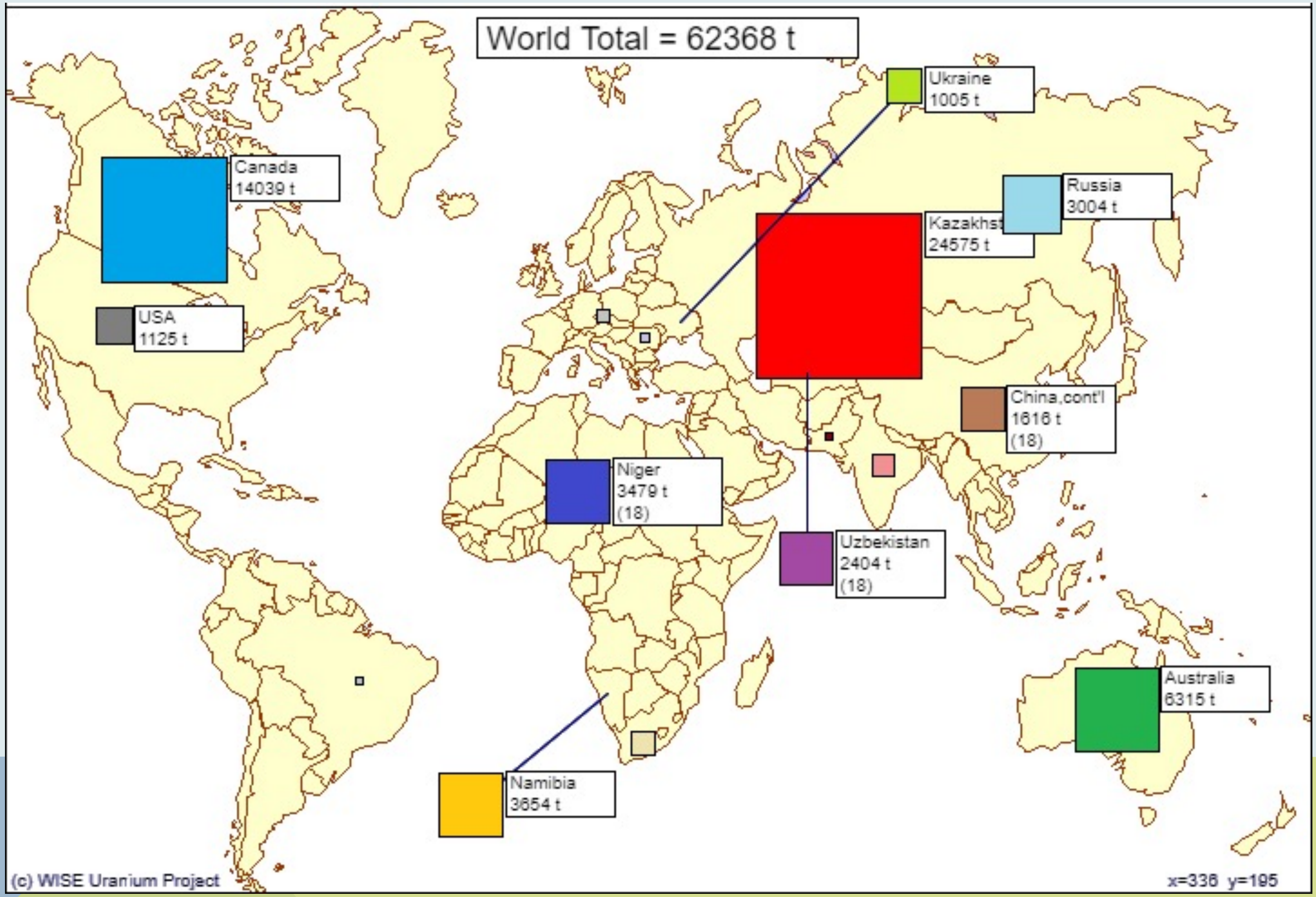


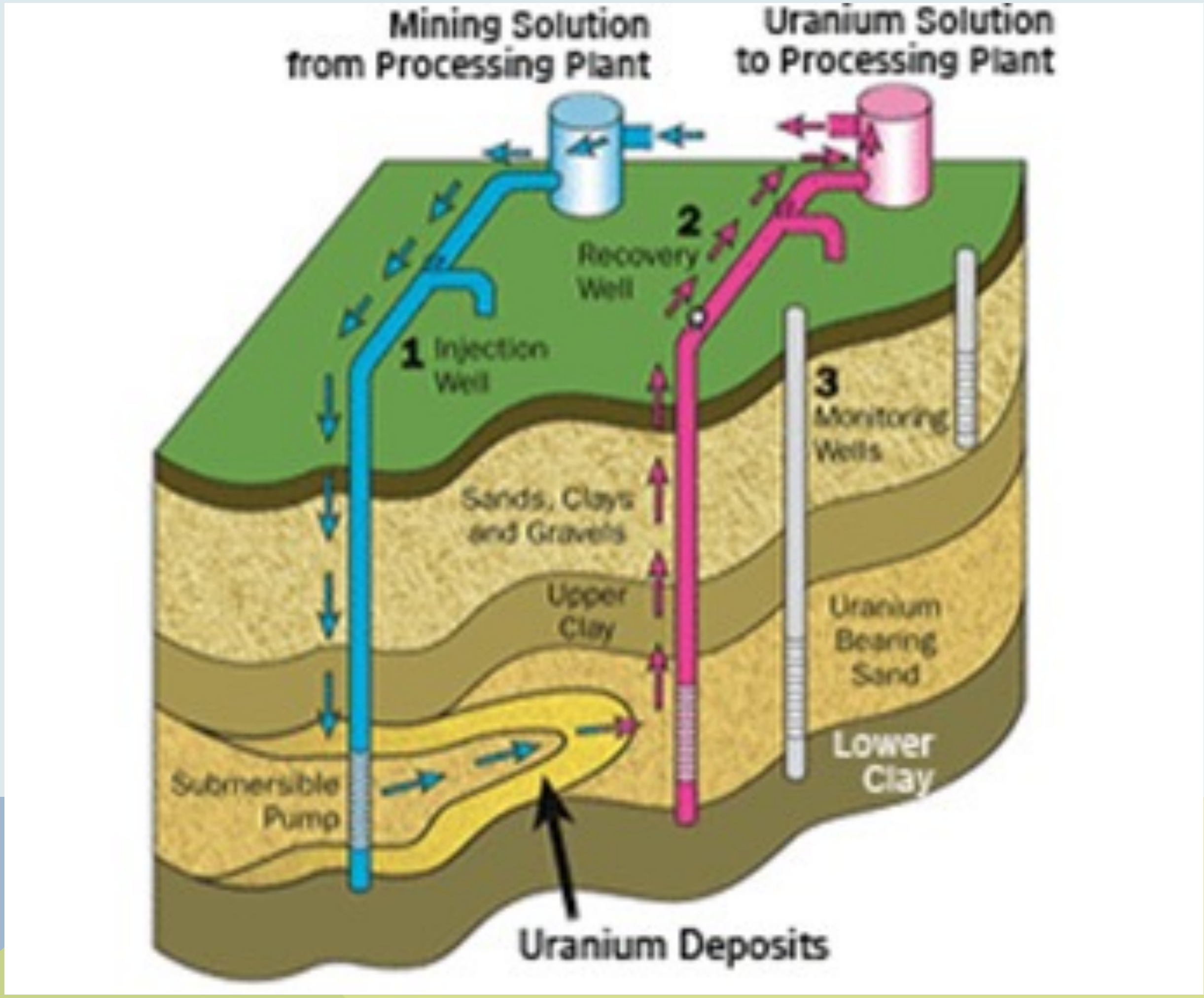

**FIGURE 3**

# CONVENTIONAL URANIUM MINING

**Underground**

**Open Pit**

# IN SITU RECOVERY MINING METHOD




1. Injection Wells

2. Recovery Wells

3. Monitoring Wells

# YELLOWCAKE

# BASIC STAGES OF ONCE-THROUGH URANIUM-BASED FUEL CYCLES

1. Uranium Mining and Milling
2. Conversion to Uranium Hexafluoride ($UF_6$)
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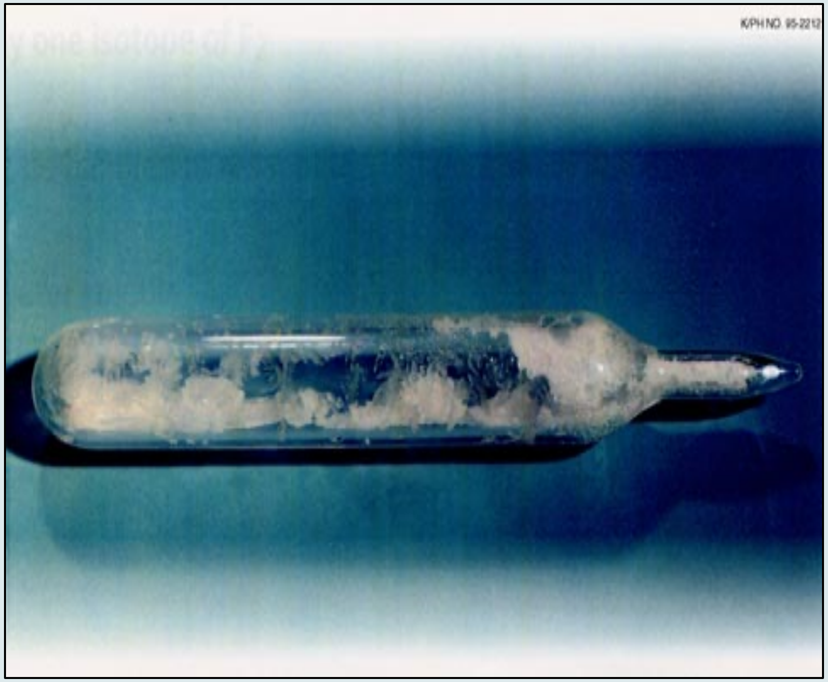
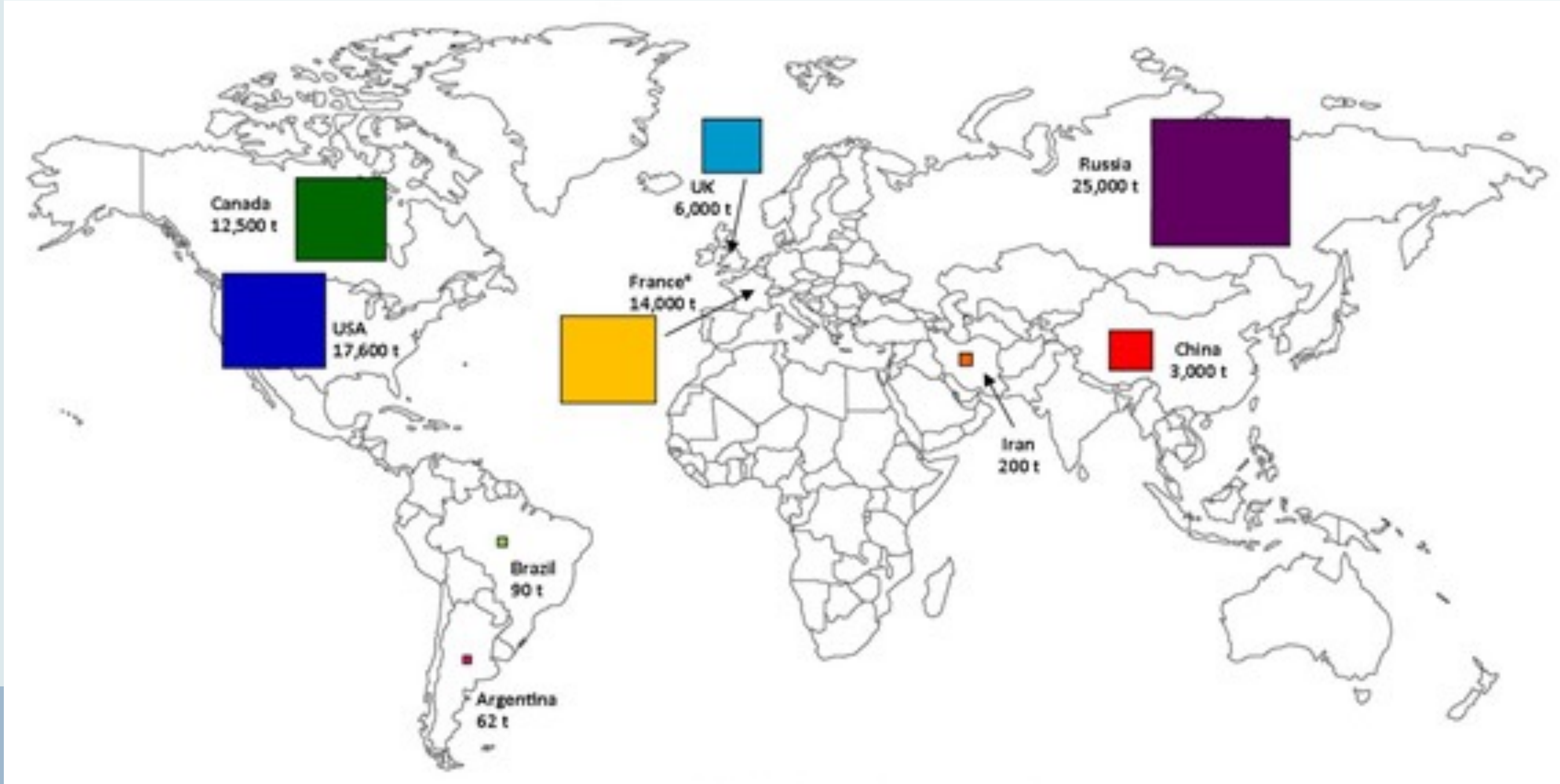
# $UF_4$ (GREEN SALT) AND $UF_6$ (URANIUM HEXAFLUORIDE)



# HEXAFLUORIDE CONVERSION FACILITY– LARGE & RARE

Port Hope in Ontario, Canada

# MAJOR HEXAFLUORIDE $UF_6$ PRODUCERS




* Capacity for France excludes Comurhex II, under construction, estimated capacity of 15,000 t/year

[t U/year] metric tons uranium/year

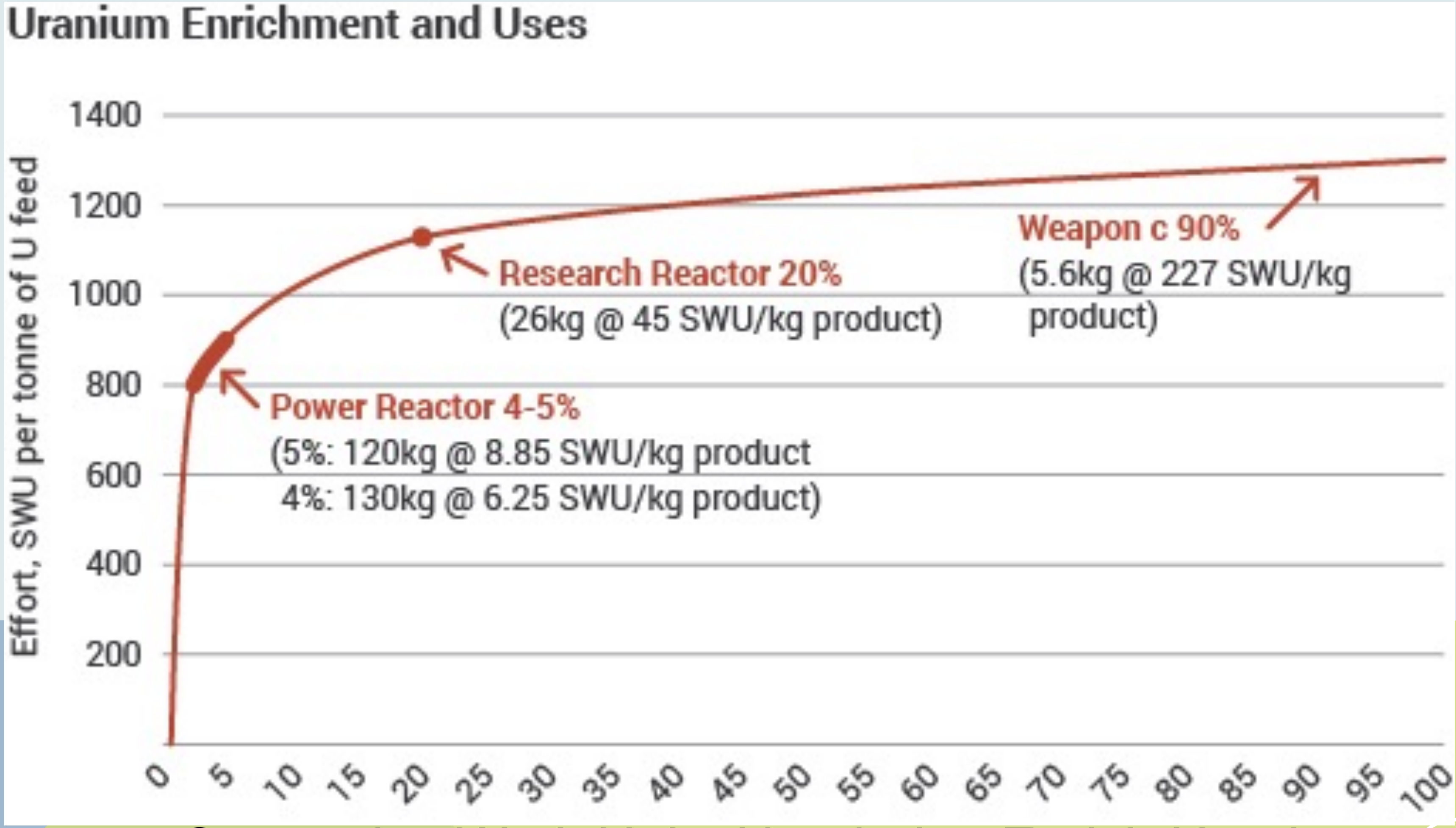
# 2. WHAT ARE THE MOST POPULAR METHODS OF ENRICHING URANIUM?

# MOST COUNTRIES THAT ENRICH URANIUM USE CENTRIFUGES

**Gaseous Diffusion:** Argentina

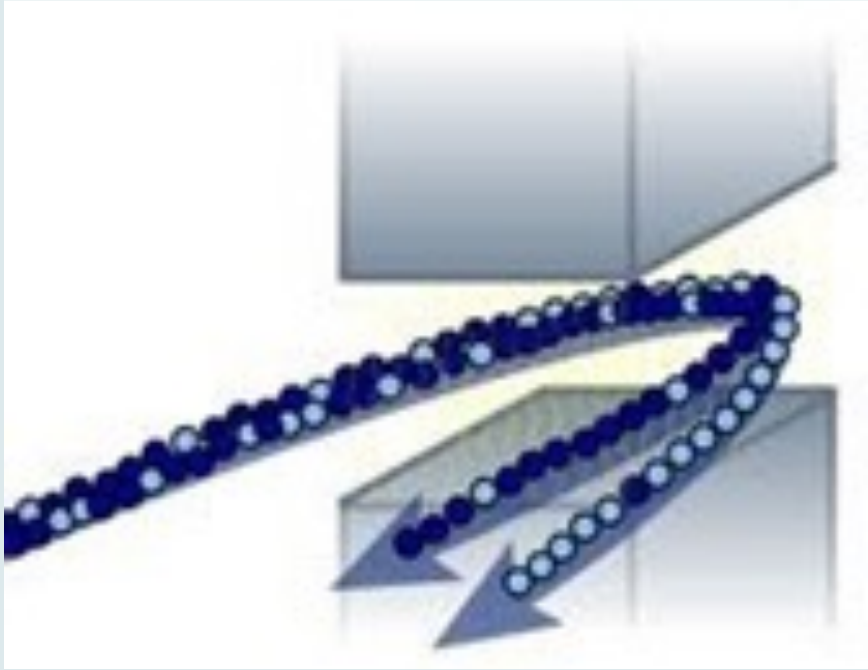
**Centrifuge:** Brazil, U.S.-URENCO, Holland, France, UK, Germany, Russia, China, Japan, Iran, India, Pakistan, North Korea

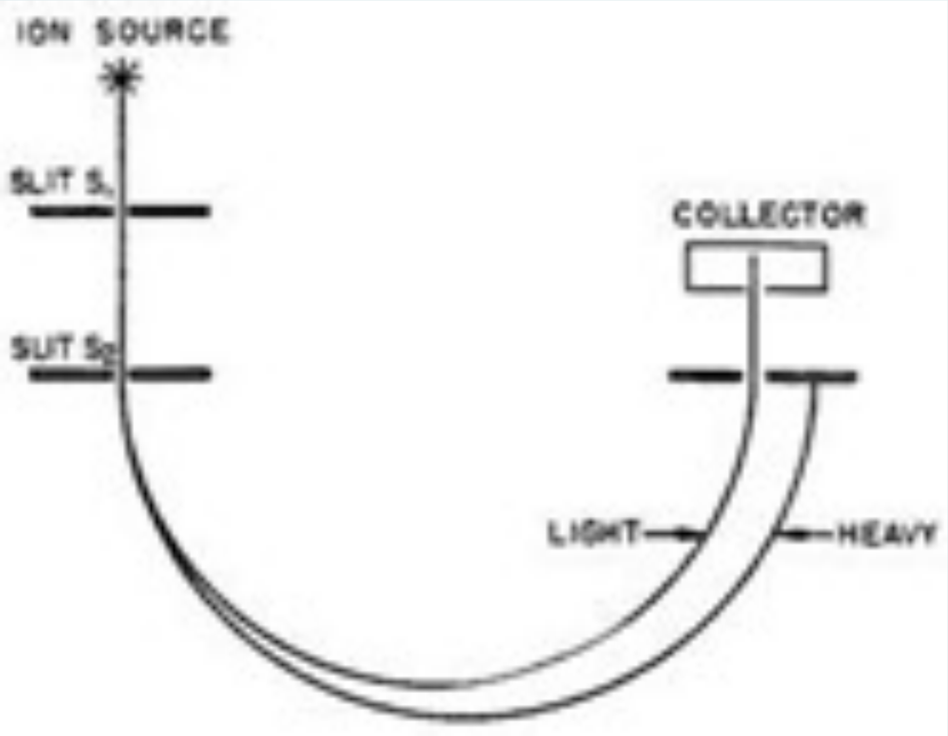
# THE EFFORT NEEDED TO ENRICH U TO 3-5% IS HALF OF WHAT IS NEEDED TO ENRICH TO WEAPONS-GRADE U




Separative Work Units Needed to Enrich Uranium to Power, Research, and Weapons grades

# ELECTRIC MAGNETIC ISOTOPE SEPARATION (EMIS) EXPLOITS DIFFERENT WEIGHTS OF U235 AND U238





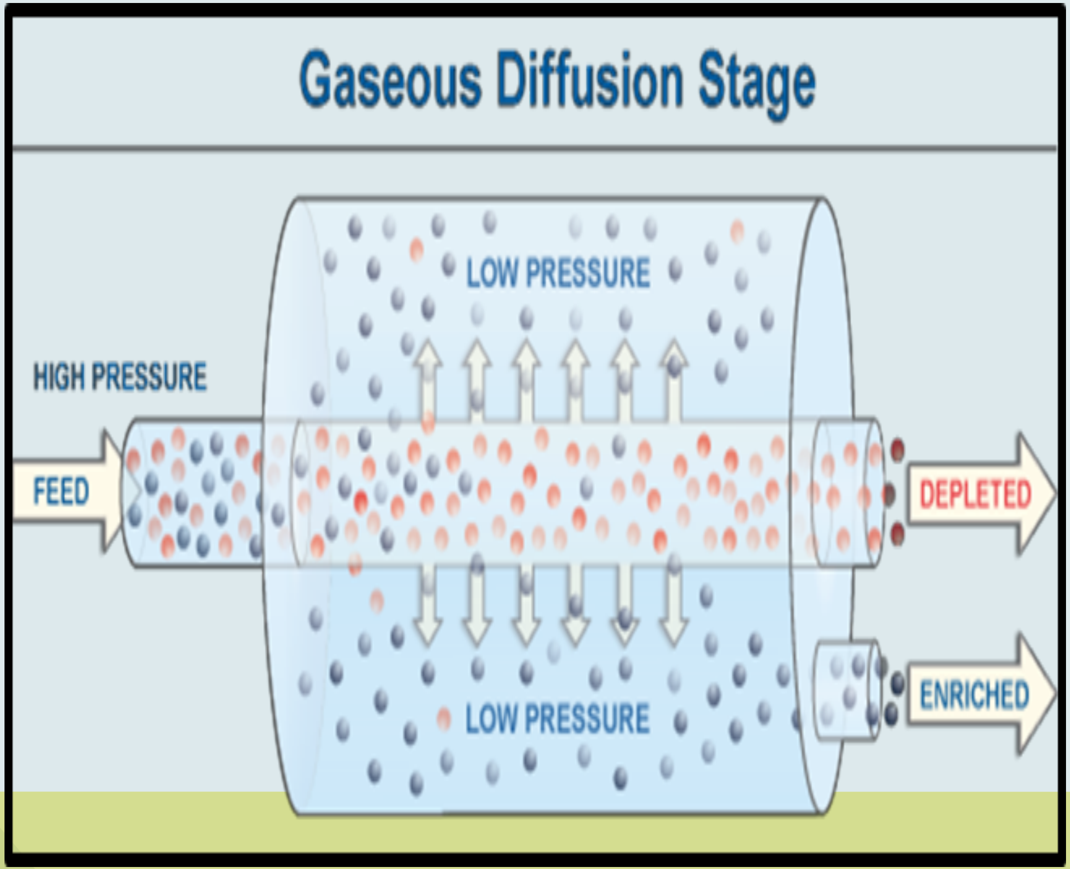
# THE Y-12 PLANT AT OAK RIDGE, TENNESSEE USED EMIS

The Y-12 Plant

Alpha Track Calutron at the Y-12 Plant at Oak Ridge, Tennessee

# EMIS "CALUTRON" WAS DISCOVERED IN IRAQ IN 1991

# GASEOUS DIFFUSION ALSO EXPLOITS DIFFERENT WEIGHTS OF U238 & U235



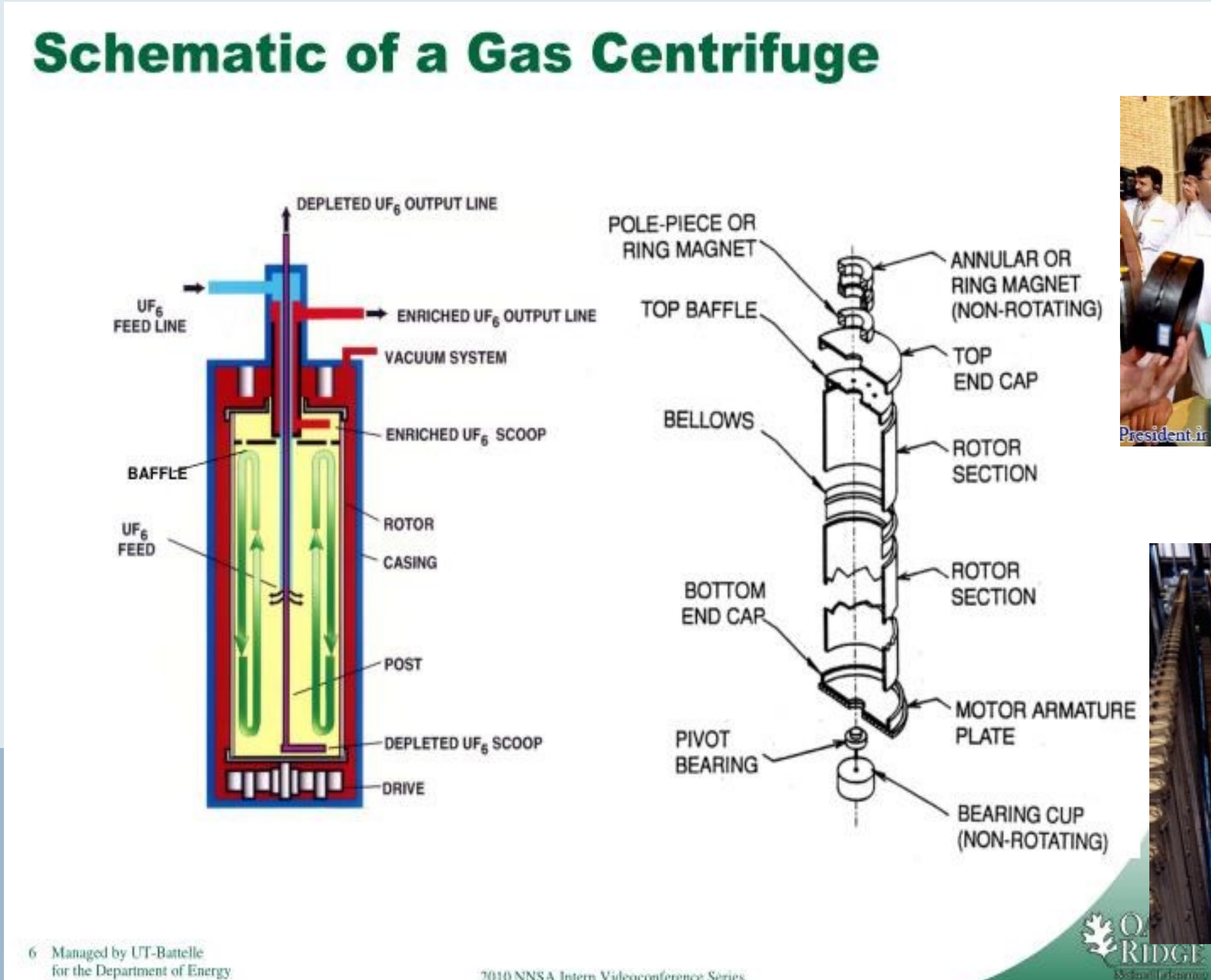
# 1ST GASEOUS DIFFUSION PLANT WAS ONE OF THE WORLD'S LARGEST CONSTRUCTION PROJECTS

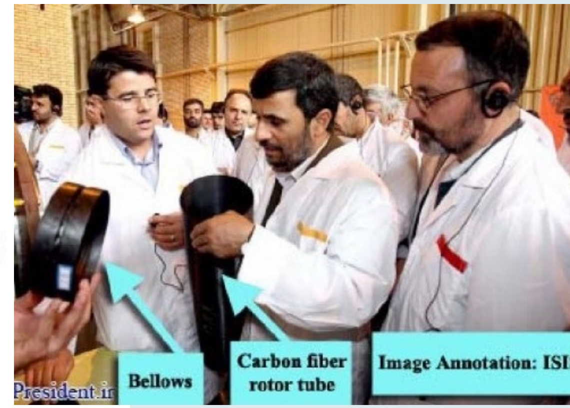
**K-25 Plant, Oak Ridge, Tennessee, The first gaseous diffusion plant**

# FRENCH GASEOUS DIFFUSION PLANT IS POWERED BY 4 NUCLEAR REACTORS

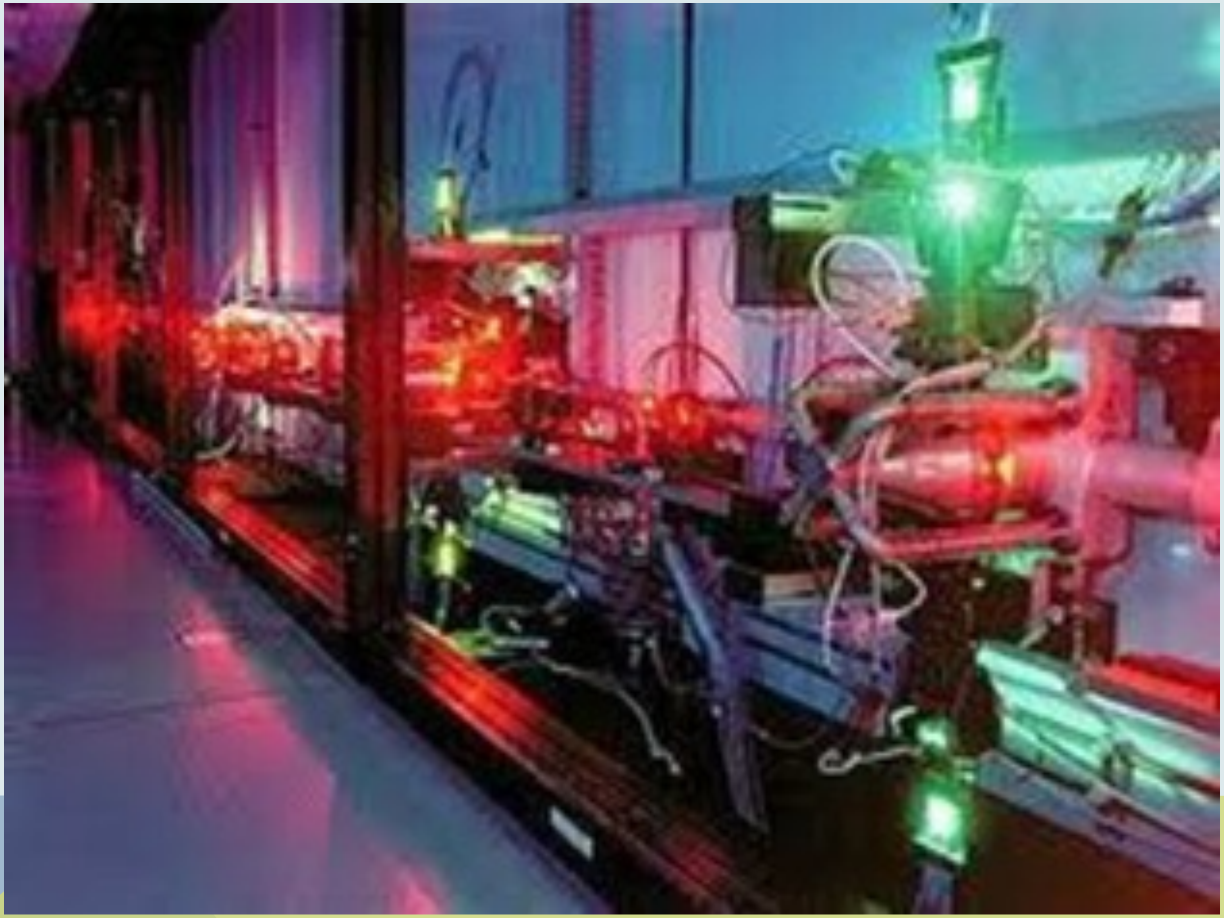
French gaseous diffusion plant powered by nearly 4 gigawatts electrical, four nuclear power reactors.

# GAS CENTRIFUGE COMPONENTS



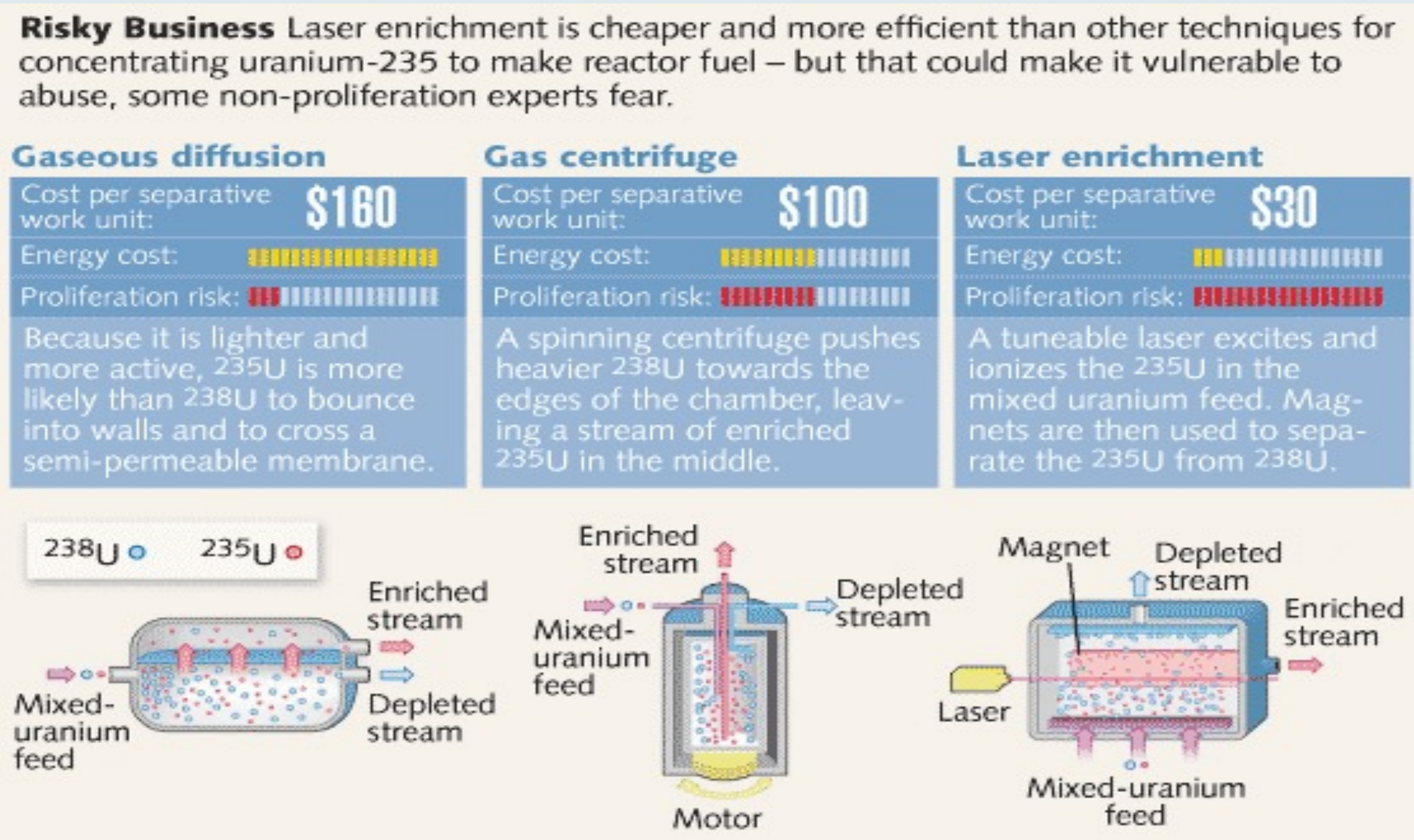




# THE AVLIS (ATOMIC VAPOR LASER ISOTOPE SEPARATION) PROCESS



# SEPARATION OF ISOTOPES BY LASER EXCITATION (SILEX): SMALLER, CHEAPER STILL

# PRICE AND PROLIFERATION RISK COMPARISON OF DIFFUSION, CENTRIFUGE, AND SILEX ENRICHMENT



# BASIC STAGES OF ONCE-THROUGH URANIUM-BASED FUEL CYCLES

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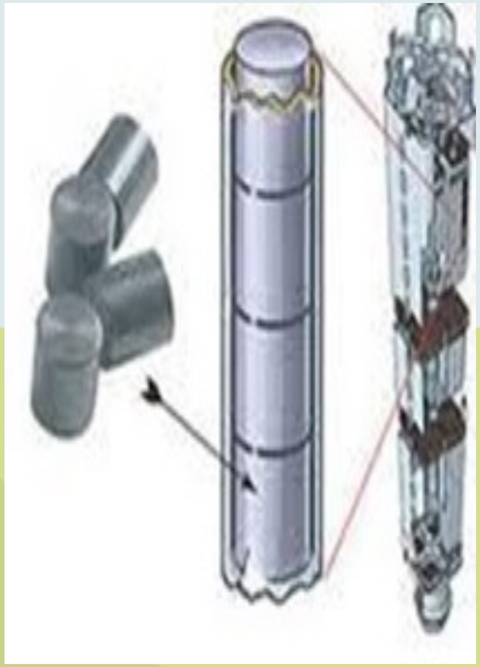
# FUEL FABRICATION

Zirconium Alloy (or Similar) Tubes for Cladding

Ceramic Uranium Dioxide Pellets



Left: Individual fuel pellets.

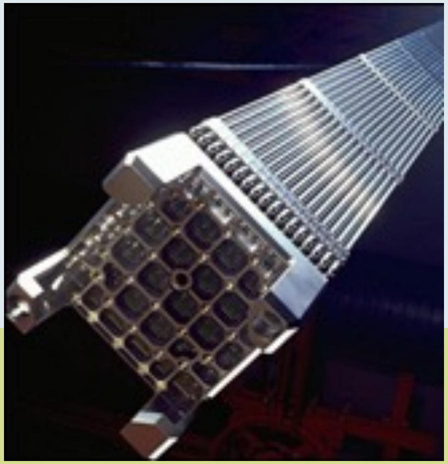
Center: Pellets are assembled into a fuel rod

Right: Fuel rods are bundled together in a fuel assembly

# FUEL ROD AND FUEL ASSEMBLY PROCESS

A technician arranges fuel pellets in a trough before sliding the cladding over them.

Completed Fuel Rods

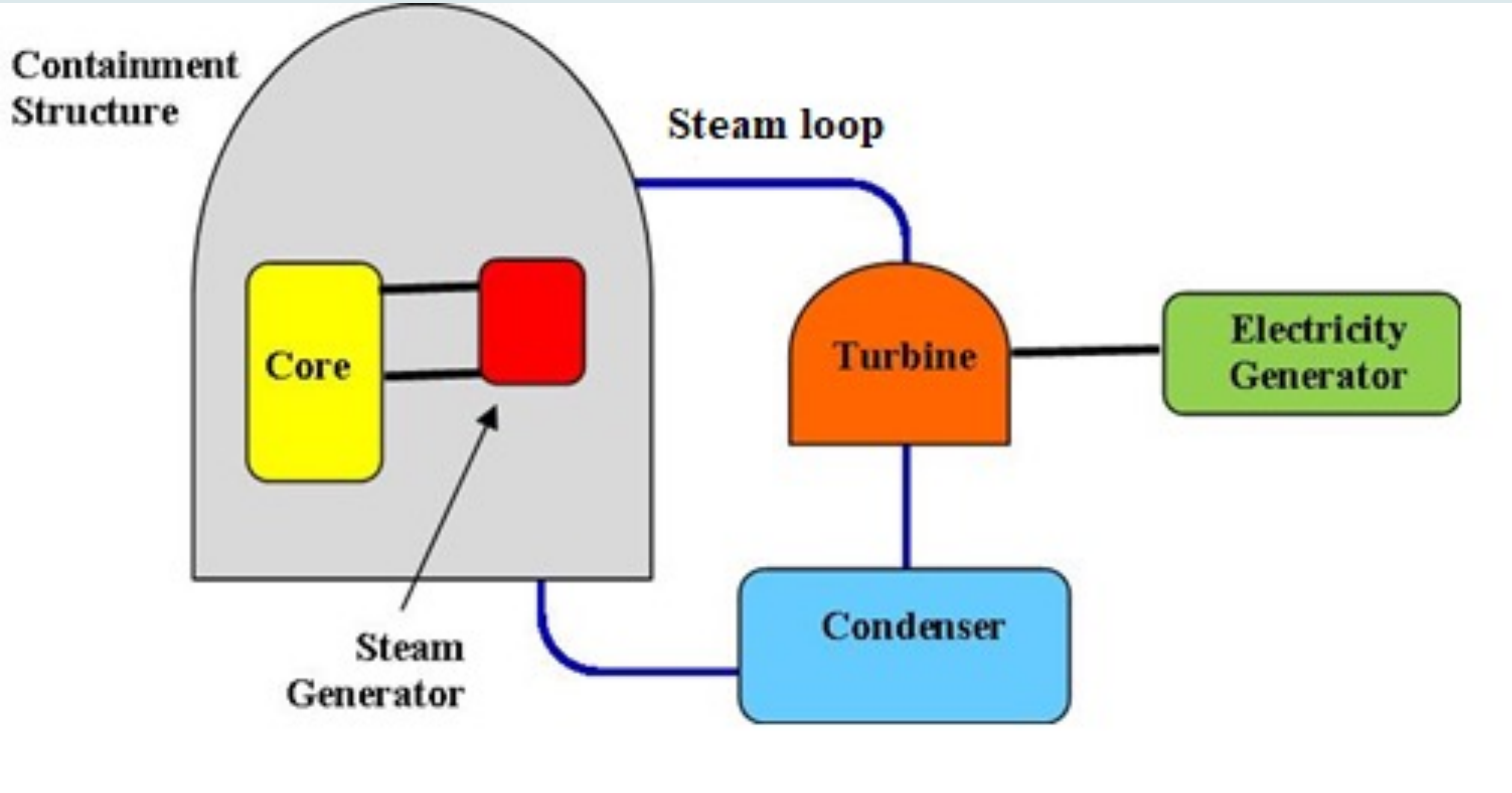


Fuel Rod Assembly

Fuel Assemblies in Reactor Core

# 3. WHAT ARE THE DIFFERENT TYPES OF NUCLEAR REACTORS AND HOW PROLIFERATION PRONE IS EACH?

# SIMPLIFIED SCHEMATIC OF A NUCLEAR REACTOR



# BIGGEST NUCLEAR POWER PLANT COMPONENTS


**Nuclear core and steam generators (during refueling)**

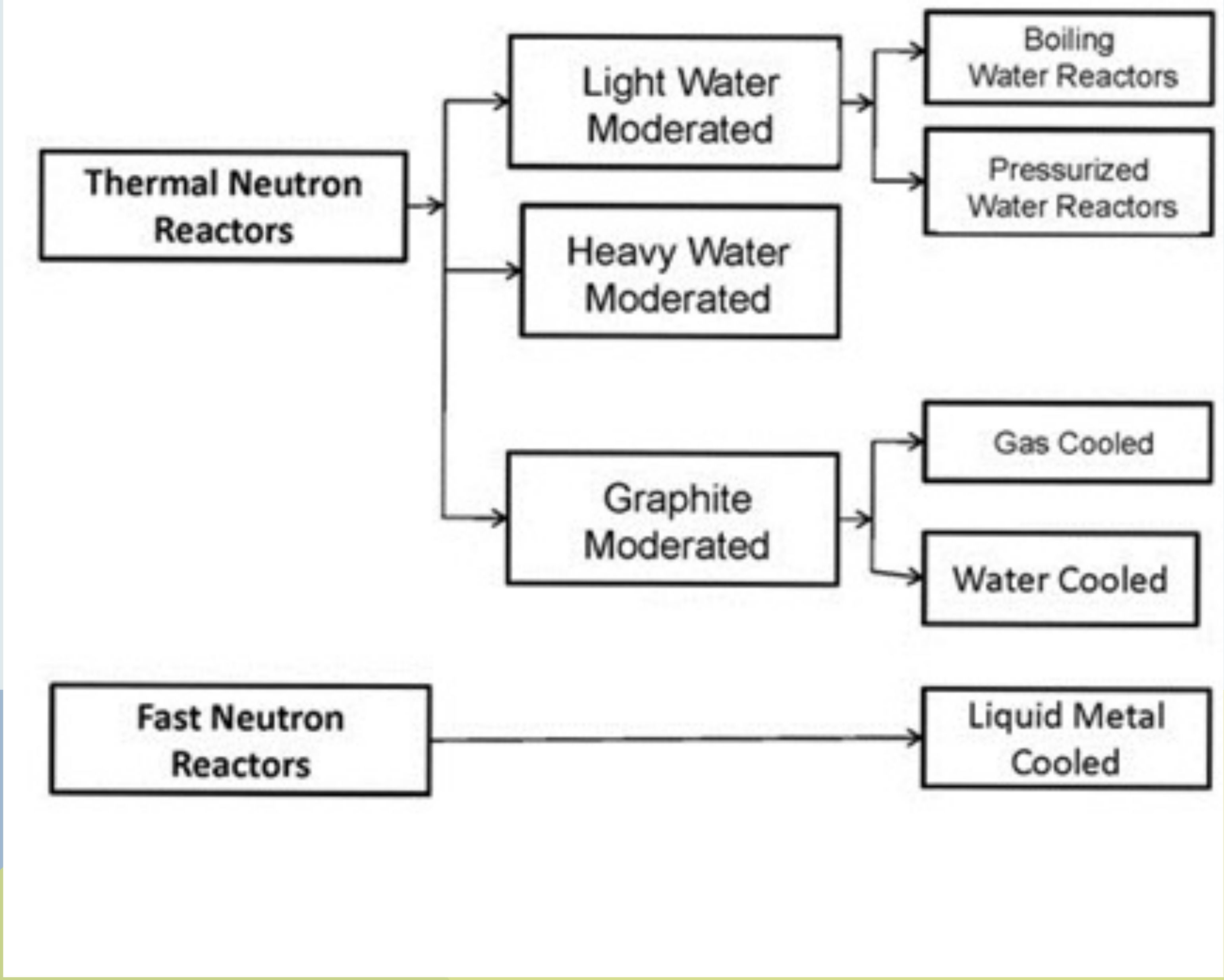

**Steam Turbines**


**Cooling Towers**

# MAJOR TYPES OF NUCLEAR REACTORS

1. Early Graphite Reactors
2. Magnox Reactor
3. Heavy Water Reactor (HWR)
4. Liquid-Metal Fast Breeder Reactor (LMFBR)
5. Light Water Reactors (LWR)—Pressurized (PWR) and Boiling (BWR)
6. RBMK
7. High-temperature Gas Cooled Reactor (HTGR)

# REACTOR SPECIES OR GROUPS

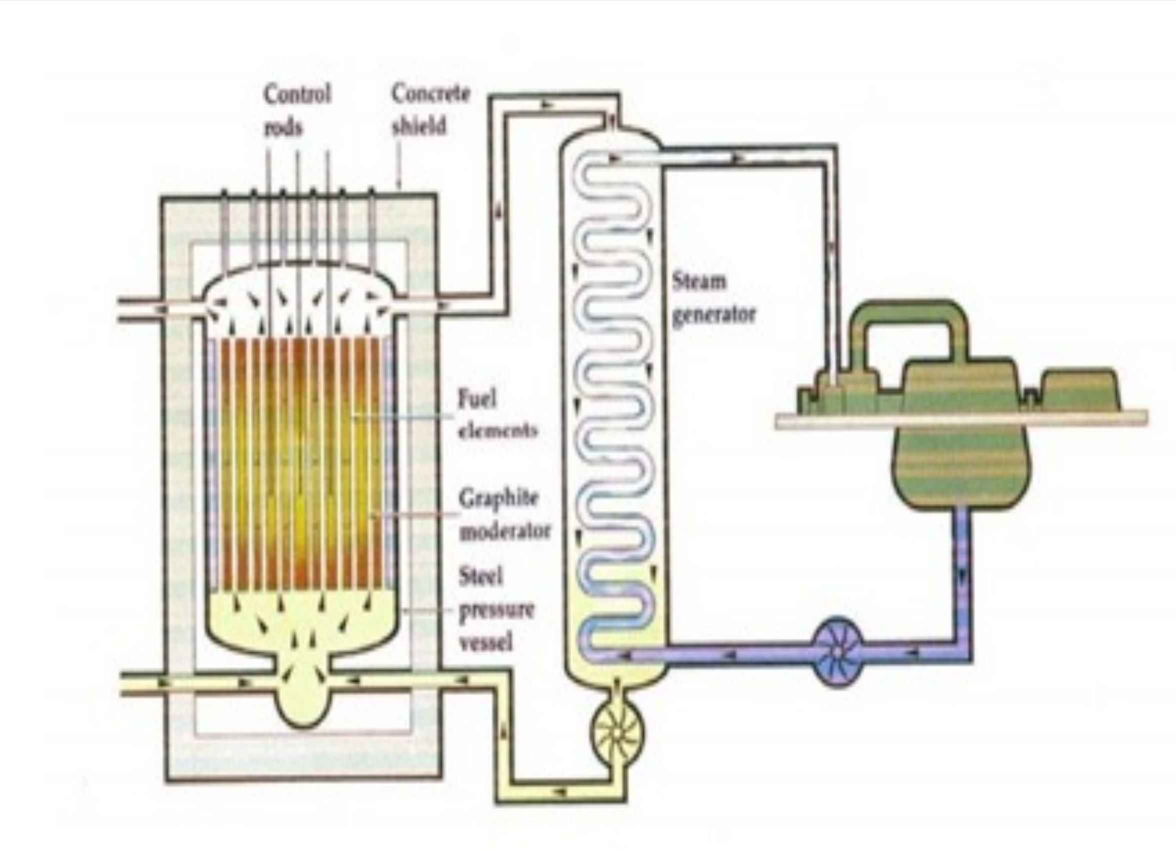


# FIRST REACTORS: GRAPHITE MODERATED


Chicago Pile-1


B Reactor

# MAGNOX REACTOR: UK DUAL-USE GRAPHITE DESIGN

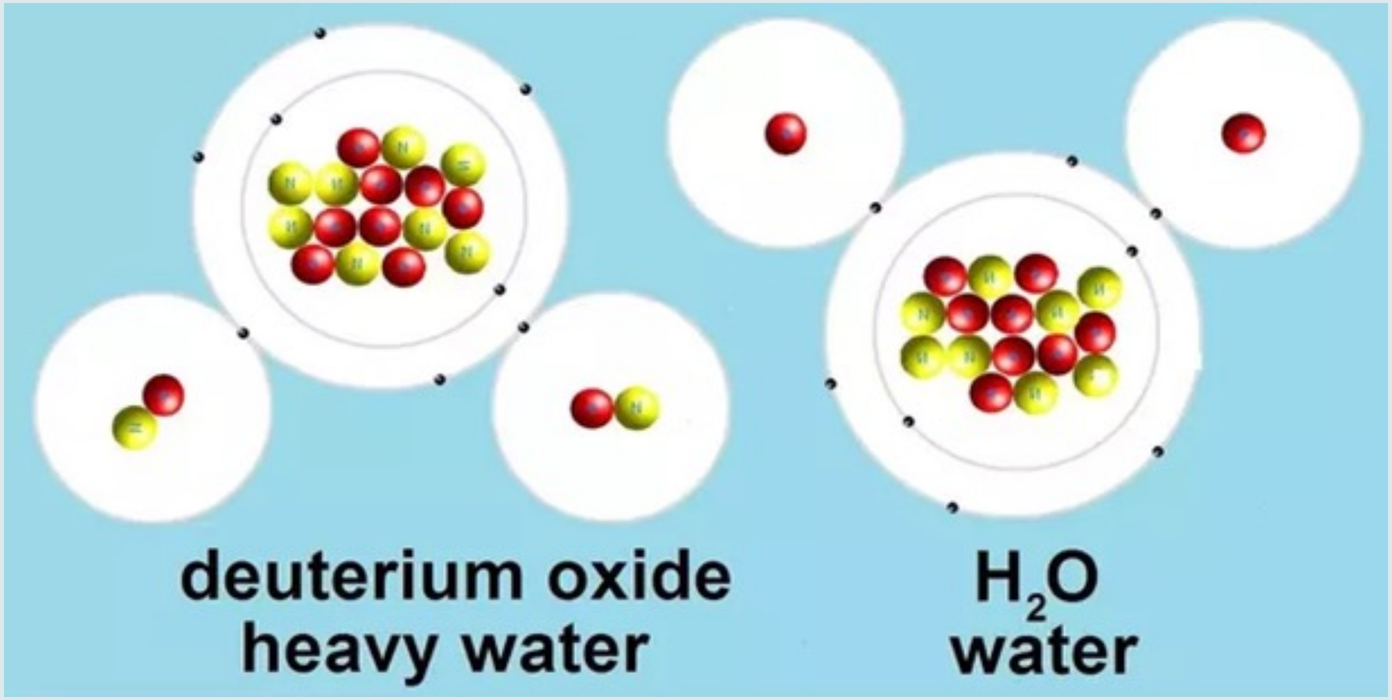



| | |
|---|---|
| Fuel | Natural Uranium |
| Moderator | Graphite |
| Coolant | Air |
| Refueling | On-load |

# WYLFA MAGNOX NUCLEAR PLANT, UK

# YONGBYON REACTOR: A MAGNOX DESIGN

# ATOMIC STRUCTURE OF HEAVY WATER $D_2O$ VS $H_2O$



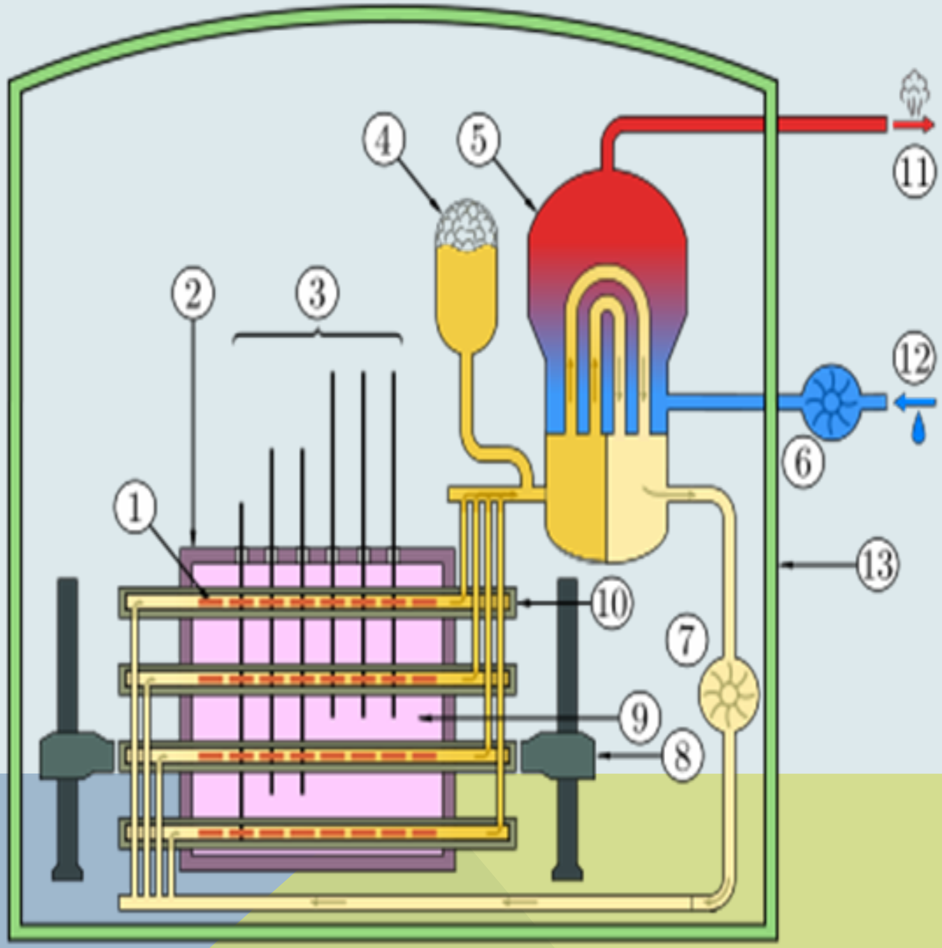

**Frozen D2O (at right) sinks in light water while frozen H2O floats**

# HEAVY WATER PRODUCTION

The Arak heavy water project located 120 miles southwest of Tehran

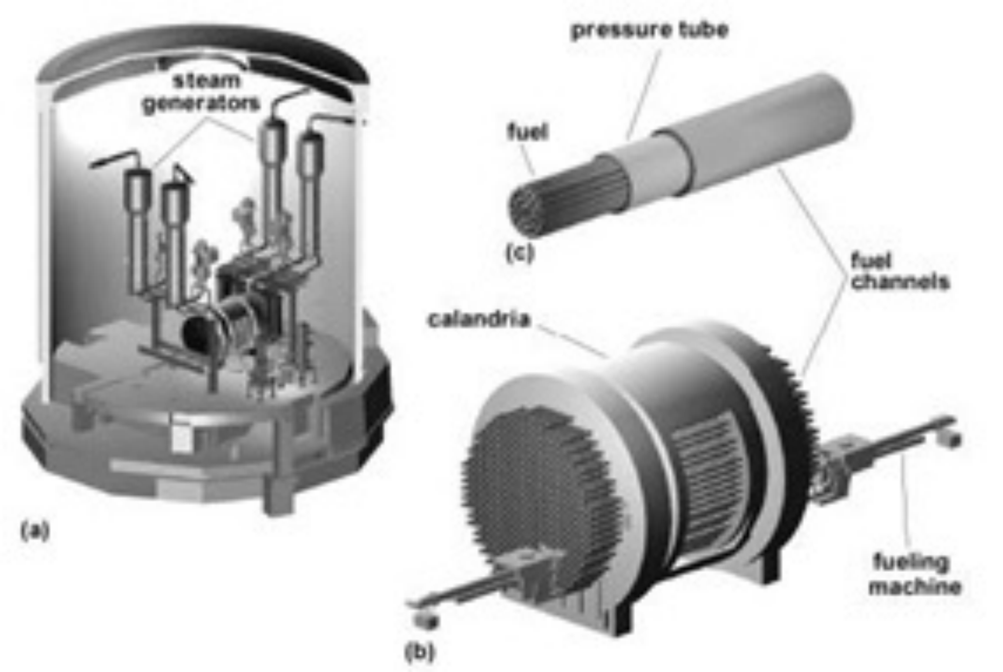
Whiteshell, UK

# HEAVY WATER REACTORS



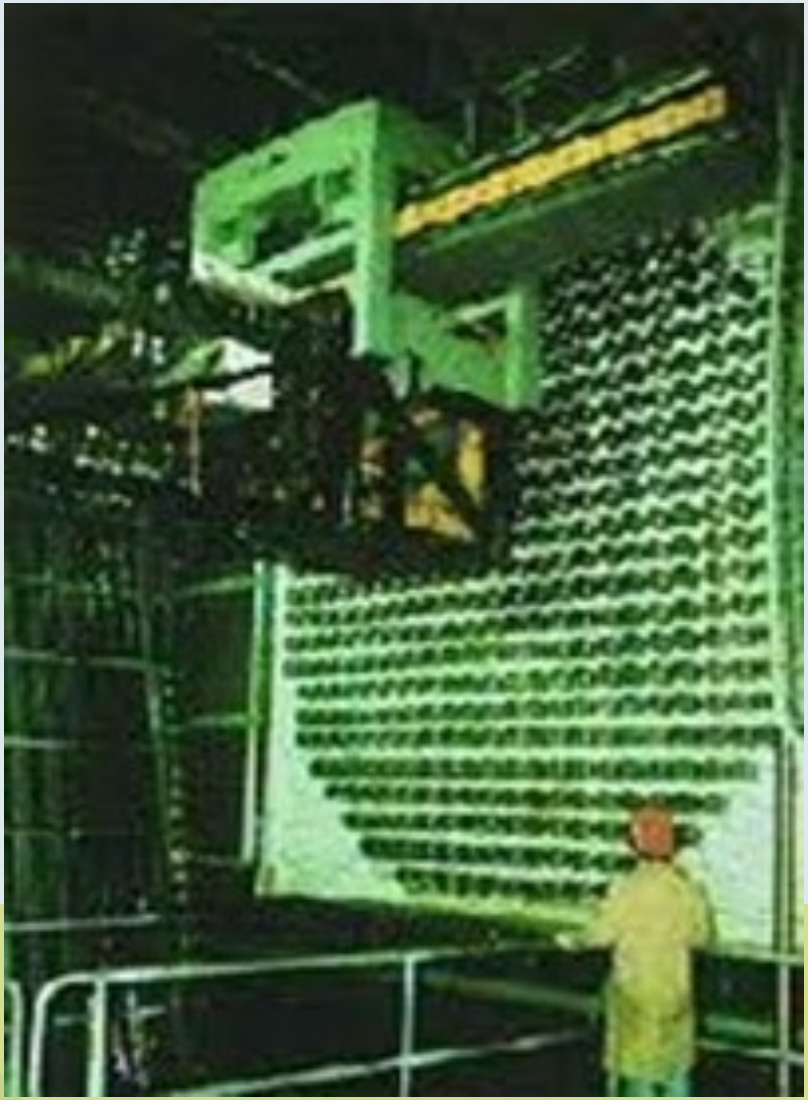

1. Fuel bundle
2. Calandria (reactor core)
3. Adjustor rods
4. Heavy water pressure reservoir
5. Steam generator
6. Light water pump
7. Heavy water pump
8. Fueling machines
9. Heavy water moderator
10. Pressure tube
11. Steam going to steam turbine
12. Cold water returning from turbine
13. Containment building of reinforced concrete

# HEAVY WATER REACTORS CONTINUED




| | |
|---|---|
| Fuel | Natural uranium clad in zircaloy |
| Moderator | Heavy Water |
| Coolant | Heavy Water |
| Refueling | On-load |

# ON-LINE REFUELING—HWRS



CANDU Reactor

# COUNTRIES WHO OPERATE OR USED TO OPERATE HWRS

**Countries that <u>operate</u> HWRs:** India, Argentina, Pakistan, Romania, Israel, China, and South Korea, Iran, Canada

**Countries that <u>used to operate</u> HWRs:** Germany, Sweden, Taiwan, and the United States, Russia, France

# IR-40 HEAVY WATER REACTOR NEAR ARAK, IRAN

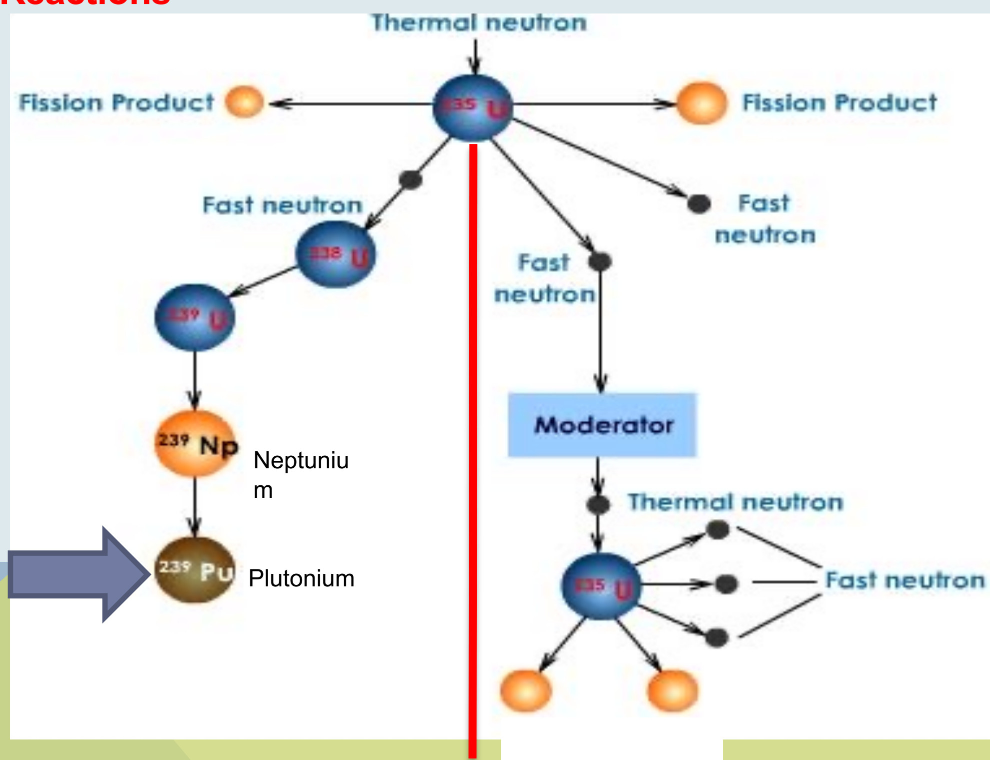
# SOME HEAVY WATER TRANSMUTES INTO TRITIUM IN HWRS. THIS TRITIUM MUST BE EXTRACTED FOR SAFETY REASONS BUT CAN ALSO BE USED FOR H-BOMBS

Wosong Tritium Removal Facility:
ROK Has Produced and Stockpiled Enough Tritium (4 kgs.) to Boost 1,000 Weapons

# CONVENTIONAL REACTORS EXPLOIT THERMAL REACTIONS, FAST REACTORS EXPLOIT FAST ONES

**Fast Neutron Reactions**

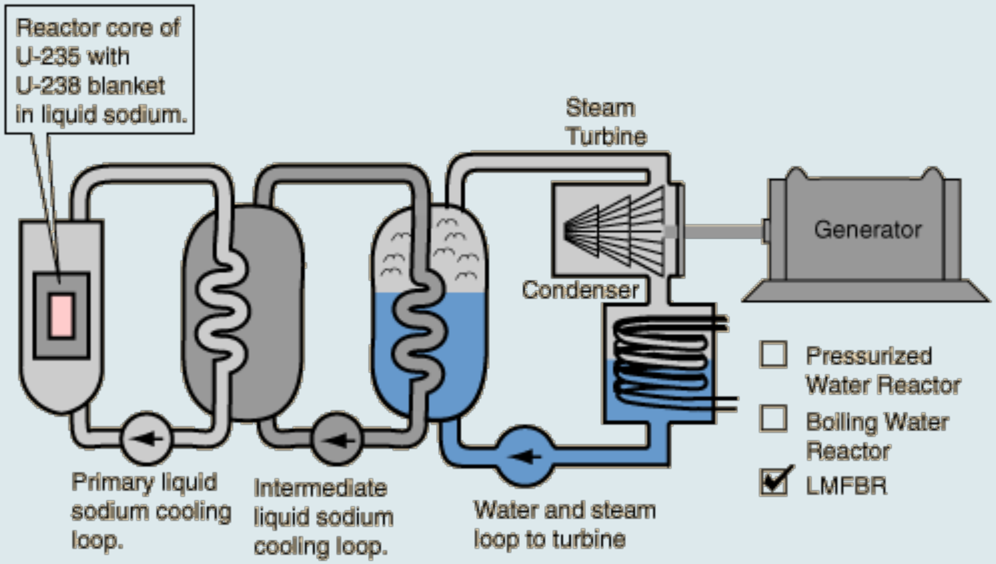
**Thermal Neutron Reactions**

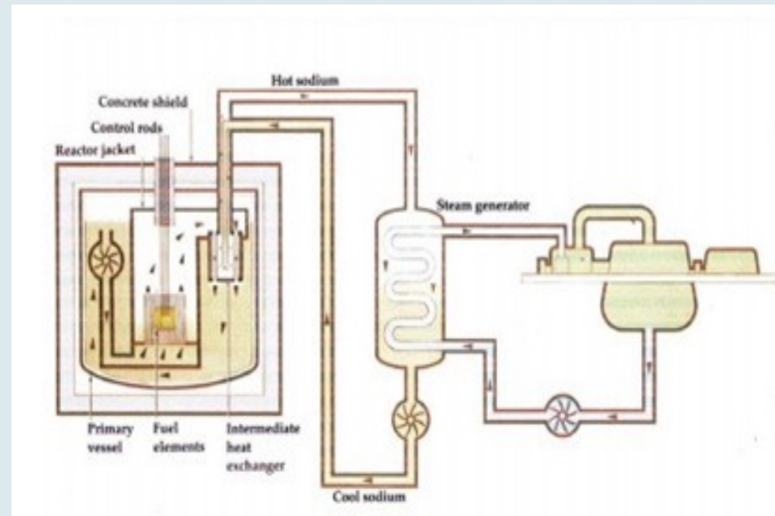



**Weapons-grade plutonium**

Popular neutron moderators include light water, heavy water, and graphite

# LIQUID METAL FAST BREEDER REACTOR (LMFBR): FIRST REACTOR TO PRODUCE ELECTRICITY




**Sodium-Cooled Fast Reactor**

| | |
|---|---|
| **Fuel** | **Pu or MOX- clad in stainless steel** |
| **Moderator** | **None** |
| **Coolant** | **Liquid sodium** |
| **Refueling** | **Off-load** |

# LIQUID METAL FAST BREEDER REACTORS ALSO HAVE BEEN USED TO MAKE BOMB PLUTONIUM

**India's prototype fast breeder reactor under construction at Kalpakkam**

**Phénix, prototype fast breeder reactor in Marcoule, France – shut down in 2009**

# FAST BREEDER REACTORS ARE OFF-LINE FUELED

# FAST BREEDER REACTOR STATES

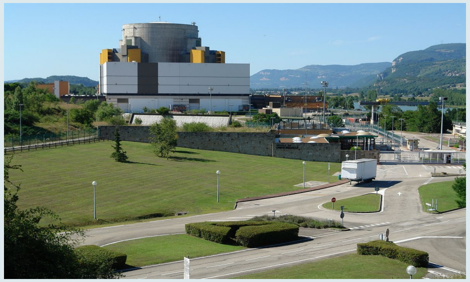
**Countries that operate FBRs:** China, Russia

**Countries constructing FBRs:** India, China

**Countries with plans for FBRs, but not currently operating:** Japan, South Korea, France, U.S.

**Countries that have had FBRs in the past, but aren't currently operating:** U.S., France, U.K., Germany, Japan

# COMMERCIAL FAST BREEDERS: FAILED & ABANDONED

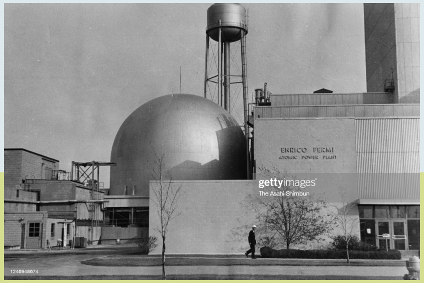


Superphenix, France, used to make bombs

Monju, Japan


Kalkar, Germany

Dounrey, UK




Enrico Fermi, Detroit

# REMAINING BREEDERS: QUESTIONABLE

Fast breeder reactor, India. To be used to make weapons

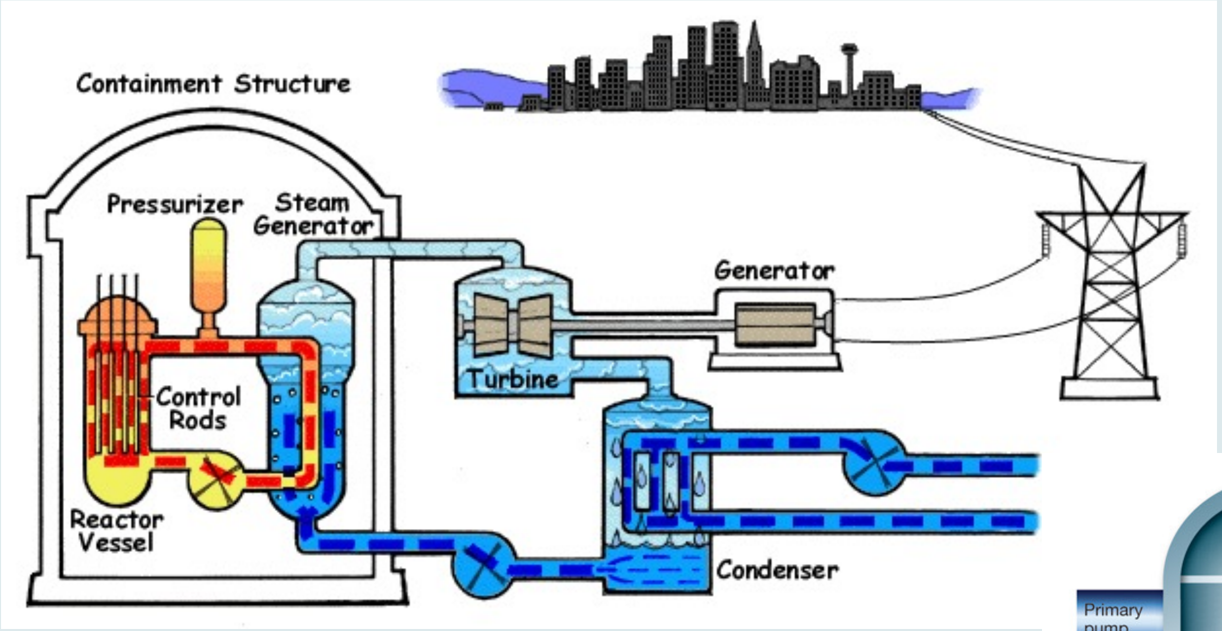

Fast breeder reactor, Russia. Over budget, completion delayed, tech exported to PRC


Experimental 20 MWe fast breeder reactor, China

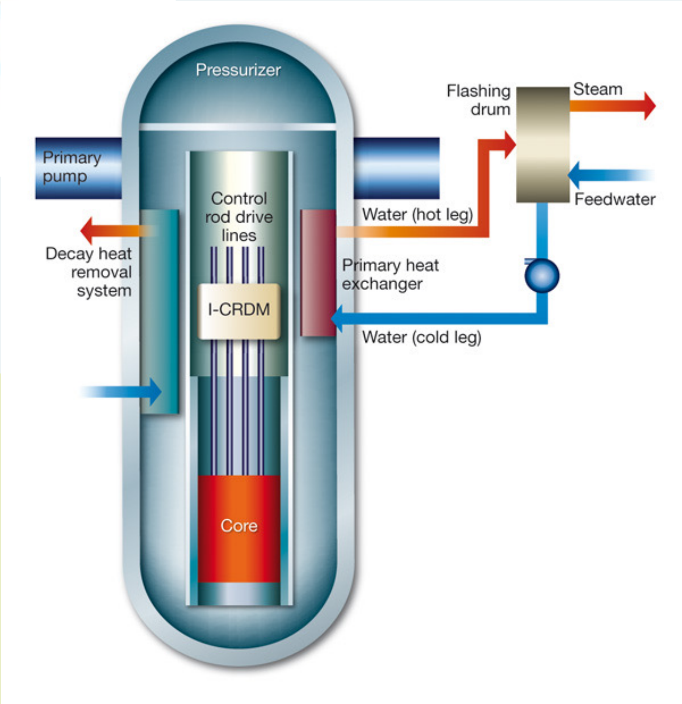
First 600 MWe fast breeder reactor, China

Second 600 MWe fast breeder reactor, China

# LIGHT-WATER REACTOR (PWR)




Typical Pressurized Water Reactor

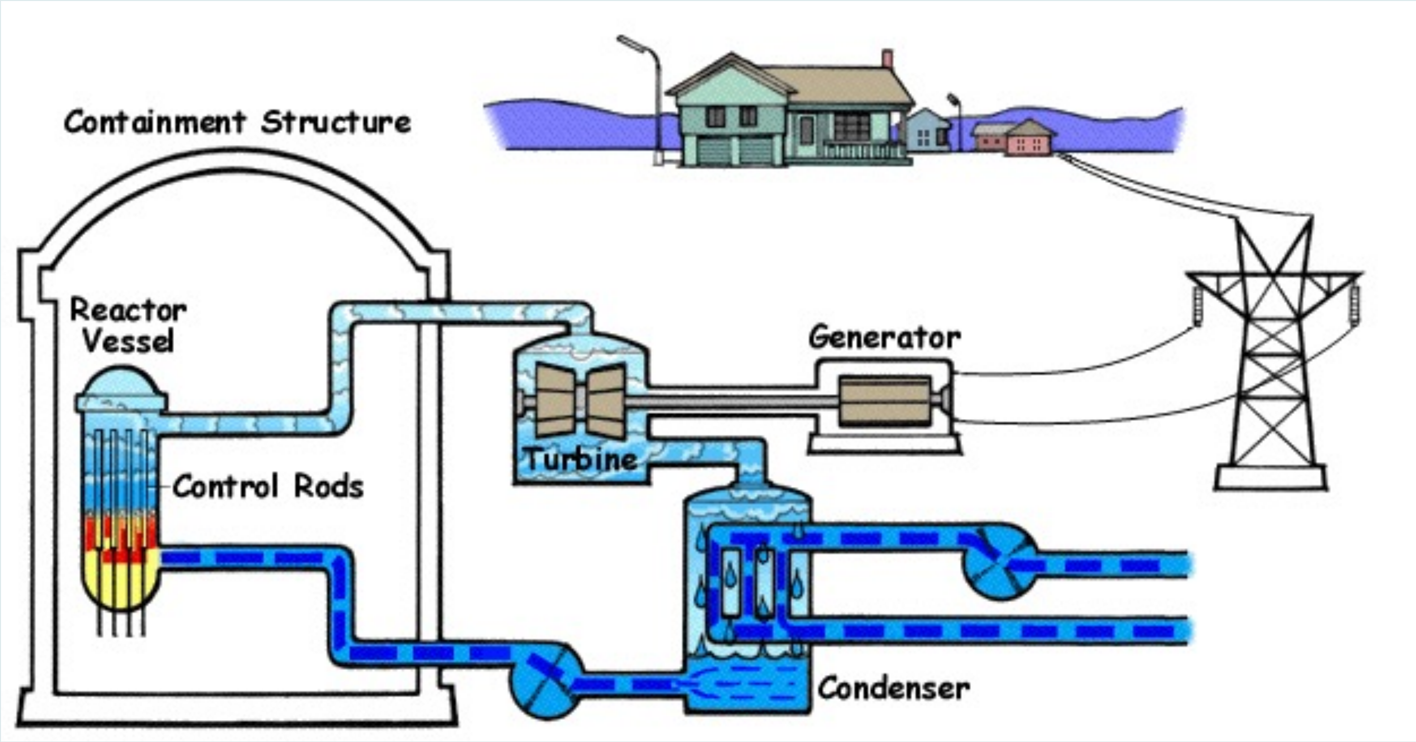



| | |
|---|---|
| Fuel | LEU |
| Moderator | Light Water |
| Coolant | Light Water |
| Refueling | Off-load |

# FIRST LIGHT WATER REACTOR WAS DESIGNED FOR SUBMARINES

# THREE MILE ISLAND NUCLEAR POWER PLANT, U.S.

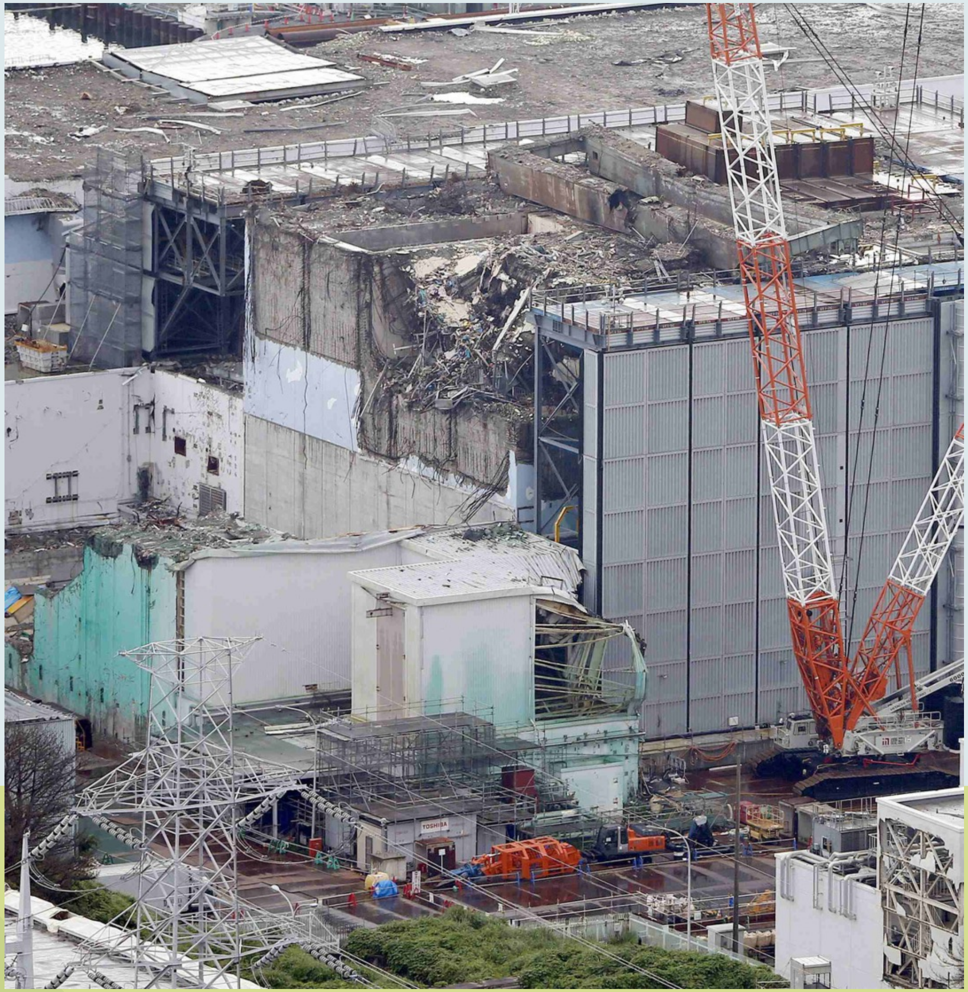
# LIGHT-WATER REACTOR (BWR)




Typical Boiling-Water Reactor

| | |
|---|---|
| Fuel | LEU |
| Moderator | Light Water |
| Coolant | Light Water |
| Refueling | Off-load |

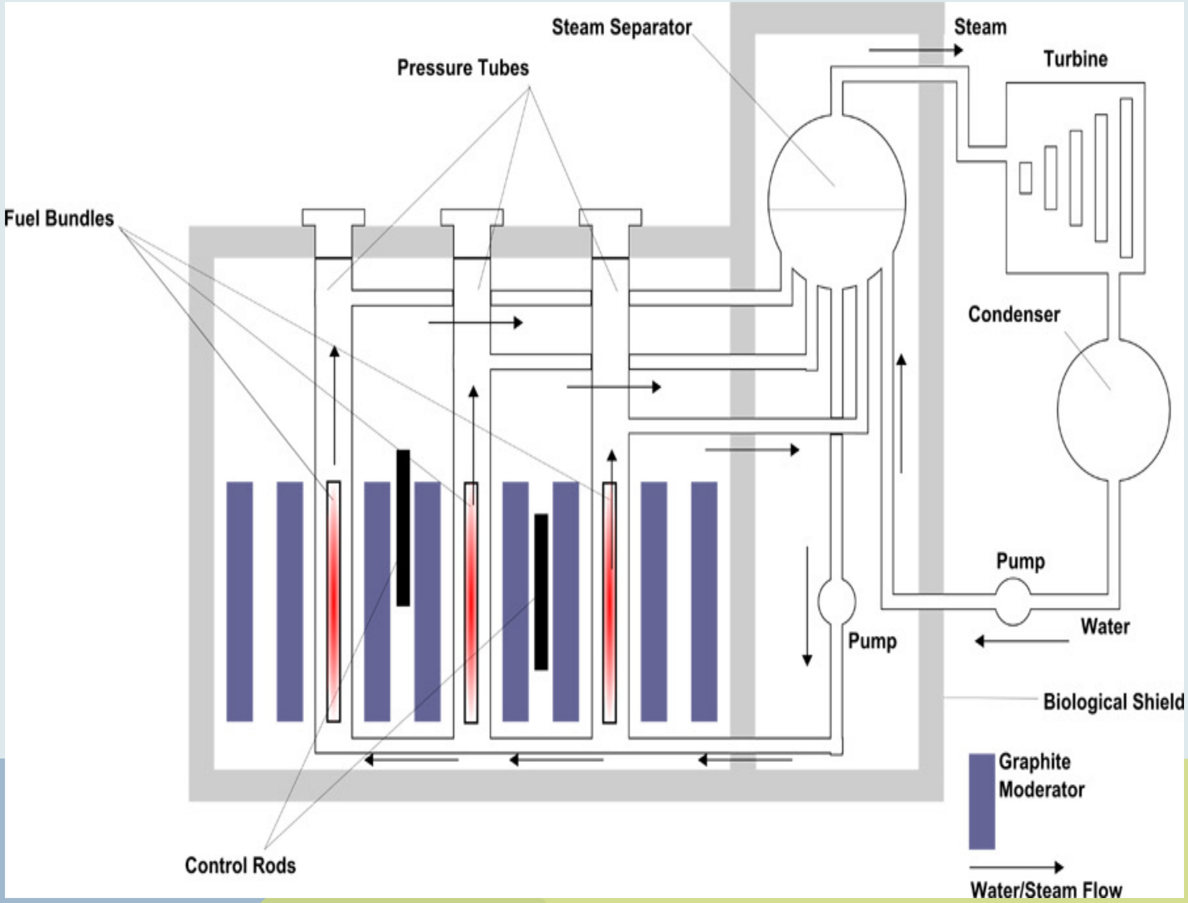
# FUKUSHIMA DAIICHI NUCLEAR POWER PLANT, JAPAN



# LWRS ARE OFF-LOAD FUELED

**LWR refueling**

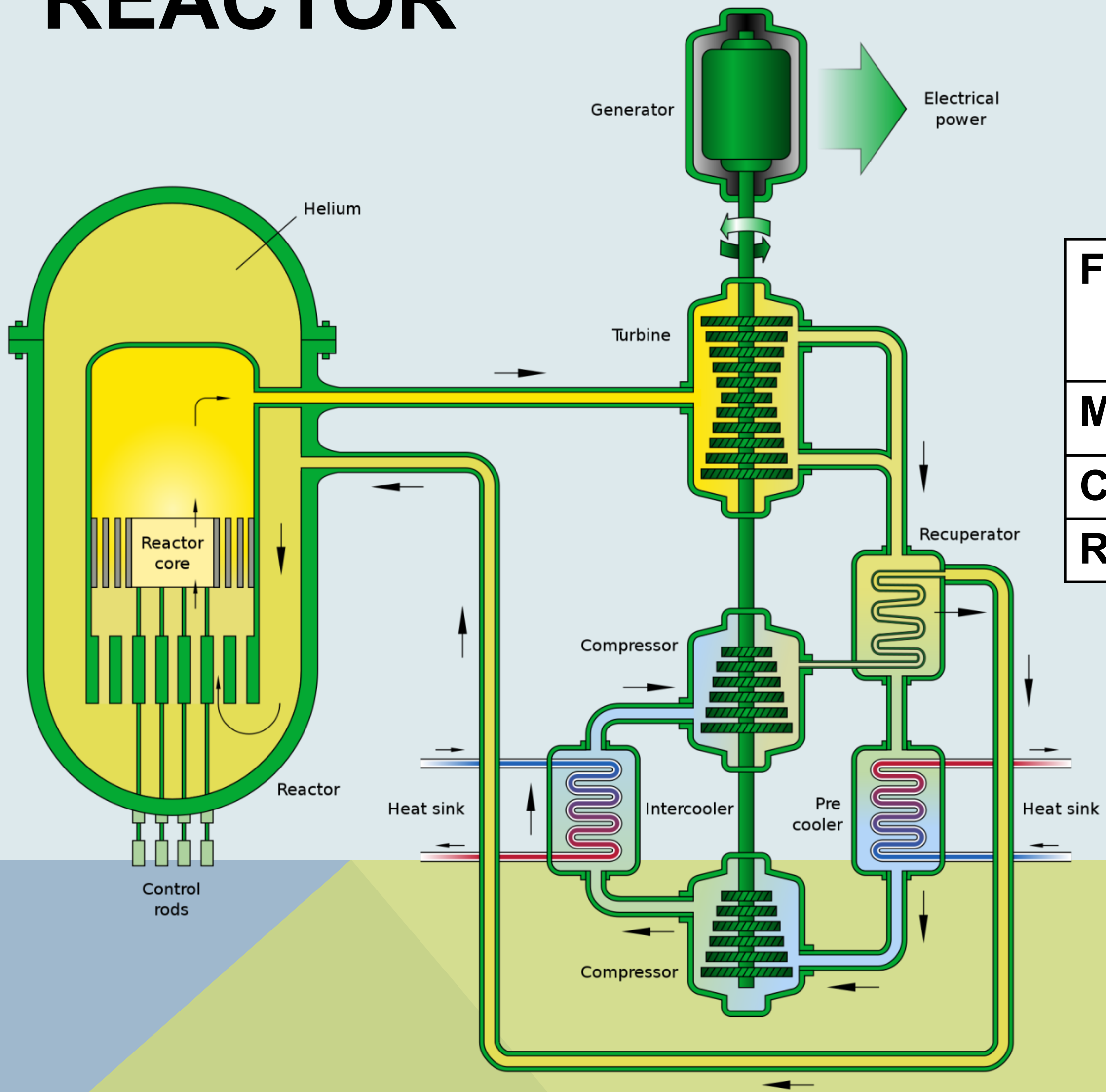
# RBMK (REACTOR BOLSHOY MOSHCHNOSTY KANALNY)




| | |
|---|---|
| **Fuel** | **LEU clad in zircaloy** |
| **Moderator** | **Graphite** |
| **Coolant** | **Light Water** |
| **Refueling** | **On-line** |

# CHERNOBYL NUCLEAR POWER PLANT, UKRAINE

# HIGH TEMPERATURE GAS COOLED REACTOR

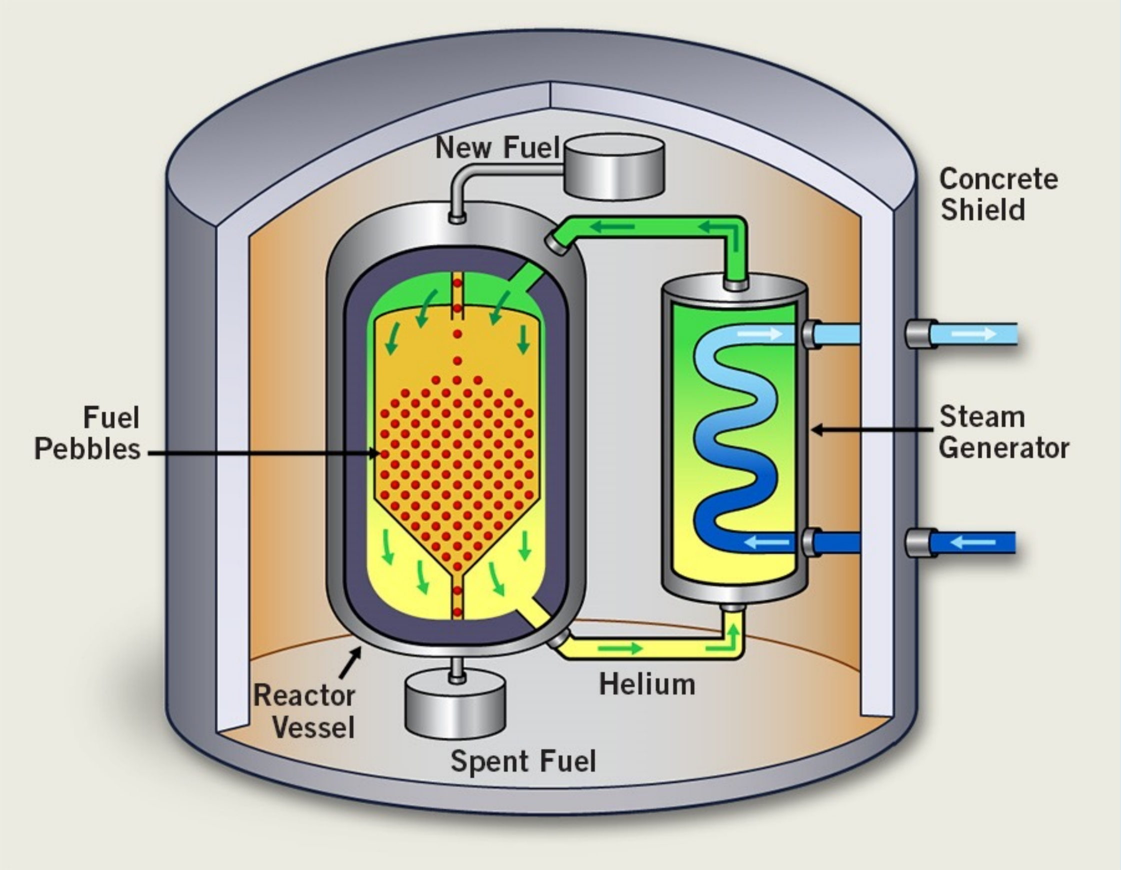



| | |
|---|---|
| Fuel | Uranium clad in a graphite matrix |
| Moderator | Graphite |
| Coolant | Helium |
| Refueling | Off-load |

# FORT ST. VRAIN POWER STATION WAS A ONE-OFF

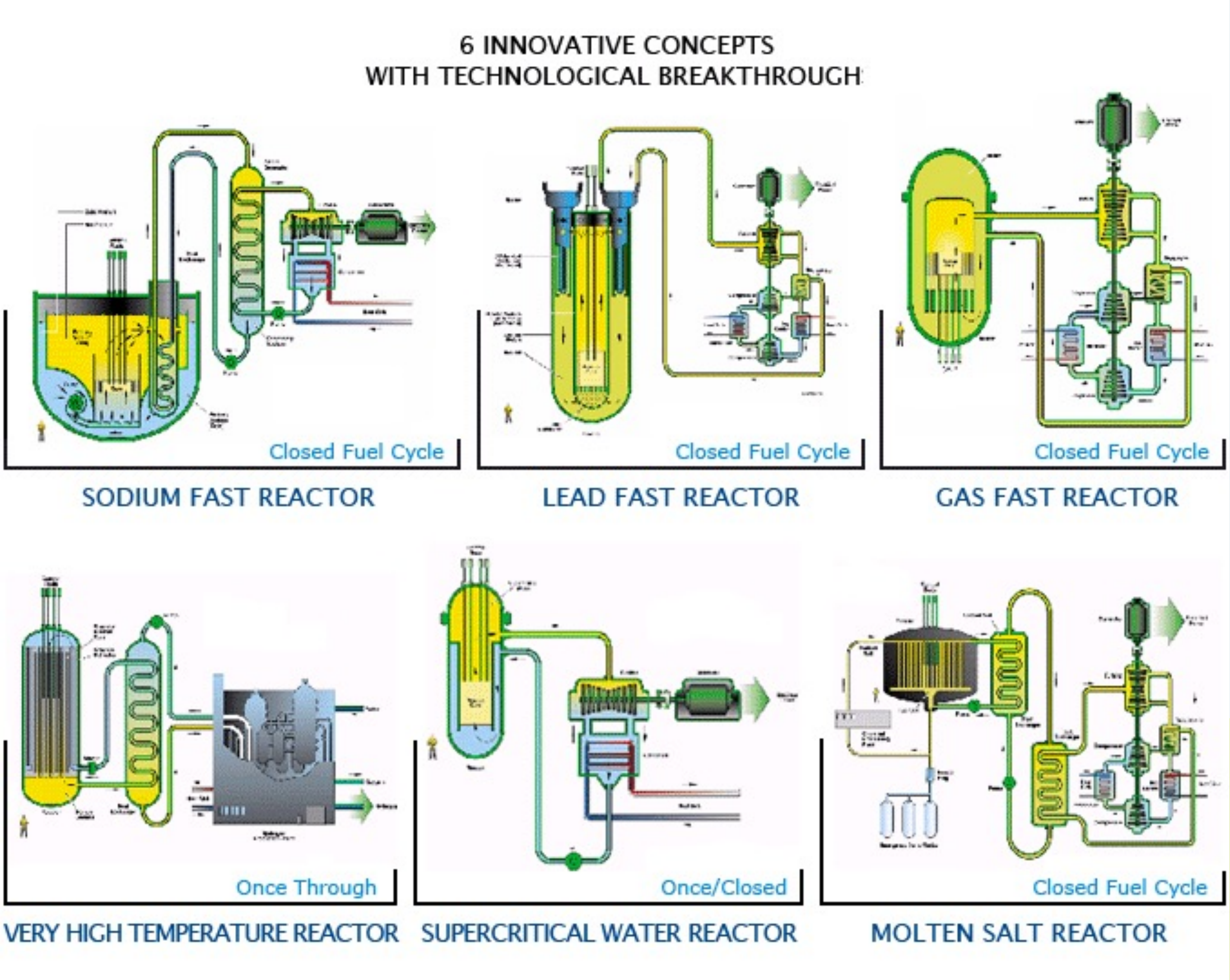
**Fort St. Vrain Power Station, HTGR. It operated from 1976 to 1989.**

# ON-LINE REFUELING—HTGC (PEBBLE BED)

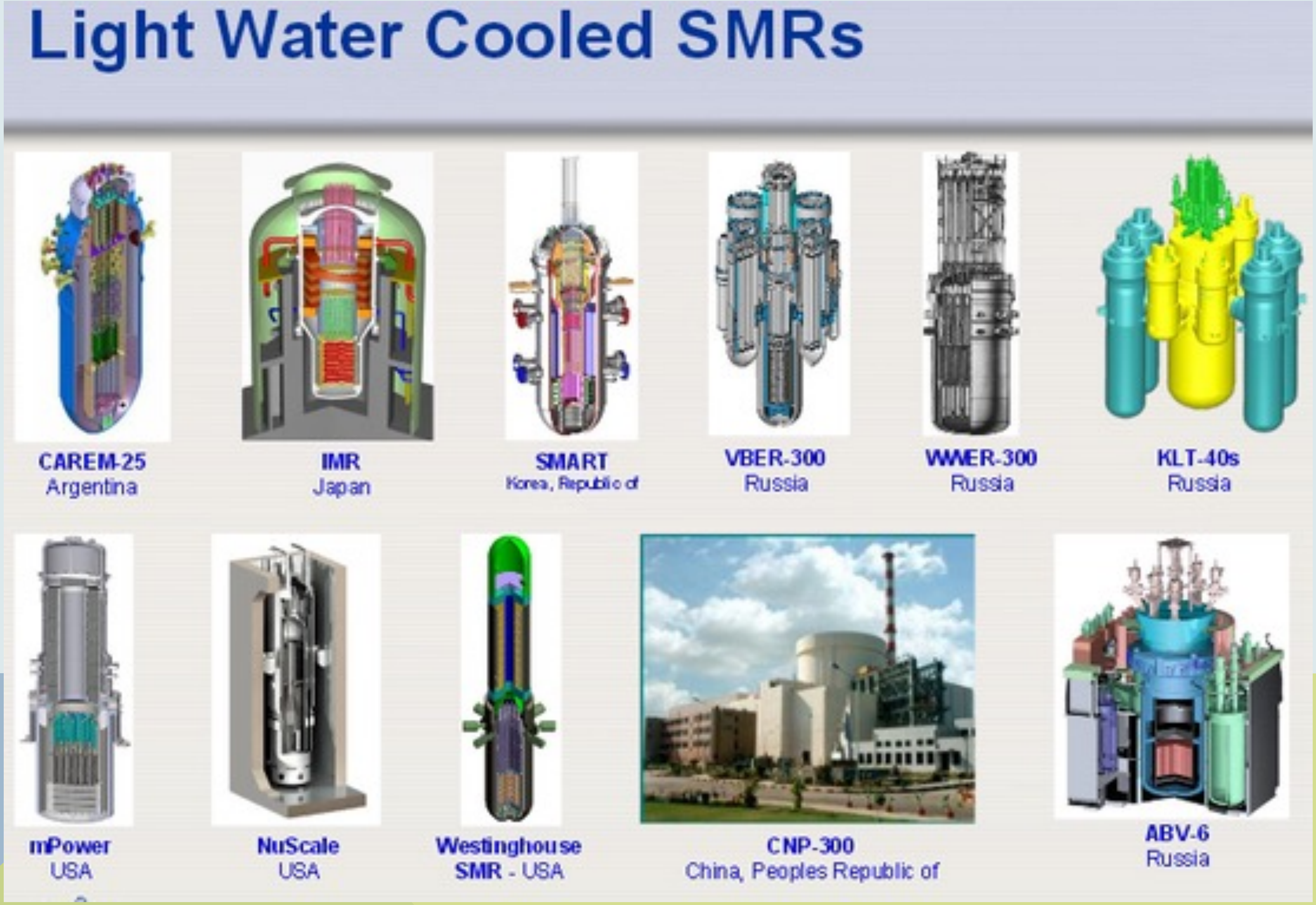



Under construction in China

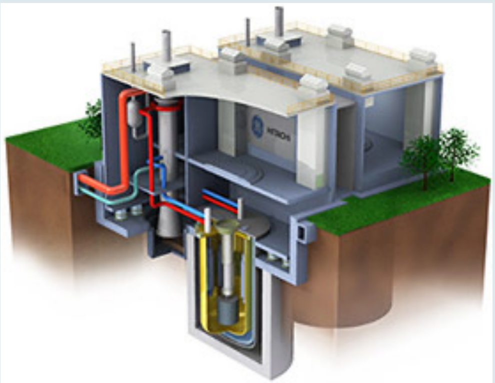
# GENERATION IV REACTORS

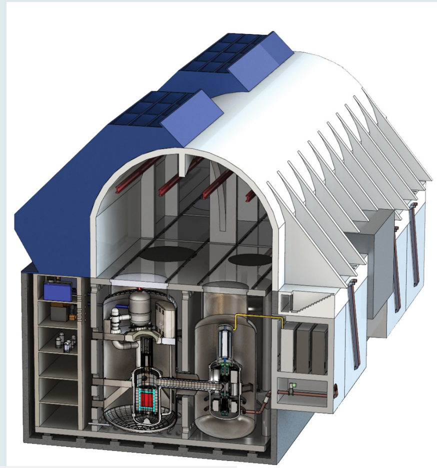


# SMALL MODULAR LWRS



# FAST SMALL MODULAR REACTOR

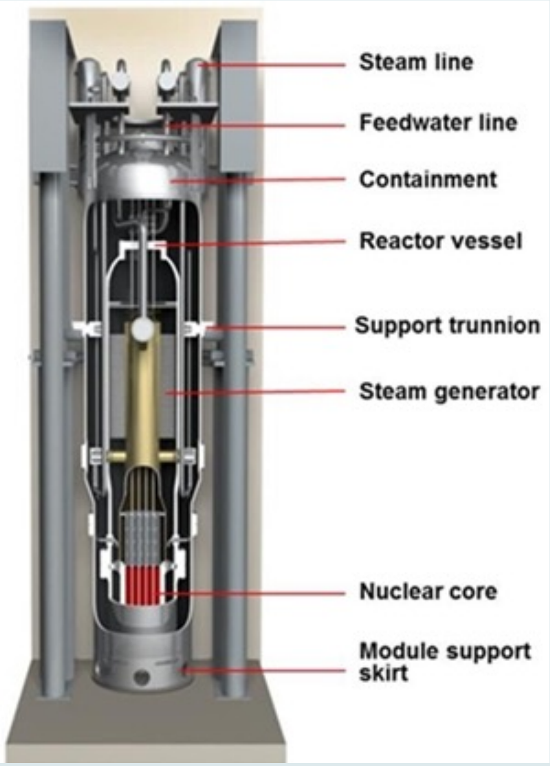


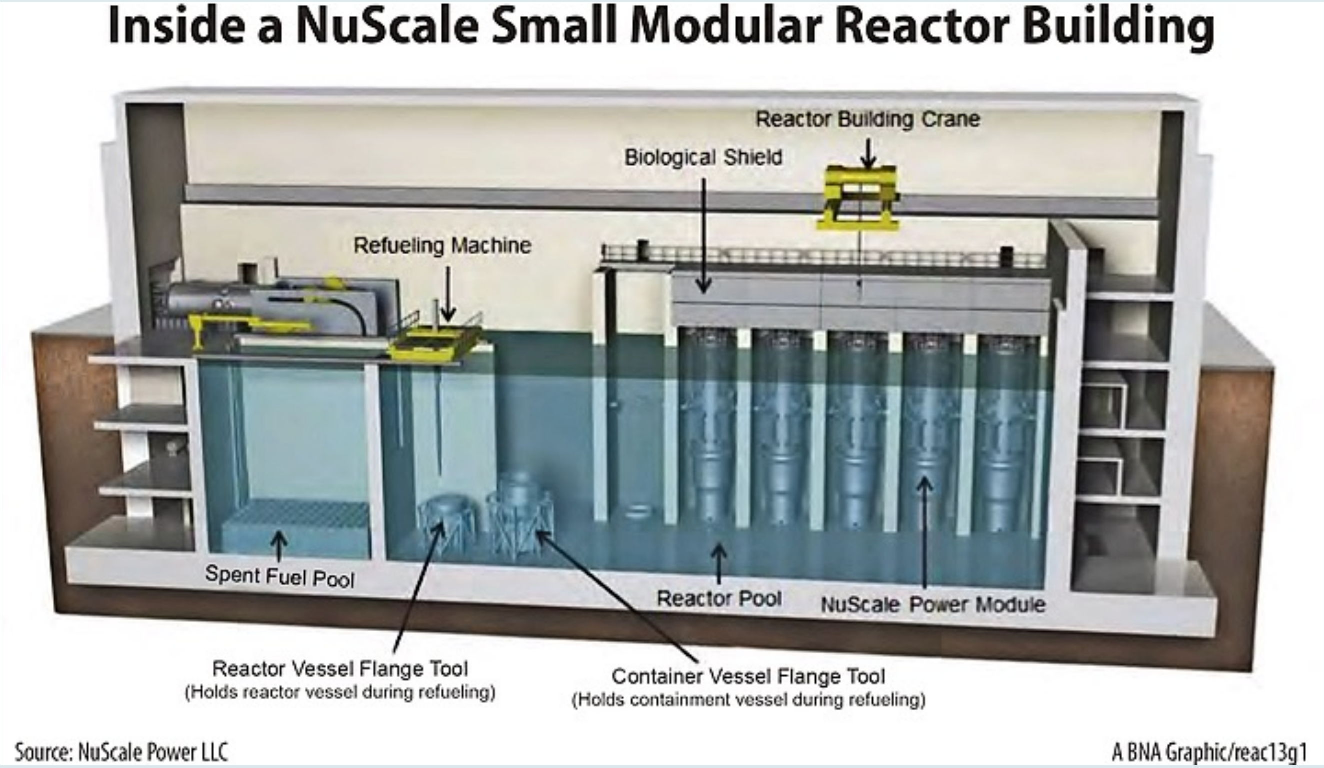






# NUSCALE REACTOR



# SUMMARY OF REACTOR CHARACTERISTICS BY TYPE

| Type of Reactor | Magnox Reactor | High Temperature Gas-Cooled Reactor (HTGR) | Pressurized Water Reactor (PWR) | Boiling Water Reactor (BWR) | Heavy Water Reactor (CANDU) | Liquid Metal Fast Breeder Reactor (LMFBR) |
|---|---|---|---|---|---|---|
| Name of Example | Chapelcross (UK) | Fort St. Vrain (USA) | Zion (USA) | Browne Ferry 2 (USA) | Pickering (Canada) | Phenix (France) |
| Heat Output | 840 MWt | 842 MWt | 3250 MWt | 3293 MWt | 1744 MWt | 563 MWt |
| Electrical Output | 275 MWe | 330 MWe | 1050 MWe | 1065 MWe | 308 MWe | 233 MWe |
| Fuel | Natural Uranium Metal clad in Magnox alloy | Uranium carbide particles, enriched, coated in graphite matrix | Uranium oxide, 3% enriched, clad in Zirconium | Uranium oxide, 2.2% enriched, clad in zircaloy | Natural uranium oxide clad in zircaloy | Mixed uranium and plutonium oxide (MOX), 20 -27% enrichment, clad in stainless steel |
| Moderator | Graphite | Graphite | Light water | Light water | Heavy Water | None |
| Coolant | Carbon dioxide gas | Helium | Light water | Light water | Heavy water | Liquid sodium |
| Refueling | On-load | Off-load | Off-load | Off-load | On-load | Off-load |

# PLUTONIUM PRODUCTION BY REACTOR TYPE

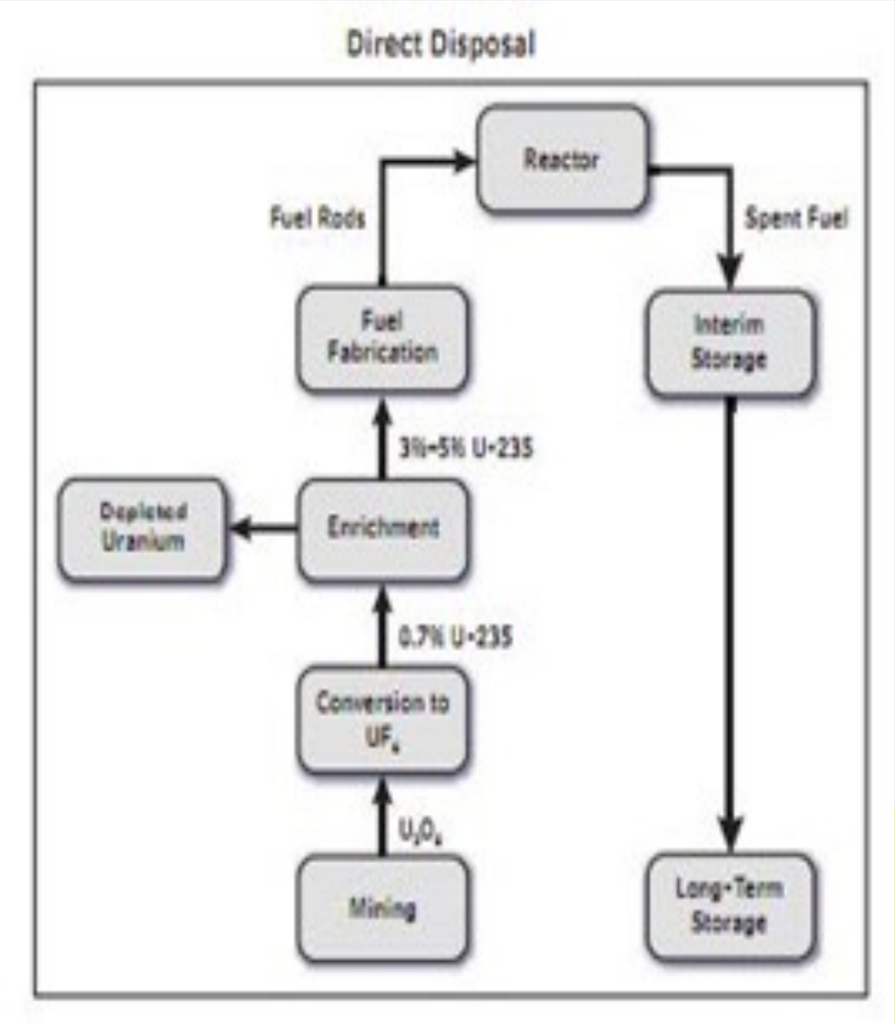
| Fissile Material Produced by a 1,000 MWe Reactor Operating at 70% Load Factor for One Year | | |
|---|---|---|
| **Reactor Type** | **Initial Fuel (Enrichment)** | **Produced Pu (kg)** |
| Light-Water Reactor | $U^{235}$ (3%) | 175* |
| High Temperature Gas-Cooled Reactor | $U^{235}$ (93%) | 29 (plus 64kg $U^{235}$) |
| Canadian Deuterium-Uranium (CANDU) | U (natural) | 360 |
| Fast Breeder Reactor | MOX | 300 |

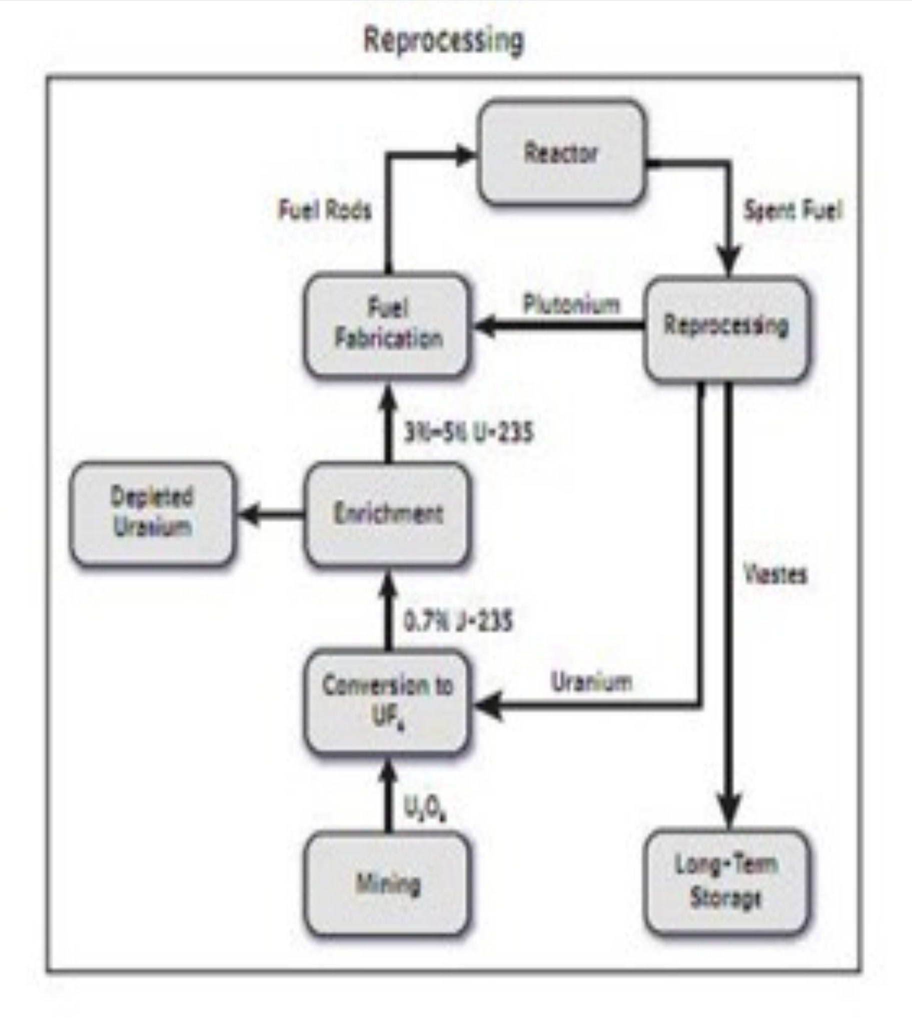
** For a LWR that has been operating for over 36 months.*

*Note that low-enriched reactors produce more plutonium than high enriched reactors (the fast breeder reactor uses plutonium as fuel, so much of what is produced will actually be reused as fuel). Again, production in a CANDU is the highest for a given power generation.*

# 4. WHAT CAN BE DONE WITH SPENT REACTOR NUCLEAR FUEL?

# DIRECT DISPOSAL VS. REPROCESSING



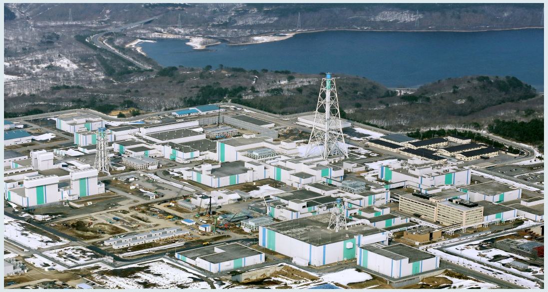
# COMMERCIAL REPROCESSING: A MAJOR UNDERTAKING

**Rokkasho, Japan: over 20 billion spent, under construction since 1993**

# E. ASIA REPROCESSING: A FUTURE HEADACHE

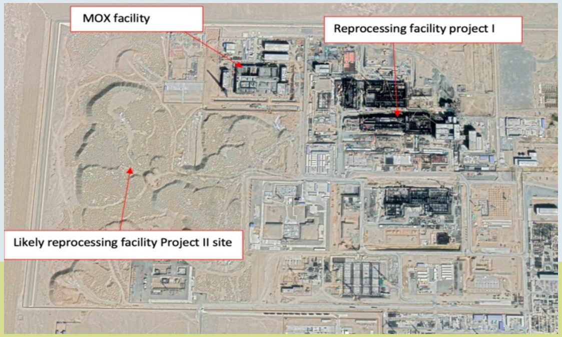
PRC 50 tHM/yr Pilot plant: ~100 bombs worth of plutonium/yr

Possible PRC 800 tHM/yr EDF plant: ~1200+ bombs worth of pu/yr



**Japan’s 800 tHM/yr plant: ~1,200+ bombs’ worth pu/yr, to open 2023**

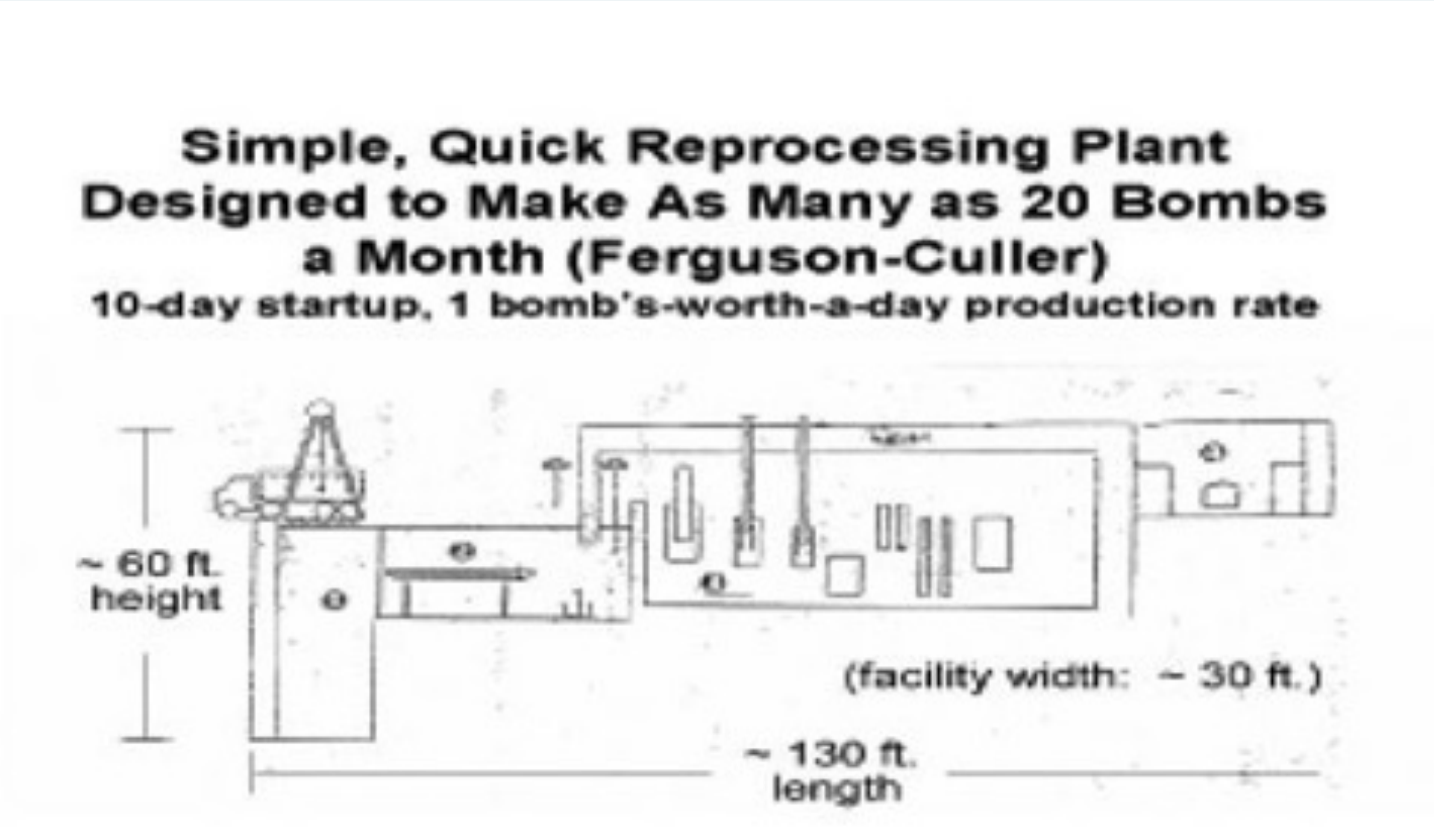

1st PRC 200 tHM/yr plant under construction to be on line by 2025




2nd PRC 200 tHM/yr reprocessing plant to be on line before 2030

ROK Experimental Pyroprocessing Facility, funding frozen

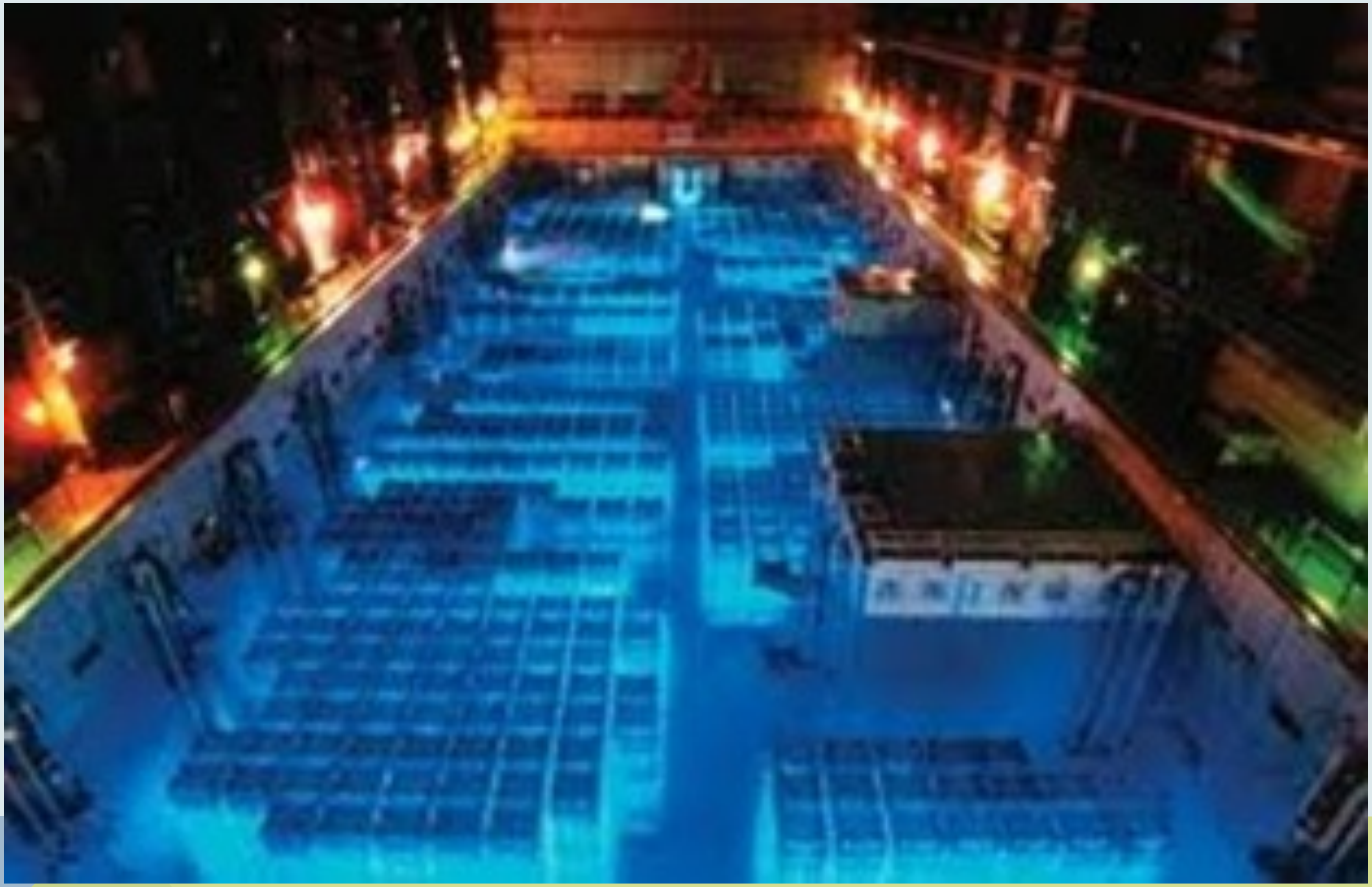
# FERGUSON CULLER DESIGN: SMALL, CHEAP, AND QUICK



# REPROCESSING STEPS

1. Cooling
2. Head-end treatment
3. Separation/Extraction
4. Conversion of plutonium nitrate to plutonium oxide
5. Storage of radioactive wastes

# COOLING

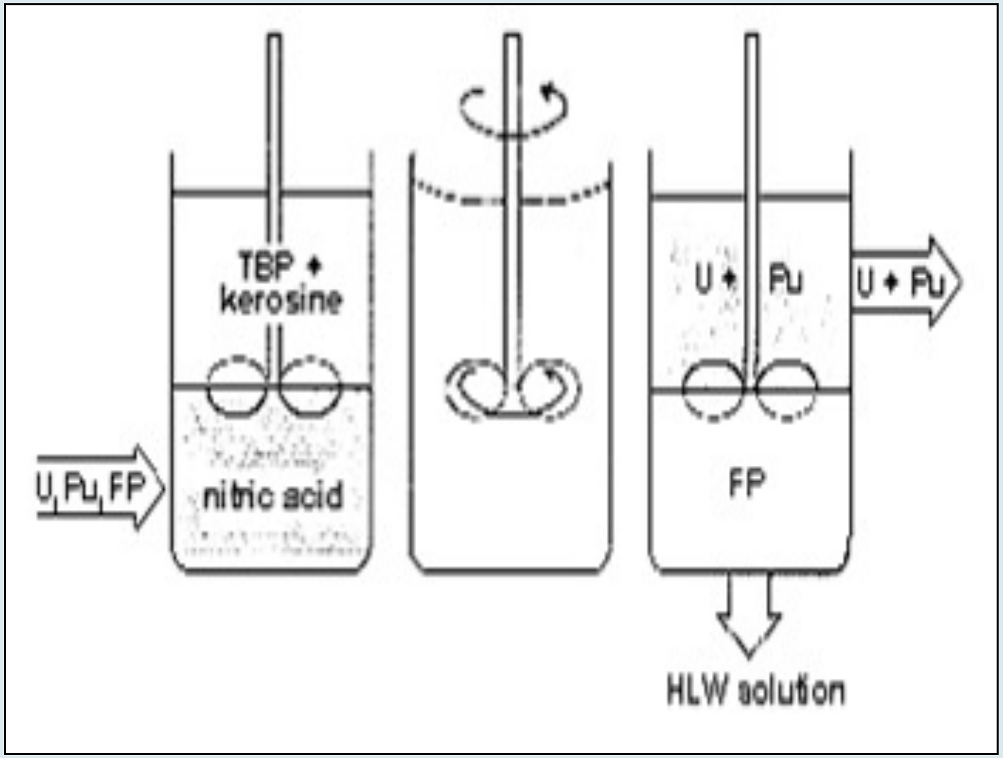


**Cooling Pool**

# HEAD-END TREATMENT


**Head-End Process**

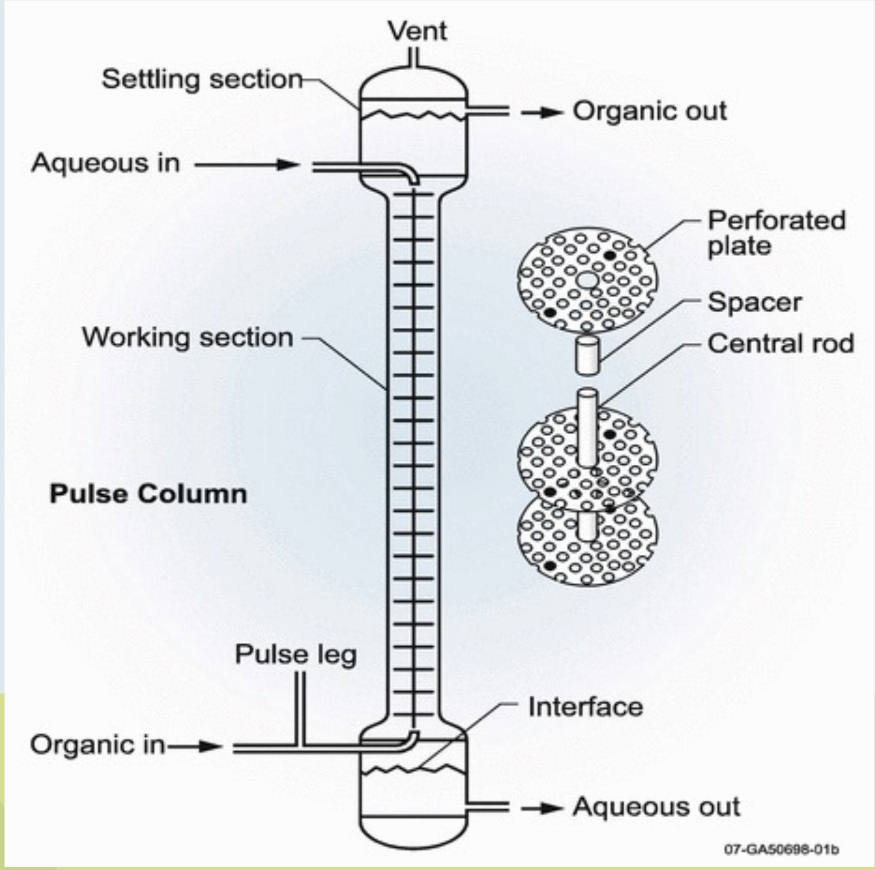
# SEPARATION/EXTRACTION




**PUREX – Extraction Process**

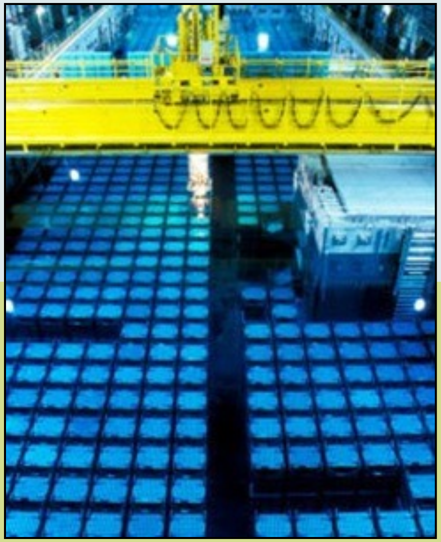
**Windscale reprocessing towers**

# REPROCESSING PULSE COLUMN

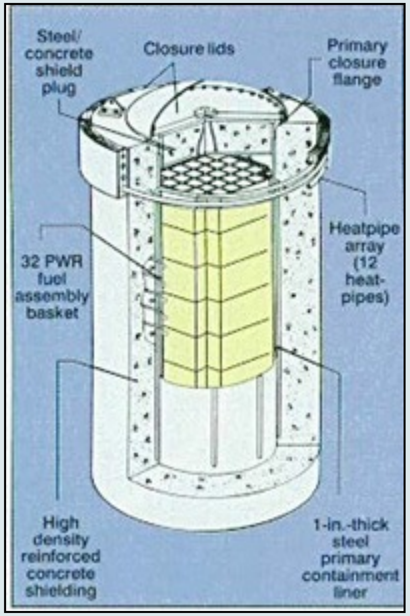


# PLUTONIUM URANIUM EXTRACTION PLANT AT HANFORD, WASHINGTON

# COOLING POOLS FOR SPENT FUEL



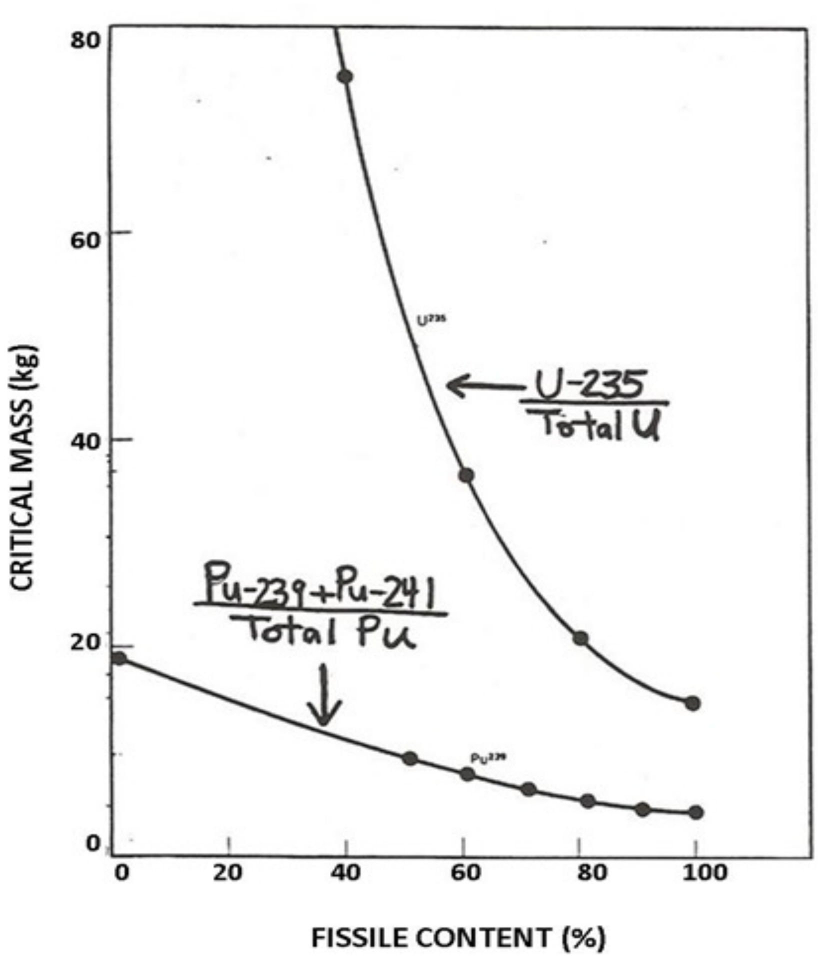
# DRY CASK STORAGE






# ADDITIONAL SLIDES

# CRITICAL MASSES OF URANIUM & PLUTONIUM AS A FUNCTION OF ISOTOPIC MIX




Critical Mass (CM)

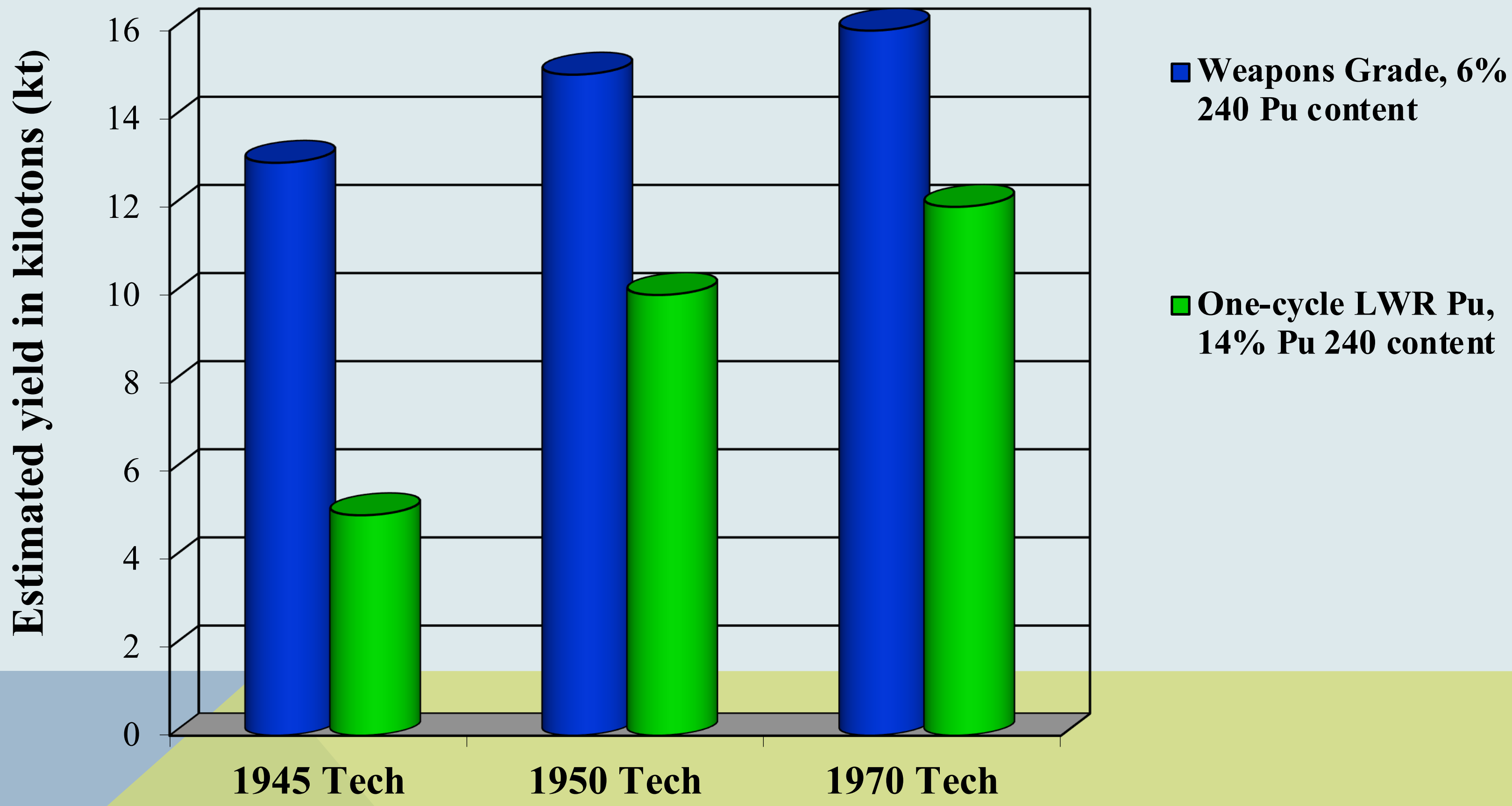
CM (U)

Infinite for $\frac{U235}{U} < \sim 10\%$

CM (Pu)

Finite for all isotopic mixes

# ESTIMATED YIELDS FOR DIFFERENT BOMB TECHNOLOGIES USING LWR PU



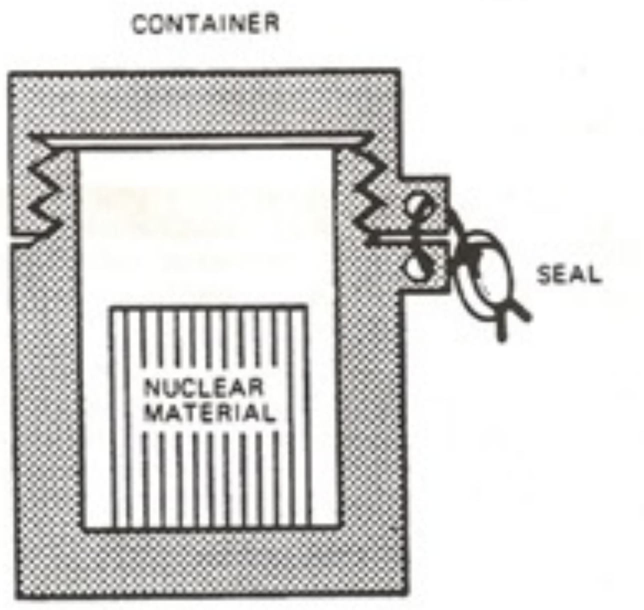
# IAEA SAFEGUARDS GUIDELINES

| Direct Use Materials | Significant Quantity |
|---|---|
| Pu | 8 kg total element (containing less than 80% Pu-238) |
| U-233 | 8 kg total isotope |
| HEU | 25 kg contained U-235 |

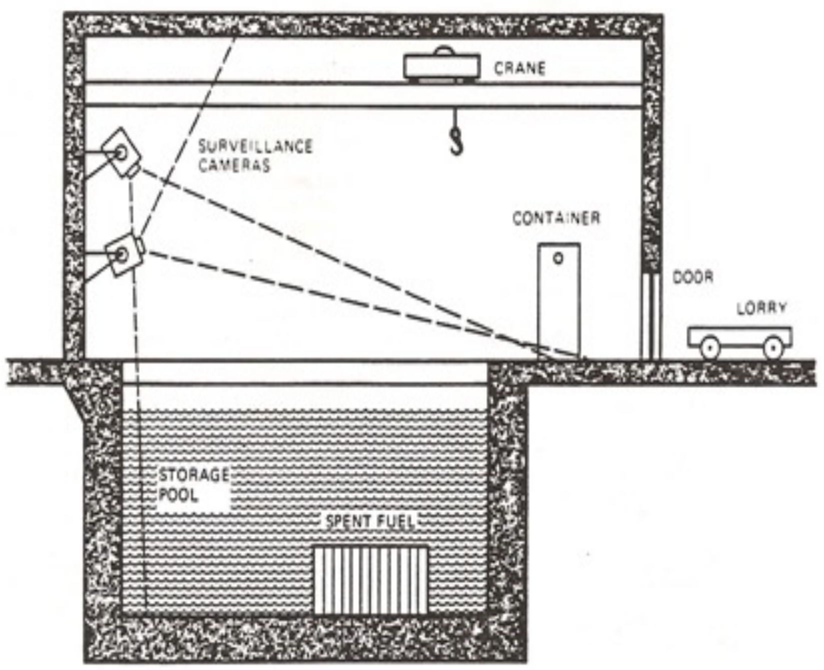
| Indirect Use Materials | Significant Quantity |
|---|---|
| LEU (U-235 <20%) | 75 kg contained U-235 (include natural and depleted U) |
| Thorium | 20 tons total element |

| Material | Timeliness Goal |
|---|---|
| Non-irradiated direct use (Pu in fresh fuel) | One Month |
| Irradiated direct use (e.g. Pu in spent fuel) | Three Months |
| Indirect use (e.g. LEU) | One Year |

# BASIC IAEA SAFEGUARDS METHODS




*Containment measures: application of seal.*

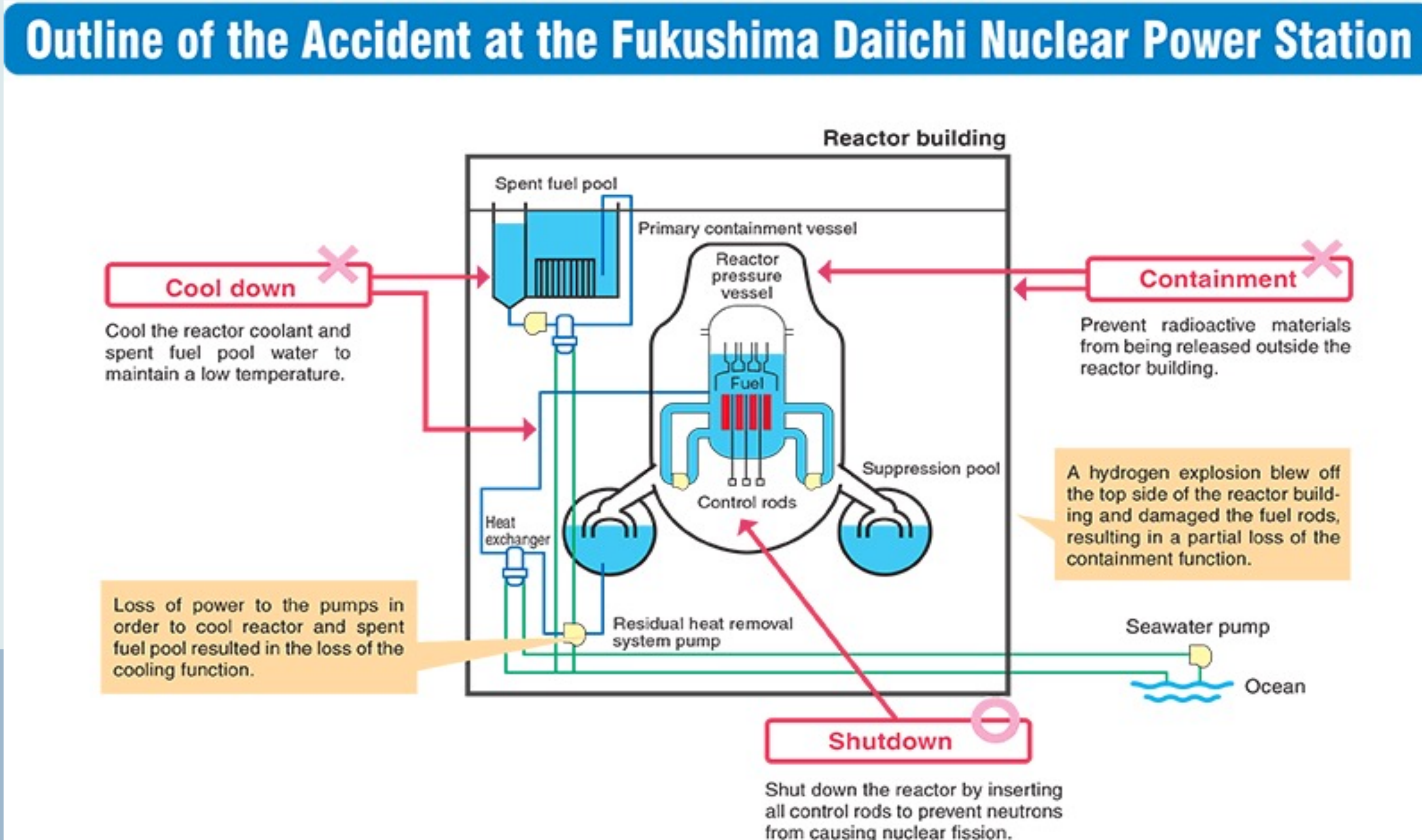



*Combined application of containment and surveillance.*

**Example of IAEA Containment**

**Example of IAEA Surveillance**

# SCHEMATIC OF FUKUSHIMA ACCIDENT



# PYROPROCESSING

**“South Korea also has advanced reprocessing technology. One professor of nuclear engineering said that "our capabilities when it comes to pyroprocessing, which involves reprocessing by using electolysis, are world-class.”**

***Chosun Ilbo, February 19, 2016***

Planned ROK Pyroprocessing Plant

# WOLSONG HEAVY WATER REACTORS


From the four CANDU-6 reactor cores and spent fuel at Wolsong, the RoK could recover 150 kg of lower-burnup fuel-grade plutonium (discharged during the first cycle after start-up—100 to 400 full-power days after start-up) and about 220 kg of higher burnup fuel-grade plutonium that could be used to fabricate more than 50 nuclear warheads with yields exceeding 20 kilotons based on pure fission solid core, levitated core or hollow core designs.

# ROK HAS PRODUCED AND STOCKPILED ENOUGH TRITIUM (4 KGS.) TO BOOST 1,000 WEAPONS

Wosong Tritium Removal Facility

# TOO MUCH PLANNED JAPANESE PLUTONIUM FOR ANY PEACEFUL PURPOSE

Rokkasho now may open Fall 2022

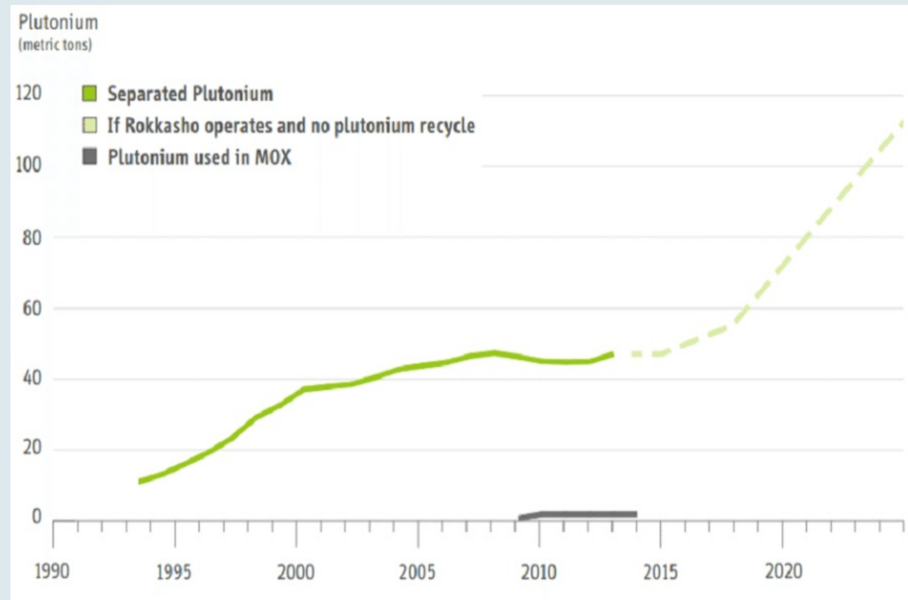



**Figure 6.1. Japan's stockpile of separated plutonium, 1993 – 2025.** The dashed line shows its projected growth if the Rokkasho Reprocessing Plant operates, beginning in the spring of 2016, at one-third capacity for three years and thereafter at design capacity (8 tons per year) and Japan's plutonium use in MOX continues to be delayed. Bottom line, Japan's cumulative use of plutonium in mixed oxide fuel for light water power reactors.[295]

# ENRICHING URANIUM FOR WHAT?

Rokkasho Uranium Enrichment Plant

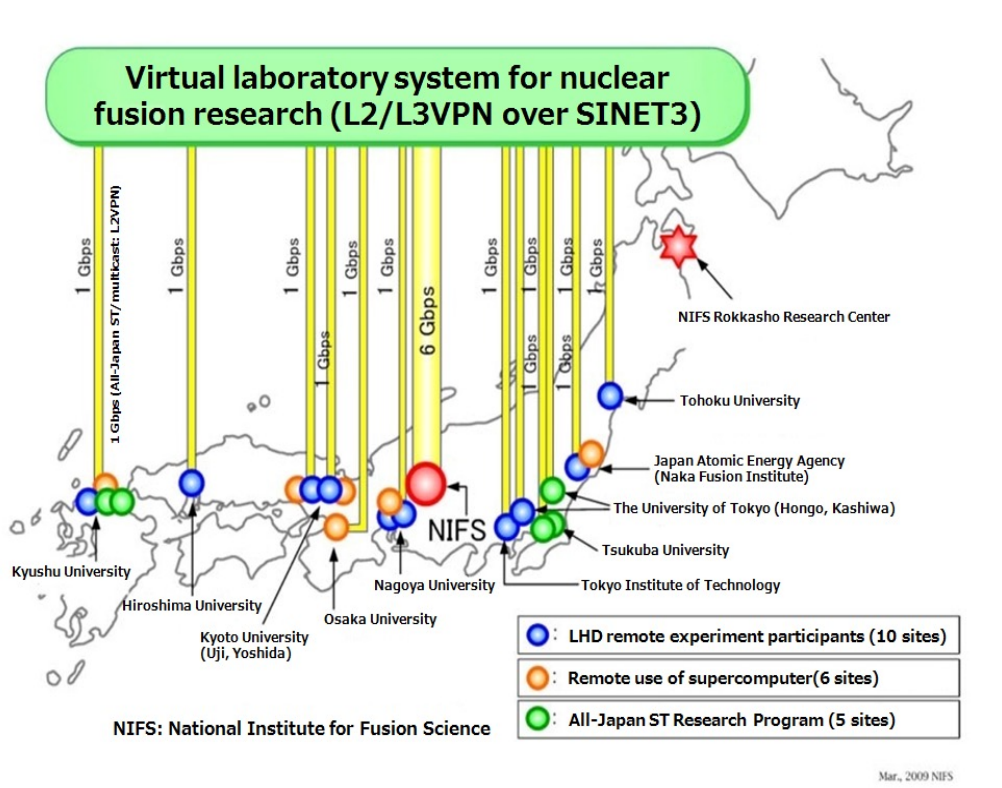
**Japan by 2022 could produce up to ~6,400 kg HEU/year or *more than 500 bombs worth per year***

# JAPAN CAN MASTER BOOSTING AND MORE

The National Institute for Fusion Science (NIFS) in Toki

Japan Atomic Energy Agency's (JAEA) Naka Fusion Institute, Ibaraki Prefecture

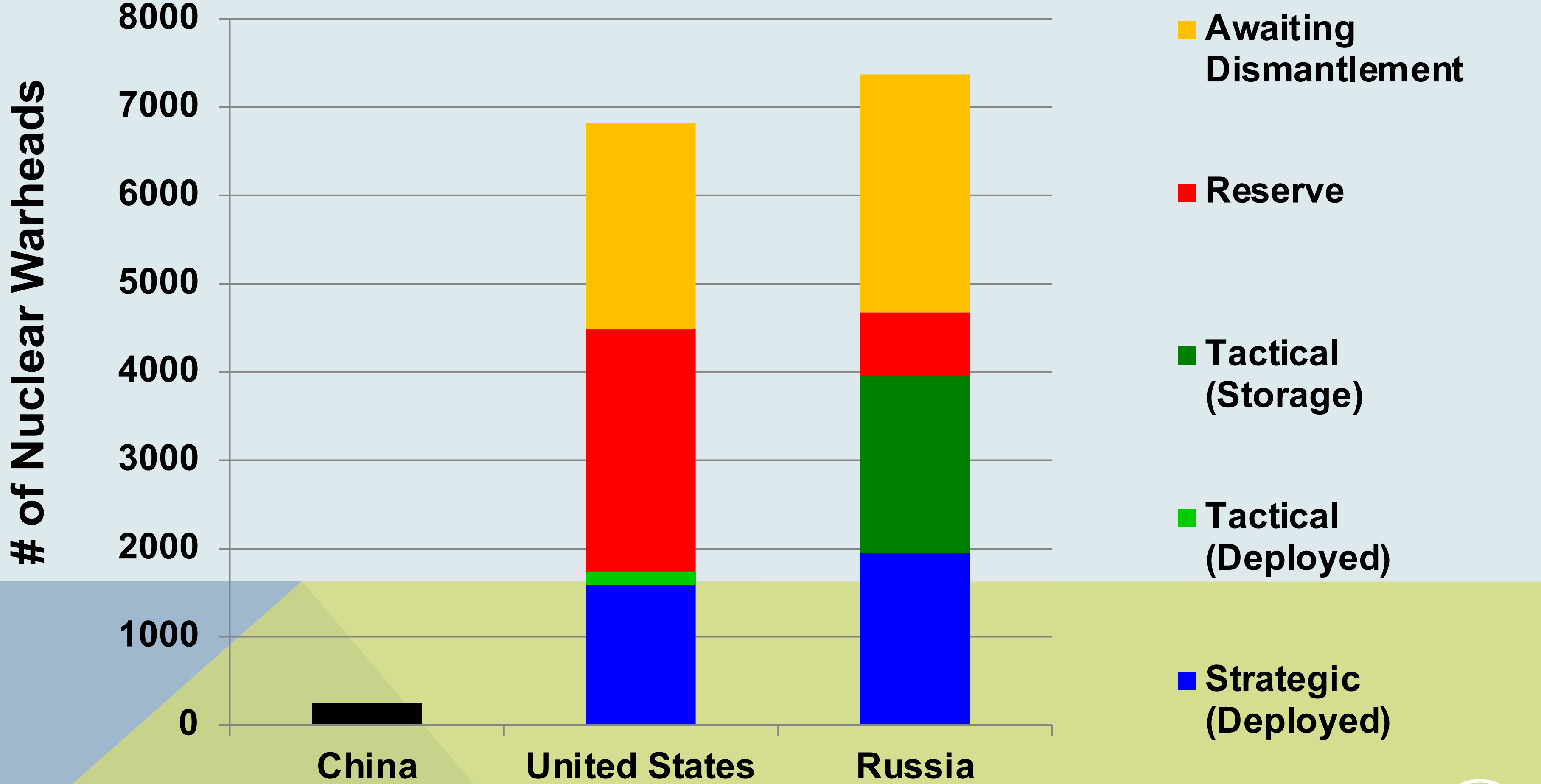
As its contribution to the International Thermonuclear Experimental Reactor (ITER) under construction in France, Japan will provide much of the high-tech components and will host an €1 billion materials testing facility – the International Fusion Materials Irradiation Facility (IFMIF).




Naka Fusion Institute, which includes the Tritium Processing Laboratory

National Institute of Fusion Research

# ESTIMATED WARHEAD INVENTORIES: PRC, US, RUSSIA






Source: http://www.tandfonline.com/doi/full/10.1080/00963402.2016.1264213 and http://www.tandfonline.com/doi/full/10.1080/00963402.2017.1290375

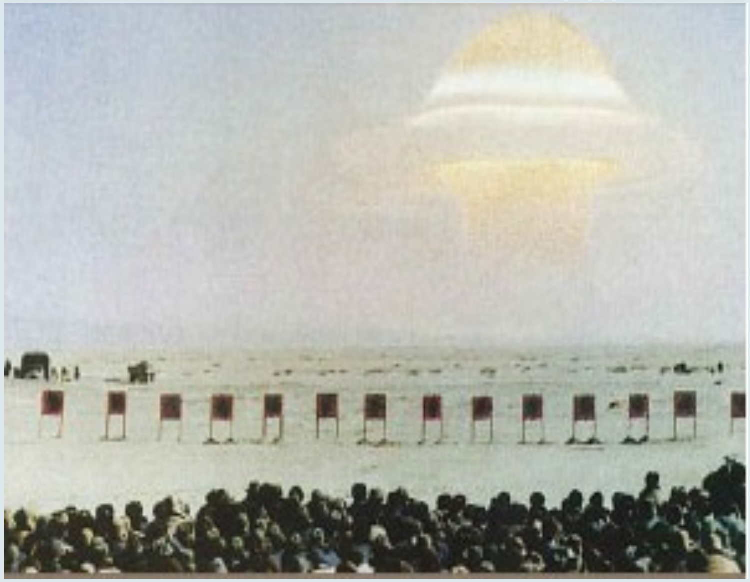
# WHAT IF CHINA DEVELOPS MANY MIRVS?

According to the Belfer Center's Hui Zhang, China's limited fissile material stockpile means that the country does not have the ability to build significantly more warheads without restarting fissile material production."

*BAS March 24, 2015, Tong and Logan*

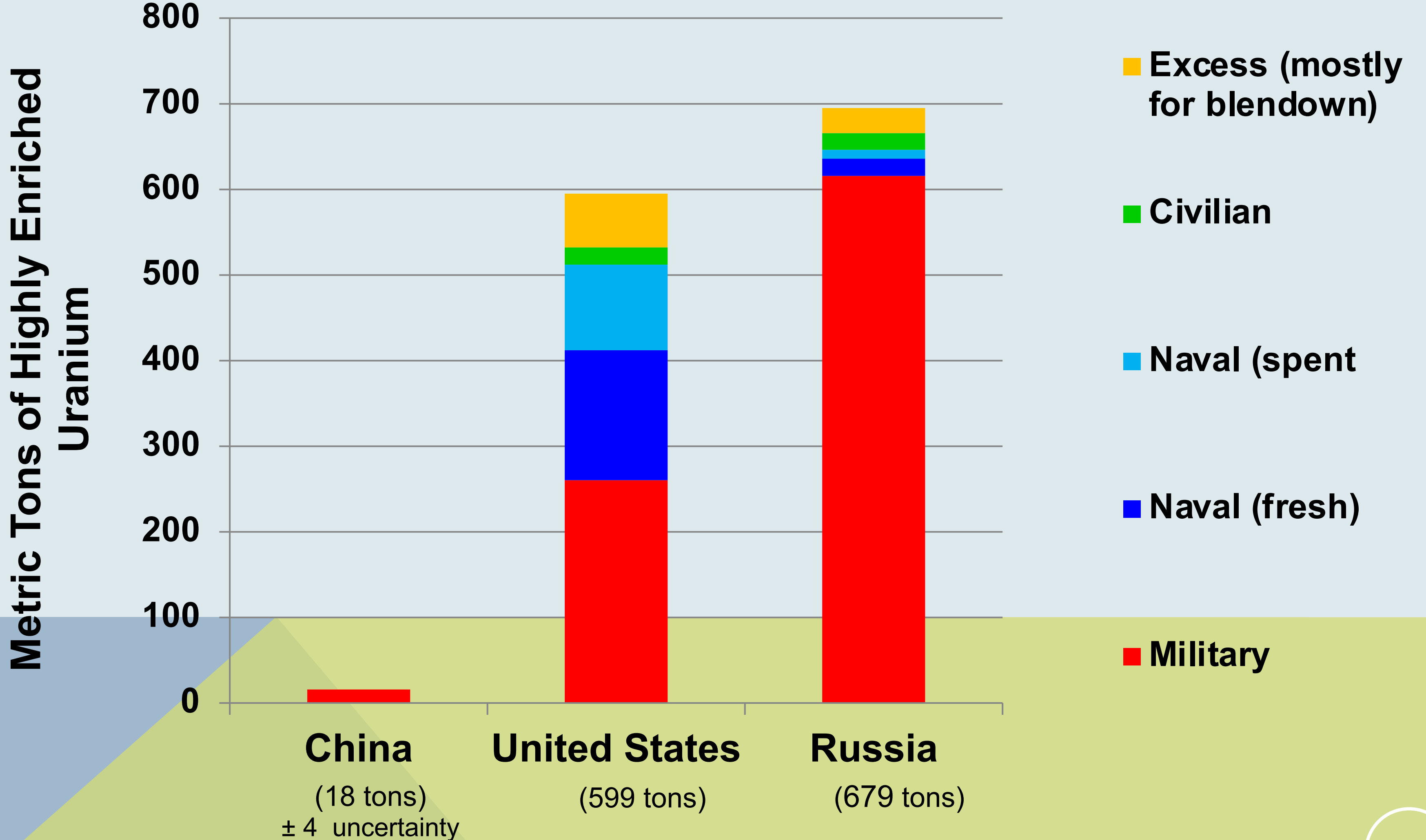
# WHAT ABOUT CHINESE TACTICAL NUCLEAR WEAPONS?

China developed and tested a neutron bomb in 1988 as a "technological reserve" - Liu Huaqiu, Senior Chinese Nuclear Scientist



Will China need tactical nuclear weapons to counter the U.S., its allies, or Russia?

# STOCKS OF HIGHLY ENRICHED URANIUM




Source: http://fissilematerials.org/library/gfmr13.pdf and http://fissilematerials.org/library/gfmr10.pdf

# PROJECTED PRC ENRICHMENT SURPLUSES BEYOND POWER REQUIREMENTS ~ 1,500 BOMBS A YEAR

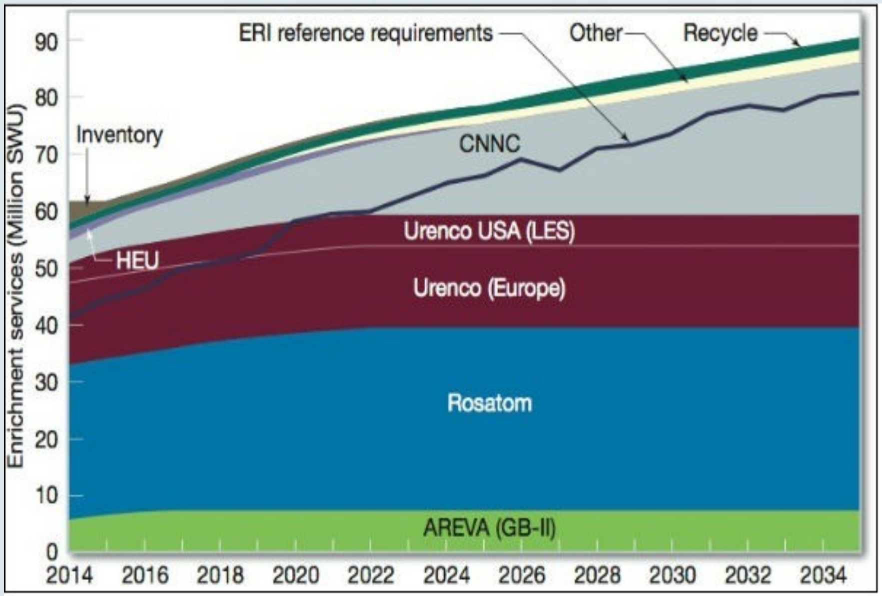
**Hanzhong and Lanzhow**

## China's has an estimated surplus of ~19,000 kg HEU

**232 SWU required to make 1 kg HEU**
Conservatively, in 2020, over 2,500 weapons worth for PRC, over 300 for Japan

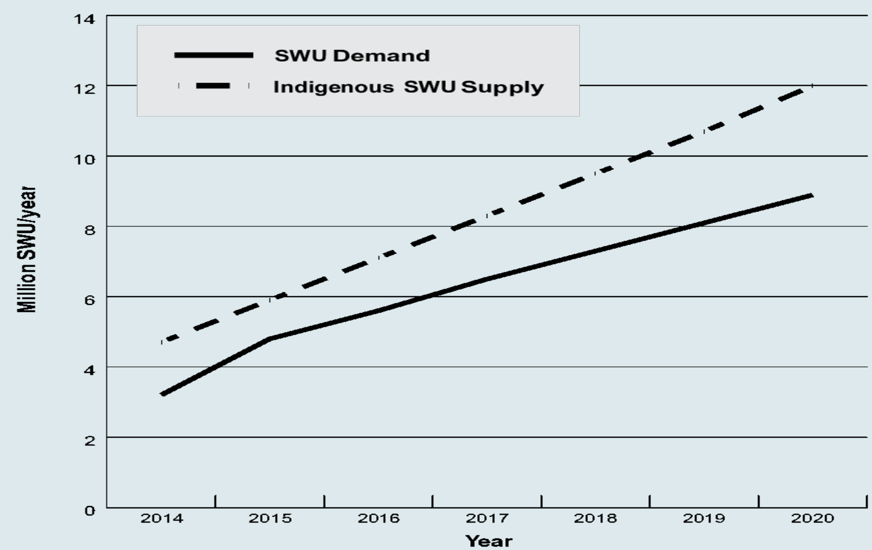
**120,000 SWU required to refuel 1-GWe reactor with LEU annually**
(66 GWe PRC, 12.5 GWe Japan in 2020)

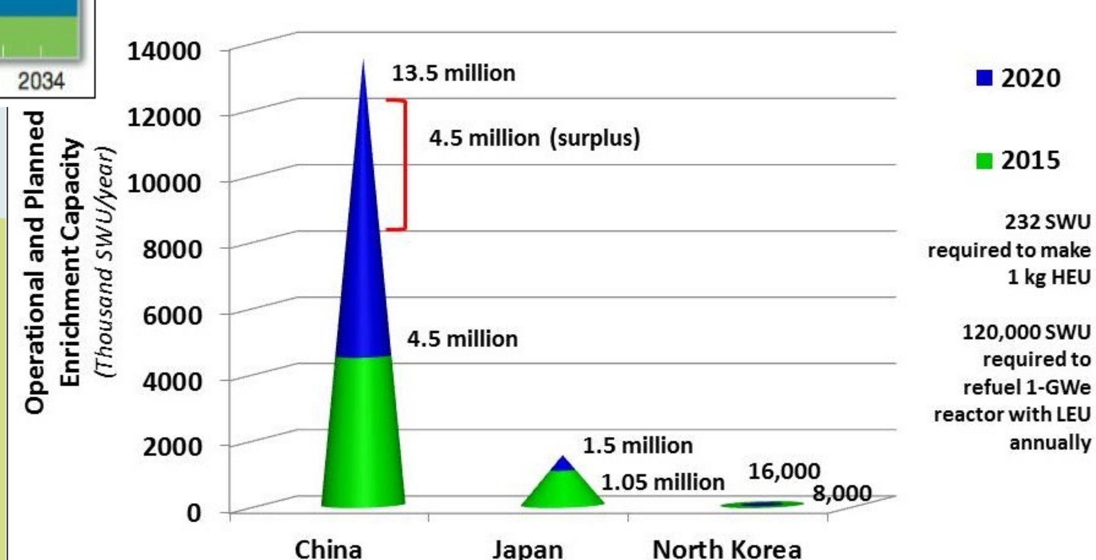
# PROJECTED URANIUM ENRICHMENT SURPLUSES IN EAST ASIA



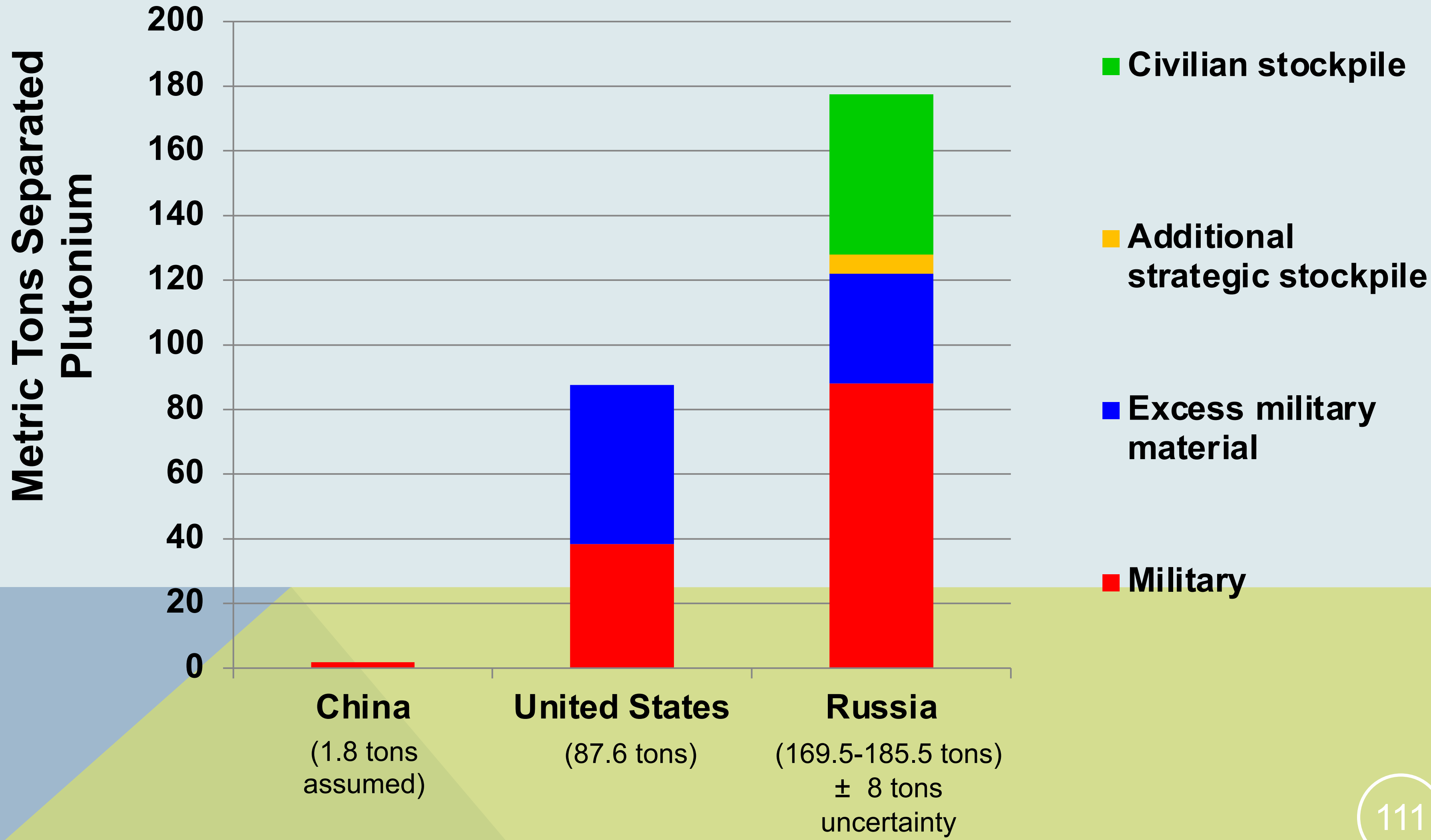

Projected enrichment supply vs demand until 2035

Figure 11: **Projection of China's SWU Supply and Demand (2014–2020)**



# TONS OF SEPARATED PLUTONIUM




Source: http://fissilematerials.org/library/gfmr13.pdf and http://fissilematerials.org/library/gfmr10.pdf

# PRC'S LIMITED PLUTONIUM PRODUCTION CAPACITY IS THE BOTTLENECK TO MANY MORE WEAPONS

PRC has only 2 plutonium production reactors

One is being dismantled

One hasn't operated since the early 1990s

If restarted, the single reactor could produce roughly 300kg of plutonium a year, only enough to make roughly 75 plutonium triggers or bombs.


Jiuquan plutonium production reactor

# PRC'S MOST IMMEDIATE ALTERNATIVE PLUTONIUM PRODUCTION OPTION: ITS HEAVY WATER REACTORS

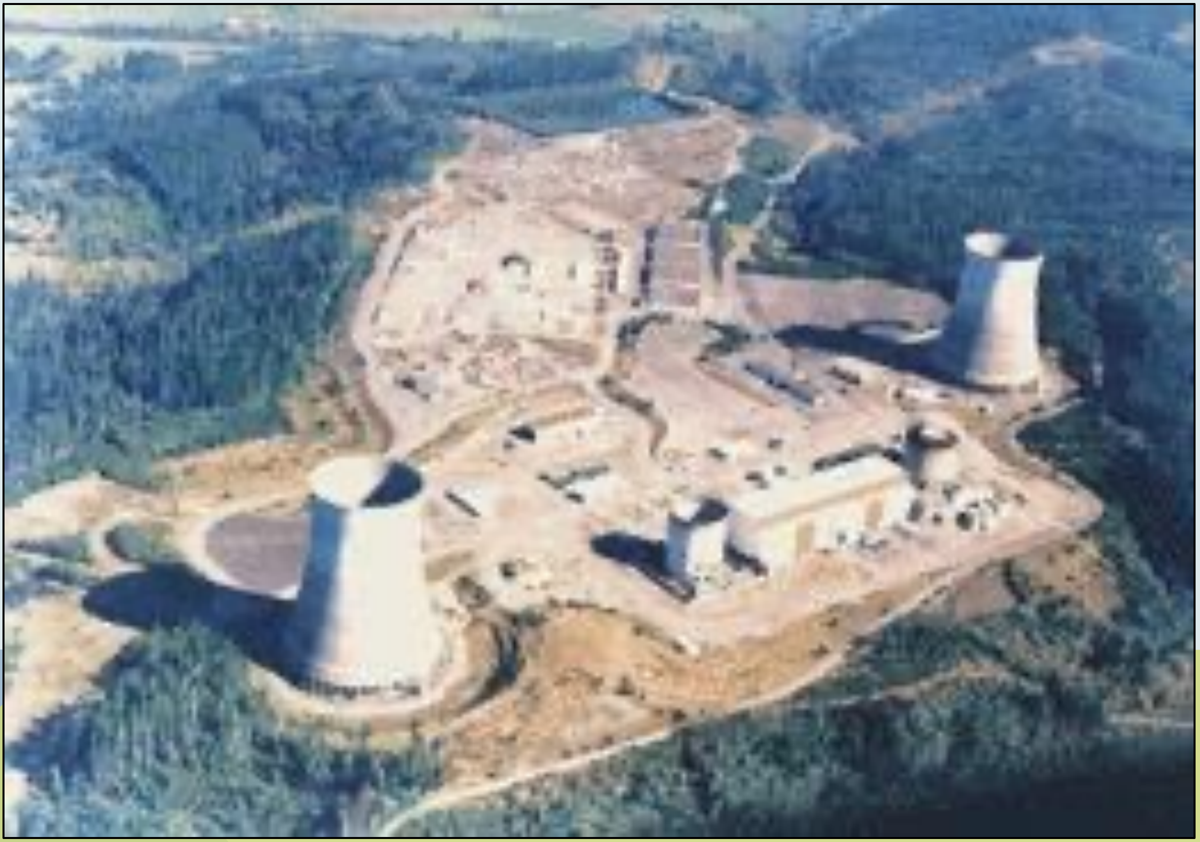
Two Candu-6 reactors (600 MWe each) at Qinshan

Capable of producing ~650 kilograms of plutonium a year

Sufficient for roughly >100 bombs a year

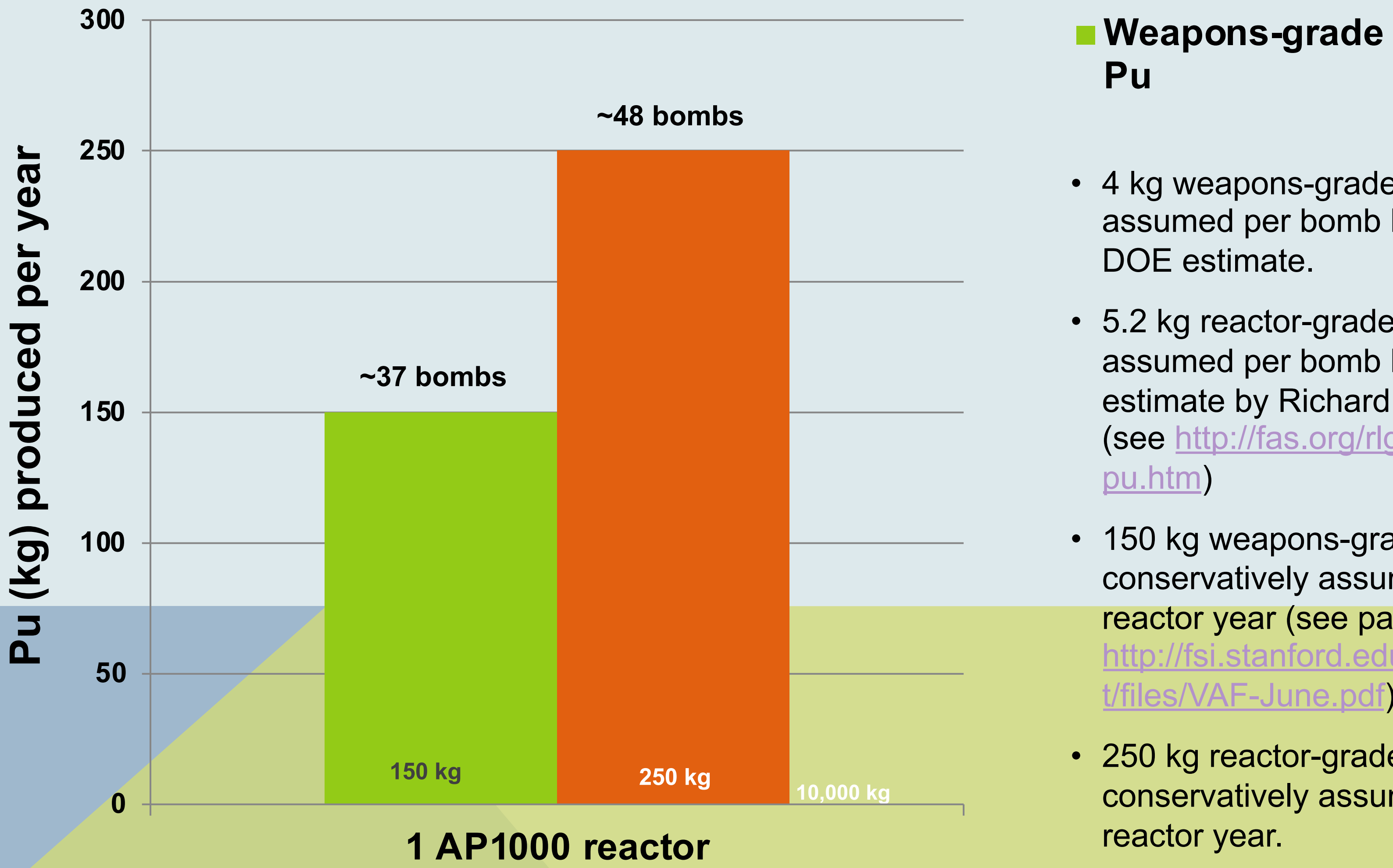
Source: https://en.wikipedia.org/wiki/CANDU_reactor

# 1987: REAGAN ADMINISTRATION PROPOSED USING WPSS LWR TO MAKE WEAPONS PLUTONIUM



Source: http://www.historylink.org/index.cfm?DisplayPage=output.cfm&File_Id=5482

# HOW MUCH PLUTONIUM COULD A 1 GWE LWR GENERATE/YEAR?

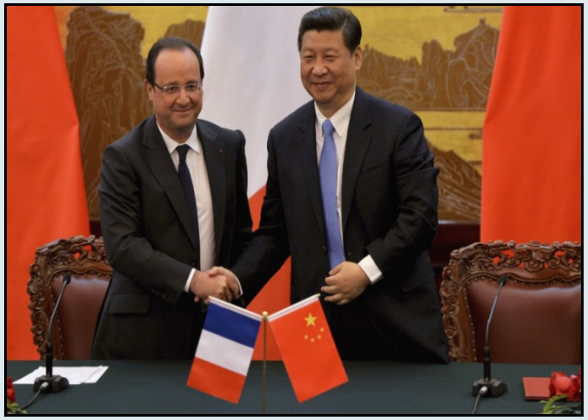



- 4 kg weapons-grade Pu assumed per bomb based on DOE estimate.
- 5.2 kg reactor-grade Pu assumed per bomb based on estimate by Richard L. Garwin (see http://fas.org/rlg/980826-pu.htm)
- 150 kg weapons-grade Pu conservatively assumed per reactor year (see page 64, http://fsi.stanford.edu/sites/default/files/VAF-June.pdf)
- 250 kg reactor-grade Pu conservatively assumed per reactor year.

# PRC'S OTHER PLUTONIUM PRODUCTION BOTTLENECK: LACK OF A LARGE, RELIABLE REPROCESSING PLANT


China has decommissioned its large military reprocessing plant

# SOLUTION 1: BUY FRENCH REPROCESSING PLANT



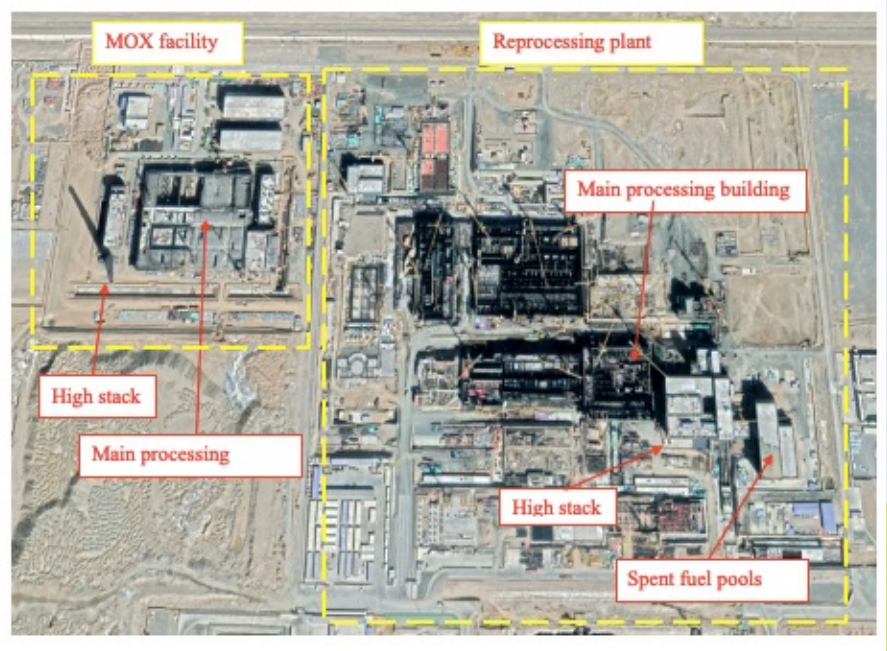
**Presidents Francois Hollande and Xi Jinping**
France agrees to build PRC a large commercial reprocessing plant at Jianyuguan

Planned 800 tHM/yr EDF plant: ~1600 bombs worth of pu/yr

# SOLUTION 2: BUILD AND OPERATE YOUR OWN REPROCESSING PLANTS

Images of 50tHM/year Chinese Reprocessing plant at the Jiuquan Atomic Energy Complex, fully operational 2017, 500 kgs pu/yr

China 200 tHM/year reprocessing plant under construction, operational by 2025? 2,000 kgs  pu/yr



# CHINESE FAST REACTORS

China Experimental Fast Reactor, 20 MWe, operational 2010

China Fast Reactor, 600 Mwe (110 wfpu/year), operational 2026?

# EAST ASIAN REPROCESSING PLANTS

800 tHM/yr Rokkasho plant: ~1,600 bombs' worth pu/yr, 2021 planned opening

50 tHM/yr Pilot plant: ~100 bombs worth of plutonium/yr

200 tHM/year plant is now under construction: ~400 bombs worth of pu/yr

ROK Experimental Pyroprocessing Facility

Planned 800 tHM/yr EDF plant: ~1600 bombs worth of pu/yr