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Title: Nuclear Fuel Cycle Introductory Concepts

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Nuclear Fuel Cycle: Introductory Concepts

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Introduction

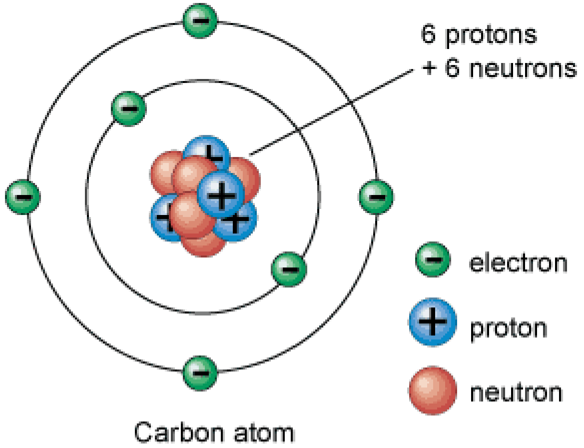
- Roughly 12% of the world's energy is supplied by nuclear power*
- 8 Countries have declared that they possess nuclear weapons
- The nuclear fuel cycle concerns the life of nuclear material:
  - extraction from the earth in raw form
  - processing and enrichment
  - use in reactors or weapons
  - reprocessing or disposal

*http://web.mit.edu/12.000/www/m2016/finalwebsite/solutions/newmines.html

Introduction

- The basic fuel material for the generation of nuclear power is uranium (and to a lesser extent thorium)
  - however, these fuels change in state as they are irradiated in the reactor
- The stages before the reactor are called the Front-end of the fuel cycle
- The stages following the reactor are called the Back-end of the fuel cycle

Elements, Nuclides, and Isotopes



<u>Constituents of the Atom</u>: Protons, Neutrons, and Electrons

<u>Elements</u>: Defined by the number of protons in the nucleus

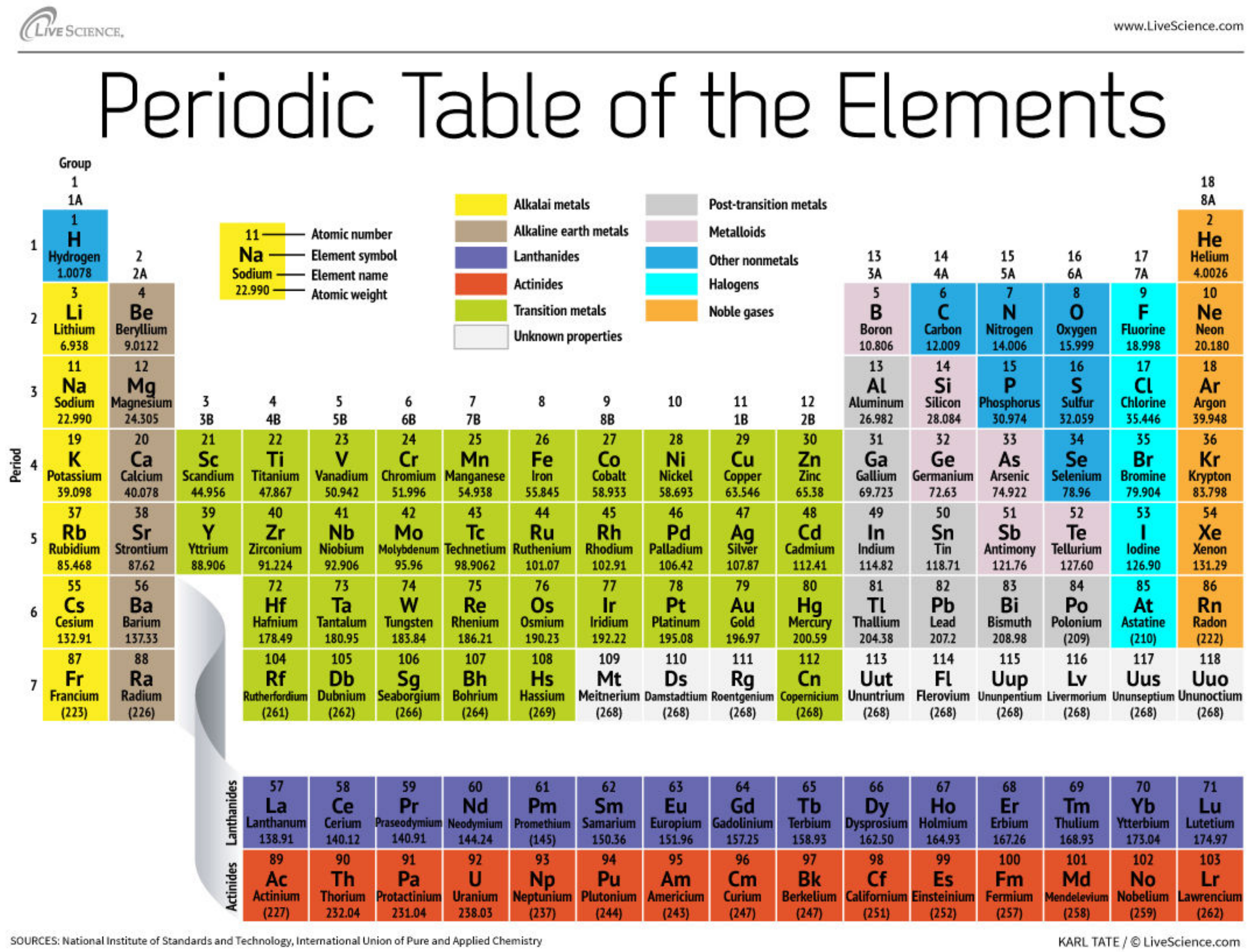
<u>Isotopes</u>: atoms from same element but with different number of neutrons

<u>Nuclides (or Radionuclides):</u> a more general term specifying element and atomic mass

^{12}C (Carbon-12):

a) has 6 protons and 6 neutrons
b) <u>Atomic number (Z)</u>: # of protons
c) <u>Atomic Mass (A):</u> # of protons + neutrons

Elements, Nuclides, and Isotopes



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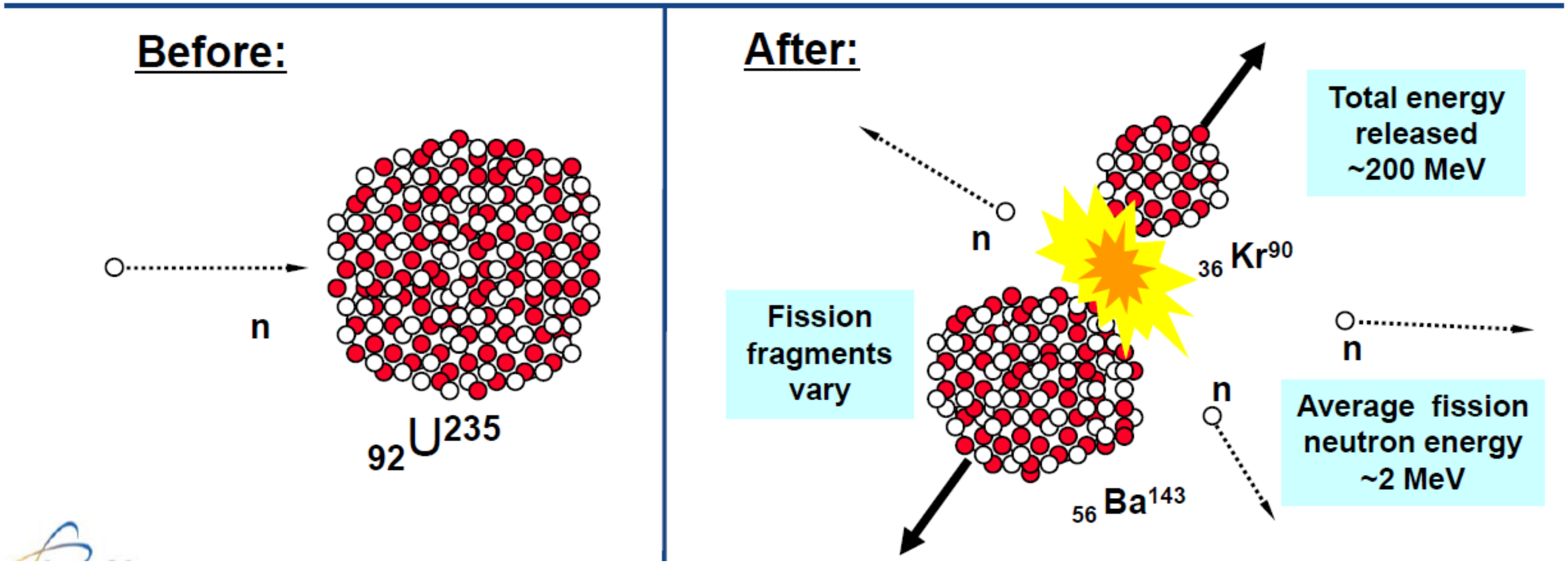
Categories of Nuclides

- Stable Nuclides
  - Structure and energy of nucleus does not change naturally
- Radioactive Nuclides
  - Nucleus changes by reactions such as alpha, beta, gamma, decay or spontaneous fission
- Fissionable Nuclides
  - Fission can be induced by a neutron of sufficient energy
- Fissile Nuclides
  - Fission can be induced by a neutron of *any* energy

Induced Fission

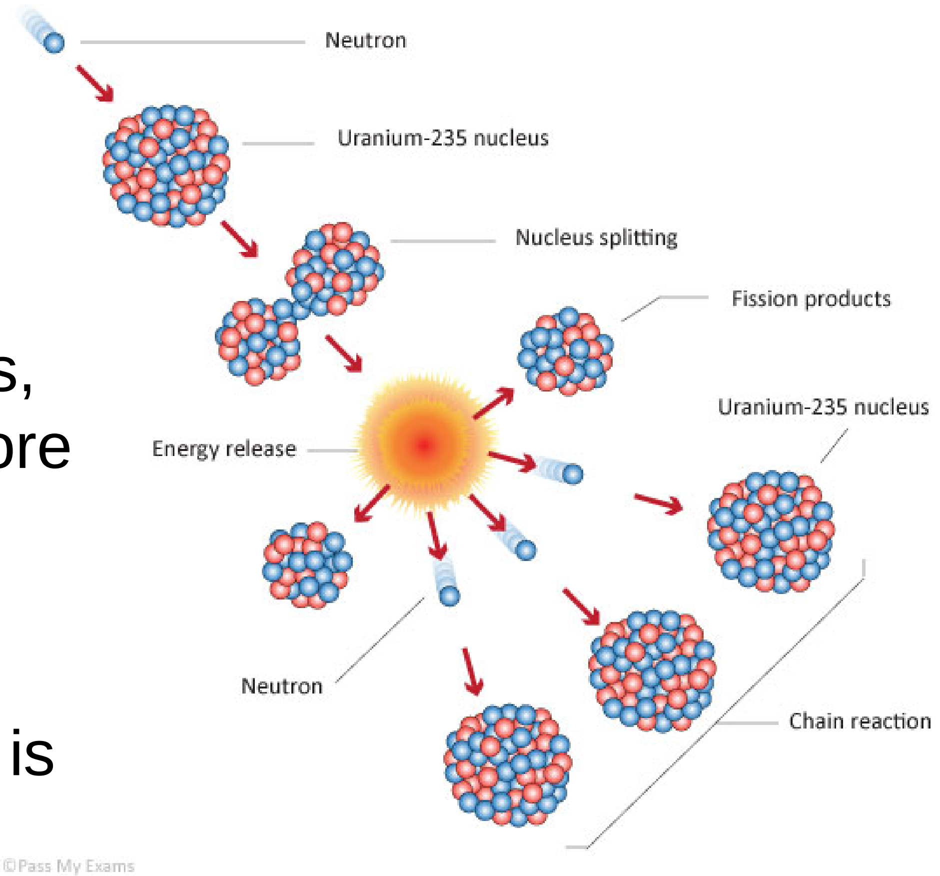
- One of many possible reactions that can occur when a neutron interacts with ^{235}U, ^{239}Pu, or another fissionable nuclei
- Large energy release per reaction
- Additional neutrons released (opens possibility of a fission chain reaction)



Nuclear Chain Reaction

<u>Chain Reaction</u>: a neutron fissions a nucleus, which releases 1 or more neutrons, which subsequently split more nuclei, and so on …

Each time a fission occurs about ~200 MeV of energy is released.



Energy from Fission

- The fission of 1 g of uranium or plutonium per day liberates about 1 MW. This is the energy equivalent of 3 tons of coal or about 600 gallons of fuel oil*

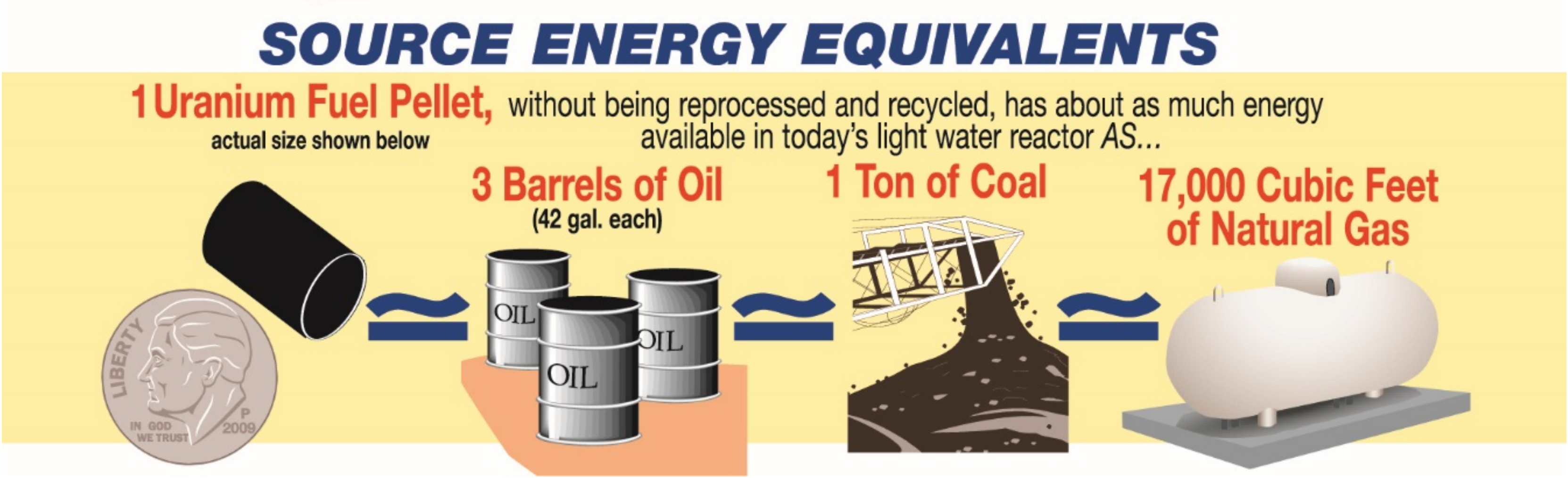


Figure from the American Nuclear Society

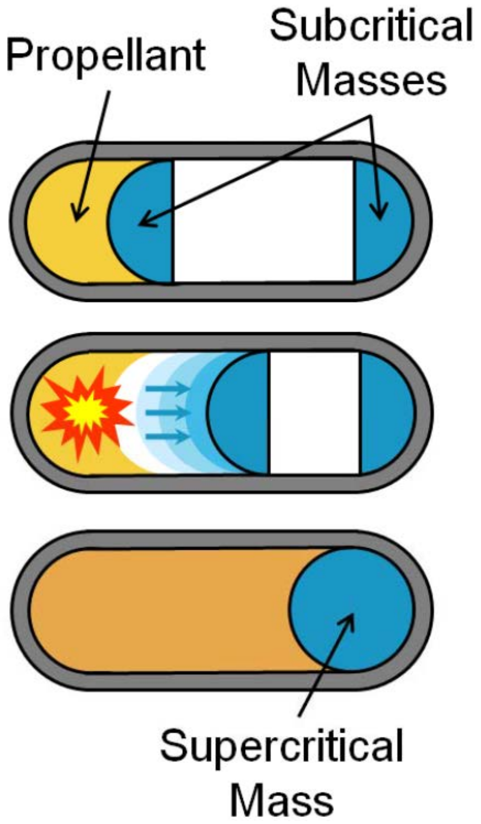
*http://www2.lbl.gov/abc/wallchart/chapters/14/1.html

Special Nuclear Material

- Special Nuclear Material (SNM):
  - Highly-Enriched Uranium (HEU): Key Nuclide is ^{235}U
  - Plutonium: Key Nuclide is ^{239}Pu
  - ^{237}Np
  - ^{233}U
  - Others but they are less common
- All of above listed nuclides are 'fissionable'. Of these, all <u>except</u> ^{237}Np are *fissile*.
- SNM is very dense in metal form and is composed of elements with high atomic numbers.
- Gram for gram SNM is not very radioactive compared to common sources like ^{137}Cs (Note: except ^{233}U items with high (ppm) ^{232}U concentrations).

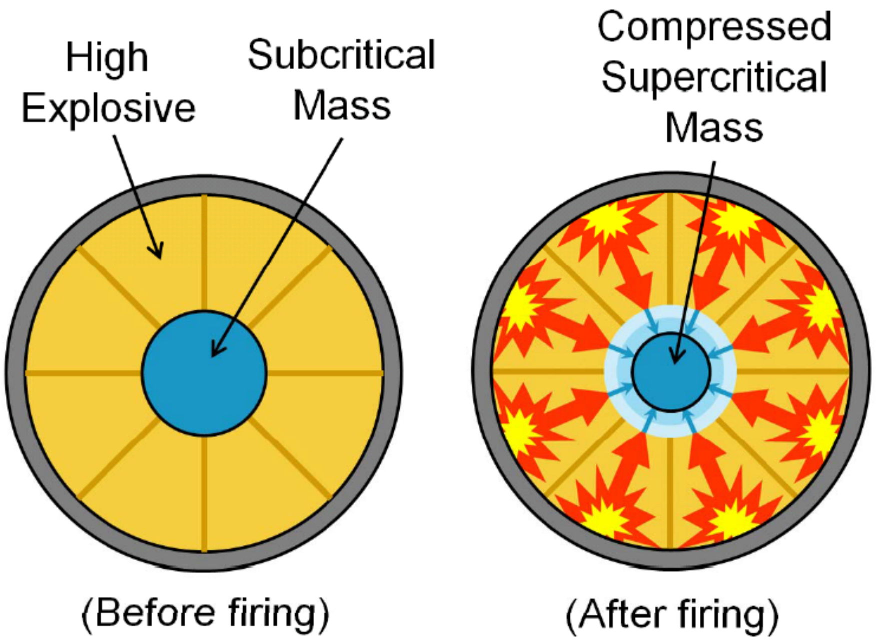
Why we worry about SNM

Gun-Type



HEU, U-233, Np-237

Implosion



HEU, U-233, Np-237, and WGPu

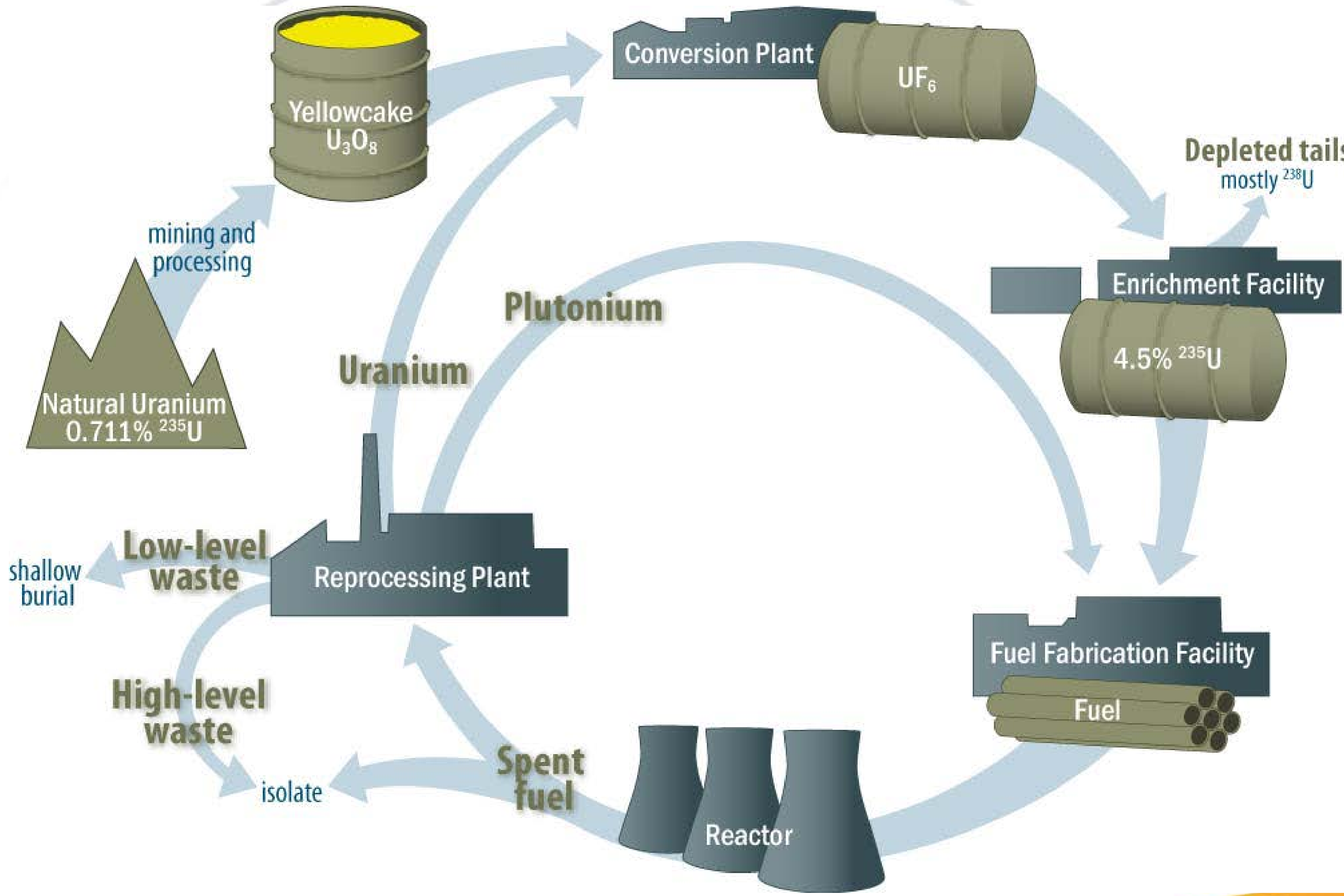
Uranium vs. Other Materials

- Uranium (^{238}U, ^{235}U, ^{234}U)
  - Naturally abundant in the form of ore
  - Contributes to the natural radiation background (mainly U-238 progeny)

- Other materials (transuranics) such as plutonium and neptunium are generally created in reactors and not found in nature.

Nuclear Fuel Cycle General Flow

Los Alamos NATIONAL LABORATORY EST.1943



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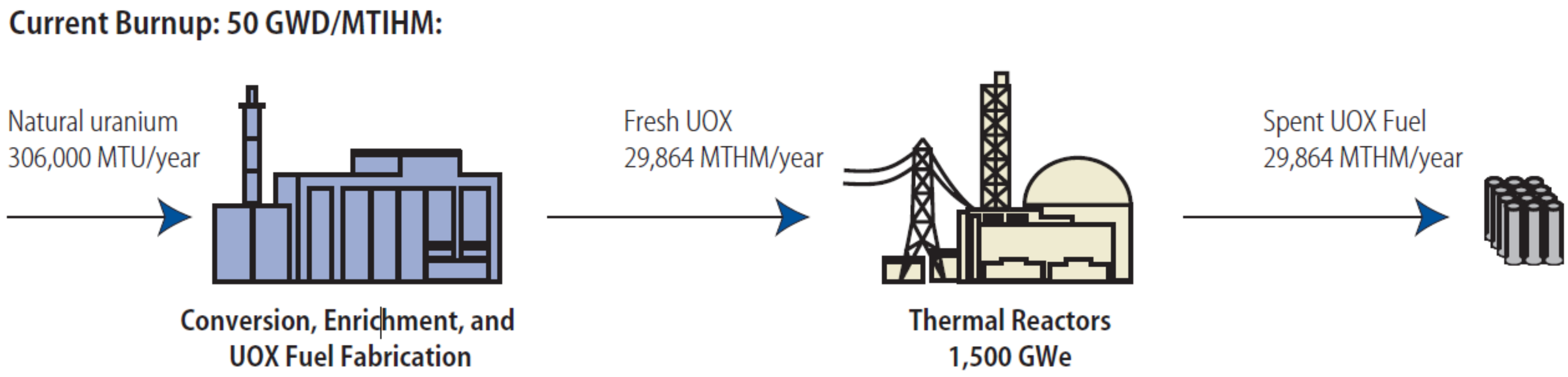
Open Fuel Cycle

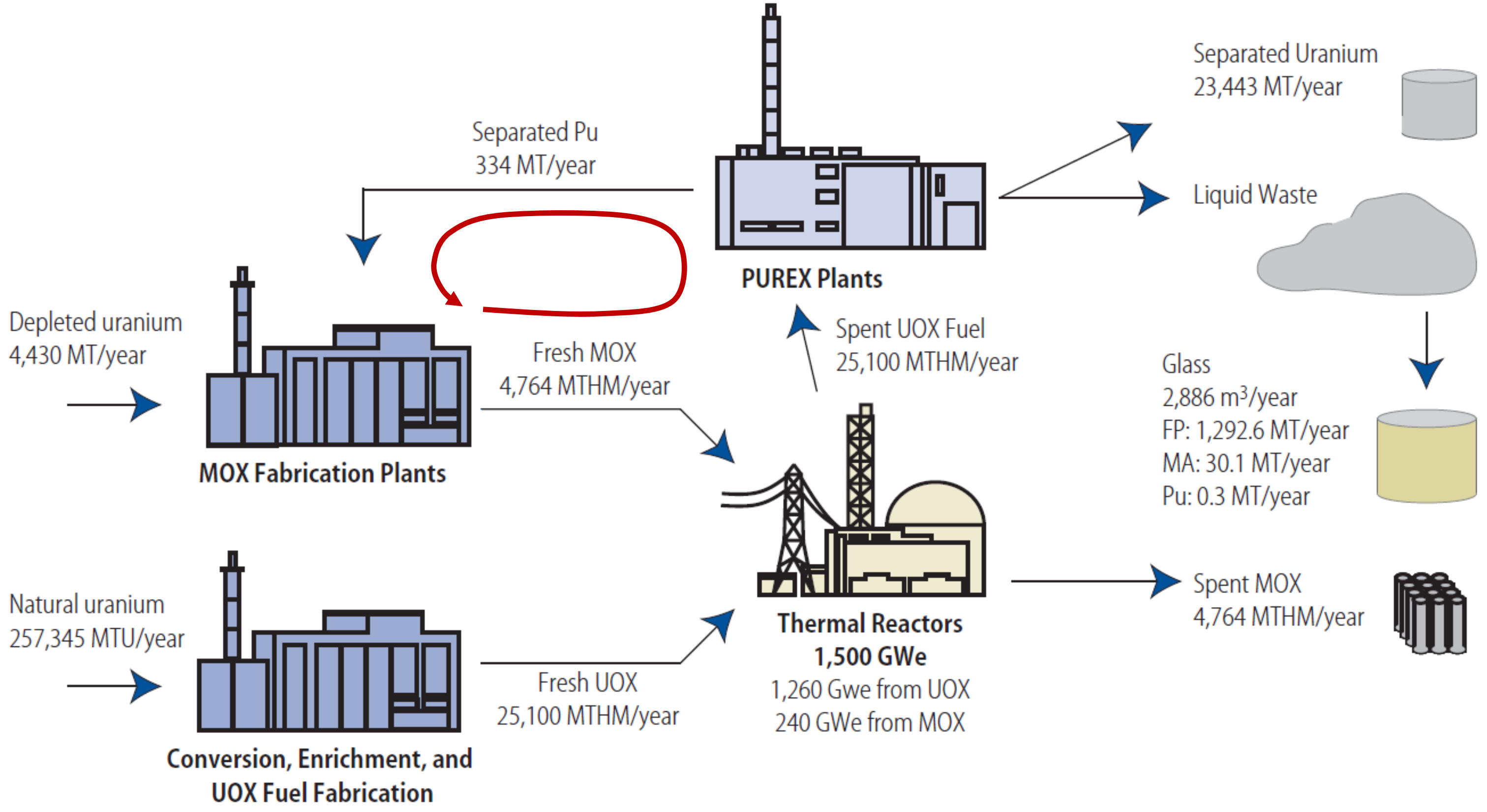
In the Open Fuel Cycle (or Once-Through Fuel Cycle) spent fuel discharged from the reactor and treated as waste.



http://web.mit.edu/nuclearpower/pdf/nuclearpower-ch4-9.pdf

Closed Fuel Cycle Example

In the Closed Fuel Cycle, spent fuel is re-processed so that uranium and plutonium can be extracted and re-cycled in a reactor.



http://web.mit.edu/nuclearpower/pdf/nuclearpower-ch4-9.pdf

Country Summary: USA

- Material Acquisition
  - Mining is small scale in the US today with most material being purchased from foreign suppliers
- Processing
  - The US currently has one uranium conversion facility and one enrichment facility
- Reactors
  - 100 supplying ~20% of electricity
- Reprocessing
  - None currently
- Declared Nuclear Weapons State

Country Summary: USA

- World's largest producer of nuclear power
  - 30% of worldwide nuclear generation of electricity.
- 100 nuclear reactors
  - produced 798 billion kWh in 2015, ~20% of total electrical output.
  - There are four reactors under construction.
- Government policy changes since the late 1990s have helped pave the way for significant growth in nuclear capacity.
- Issues with New Development in US Nuclear Power
  - liberalized wholesale electricity markets
    - Private electricity generation investment is focused on minimizing commercial risk to investors, typically resulting in low-capital-cost natural-gas-fueled power plants.
  - lower gas prices since 2009

2016 Nuclear Reactor Map USA

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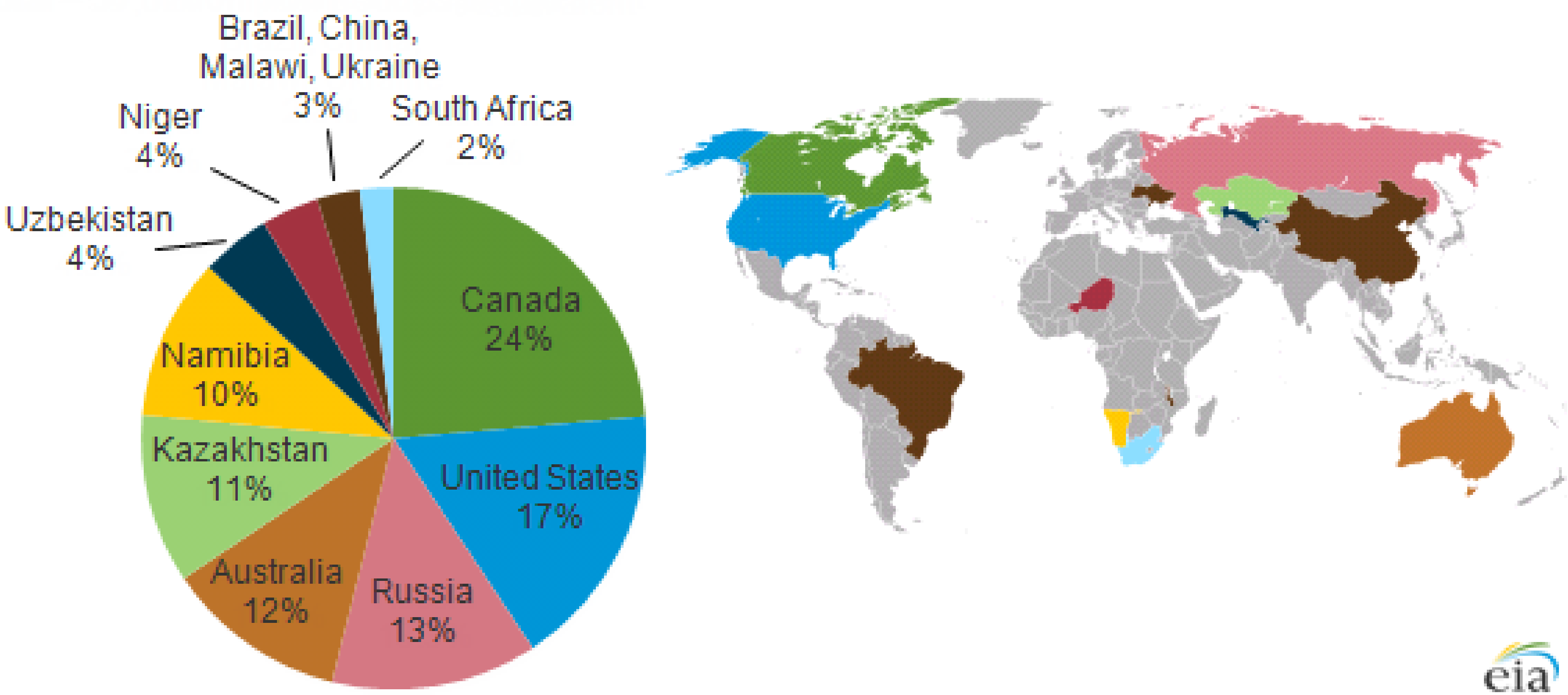
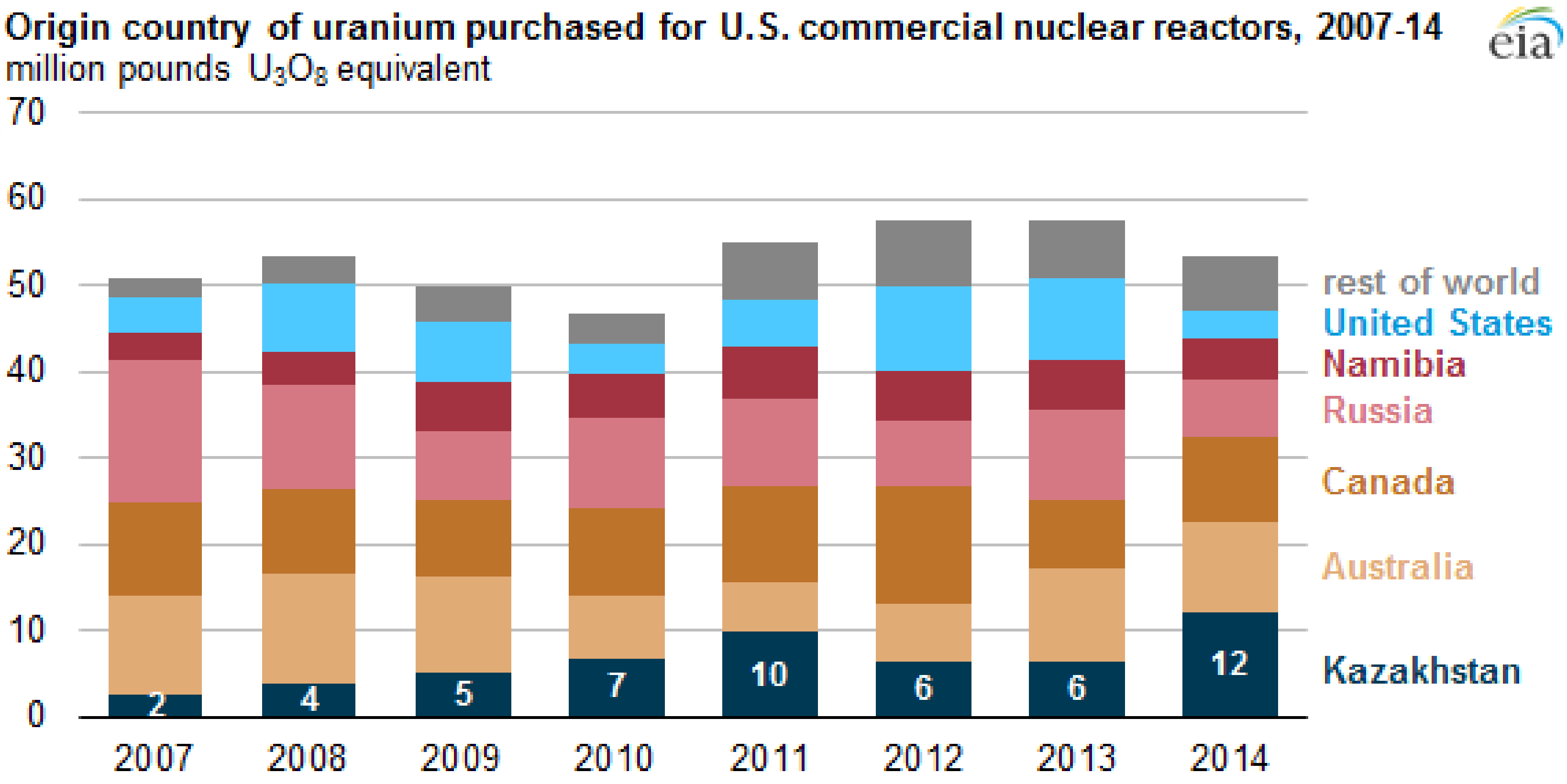
2012 US Acquisition of Uranium

Uranium purchased by owners and operators of U.S. commercial nuclear reactors (2012)
total = 58 million pounds U_3O_8 equivalent



http://www.eia.gov/todayinenergy/detail.php?id=12731

US Acquisition of Uranium 2007-14

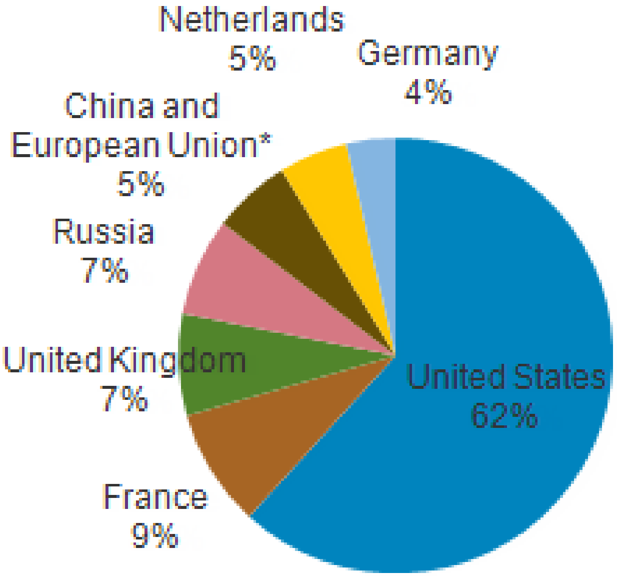


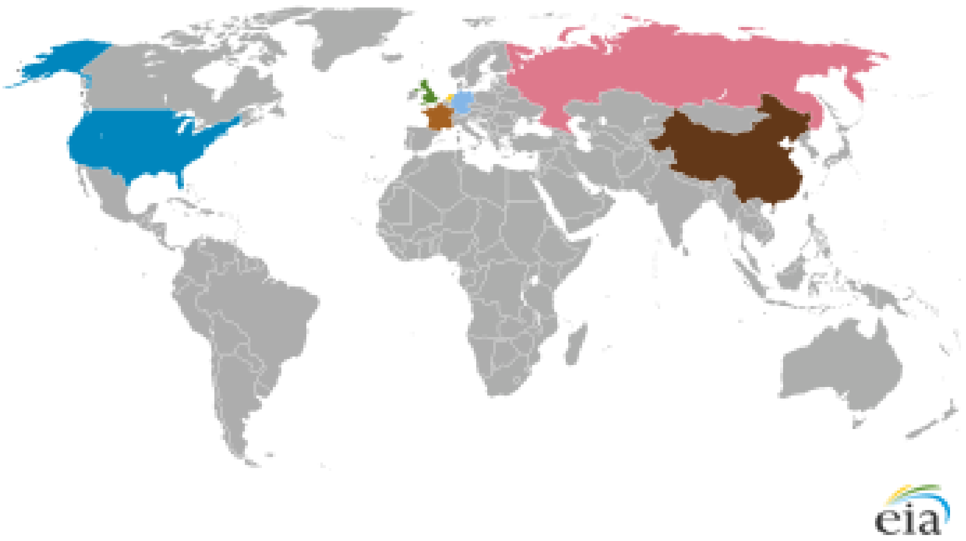
http://www.eia.gov/

2012 Enrichment of US Uranium

Deliveries of natural UF_6 by owners and operators of U.S. commercial nuclear reactors to enrichers in the following countries (2012)

total = 52 million pounds U_3O_8 equivalent





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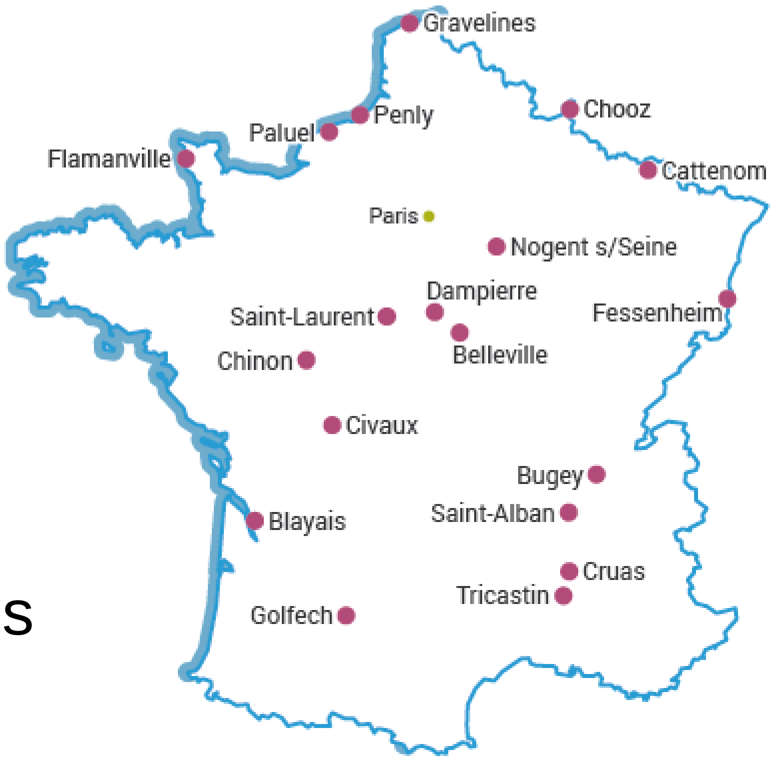
Country Example: Russia

- Material Acquisition
  - Significant natural resources (~9% of world) and mining operations producing ~3000 tonnes U ore per year
- Processing
  - Multiple conversion and enrichment facilities
- Reactors
  - 35 supplying 18% of electricity, ~9 under construction
- Reprocessing
  - Multiple reprocessing plants and products
- Declared Nuclear Weapons State

Country Example: France

- 75% of its electricity from nuclear energy
- World's largest net exporter of electricity,
- France has been very active in developing nuclear technology.
  - Reactors and especially fuel products and services are a significant export.
- About 17% of France's electricity is from recycled nuclear fuel.
- Declared Nuclear Weapons State

Nuclear Power Plants in France



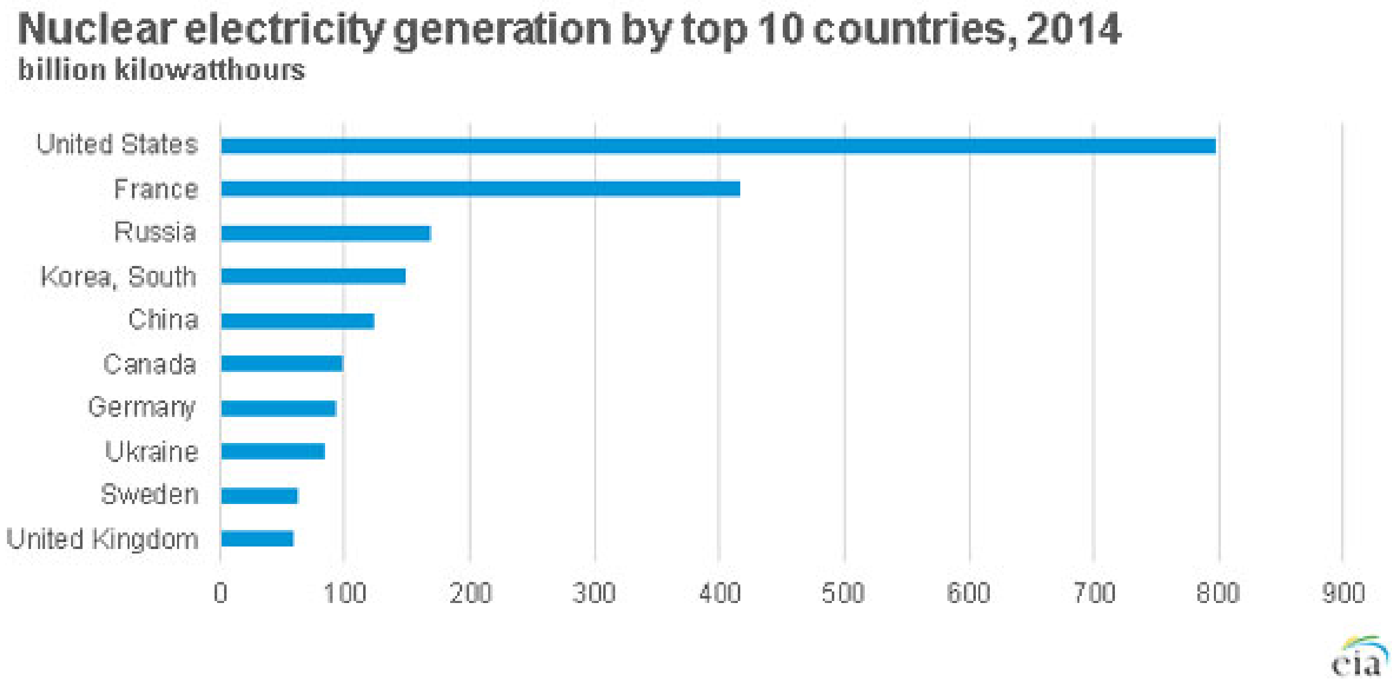
Source: World Nuclear Association

Country Example : France

- 12,400 tonnes of uranium oxide concentrate (10,500 tonnes of U) per year for its electricity generation
  - Mostly from AREVA in Canada and Niger
  - Australia, Kazakhstan and Russia
- Self-sufficient otherwise with conversion, enrichment, uranium fuel fabrication and MOX fuel fabrication plants operational (together with reprocessing and a waste management program). http://www.world-nuclear.org/information-library/country-profiles/countries-a-f/france.aspx

Summary

The nuclear fuel cycle is a complex entity, with many stages and possibilities, encompassing natural resources, energy, science, commerce, and security, involving a host of nations around the world



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