ACS, MSU Science Cafe

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Radiation, Radioactivity, What’s the Difference and How do they relate to Nuclear Power ?

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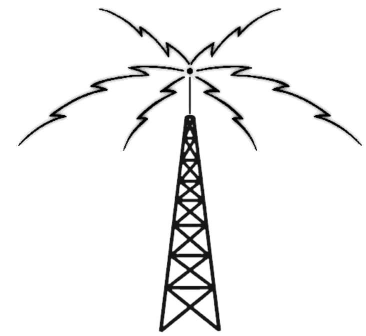
Much more detail in CEM 485, Spring/2o1o
http:/www.chemistry.msu.edu/courses/CEM485/Index.html

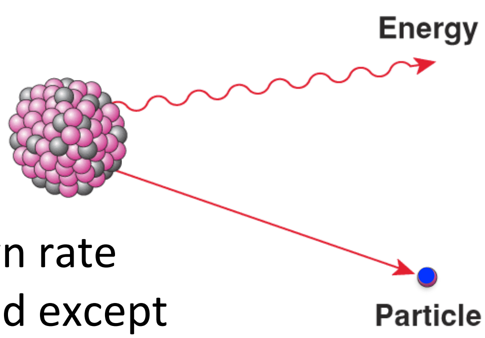
What's in a word ?

Toast as compared to Toaster

Radio tower as compared to Radio Wave

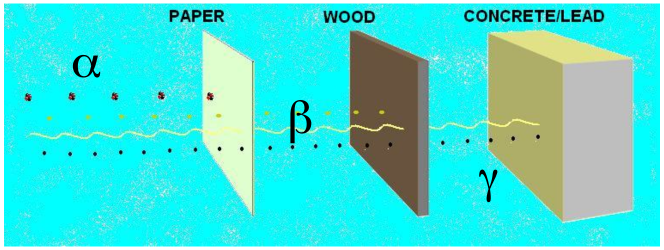


Radioactivity as compared to Radiation ?



Radioactive nucleus
- Will decay at its own rate
- It can't be destroyed except by a nuclear reaction

Radiation
- Generally emitted at one time
- Moves in a straight line, at or near the speed of light
- Can be absorbed, depending on flavor



Part 1 – Power & Reactors

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Nuclear Power, Nuclear Reactors

-- Background

--- Basics of Energy (or Power) Flow

--- Power in Michigan

--- Power in Japan

--- Reactor types

-- Nuclear Fission process

--- fissile nuclei

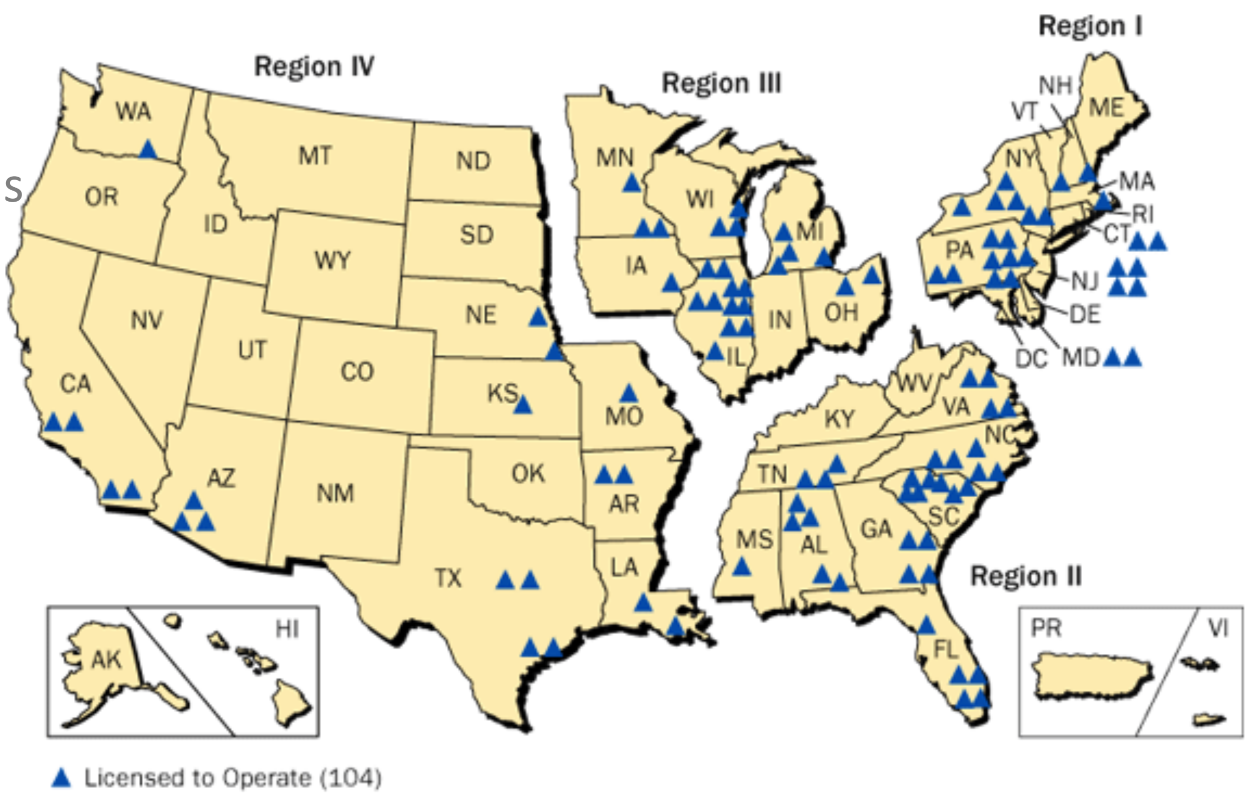
--- fission fragments

-- Nuclear Fission Operations

--- spent fuel

--- reactors in France

http://www.nrc.gov/info-finder/reactor/



US Total Energy Flow

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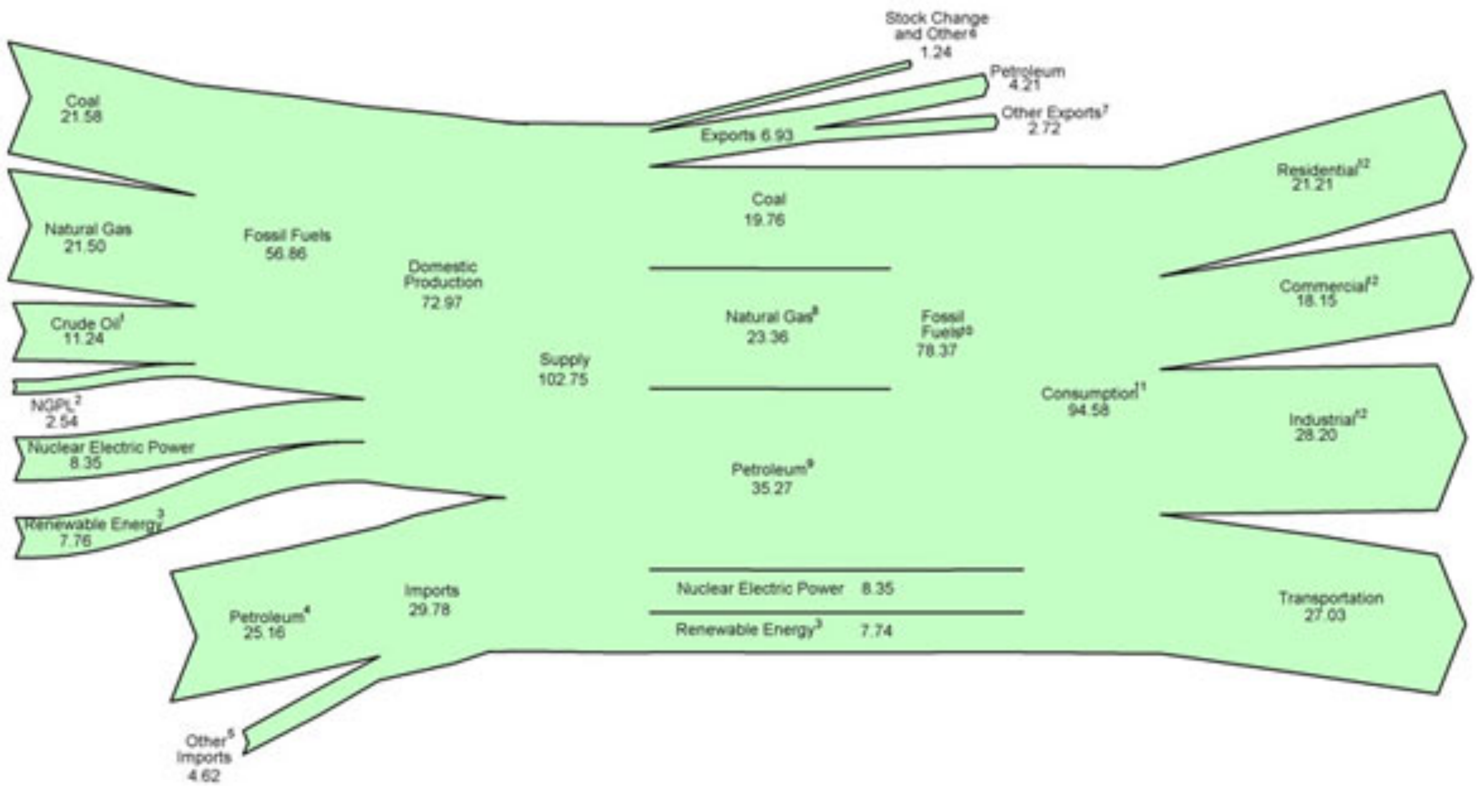


Q: What's a Quad in SI units?

US Energy Consumption 2oo9, 94.6 Quads

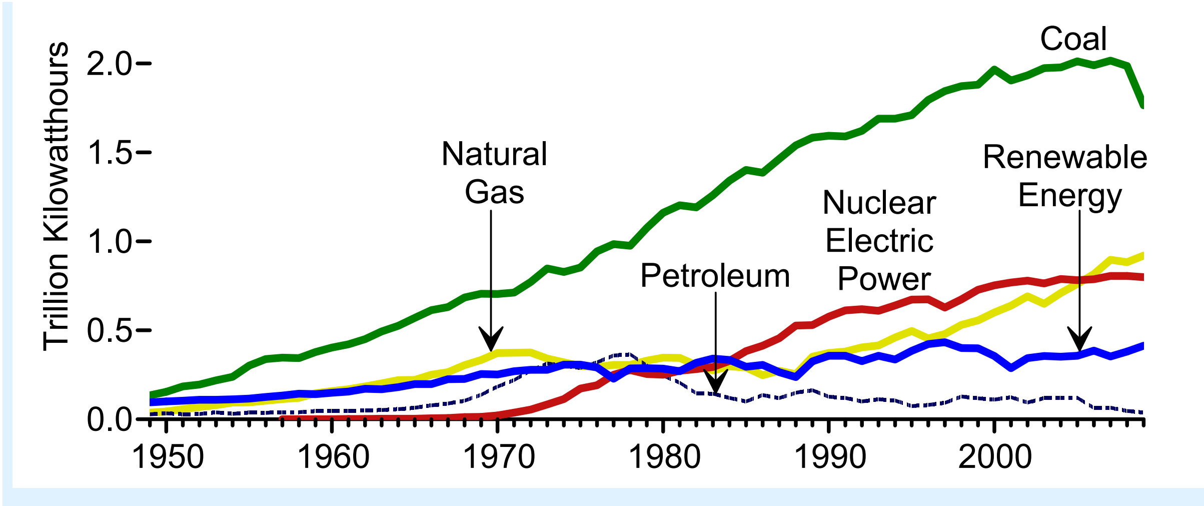
1 Quad = 1 Quadtrillion BTU
10^{15} BTU * 1055. J/BTU ~ 1×10^{18} J
(BTU = ΔE for 1 lb of water, 1^{o} F)

http://www.eia.doe.gov/totalenergy/data/annual/diagram1.cfm

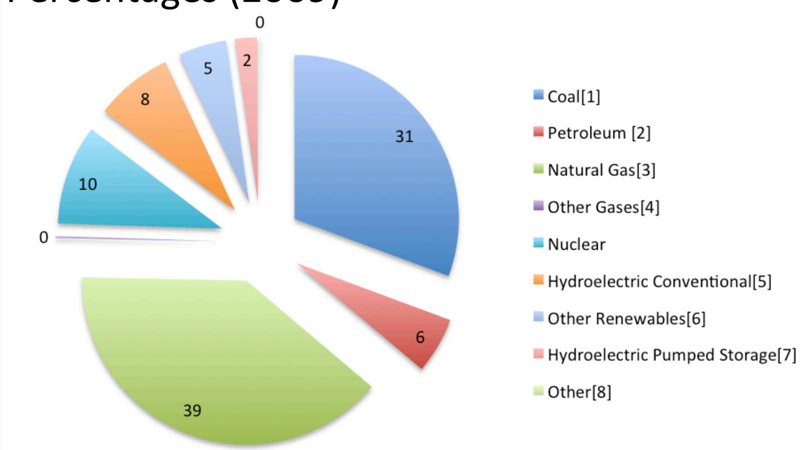
Power = 94.6 $\times10^{15}$ BTU / 305. $\times10^{6}$ people = 310 $\times10^{6}$ BTU/person
(note that the US is only 5% of world population)

Electrical Power in US & MI

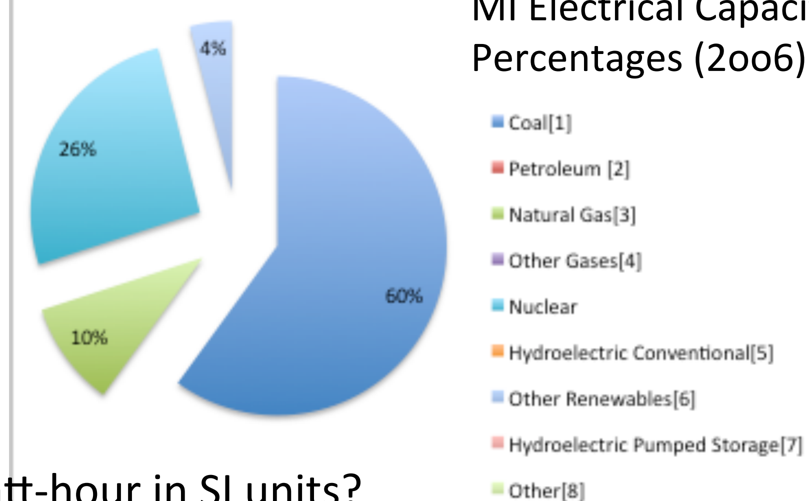
U.S. Energy Information Administration / Annual Energy Review 2009



US Electrical Capacity Percentages (2oo9)



MI Electrical Capacity Percentages (2oo6)



Q: What's a kilowatt-hour in SI units?

$$1kW\ hr = 10^3 W\ hr * \frac{J/s}{W} * 3600 \frac{s}{hr}$$

$$1kW\ hr = 3.6x10^6 J \approx 4\,MJ$$

Electrical Power in Japan

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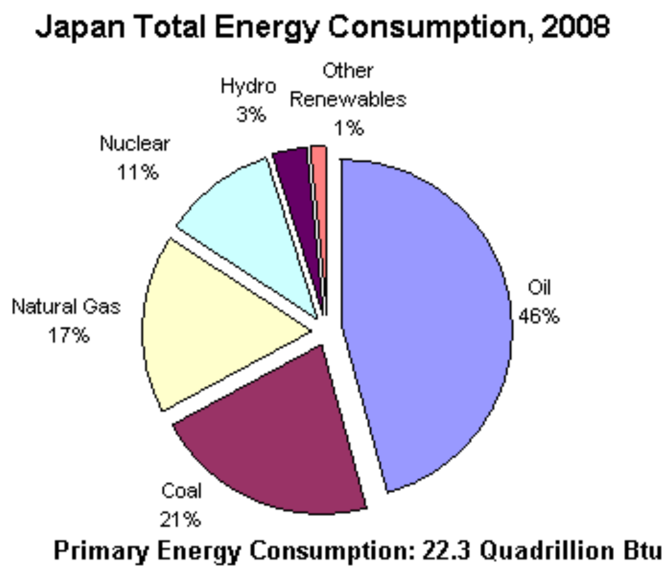
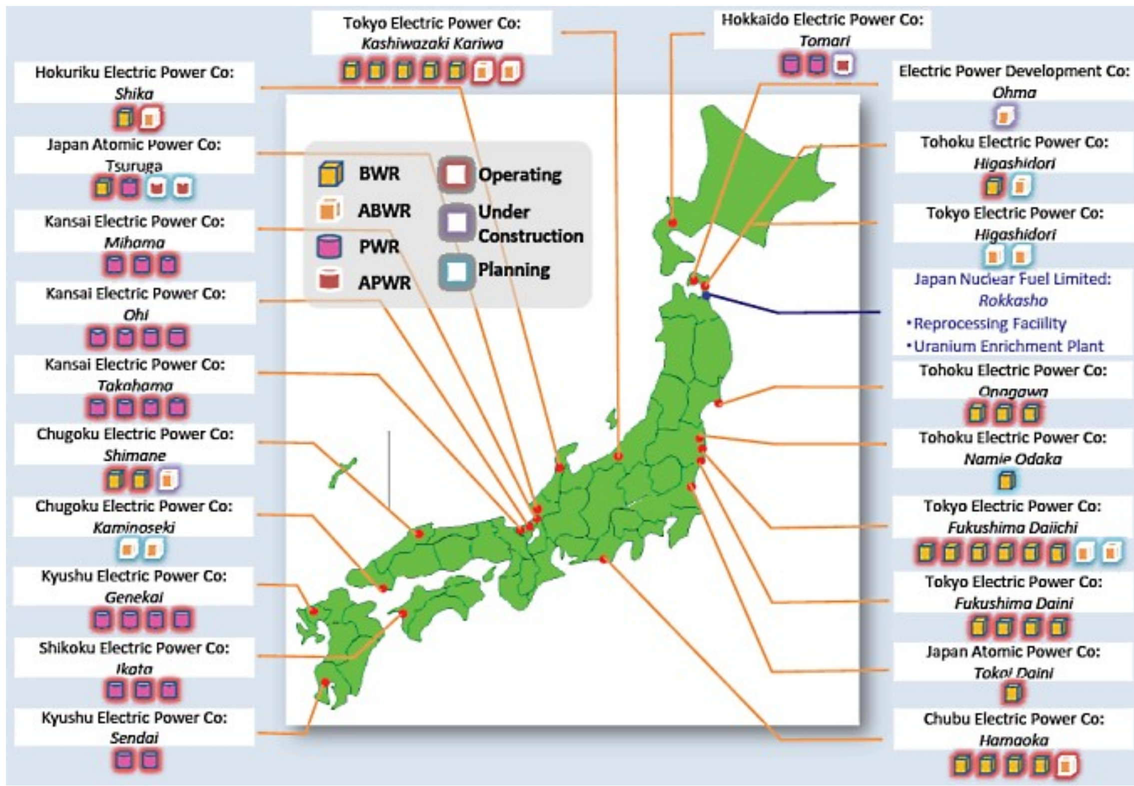
- Japan is only ~16% energy self-sufficient … 176 Million BTU/person
- The country's 50 main reactors provide some 30% of the country's electricity and this was expected to increase to at least 40% by 2017 with 2 more under construction.
- The destruction of Fukushima Units 1 to 4 will remove ~6% of capacity
- Japan has a full fuel cycle set-up, including enrichment and reprocessing of used fuel for recycle.



Source: EIA
http://www.eia.doe.gov/cabs/Japan/Full.html



http://www.world-nuclear.org/info/inf40.html

Michigan Nuclear Power Plants

Two D.C.Cook Power plants in Benton Harbor are pressurized water reactors, with
1,048 net megawatt-electrical (MWe) Unit 1
1,107 net MWe Unit 2

N.B. MW-thermal is not MW-electrical

Fermi 2 plant in Monroe, is a boiling water reactor with 1122 net MWe

Palisades plant in South Haven, is a pressurized water reactor with 778 net MWe

Pressurized Water Reactor (PWR)

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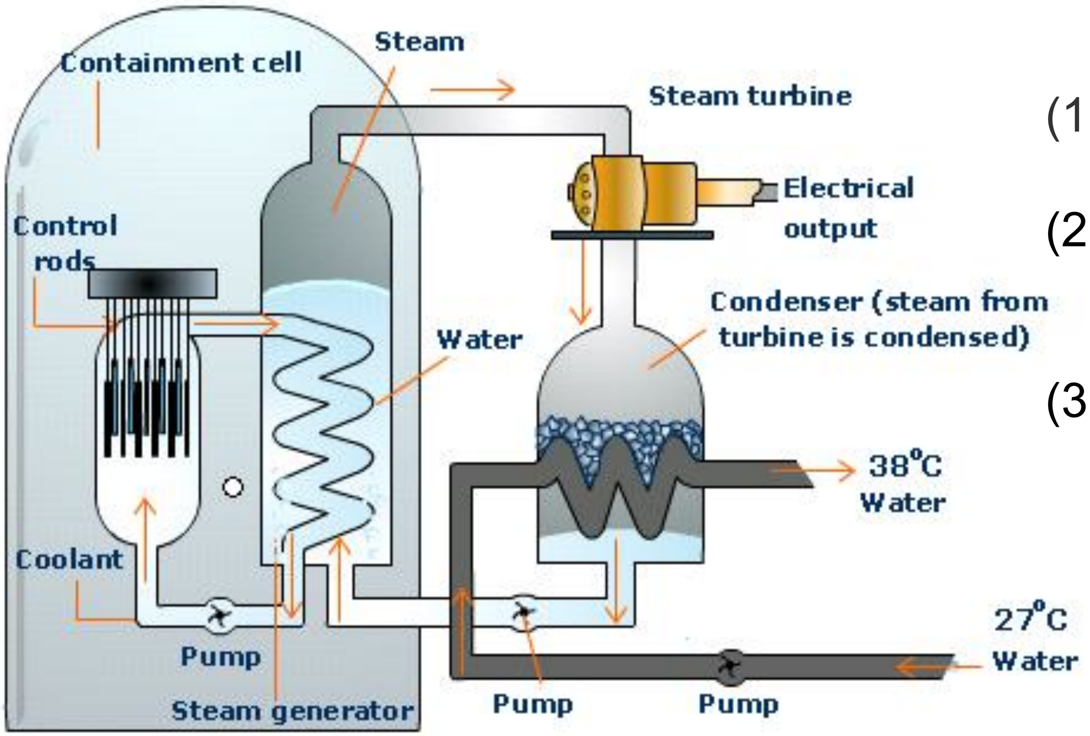


(1) the reactor core creates heat from nuclear fission

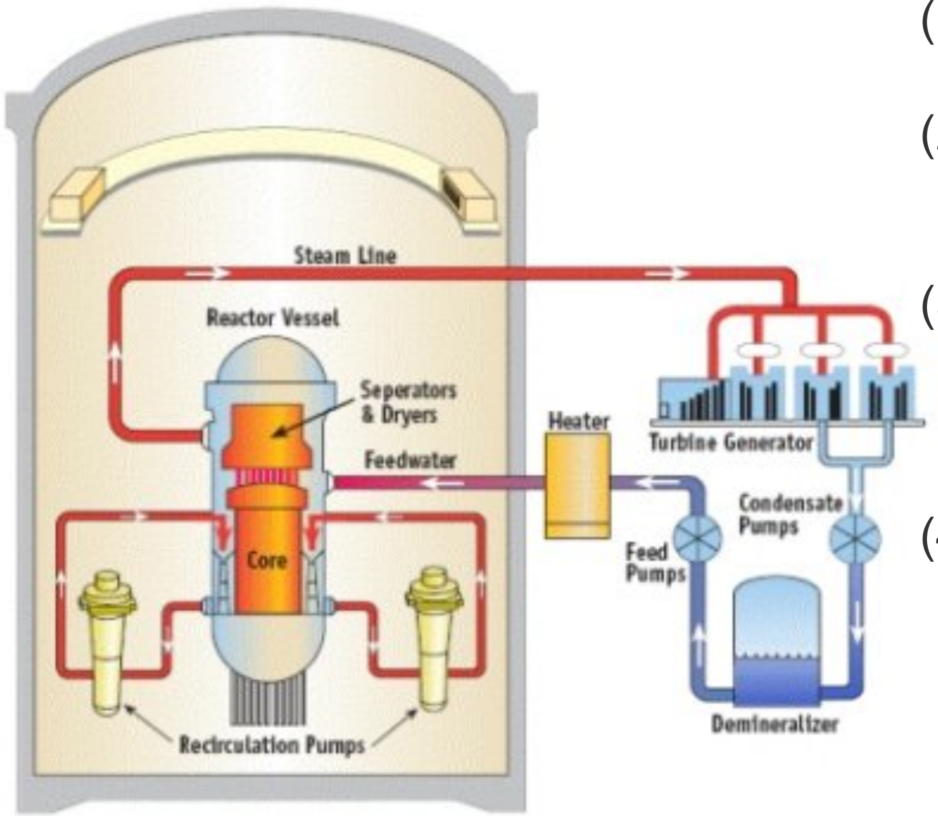
(2) pressurized-water in the primary coolant loop carries the heat to a steam generator

(3) the steam generator uses the heat from the primary coolant loop to vaporize water in a secondary loop producing steam

(4) The steam turns the main turbine and generator, which produces electricity. The "used" steam is exhausted to the condenser where it is condensed into liquid water. The resulting water is pumped out of the condenser, reheated, and sent back to the steam generator (another loop).

(5) The reactor's core contains fuel assemblies which are cooled by liquid water under high pressure (~1ooo psi), which is force-circulated by electrically powered pumps. Not shown: Emergency cooling water is supplied by other pumps which can be powered by onsite diesel generators.

Boiling Water Reactor (BWR)



(1) the reactor core creates heat from nuclear fission

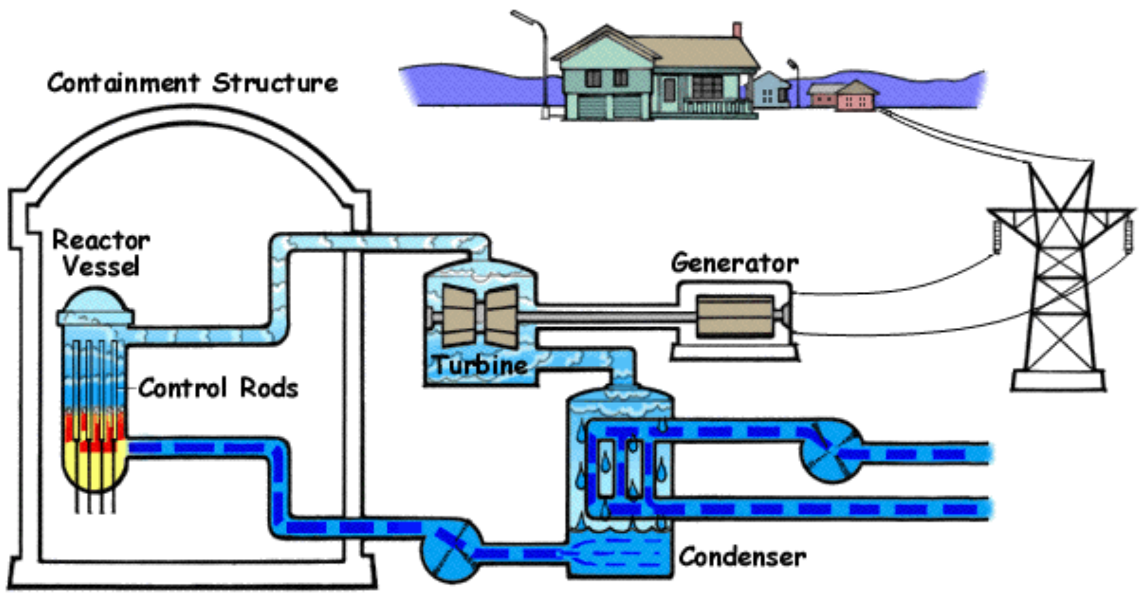
(2) all the water is in one common loop. A steam-water mixture is produced when water moves through the hot core

(3) the steam-water mixture leaves the top of the core and enters the two stages of moisture separation where water droplets are removed,

(4) the steam line directs the steam to the main turbine causing it to turn the turbine generator, which produces electricity. The "used" steam is exhausted to the condenser where it is condensed into liquid water.

(5) The reactor's core contains fuel assemblies which are cooled by liquid water, which is also force-circulated by electrically powered pumps. Not shown: Emergency cooling water is supplied by other pumps which can be powered by onsite diesel generators.

Overall Schematics



BWR

Nuclear Regulatory Commission Graphics

Part 2 – Fission Process

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Nuclear Power, Nuclear Reactors

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--- spent fuel

--- reactors in France

Isotopes & Fissile Nuclei

All chemical elements have a range of isotopes, i.e. a variable number of neutrons (mass) for a fixed number of protons.

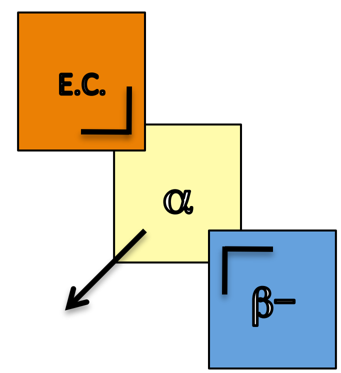
Of all of the possible nuclei, only three undergo fission after low energy neutron capture that can be obtained in quantity, and are called ‘fissile’ nuclei.

^{235}U … natural

^{239}Pu … make from ^{238}U

^{233}U … make from ^{232}Th

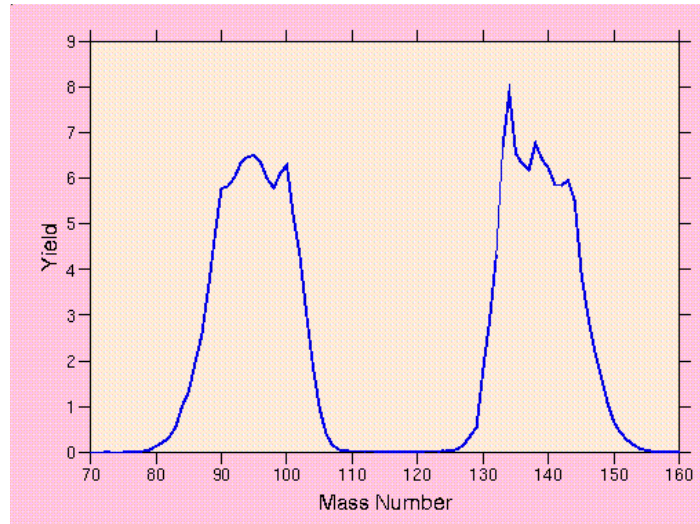
										246 Bk 1.8 d	247 Bk 1.7 ky	248 Bk 9 y	249 Bk 330 d	
						241 Cm 33 d	242 Cm 163 d	243 Cm 30 y	244 Cm 18 y	245 Cm 8.5 ky	246 Cm 4.7 ky	247 Cm 16 My	248 Cm 0.3 My	249 Cm 64 m
						240 Am 51 h	241 Am 433 y	242 Am 16 h	243 Am 7.4 ky	244 Am 10 h	245 Am 2 h			
				237 Pu 45 d	238 Pu 88 y	239 Pu 24 ky	240 Pu 6.5 ky	241 Pu 14 y	242 Pu 374 ky	243 Pu 5 h				
			235 Np 396 d	236 Np 154 ky	237 Np 23 My	238 Np 2.1 d	239 Np 2.4 d	240 Np 1.1 h	241 Np 14 m					
231 U 4 d	232 U 69 y	233 U 159 ky	234 U 159 ky	235 U 704 My	236 U 23 My	237 U 6.7 d	238 U 4.5 Gy	239 U 23 m	240 U 14 hr					
230 Pa 17 d	231 Pa 33 ky	232 Pa 1.3 d	233 Pa 27 d	234 Pa 6 hr	235 Pa 24 m	236 Pa 9 m								
229 Th 7.5 ky	230 Th 75 ky	231 Th 26 hr	232 Th 14 Gy	233 Th 22 m	234 Th 24 d									

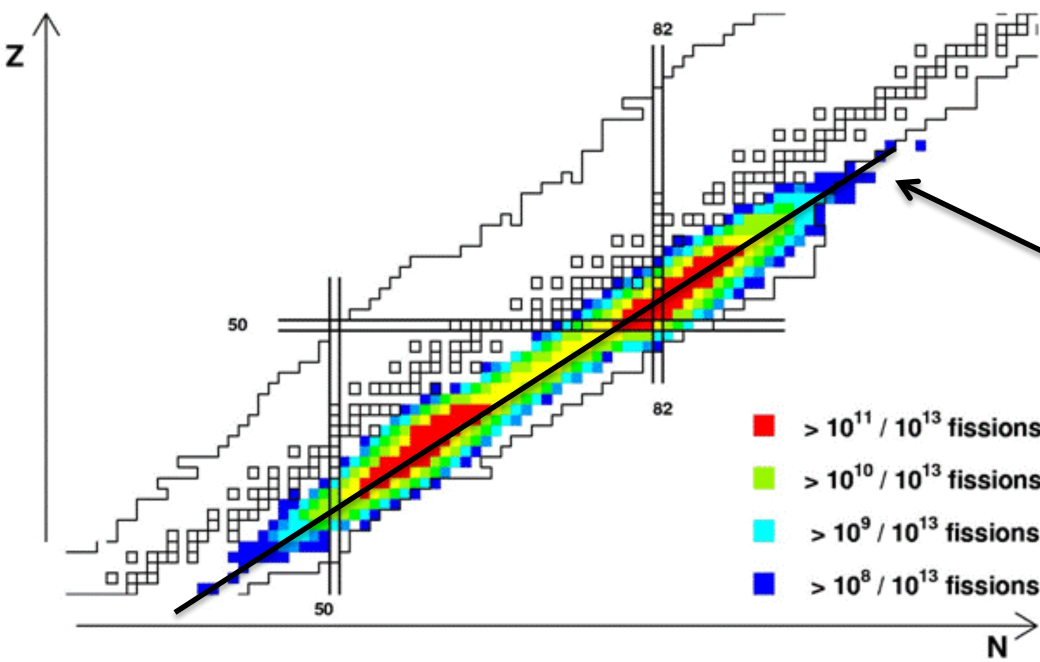


Mass and Charge of FF's

$^{1}n + ^{235}U \rightarrow (^{236}U_{144})^* \rightarrow {}^{Mass1}Z_1 + {}^{Mass2}Z_2 + {}^{1}n$'s

$Mass_1 = Mass_2 = 236/2$ – rare split
$Mass_1 \sim 140$, $Mass_2=(236-140)$ – common split





Unchanged Charge Ratio
Protons/Mass = 92/238

1 / 100
1 / 1000
1 / 10,000,
1 / 100,000,

FF and Radioactive Decay – Cesium

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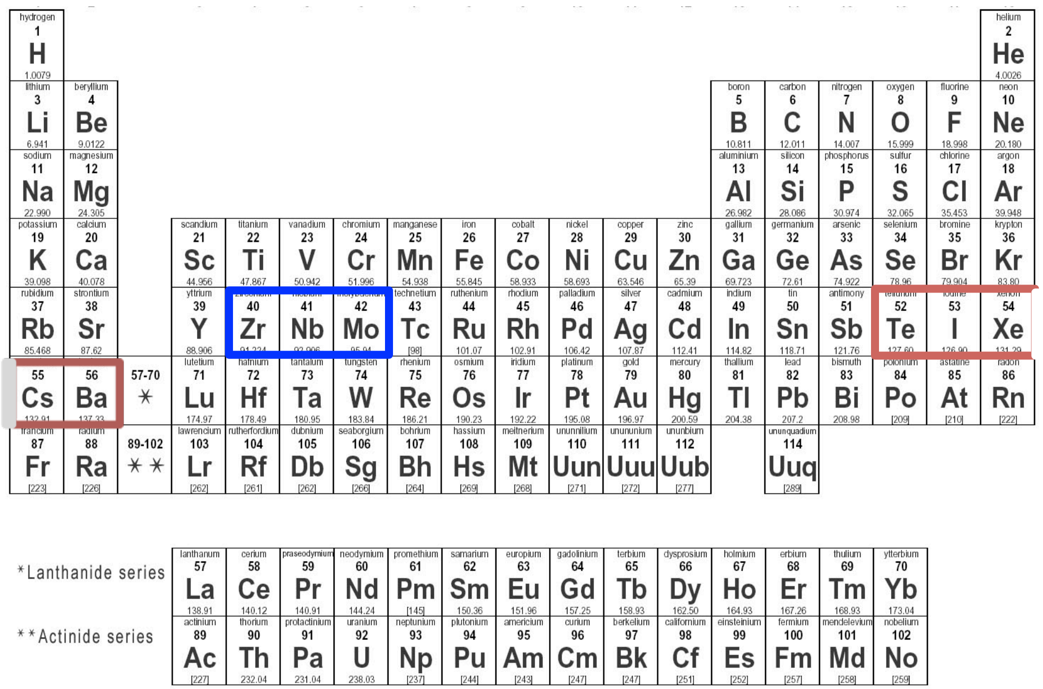
The Fission Fragments are produced with an excess of neutrons simply because the stable uranium nuclei have many more neutrons than protons …

$$^{1}n + {}^{235}U \rightarrow ({}^{236}U_{144})^* \rightarrow ({}^{Mass1}Z_1)^* + ({}^{Mass2}Z_2)^* + {}^{1}n's$$

$$Mass_1 \sim 138\ ,\ Mass_2 \sim 96 \quad \text{e.g., } 2n + {}^{137}Te_{85} + {}^{97}Zr_{57}$$

$^{97}Zr_{57}$ → ($T_{½}$ =17 hr) → $^{97}Nb_{56}$ → ($T_{½}$ =71 min) → $^{97}Mo_{55}$

$^{137}Te_{85}$ → ($T_{½}$ =2.5 s) → $^{137}I_{84}$ → ($T_{½}$ =24 s) → $^{137}Xe_{83}$ → ($T_{½}$ =3.8 min) → $^{137}Cs_{82}$ ($T_{½}$ = 30yr) → $^{137}Ba_{81}$



FF and Radioactive Decay – Iodine

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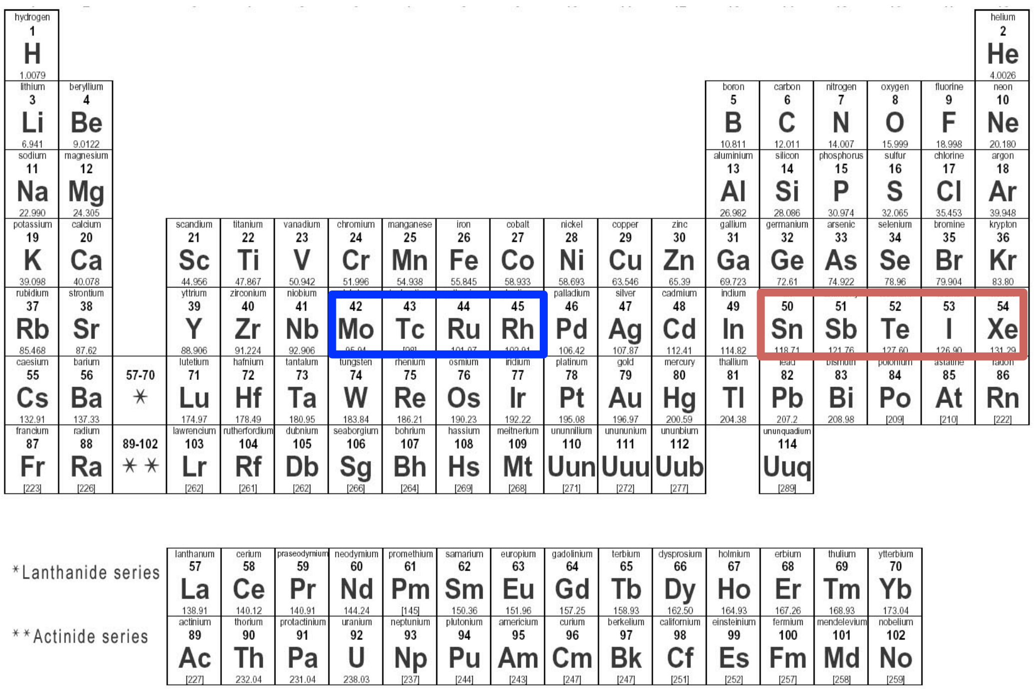
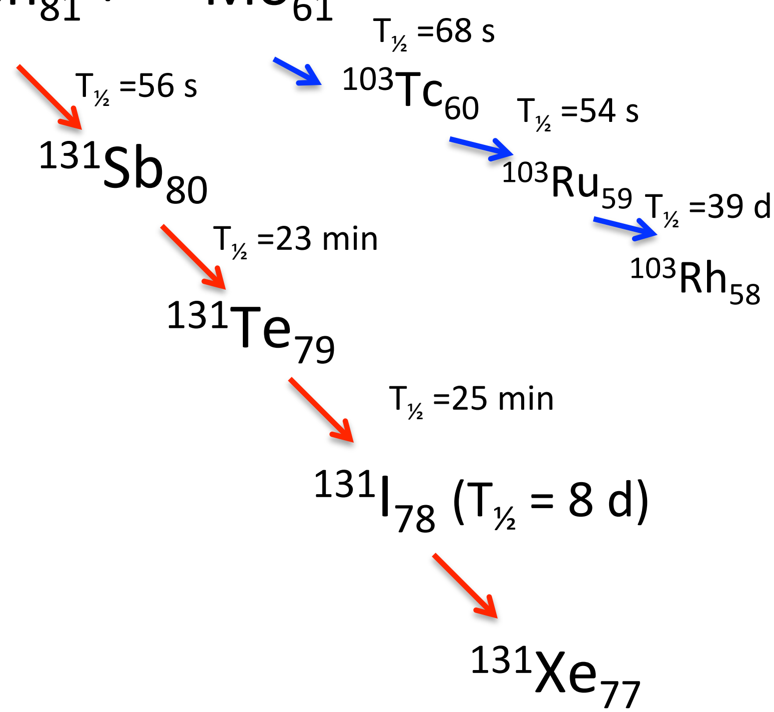
The Fission Fragments are produced with an excess of neutrons simply because the stable uranium nuclei have many more neutrons than protons …

$$^{1}n + {}^{235}U \rightarrow ({}^{236}U_{144})^* \rightarrow ({}^{A1}Z_1)^* + ({}^{A2}Z_2)^* + {}^{1}n\text{'s}$$

$$\text{Mass}_1 \sim 131\text{ , Mass}_2 \sim 103 \text{ e.g., } 2n + {}^{131}Sn_{81} + {}^{103}Mo_{61}$$





Part 3 – Fission Operation

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Nuclear Fuel Rods, Before & After

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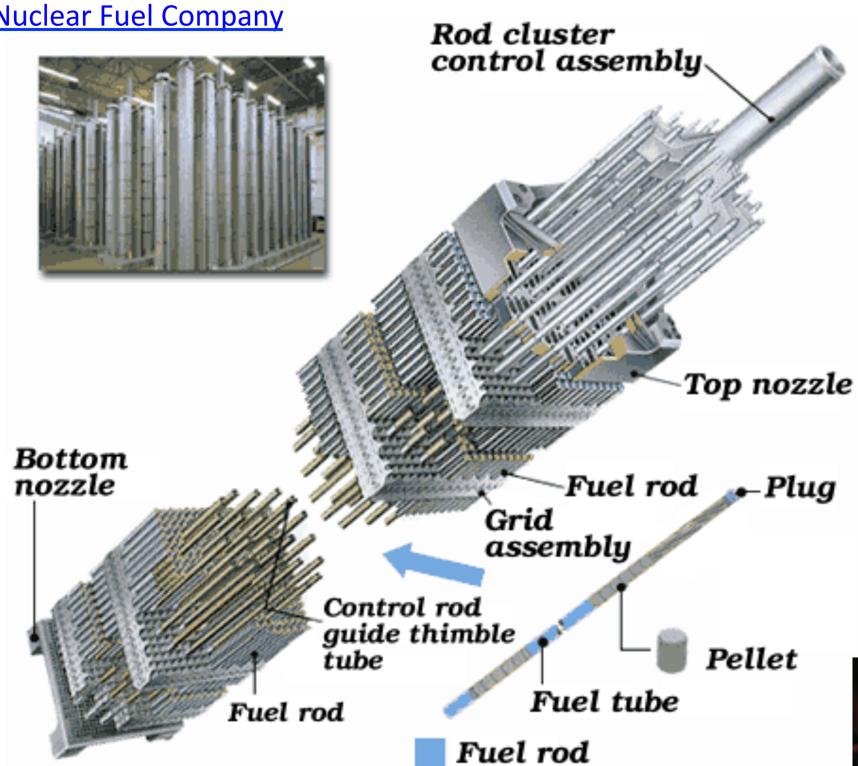
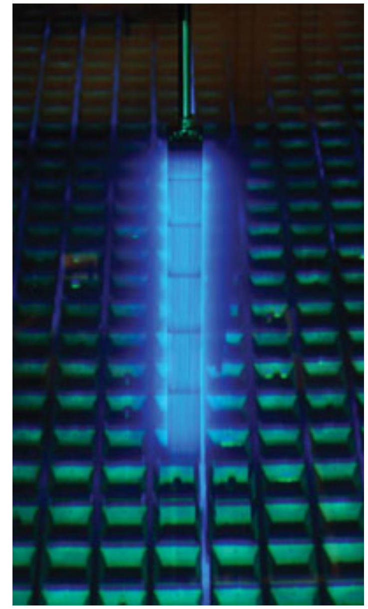
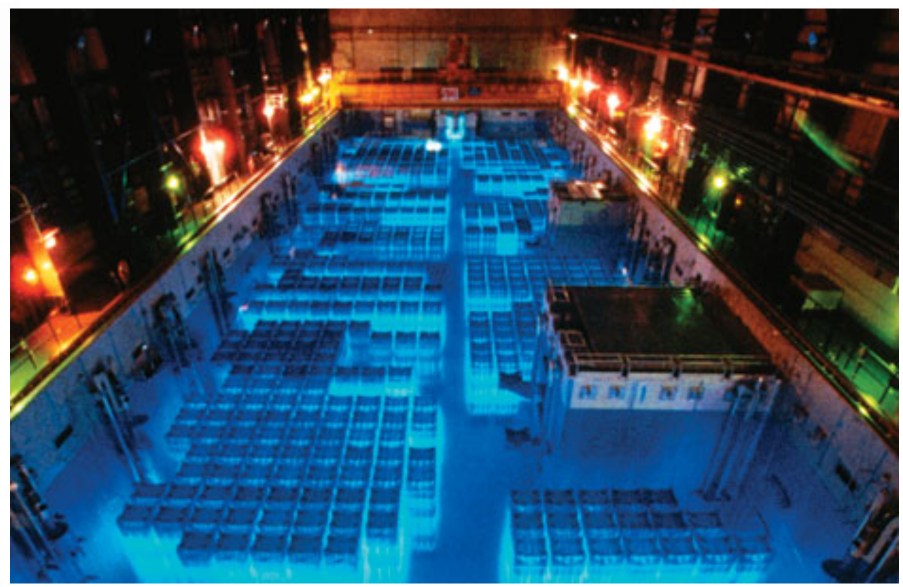
Mitsubishi Nuclear Fuel Company





Spent fuel in holding pool, before reprocessing at LaHague, France



Temporary storage in the US

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[NRC Website on Storage www.nrc.gov](http://www.nrc.gov)

"Fuel that has been stored for at least five years in water has cooled sufficiently, and its radioactivity decreased enough, for it to be removed from the spent fuel pool and loaded into casks to free up additional space in the pool for storing spent fuel newly removed from the reactor."

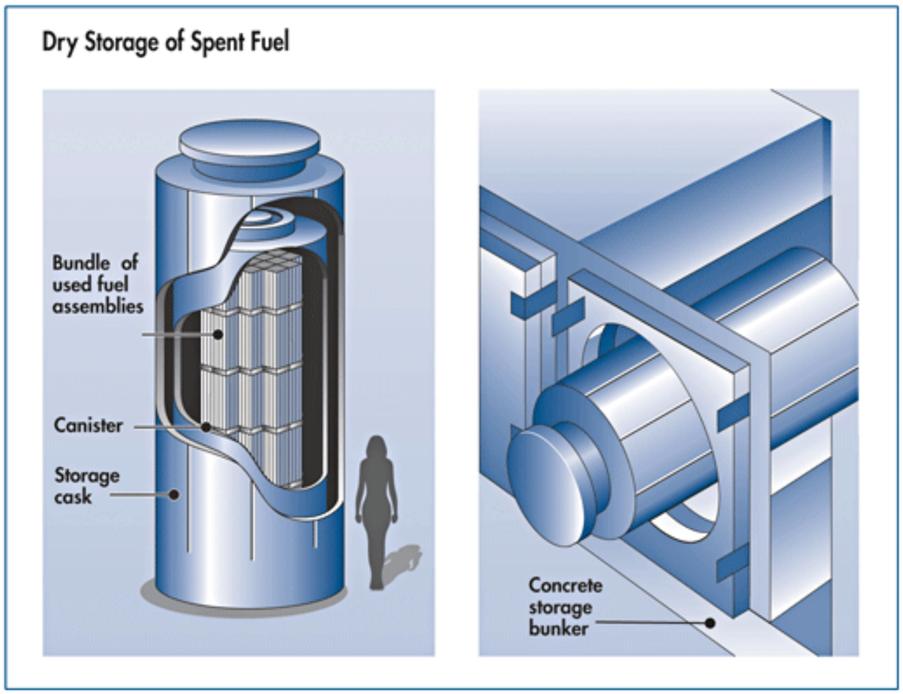
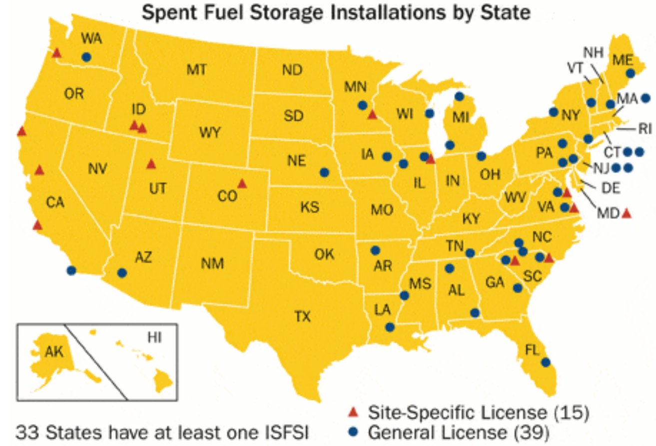


Figure 44. Licensed/Operating Independent Spent Fuel Storage Installations by State



33 States have at least one ISFSI

ALABAMA
- ● Browns Ferry
- ● Farley

ARIZONA
- ● Palo Verde

ARKANSAS
- ● Arkansas Nuclear

CALIFORNIA
- ▲ Diablo Canyon
- ▲ Rancho Seco
- ● San Onofre
- ▲ Humboldt Bay

COLORADO
- ▲ Fort St. Vrain

CONNECTICUT
- ● Haddam Neck
- ● Millstone

FLORIDA
- ● St. Lucie

GEORGIA
- ● Hatch

IDAHO
- ▲ DOE: TMI-2 (Fuel Debris)
- ▲ Idaho Spent Fuel Facility

ILLINOIS
- ▲ GE Morris (Wet)
- ● Dresden
- ● Quad Cities

IOWA
- ● Duane Arnold

LOUISIANA
- ● River Bend

MAINE
- ● Maine Yankee

MARYLAND
- ▲ Calvert Cliffs

MASSACHUSETTS
- ● Yankee Rowe

MICHIGAN
- ● Big Rock Point
- ● Palisades

MINNESOTA
- ● Monticello
- ▲ Prairie Island

MISSISSIPPI
- ● Grand Gulf

NEBRASKA
- ● Ft. Calhoun

NEW HAMPSHIRE
- ● Seabrook

NEW JERSEY
- ● Hope Creek/Salem
- ● Oyster Creek

NEW YORK
- ● Indian Point
- ● FitzPatrick

NORTH CAROLINA
- ● McGuire

OHIO
- ● Davis-Besse

OREGON
- ▲ Trojan

PENNSYLVANIA
- ● Limerick
- ● Susquehanna
- ● Peach Bottom

SOUTH CAROLINA
- ● ▲ Oconee
- ● ▲ Robinson
- ● Catawba

TENNESSEE
- ● Sequoyah

UTAH
- ▲ Private Fuel Storage

VERMONT
- ● Vermont Yankee

VIRGINIA
- ● ▲ Surry
- ● ▲ North Anna

WASHINGTON
- ● Columbia

WISCONSIN
- ● Point Beach

Note: Data are current as of June 2009
NRC-abbreviated unit names used
Source: U.S. Nuclear Regulatory Commission

Electrical Power in France

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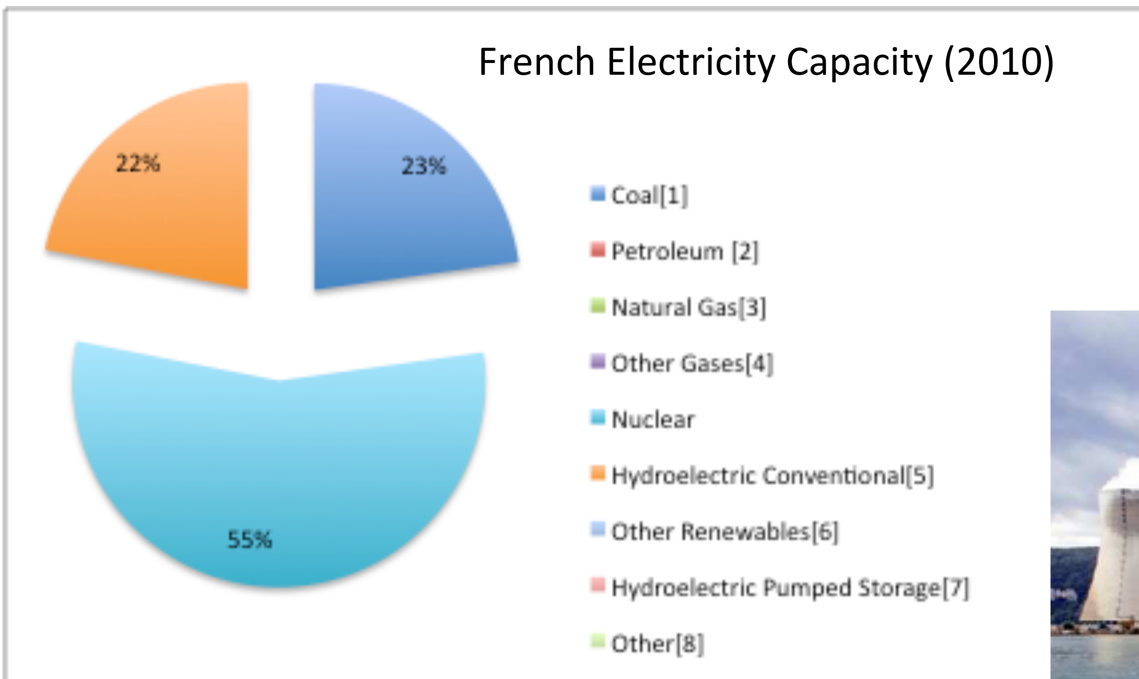
http://www.world-nuclear.org/info/inf40.html

- France derives over 75% of its electricity from nuclear energy with 59 reactors. This is due to a long-standing policy based on energy security.
- France is the world's largest net exporter of electricity due to its very low cost of generation.
- France has been very active in developing nuclear technology. Reactors, fuel products and fuel processing services are a major exports.

~62 Million people (~1/5 of USA)

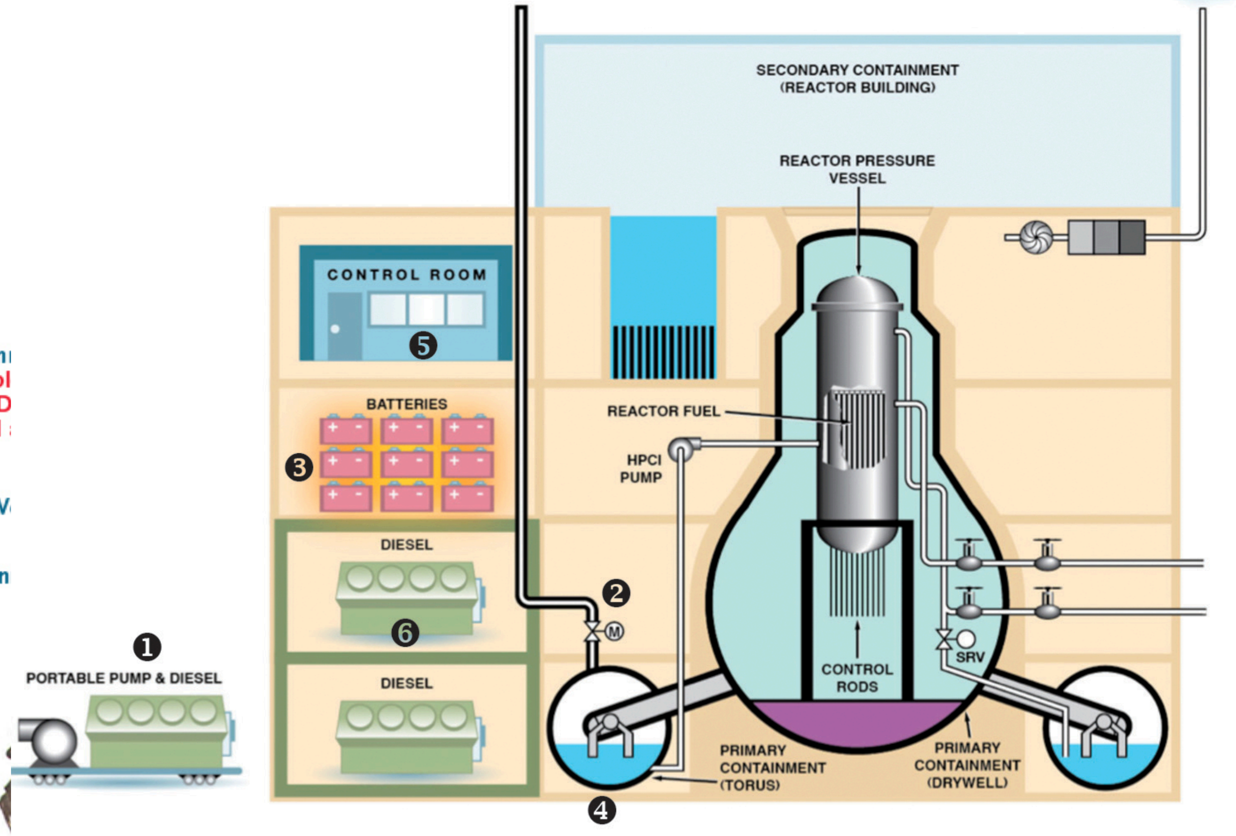


Major Modifications and Upgrades to U.S. Boiling Water Reactors with Mark I Containment Systems.

Secondary Contain
Area of Expl
at Fukushima D
Units 1

Steel Containment V

Primary Contain



1. Added spare diesel generator and portable water pump – 2002
2. Added containment vent – 1992
3. More batteries in event of station blackout – 1988
4. Strengthened torus – 1980
5. Control room reconfiguration – 1980
6. Back-up safety systems separated – 1979