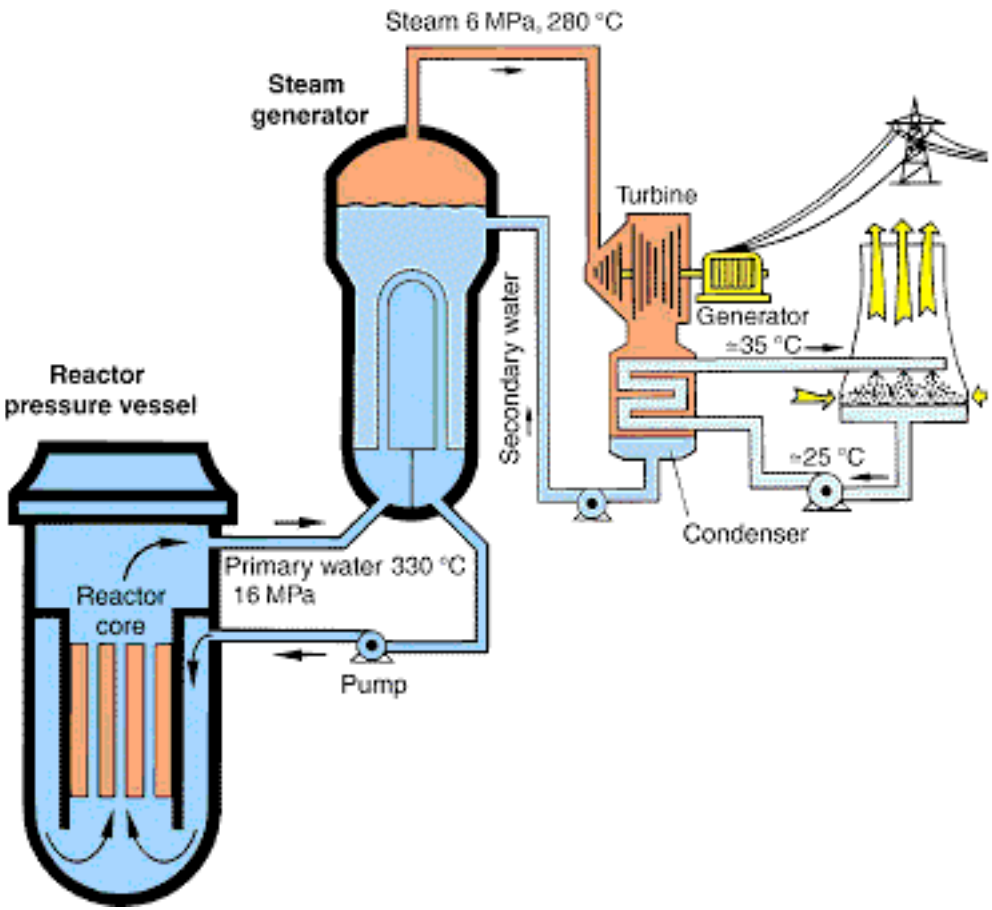
Nuclear

GEOS 24705/ ENST 24705

Nuclear power just another way of making steam

A nuclear plant is a big tea-kettle driving a steam turbine

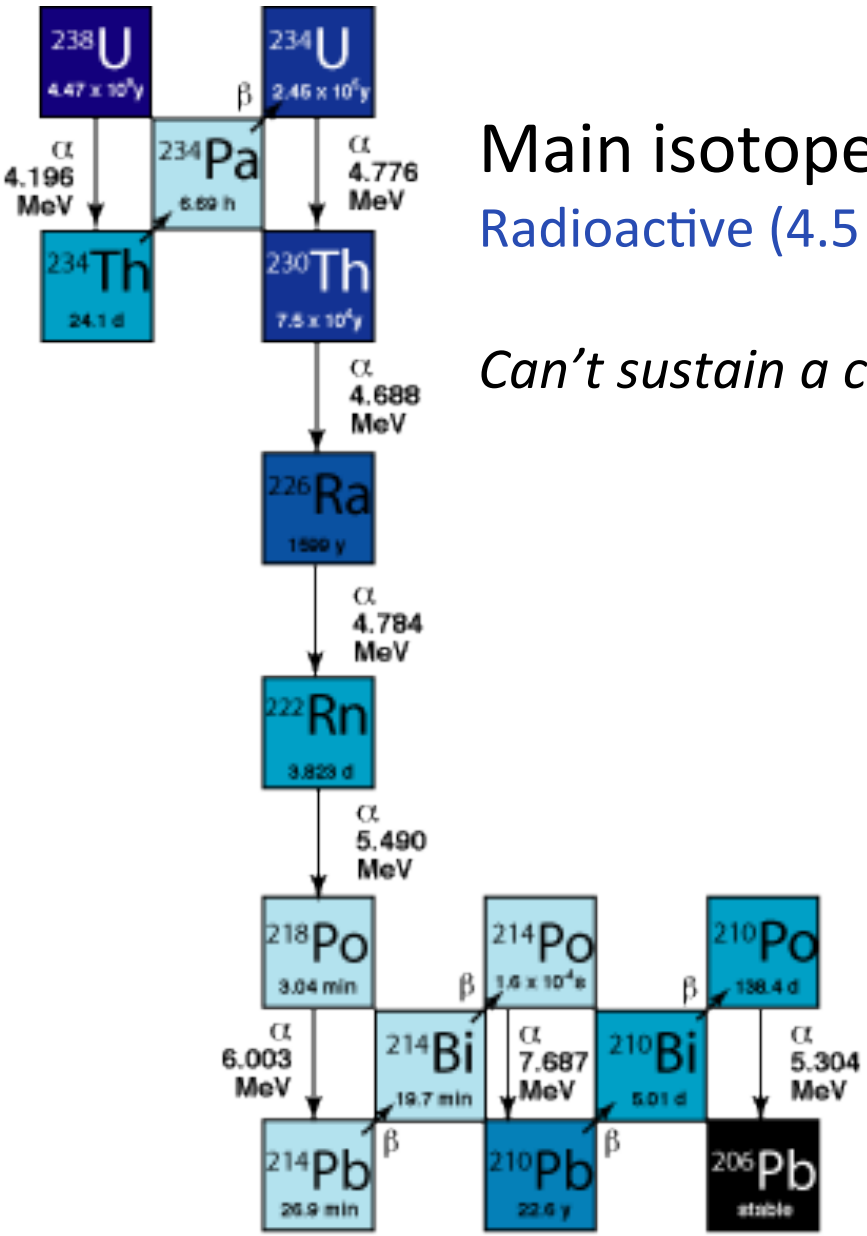


Nuclear engineering is all about keeping the system in the Goldilocks condition – not too cold and not too hot.

Most of it is thermal management

Images: copyright unknown

Uranium decay - spontaneous



Main isotope is ^{238}U (99.28%)

Radioactive (4.5 Byr half-life)

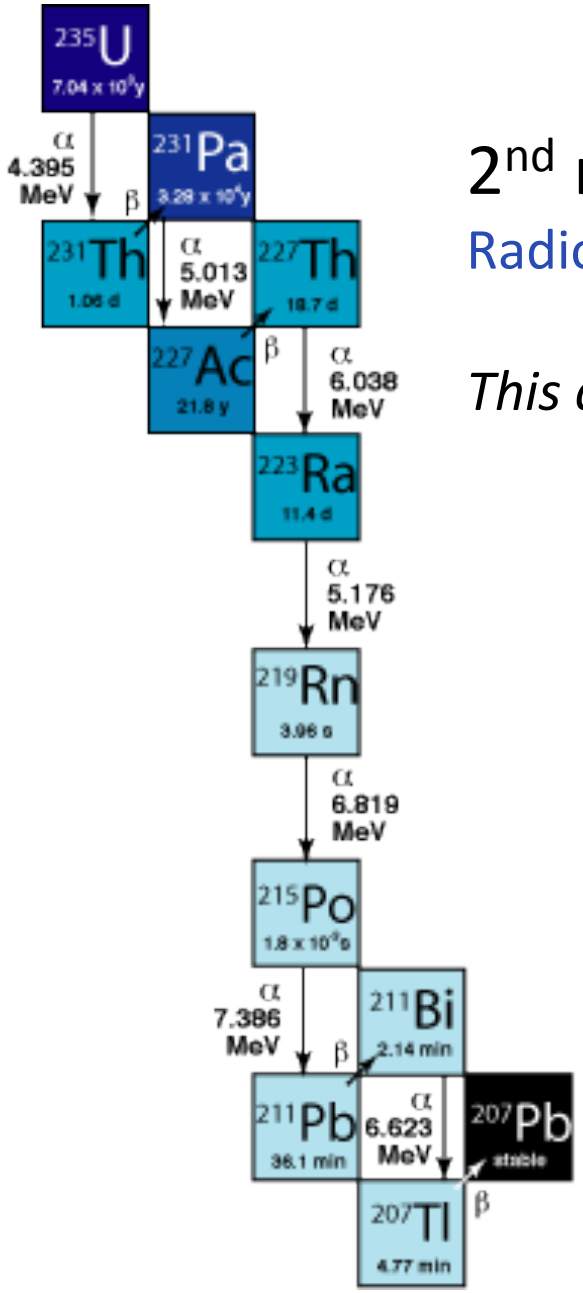
Can't sustain a chain reaction. Decays spontaneously

^{238}U -- > α + ^{234}Th

...eventually -- > ^{206}Pb

Image: Macquarie University

Uranium decay - spontaneous



2nd most abundant is ^{235}U (0.72 %)

Radioactive (700 Myr half-life)

This can decay spontaneously

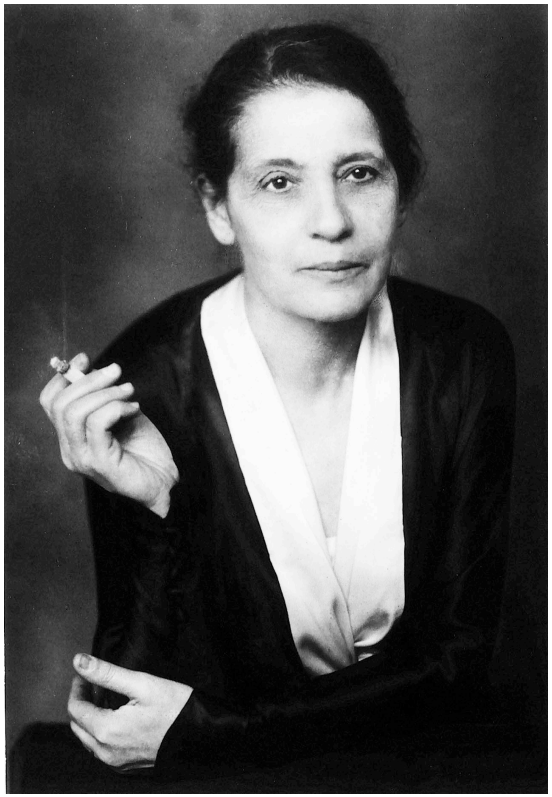
$$^{235}U \text{ --> } \alpha + {}^{231}Th$$

...eventually --> ^{207}Pb

Image: Macquarie University

Fission of uranium discovered by Lise Meitner from Otto Hahn's data in 1939

Hahn was trying to make heavier elements by neutron bombardment – didn't understand his results.



But only Hahn got the Nobel prize…

Hahn and Meitner in the laboratory, Berlin, ca. 1925
Image: Technische Universitat Munchen

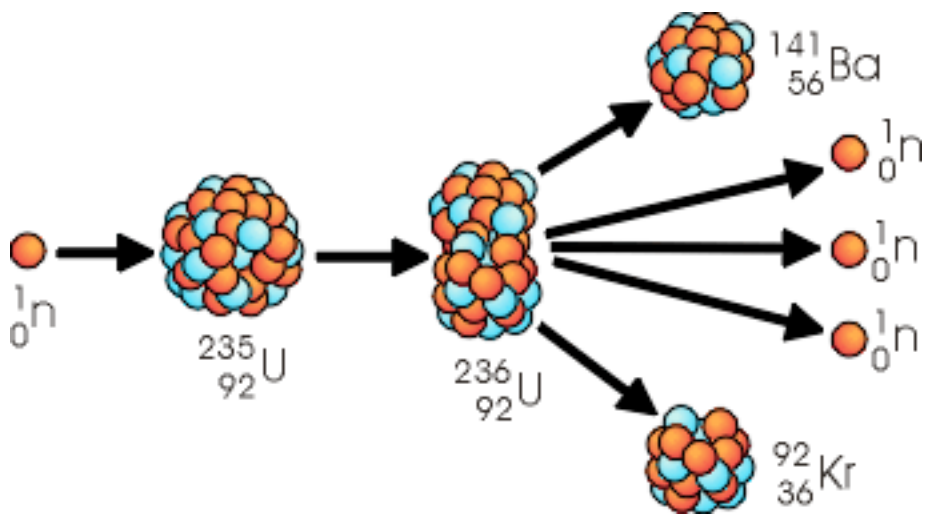
Uranium decay - bombardment

^{235}U fissions spontaneously only one in 14 billion decays
– but fissions reliably given neutron bombardment.

neutron bombardment: $^{235}U + n \text{ -- > } ^{236}U$

… instead of sticking, the new element fissions…. *(one example)*

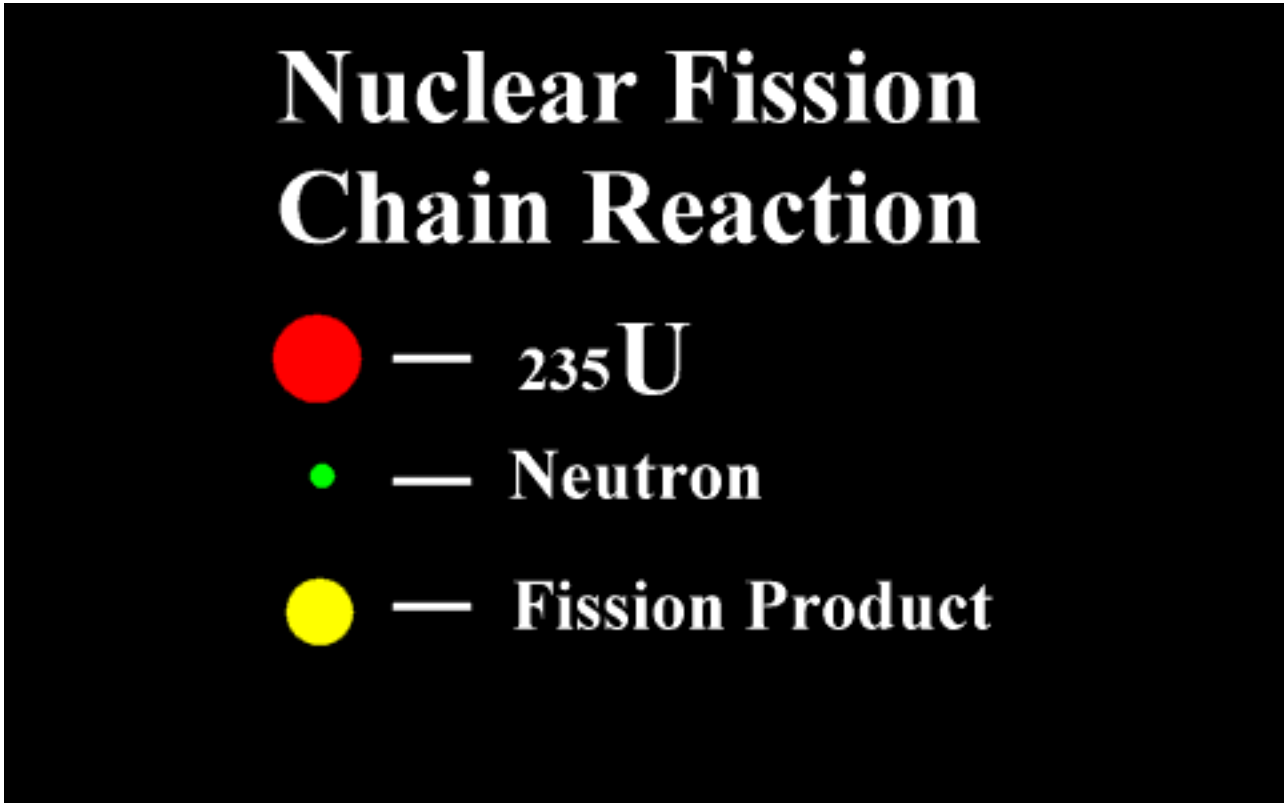
$$^{236}U \text{ -- > } ^{144}Ba + ^{89}Kr + 3n$$



Multiple neutrons produced in turn make multiple new decays. ^{235}U can sustain a fission chain reaction. (It is "fissile").

Fission products themselves are highly radioactive: decay by β emission. Short half-life: spent fuel is "hot".

Nuclear chain reactions: good if you want them, bad if not



Each fission event makes more fission events.
And each event produces heat….

For animation see
http://library.thinkquest.org/17940/texts/fission/fission.html

Nuclear reactor characterization

Can build a reactor whose only purpose is transmutation, turning one element into another – a **"breeder" reactor**.

Here the goal is to control the daughter product. *(Generally make plutonium out of uranium).* Can use breeders to reprocess spent nuclear fuel, but then you're left with fuel that contains dangerous plutonium. Reactor meltdowns are worse if using reprocessed fuel.

Or can make a **power reactor** where what you want is the heat produced in nuclear decay.

Here the goal is to control the rate of heat production. *Not too cool (low power) or too hot (meltdown).*

Nuclear power reactor heat control: management choices

CHOICES FIXED AT DESIGN TIME

- Fuel type and moderator substance

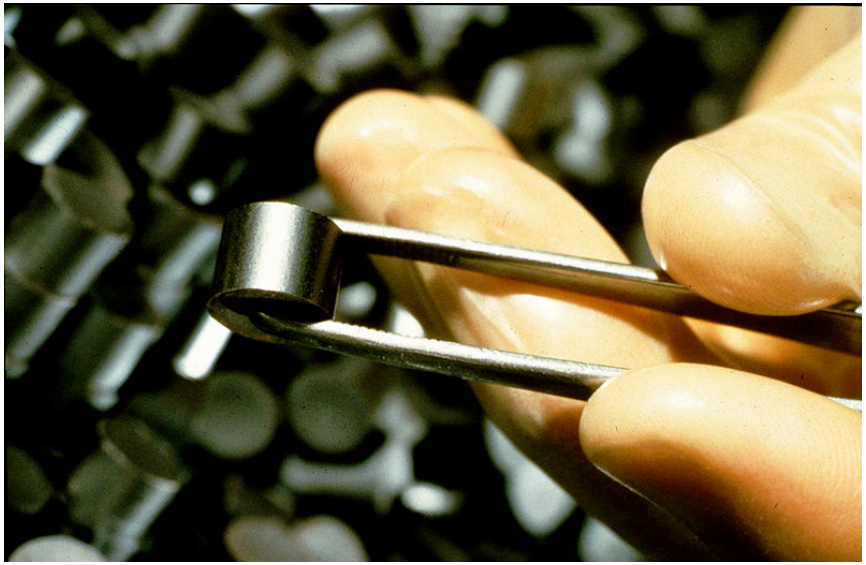
  Moderator makes neutrons more useful by slowing them down – depending on the moderator can use different blends of ^{235}U / ^{238}U. If using a great moderator can use natural abundance uranium (< 1% ^{235}U). If no moderator must enrich to > 20%.
- Composition of fuel

  Choices: % uranium and form: solid U oxide, metal alloy, liquid, or ceramic. Most fuel is oxide (UO_2) which cannot burn.
- Size/shape/arrangements of fuel rods or pellets
- Cladding on fuel
- Control rods that absorb some neutrons

OPERATIONAL MANAGEMENT

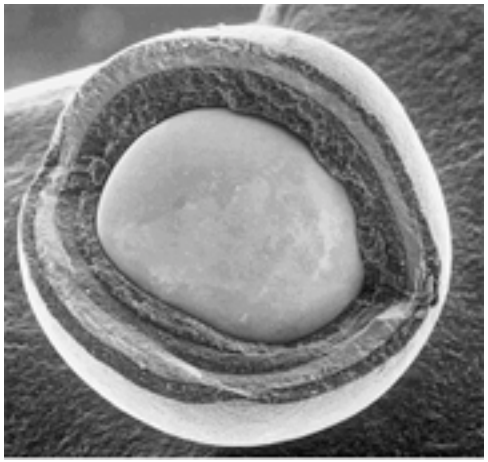
- Cool reactor (often with water as coolant)
- Separate fuel rods or pebbles in emergency

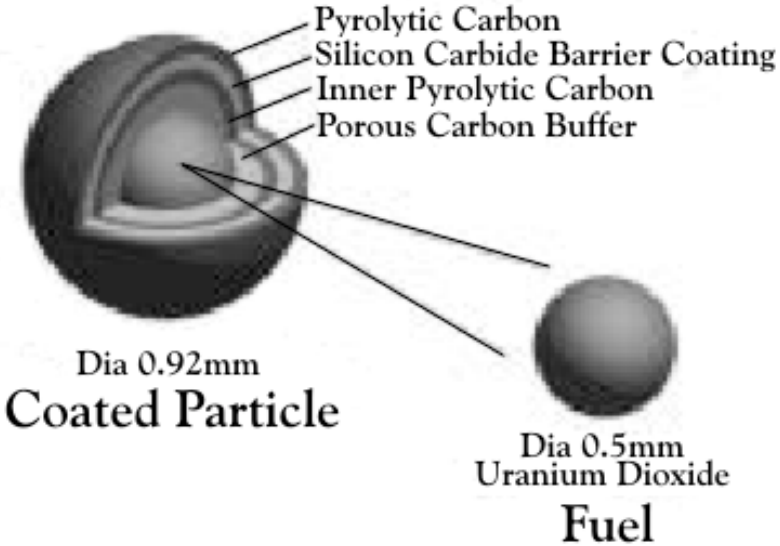
Nuclear power reactor fuel options



Uranium oxide fuel pellet

Image: Nuclear Regulatory Council

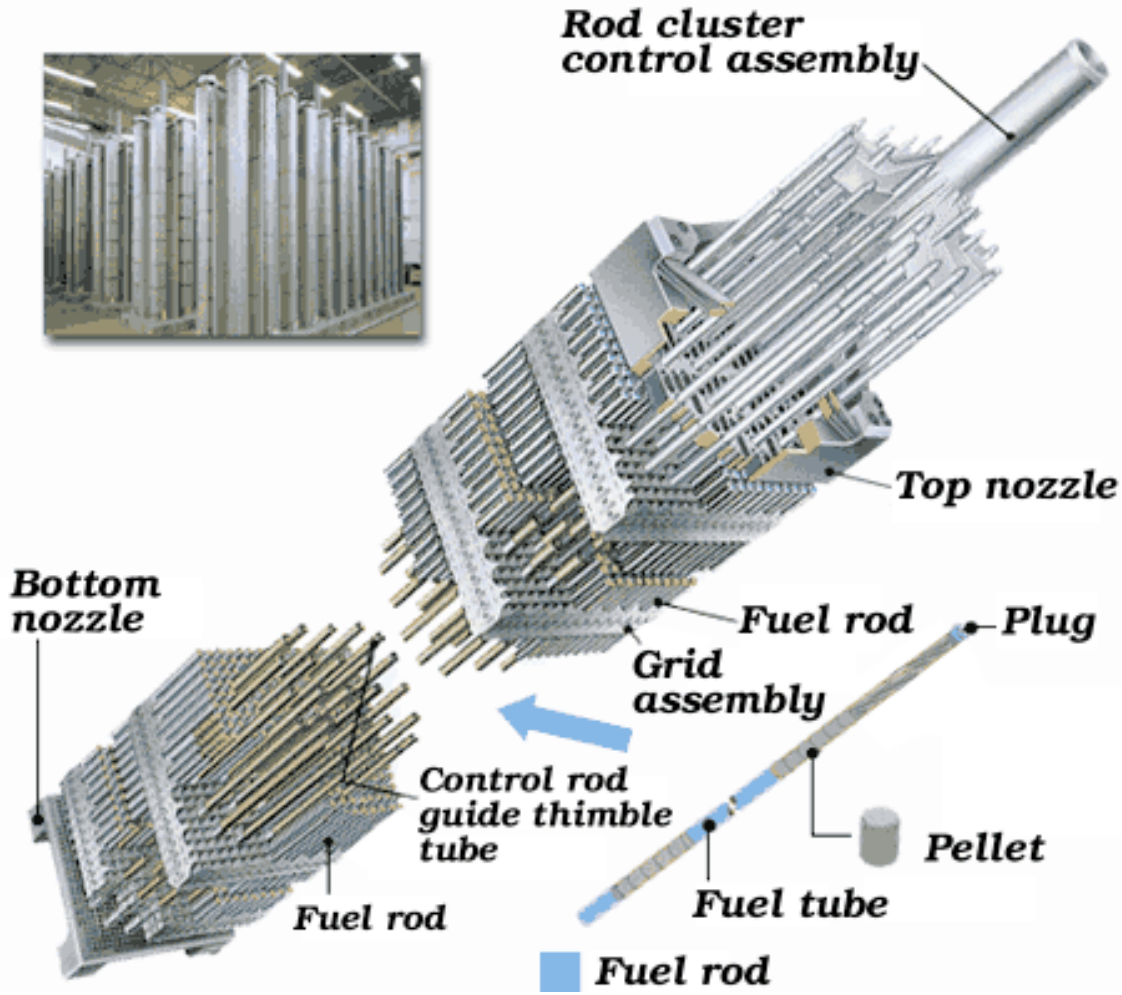




Uranium oxide "TRISO" micro fuel pebble

Image: top, US DOE, Office of Nuclear Energy, Sci. and Tech.
Bottom: ars technica openforum.

Nuclear fuel pellets must have cladding, be separable

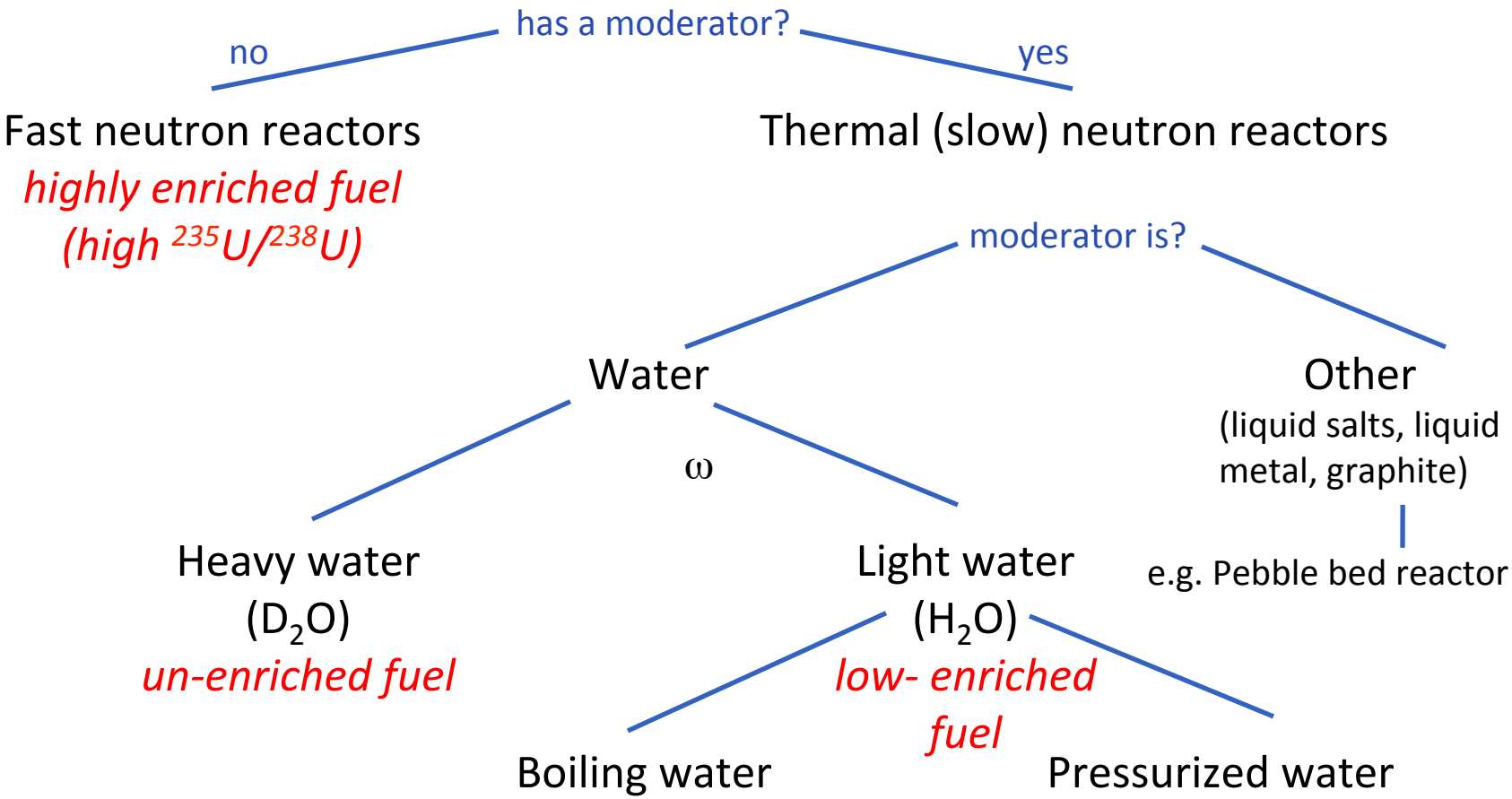


Uranium oxide pellets in fuel rod assembly
(4 m long rods, zirc. clad? for PWR reactor)
Image: Mitsubishi Nuclear Fuel Inc.

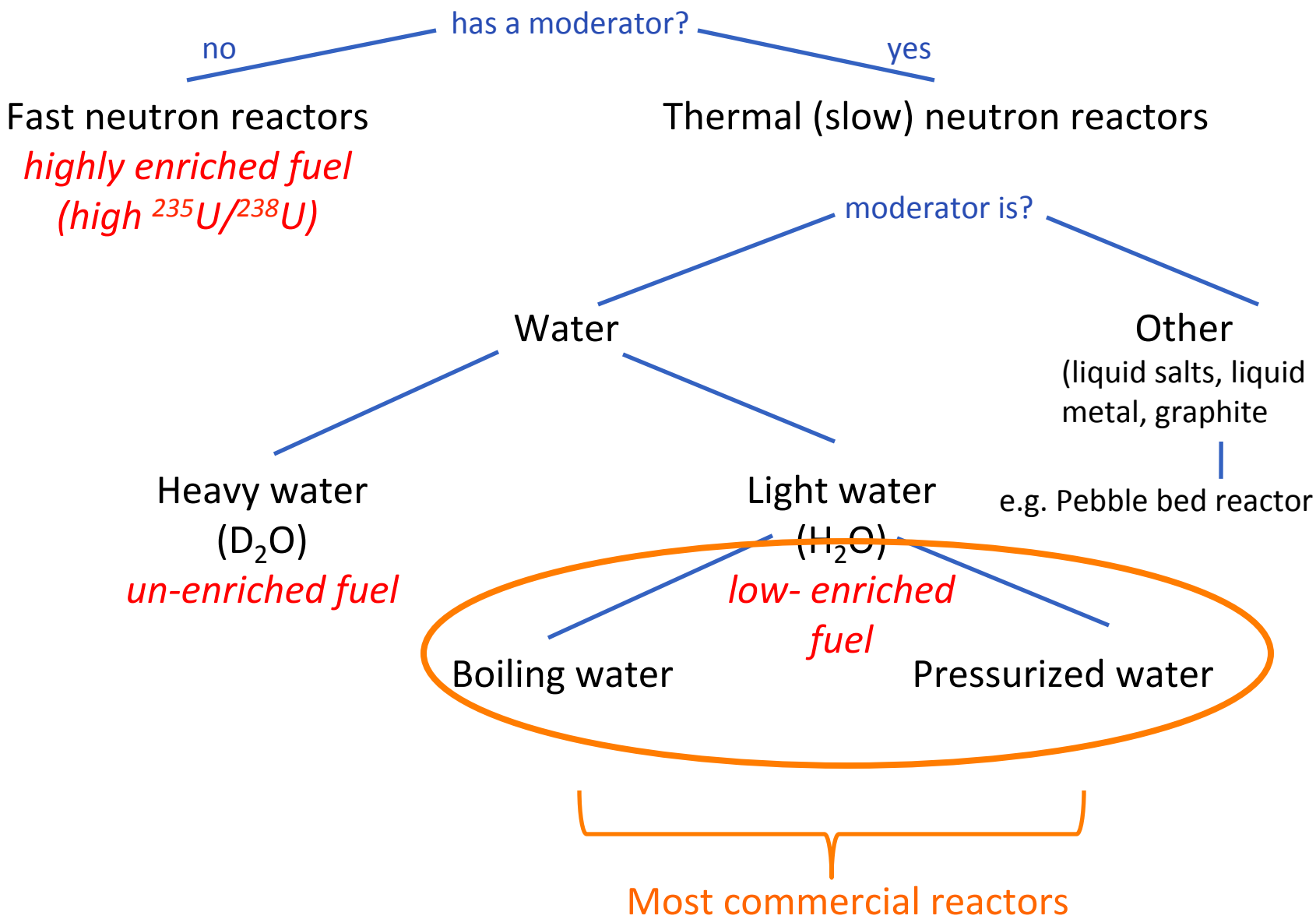
CANDU (CANada Deuterium Uranium) fuel rods, un-enriched uranium oxide pellets in ½ m zirconium tubes.

Image: Atomic Energy of Canada

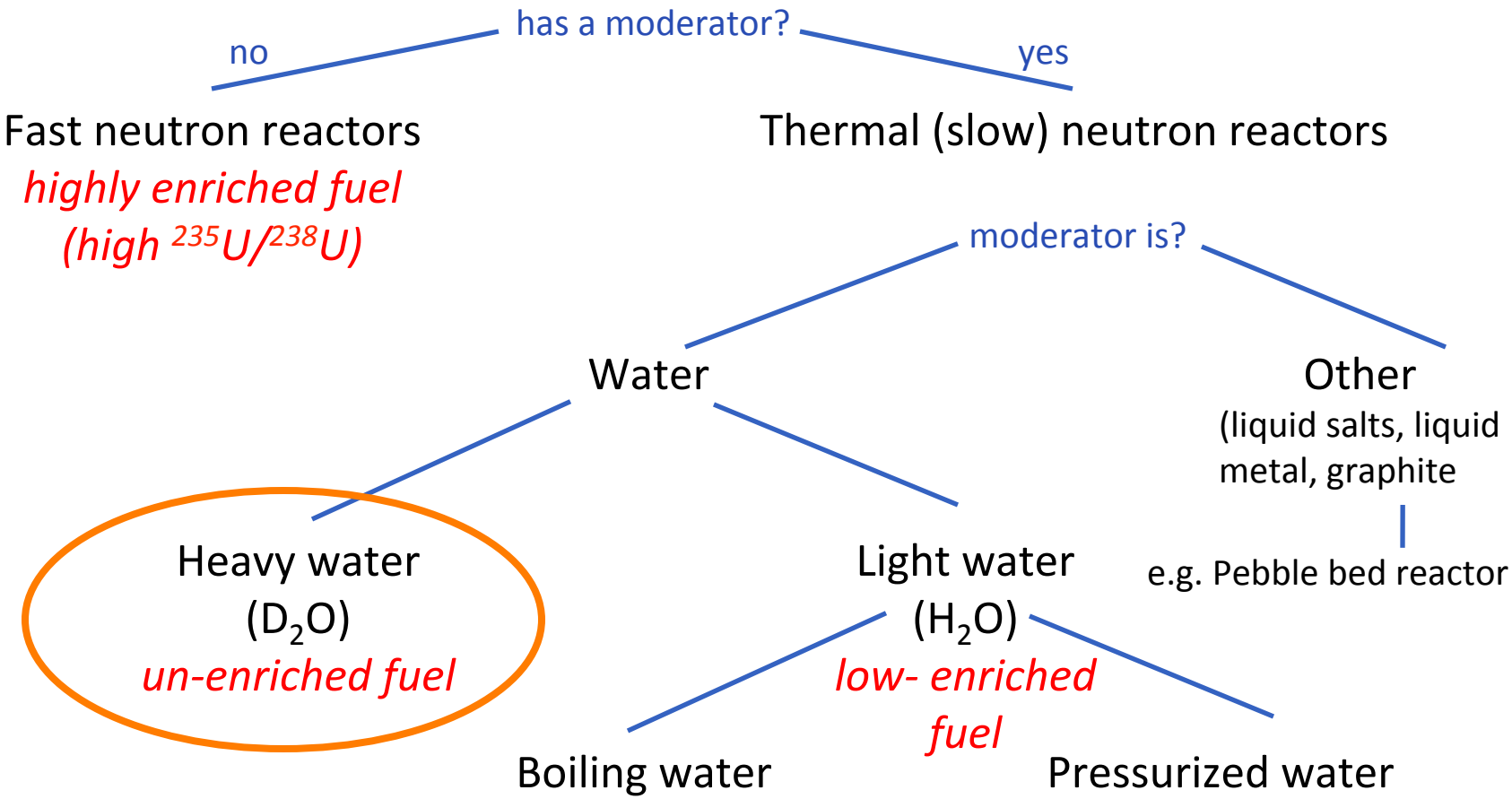
Nuclear power reactor characterization



Nuclear power reactor characterization

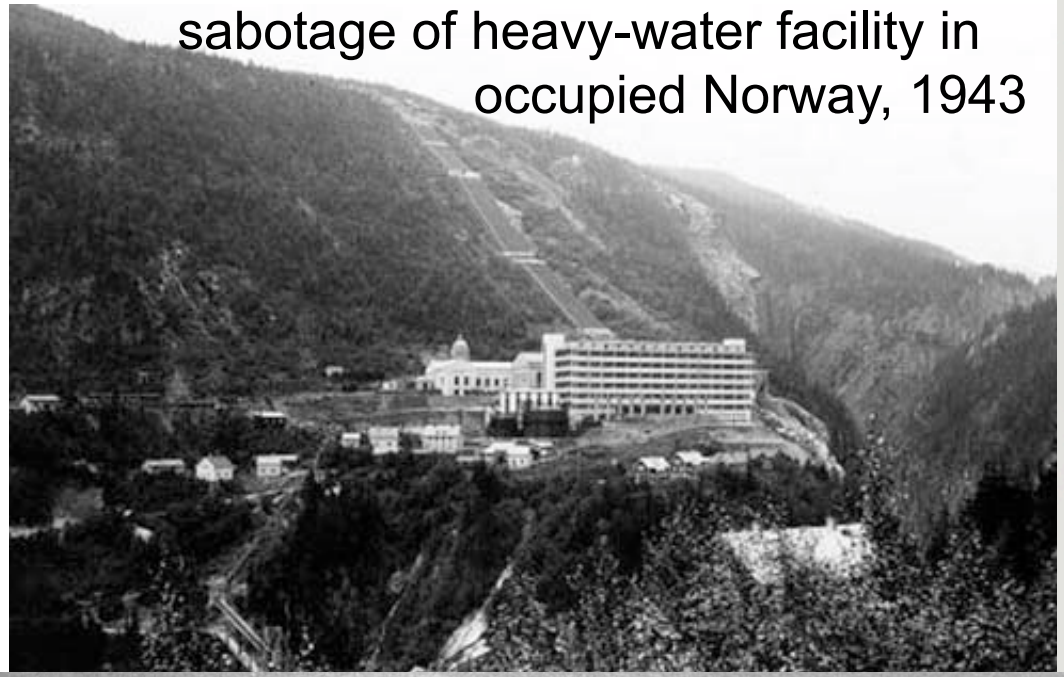


Nuclear power reactor characterization



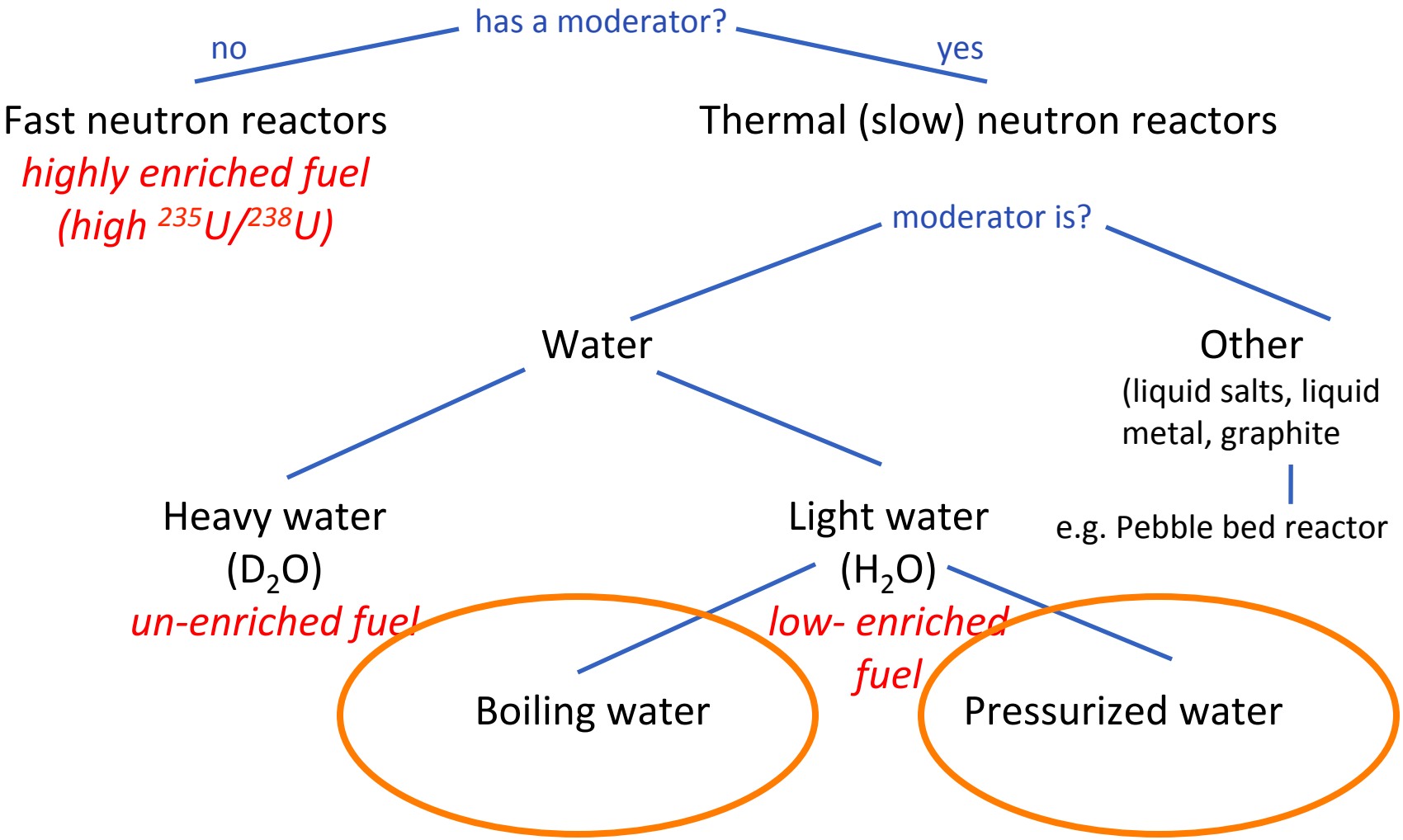
Heavy water is a great moderator, so critical for nuclear fission without enriched U

Important to development of bomb, hence sabotage of heavy-water facility in occupied Norway, 1943



Images: copyright unknown

Nuclear power reactor characterization



Pressurized-water reactor turbine water separate from fuel

3 separate water loops (reactor, turbine, and cooling water)

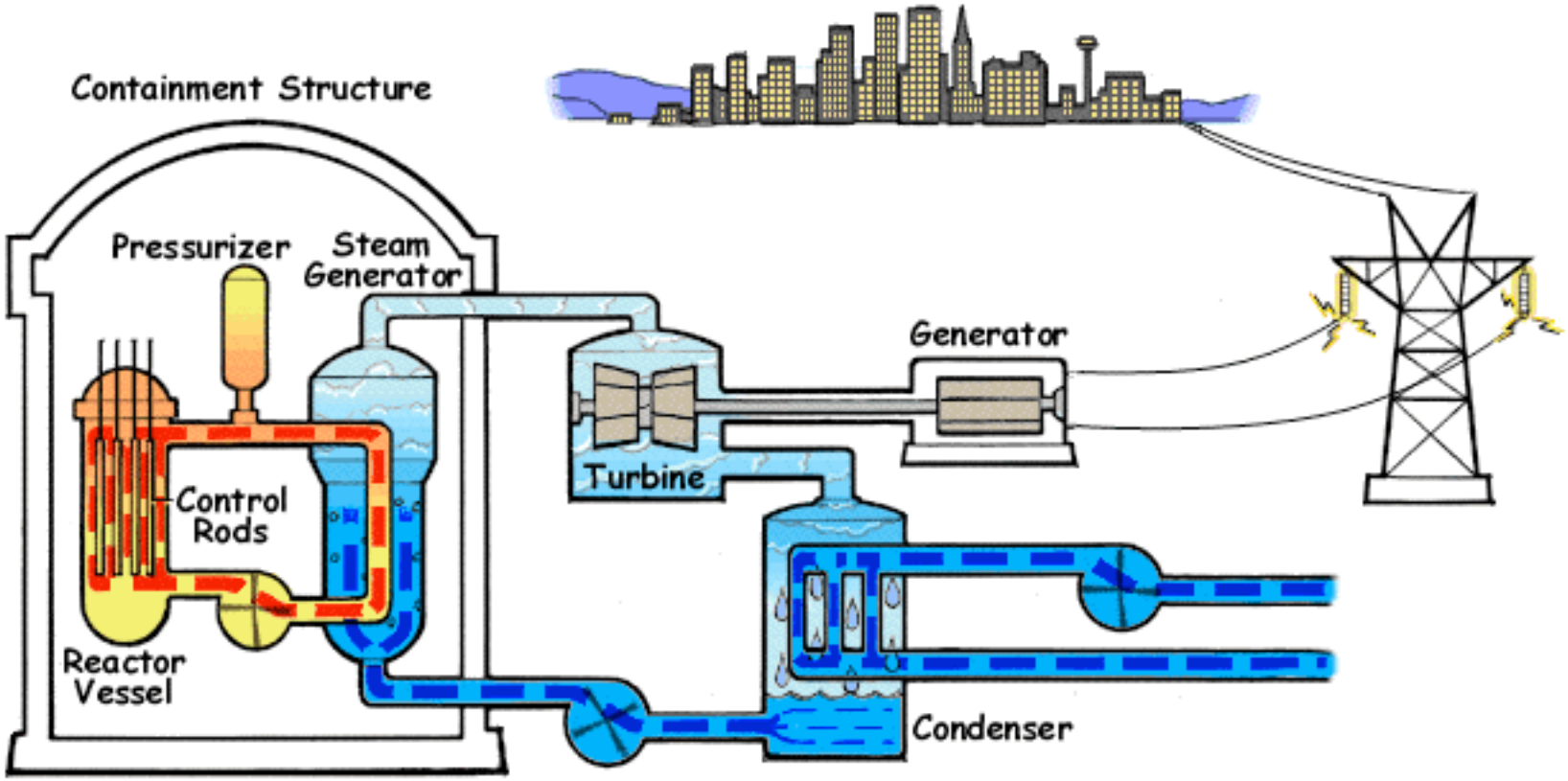


Image:Wikimedia commons

Boiling-water reactor turbine water touches fuel

2 separate water loops (reactor + turbine, cooling water)

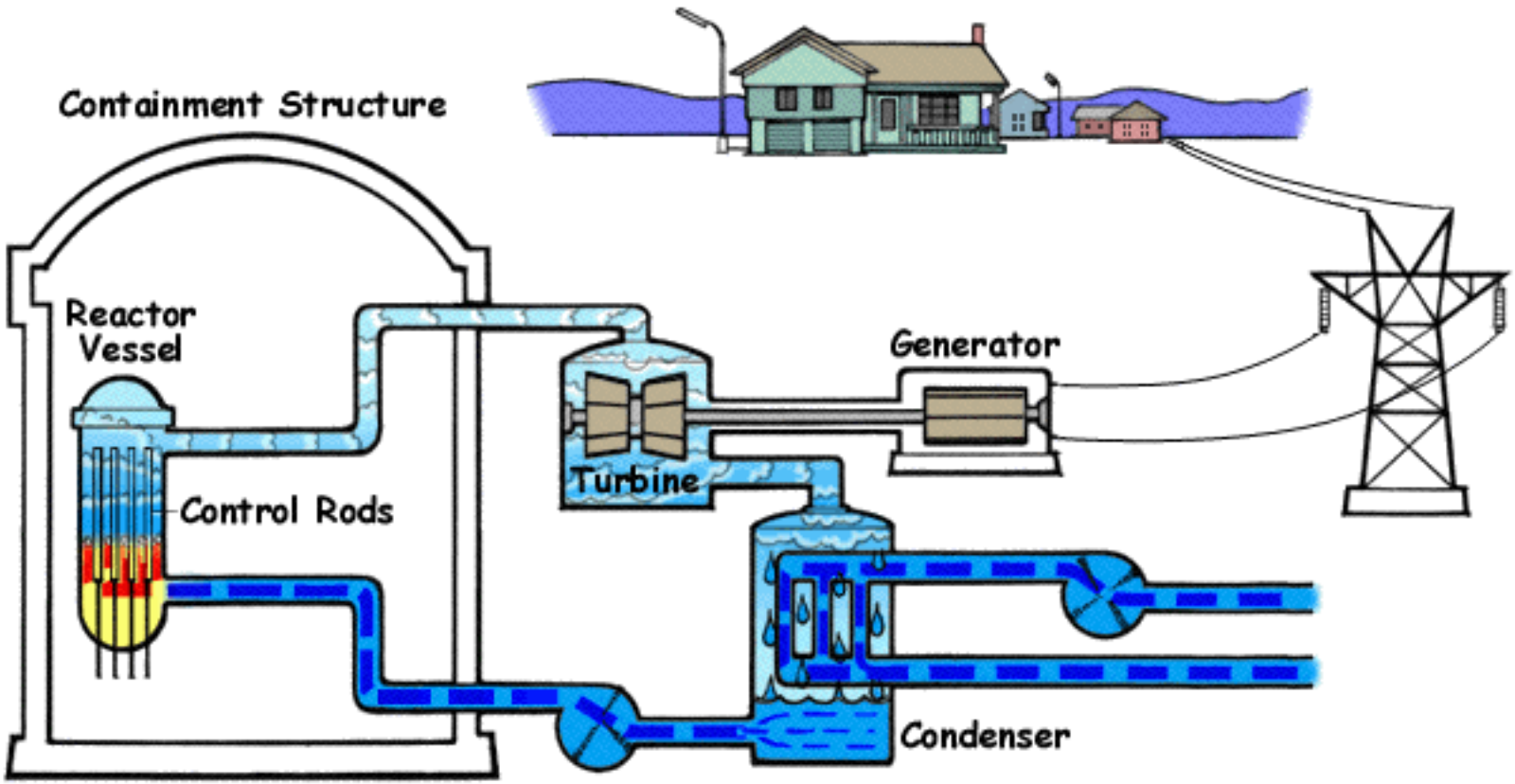
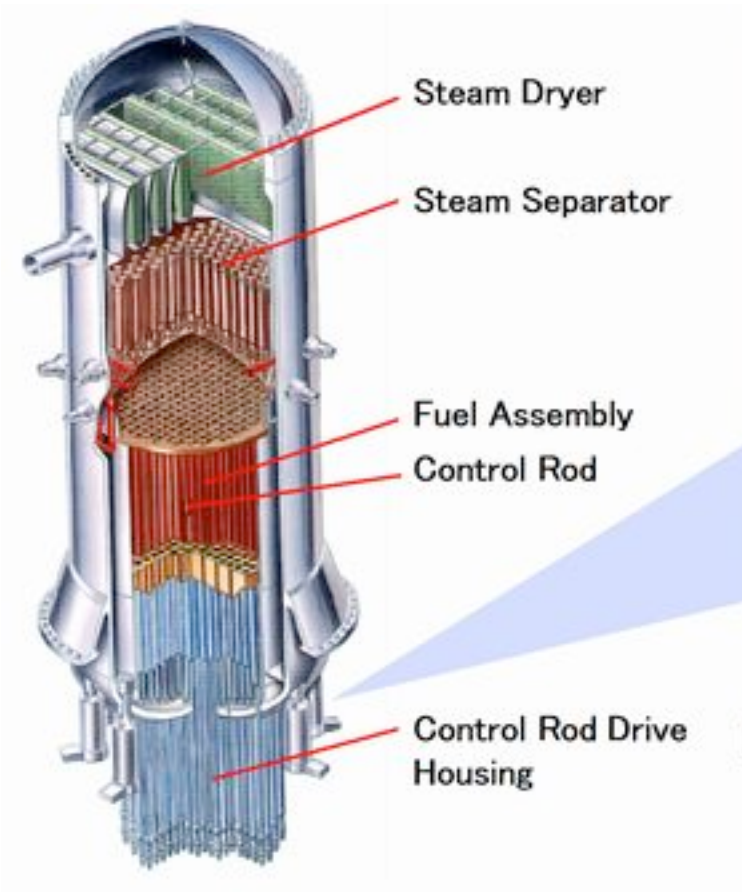


Image: Wikimedia commons

Boiling-water reactor turbine water touches fuel

Simple to build, a bit uncomfortable as a concept



Basically a BWR is a big hot pot

Images: L. source unknown,
R. dreamtime.com

Who uses boiling-water reactors?

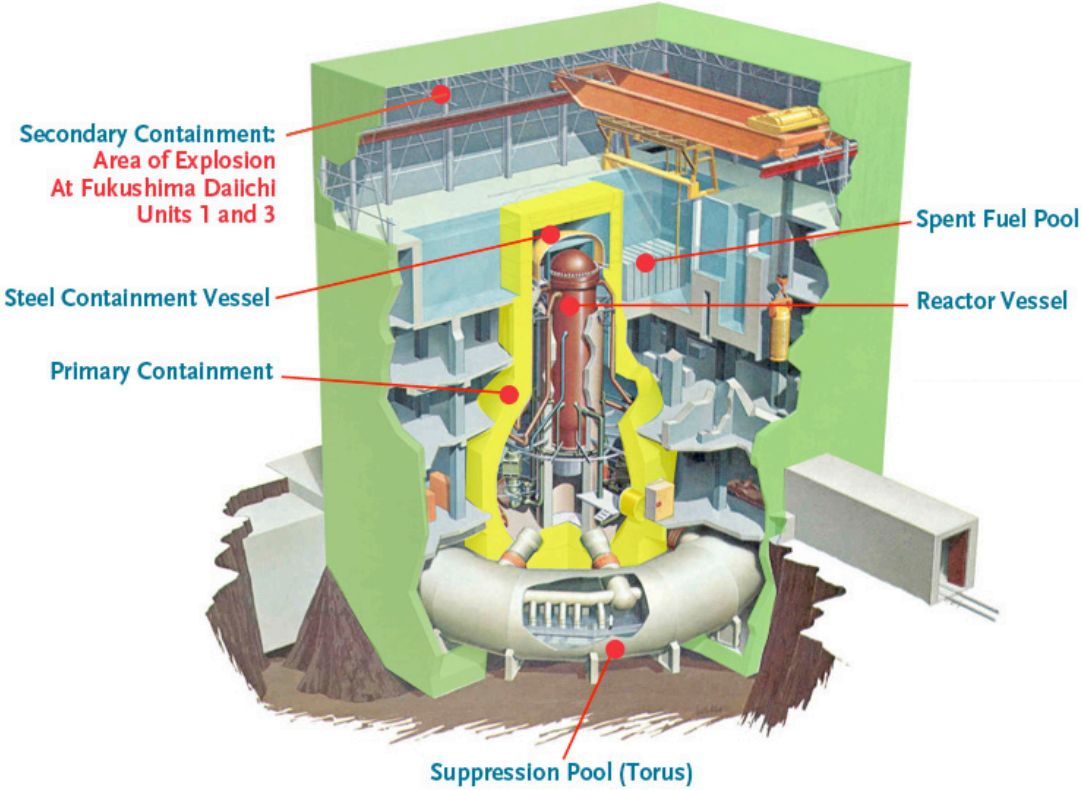
Dresden power station
(Exelon)
1970 GE Mark I BWR

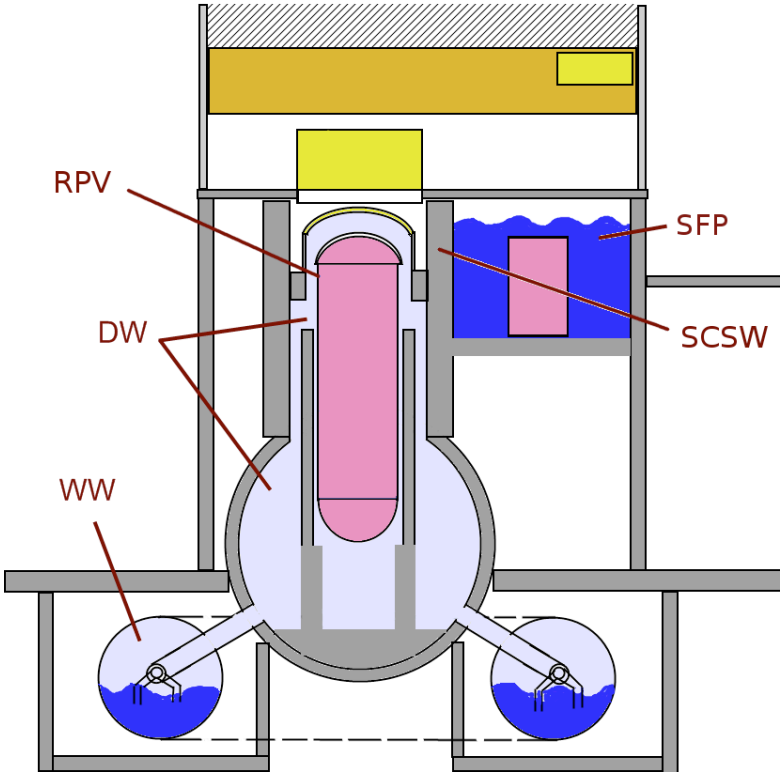
Fukushima power station
(Tokyo Elect. Power)
Units 1, 2, 6
1971 GE Mark I BWRs

Images: Top, Nuclear Power Industry news. Bottom, Reuters

Boiling-water reactor turbine water touches fuel

Worse if you don't build it very well: the GE Mark I reactor





Torus is for …..

GE Mark I Boiling-water reactor

Images: General Electric (annotation by others)

Spent nuclear fuel still very radioactive

Use only small fraction of ^{238}U, 2/3 of ^{235}U, fission products still "hotter"

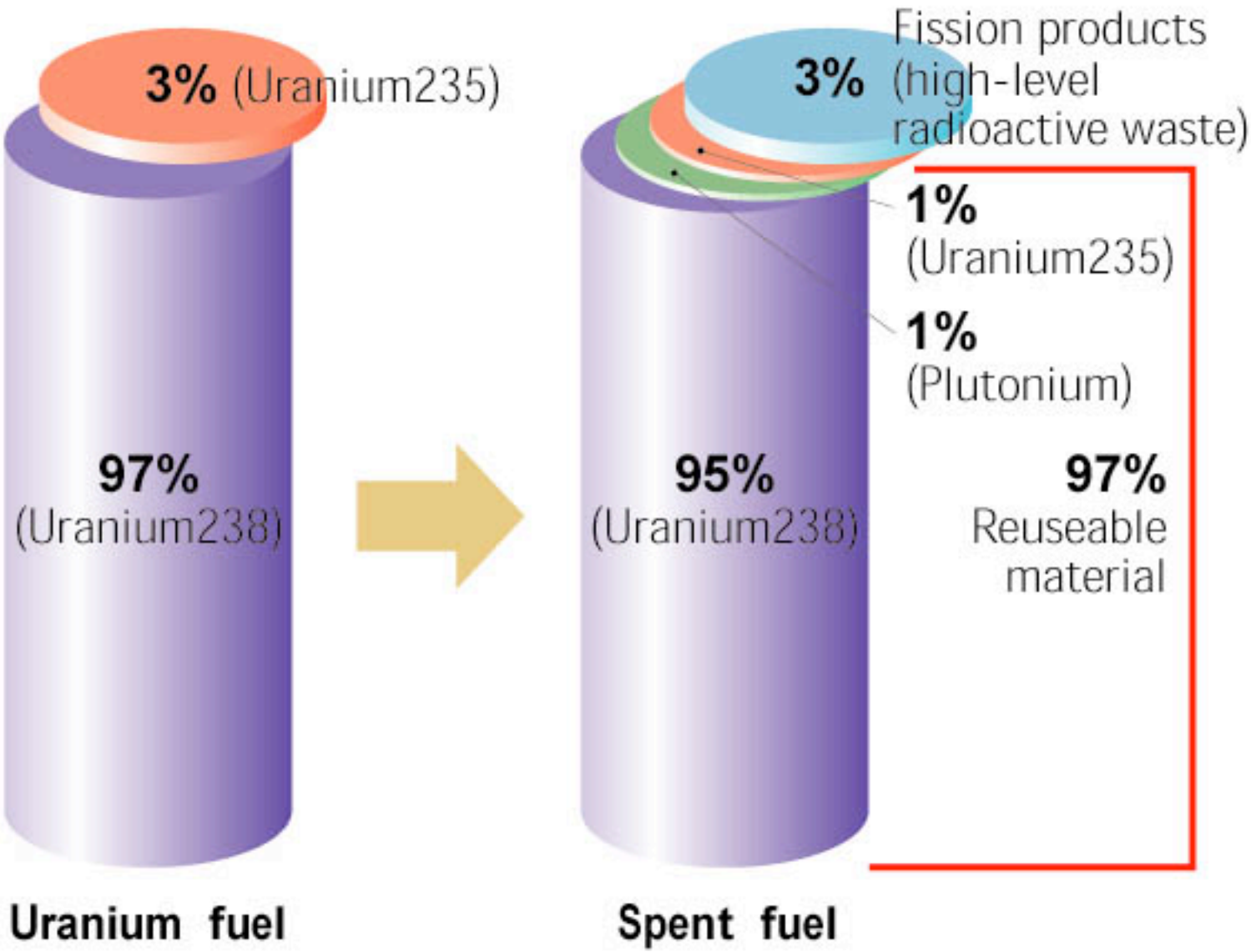


Image: Cool Hand Nuke

Spent nuclear fuel variety of half-lives in fission products

Short = dangerous immediately; long = radioactive for millenia

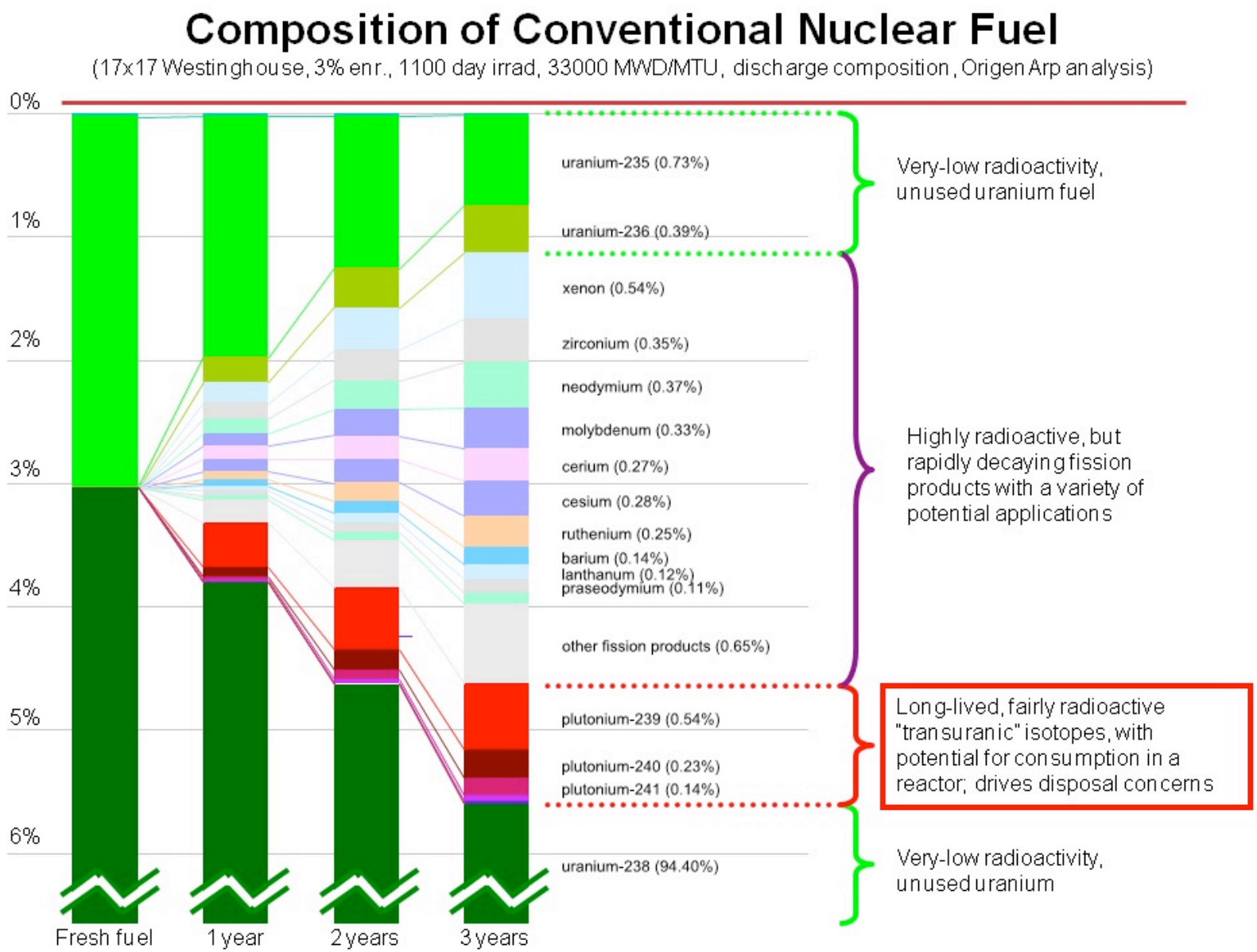


Image: Source unknown

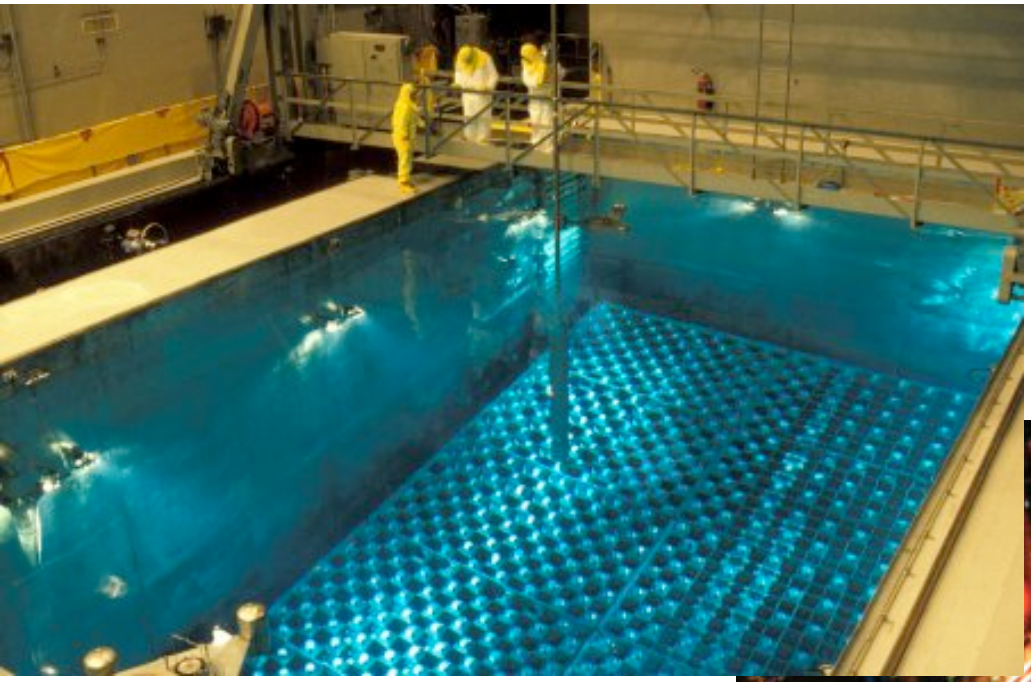
Re-use: can reprocess spent fuel in a breeder reactor

Why waste all that good radioactive stuff? Remember the reactors whose only purpose is transmutation, turning one element into another – a **"breeder" reactor**. Can use breeders to **reprocess** spent nuclear fuel and boost fissionable content until the fuel can once again support a chain reaction in a power reactor.

But… the fuel you're left contains dangerous plutonium. Reactor meltdowns are worse if using reprocessed fuel. This reprocessed fuel that has more-than-just-uranium is commonly called **"MOX"** (for "mixed oxide" fuel).

Spent nuclear fuel storage fuel pools are default strategy

No long-term national strategy for disposal, so keep in pools on site



While we ponder the best long-term solution we're doing the worst possible practice…

Energy Northwest spent fuel pool

Image: Nuclear Fuel Reprocessing Coalition

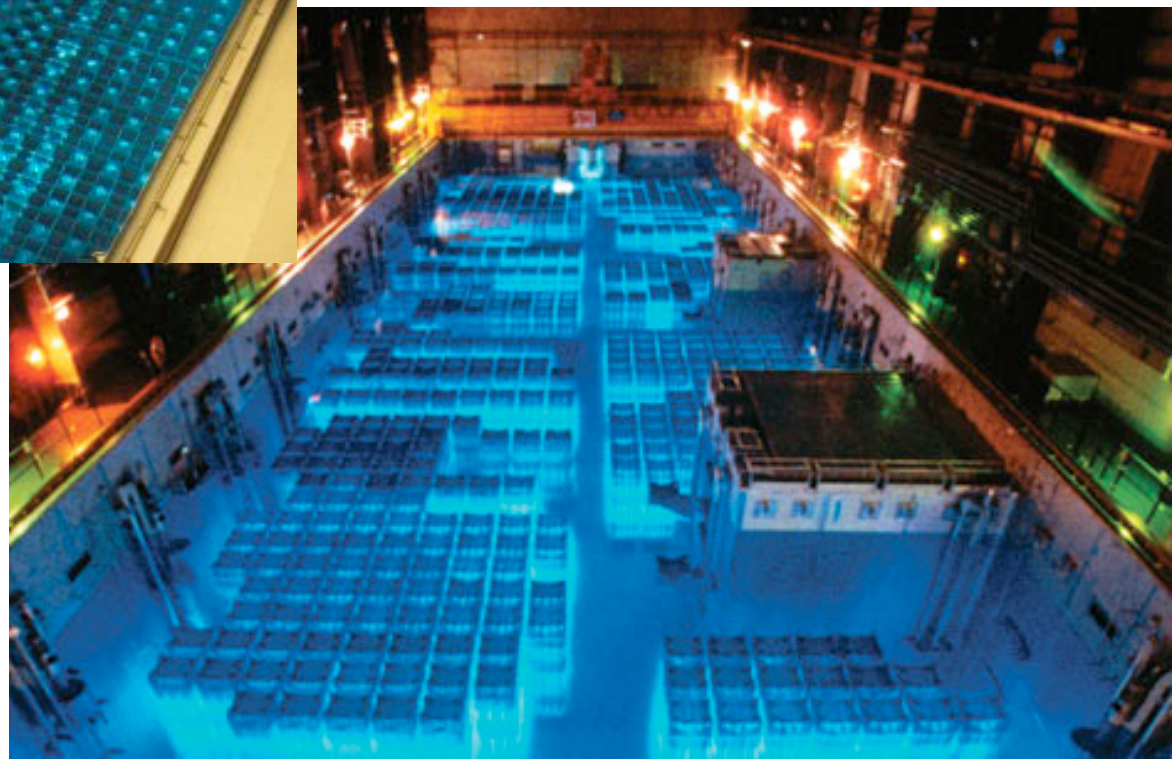


Image: source unknown