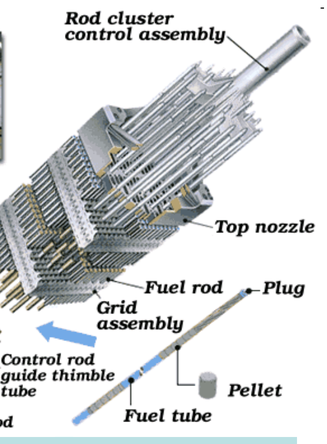
Uranium$_{235/238}$ Light-Water Reactors

2 types: Pressurized-Water (PWRs) & Boiling-Water Reactors (BWRs)

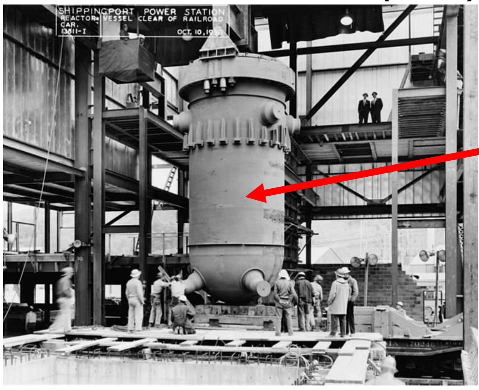
Modern U$_{235/238}$ Centrifuge

Workers



Fuel Centrifuge-Enriched to ~3% U$_{235}$

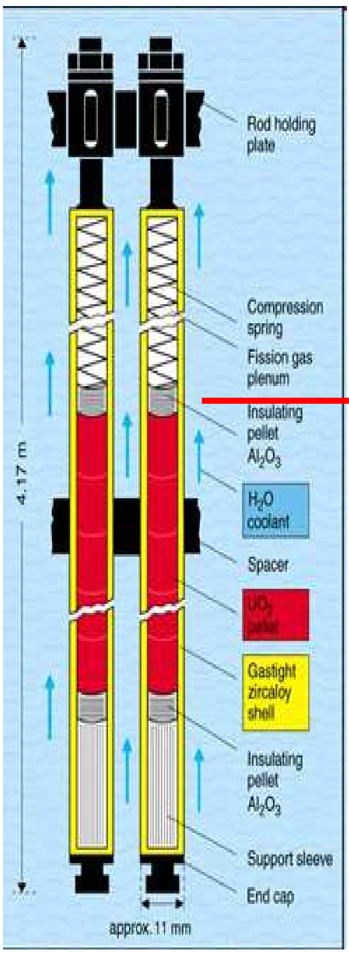
First Commercial US Reactor (60MW)

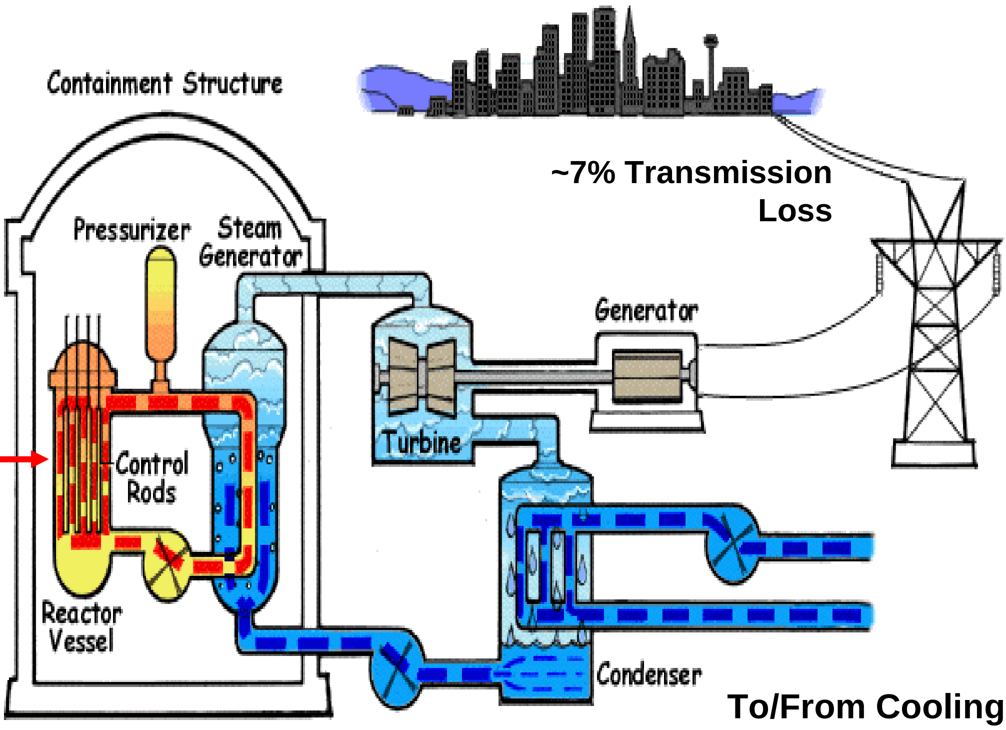


Shippingport, Penn, 1954-56

Modern Fuel Assemblies. Only ~6% of Uranium is consumed before rods must be removed & stored or reprocessed – ~300 tons Uranium needed per GW-Year.

Fuel Rods





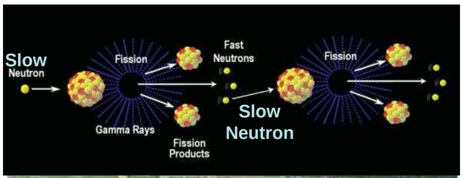
~7% Transmission Loss

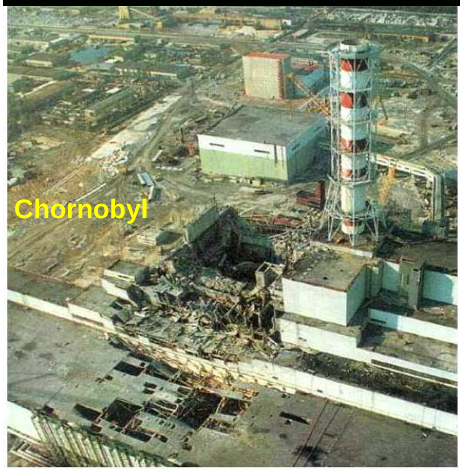
To/From Cooling Tower, Lake or Sea

Must Contain 160 Atmospheres (>2300psi) of Pressure in Event of Reactor Runaway

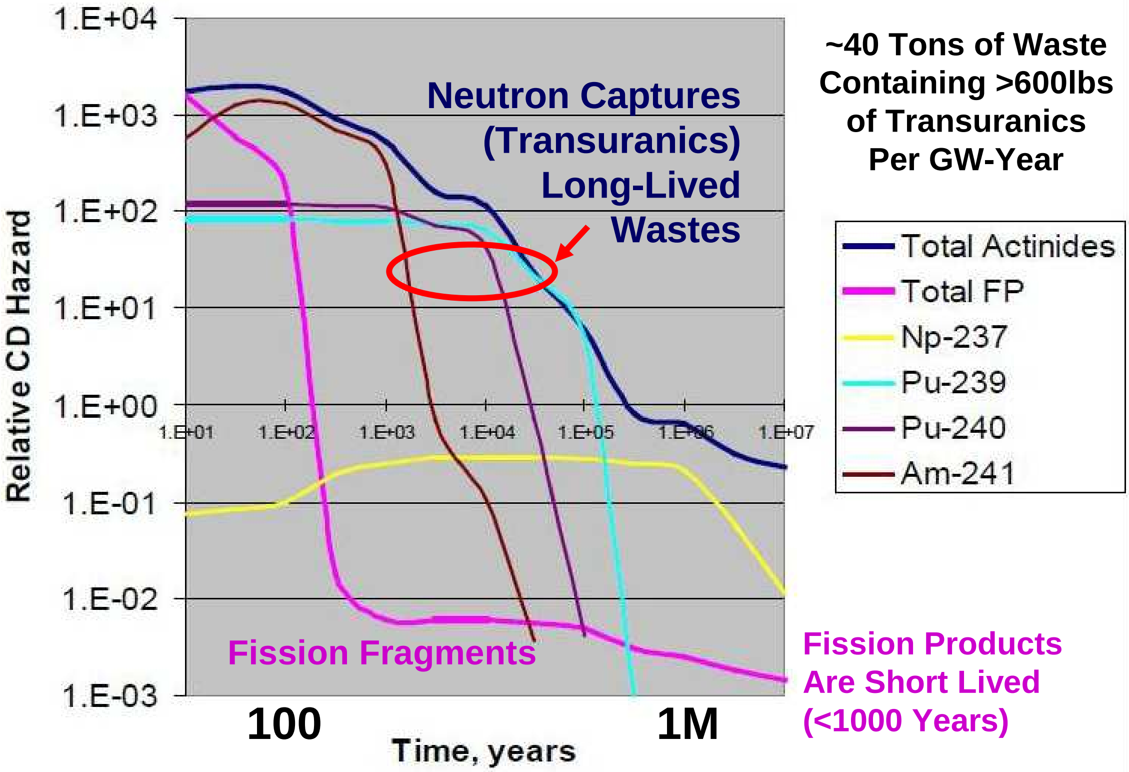
Uranium Fission

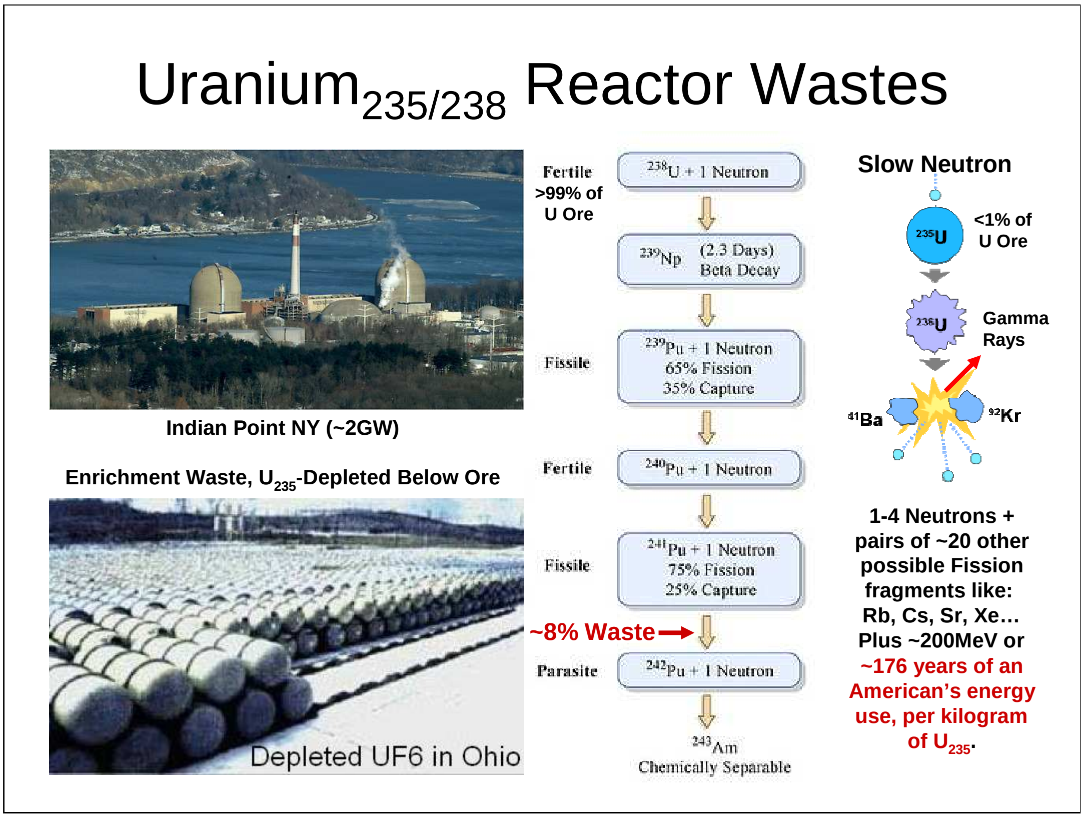
Ivy Mike (U + D) – Enewetak Atoll 1952
www.youtube.com/watch?v=h7vyKDcSTaE



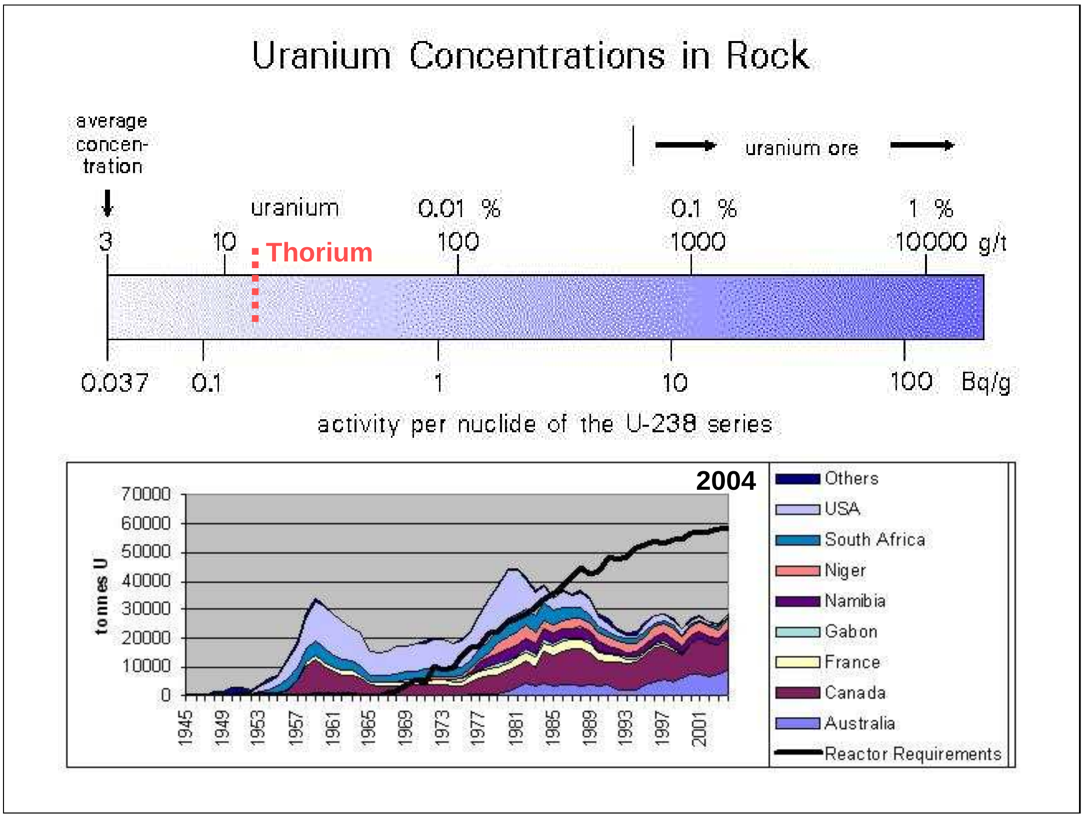


Radiotoxicity of LWR Spent Fuel




Uranium$_{235/238}$ Reactor Wastes
Indian Point NY (~2GW)
Enrichment Waste, U_{235}-Depleted Below Ore
Depleted UF6 in Ohio
Fertile >99% of U Ore
^{238}U + 1 Neutron
^{239}Np (2.3 Days) Beta Decay
Fissile
^{239}Pu + 1 Neutron 65% Fission 35% Capture
Fertile
^{240}Pu + 1 Neutron
Fissile
^{241}Pu + 1 Neutron 75% Fission 25% Capture
~8% Waste
Parasite
^{242}Pu + 1 Neutron
^{243}Am Chemically Separable
Slow Neutron
^{235}U
<1% of U Ore
^{236}U
Gamma Rays
^{41}Ba
^{92}Kr
1-4 Neutrons + pairs of ~20 other possible Fission fragments like: Rb, Cs, Sr, Xe… Plus ~200MeV or ~176 years of an American's energy use, per kilogram of U_{235}.


38,000 UF6 Waste Cans, KY
The Outcasts of Uranium Enrichment for 10% of the LWRs We'd Need to Replace Coal



>90% U Ore Wasted
>250 Tons/GW-Year

Production from mines (tonnes U)

Country	2003	2004	2005	2006	2007	2008	2009
Kazakhstan	3300	3719	4357	5279	6637	8521	13820
Canada	10457	11597	11628	9862	9476	9000	10173
Australia	7572	8982	9516	7593	8611	8430	7982
Namibia	2036	3038	3147	3067	2879	4366	4626
Russia	3150	3200	3431	3262	3413	3521	3564
Niger	3143	3282	3093	3434	3153	3032	3243
Uzbekistan	1598	2016	2300	2260	2320	2338	2429
USA	779	878	1039	1672	1654	1430	1453
Ukraine (est)	800	800	800	800	846	800	840
China (est)	750	750	750	750	712	769	750
South Africa	758	755	674	534	539	655	563
Brazil	310	300	110	190	299	330	345
India (est)	230	230	230	177	270	271	290
Czech Repub.	452	412	408	359	306	263	258
Malawi							104
Romania (est)	90	90	90	90	77	77	75
Pakistan (est)	45	45	45	45	45	45	50
France	0	7	7	5	4	5	8
Germany	104	77	94	65	41	0	0
total world	**35 574**	**40 178**	**41 719**	**39 444**	**41 282**	**43 853**	**50 572**
tonnes U_3O_8	41 944	47 382	49 199	46 516	48 683	51 716	59 640
percentage of world demand			65%	63%	64%	68%	76%

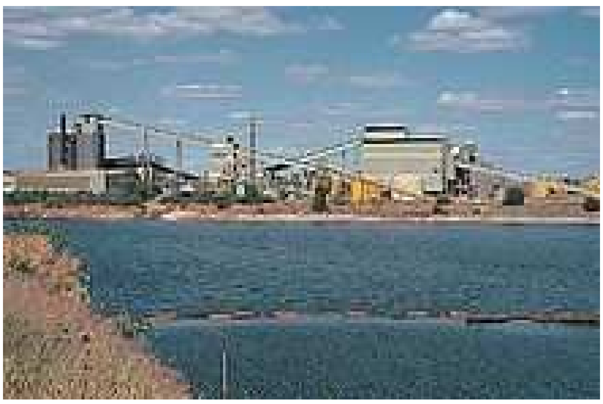
WNA Market Report data

Uranium Mining & Wastes

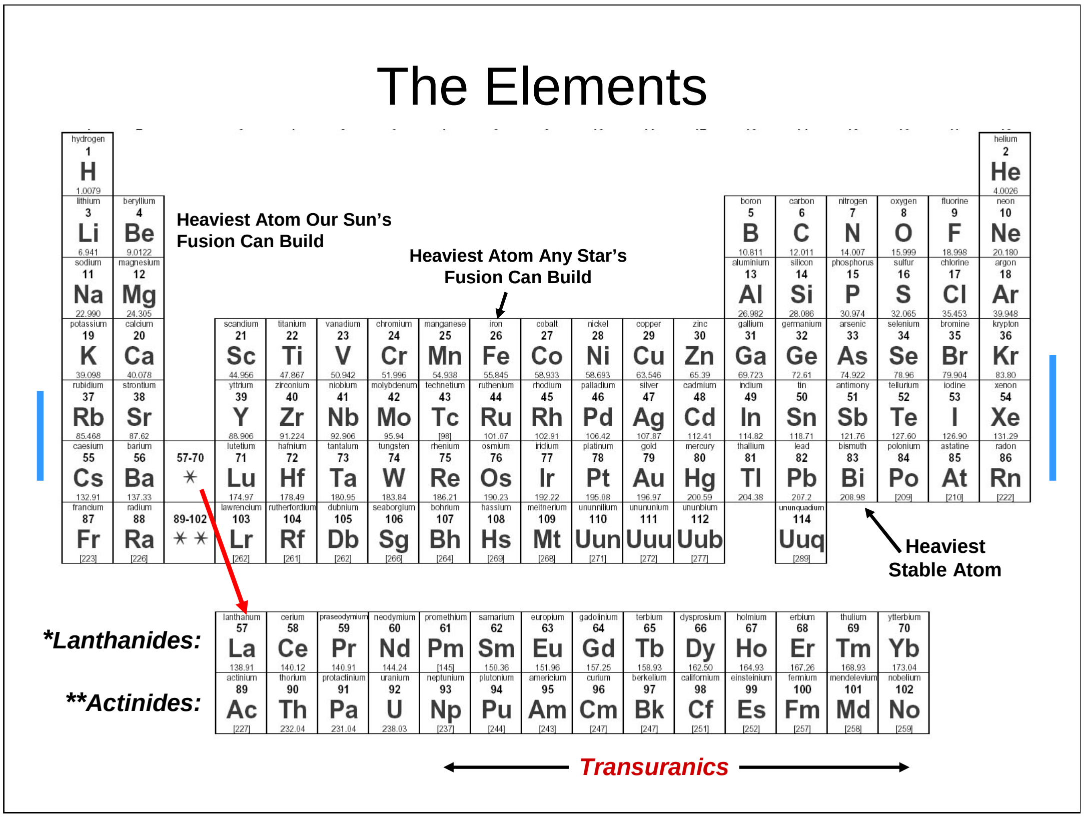
Uranium content of ore is often only 0.1% to 0.2%, so large amounts of rock must be mined:

Even in an Australian national park,

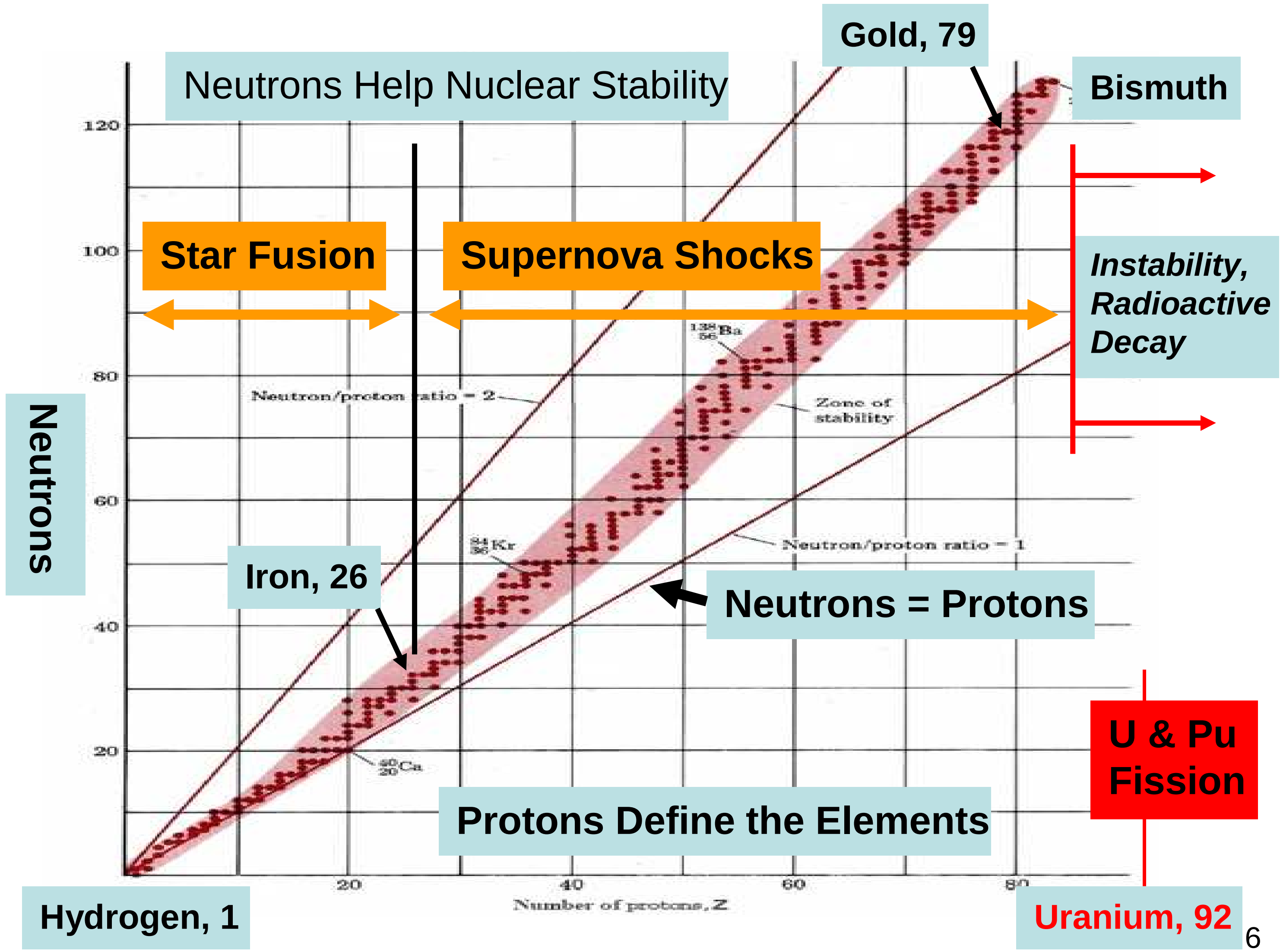
And tailings piled:



or the Navajo Nation…



The Elements
Heaviest Atom Our Sun's Fusion Can Build
Heaviest Atom Any Star's Fusion Can Build
Heaviest Stable Atom
H He
Li Be B C N O F Ne
Na Mg Al Si P S Cl Ar
K Ca Sc Ti V Cr Mn Fe Co Ni Cu Zn Ga Ge As Se Br Kr
Rb Sr Y Zr Nb Mo Tc Ru Rh Pd Ag Cd In Sn Sb Te I Xe
Cs Ba 57-70 * Lu Hf Ta W Re Os Ir Pt Au Hg Tl Pb Bi Po At Rn
Fr Ra 89-102 ** Lr Rf Db Sg Bh Hs Mt Uun Uuu Uub Uuq
*Lanthanides: La Ce Pr Nd Pm Sm Eu Gd Tb Dy Ho Er Tm Yb
**Actinides: Ac Th Pa U Np Pu Am Cm Bk Cf Es Fm Md No
Transuranics



Gold, 79
Neutrons Help Nuclear Stability
Bismuth
Star Fusion
Supernova Shocks
Instability, Radioactive Decay
Neutrons
Neutron/proton ratio = 2
Zone of stability
Neutron/proton ratio = 1
Iron, 26
Neutrons = Protons
U & Pu Fission
Protons Define the Elements
Hydrogen, 1
Number of protons, Z
Uranium, 92

Power Generation & Health

- We now generate 16 TeraWatts, electric
  - Wasting >50% of gross generation at customers
  - Wasting ~60% of thermal fuel value at power plant
    - **Thermal efficiency = 1 – T_{cold}/T_{hot}**
  - With health & environmental consequences
  - 'Renewables' won't help much
    - **Low energy density** => huge land/sea usage
    - Need both instantaneous & diurnal **storage**
    - **Biofuels unrealistic** with 7% photosynthesis efficiency
    - **Solar power <1kW/m^2** maximum in daylight hours
      - But, cell efficiency improving (~20% now, 40% in labs)
      - Not thermal generation, but IR = (1 – Efficiency) kW/m^2
      - Can meet DG (locally-distributed generation) needs
- We need high energy-density, localized sources

Public Health Impacts per TWh*

	Coal	Lignite	Oil	Gas	Nuclear	PV	Wind
Years of life lost: Nonradiological effects	138	167	359	42	9.1	58	2.7
Radiological effects: Normal operation					16		
Accidents					0.015		
Respiratory hospital admissions	0.69	0.72	1.8	0.21	0.05	0.29	0.01
Cerebrovascular hospital admissions	1.7	1.8	4.4	0.51	0.11	0.70	0.03
Congestive heart failure	0.80	0.84	2.1	0.24	0.05	0.33	0.02
Restricted activity days	4751	4976	12248	1446	314	1977	90
Days with bronchodilator usage	1303	1365	3361	397	86	543	25
Cough days in asthmatics	1492	1562	3846	454	98	621	28
Respiratory symptoms in asthmatics	693	726	1786	211	45	288	13
Chronic bronchitis in children	115	135	333	39	11	54	2.4
Chronic cough in children	148	174	428	51	14	69	3.2
Nonfatal cancer					2.4		

*Kerwitt et al., "Risk Analysis" Vol. 18, No. 4 (1998).

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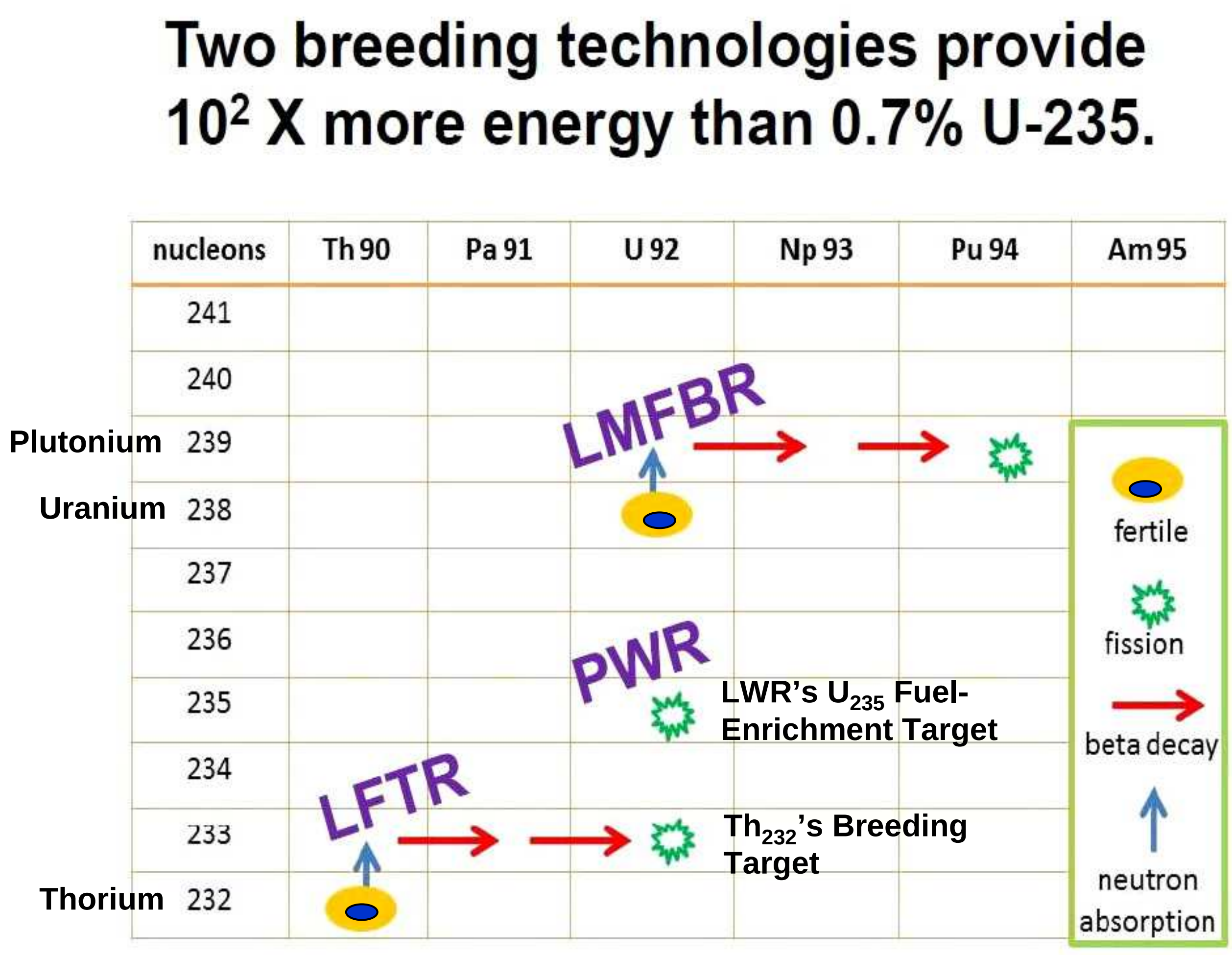
The Thorium Solution

From the 2010 Thorium Energy alliance Conference…

www.thoriumenergyalliance.com/downloads/TEAC2_KirkSorensen.pdf (**http://tinyurl.com/2fldtf5**)

…**Thorium has a special property—it breeds [via neutron/proton capture] to uranium-233** and uranium-233 fissions [more efficiently than U235 or Pu239] and gives off 2 or 3 neutrons that enable it to keep converting more thorium into uranium-233 and burning it. This means that **once we start a thorium reactor we can keep it going indefinitely just by adding thorium**. But how do we get it started? How much uranium-233 do we need? Well, most of the studies done by Oak Ridge in the 1960s indicated that **we could start a one-Gigawatt thorium reactor with about 1 tonne [2200 lbs] of uranium-233**. How much do we have right now? About one tonne. So we could only start one reactor, right? With uranium-233, yes, but we need to go about quickly "converting" our fissile materials into uranium-233 so we can start more. **Why does it only take one tonne of uranium-233 to start a thorium reactor but it takes 5-10 tonnes of plutonium to start a fast breeder?**

Here's why—things look different when you're a slowed-down [thermal or moderated] neutron versus a fast neutron [right out of a fission]. When you're a fast neutron, all of this fuel looks really small to you, and you have a lot less probability of causing fission. So you need a lot more fuel to insure that you get enough collisions with fuel to generate the energy you need. On the other hand, **when you're a slowed-down neutron, each fuel nucleus looks a lot bigger and you have a much better chance of causing a fission**. So having slowed-down neutrons makes your fuel go a lot further than using fast neutrons. This is the basic reason why **a thorium reactor with slowed-down neutrons can start with a lot less fuel** for a given power rating than a fast reactor with fast neutrons. Each little bit of fuel counts for a lot more in a reactor with slowed-down neutrons.



The Thorium Solution

We don't have to limit ourselves to just uranium-233 to start these thorium reactors. **We can use** the highly-enriched uranium that we're recovering from all of the **nuclear weapons that we are decommissioning** to help us. We can use the **plutonium we're recovering** from those weapons. We can use the plutonium that's been generated in our reactors over the last sixty years to help us.

By using slowed-down neutrons and thorium, the startup power of this fuel is magnified by about 1000 to 1500% [10-15 times] over a fast reactor.

So what should we do first? Well, the first thing we should do is **stop the Department of Energy's effort to destroy the one tonne of uranium-233 that we already have**. They don't think that that uranium-233 has any value to their mission and are going to spend $500M to mix it with uranium-238 [Uranium ore] and throw it away in the desert. That's a bad idea. We're going to need that one tonne and a whole lot more.

The next step is to **get going on the research and development of the liquid-fluoride thorium reactor**. This is the machine that can burn thorium as a fuel and only needs about a tonne of U-233 or other fissile material to start it up. **The US hasn't invested any money to develop LFTR since 1974**, the year I was born. **Other countries are making investments**. We need to get going before we get completely left behind on something that we invented.

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http://tinyurl.com/29mem3x (Kutsch video)
http://tinyurl.com/2av6row (Hargraves & Moir)
http://tinyurl.com/ye6leml
http://tinyurl.com/25mqqkd (Cannara)

Liquid Fuel Reactors

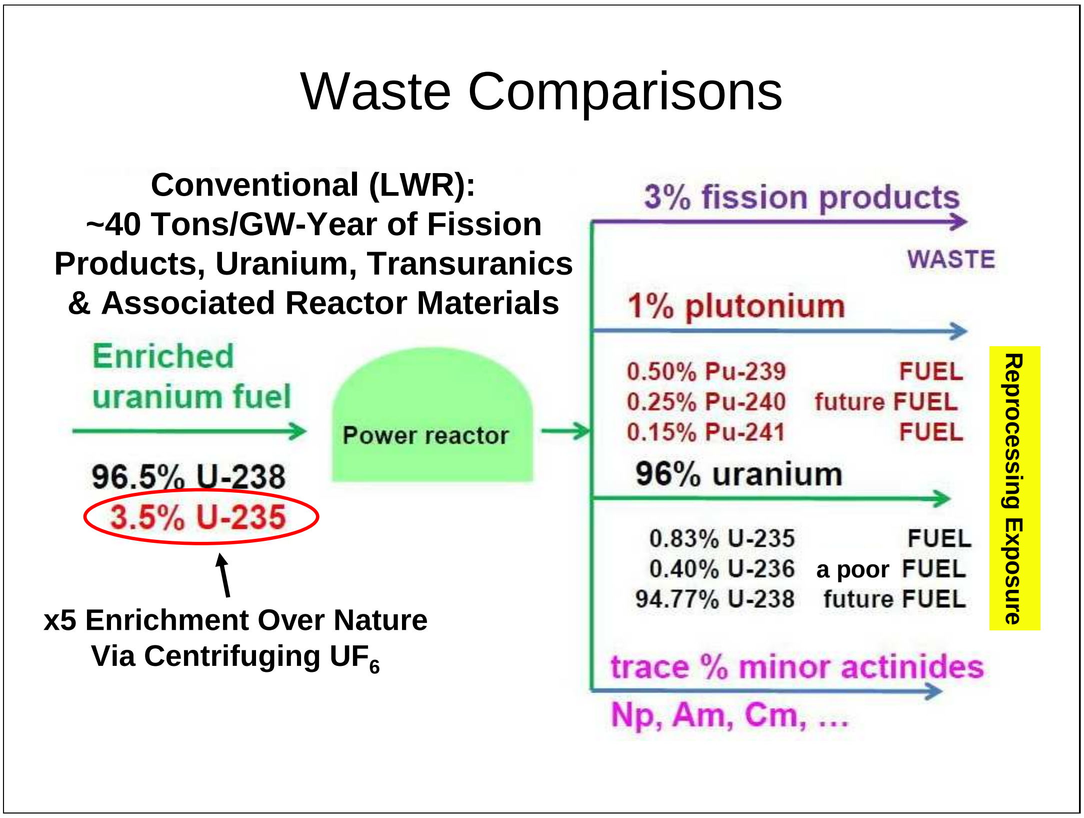
http://tinyurl.com/2av6row

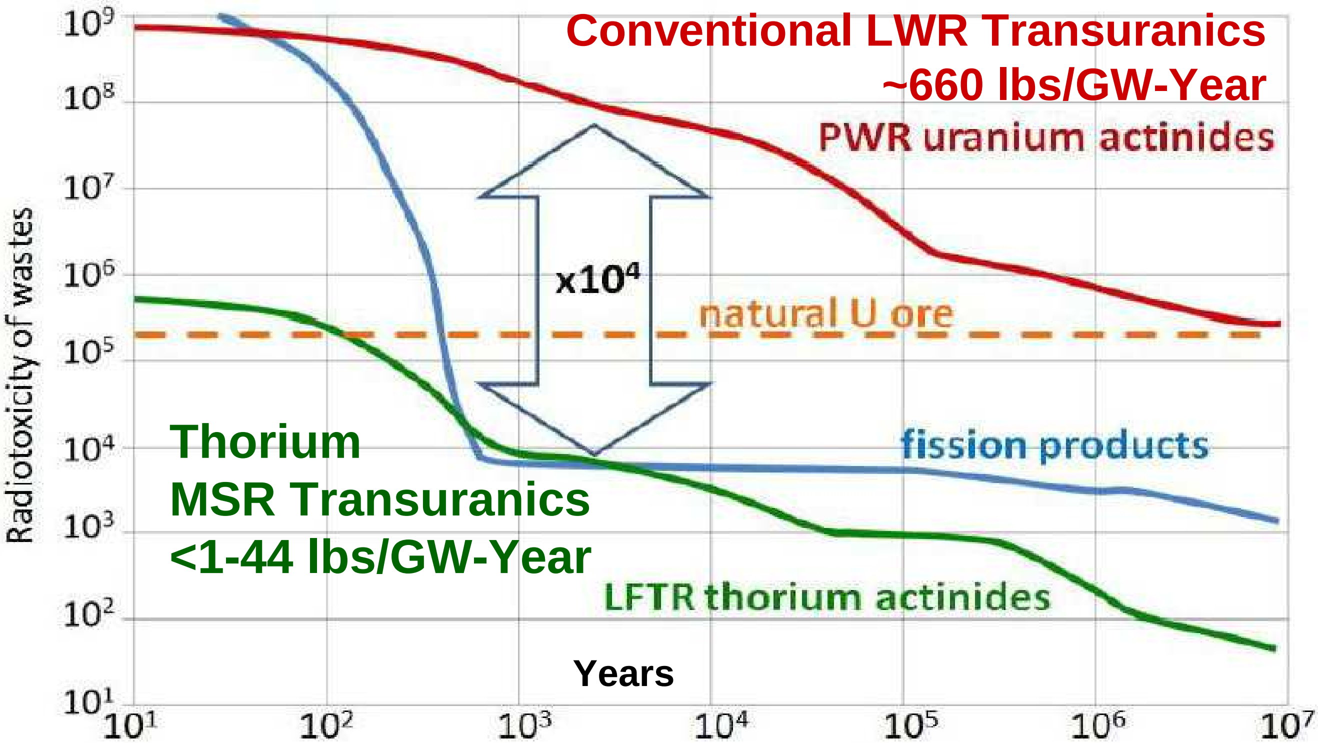
Molten salt coolants

with dissolved uranium and thorium fluorides

promise reactors that can generate electric power cheaper than coal

Estimate	Year	$/watt	2009 $/watt
Sargent & Lundy	1962	0.650	4.64
Sargent & Lundy ORNL TM-1060	1965	0.148	1.01
ORNL-3996	1966	0.243	1.62
Engel et al, ORNL TM7207	1978	0.653	2.16
Moir	2000	1.580	1.98

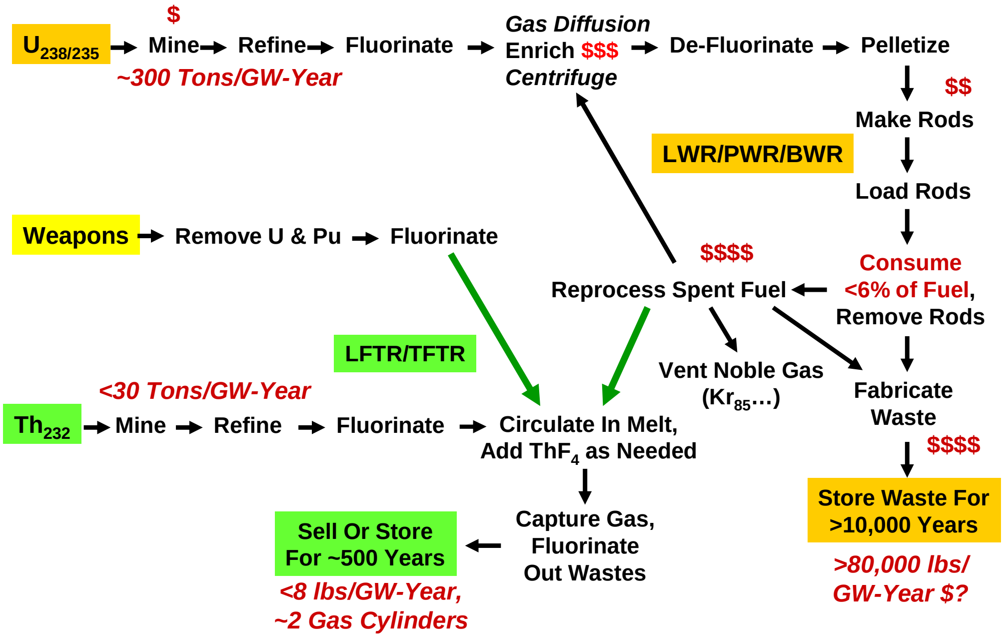




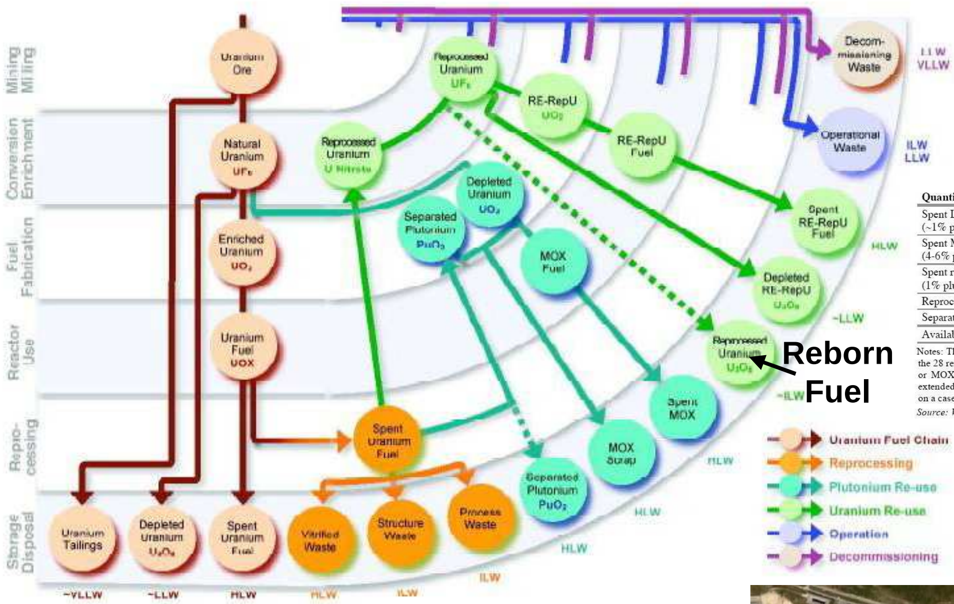
For 30 years total:	FUJI-U3 (1GWe)	Relative to 1GWe BWR
Fissile requirement	7.8 t (reusable)	32%
Pu production	4 kg	0.1%
MA (Np/Am/Cm) production	23 kg	4 %

Japanese Example ~60 lbs in 30 GW yrs

Uranium$_{235}$ Versus Thorium$_{232}$ Cycle



French Reprocessing:

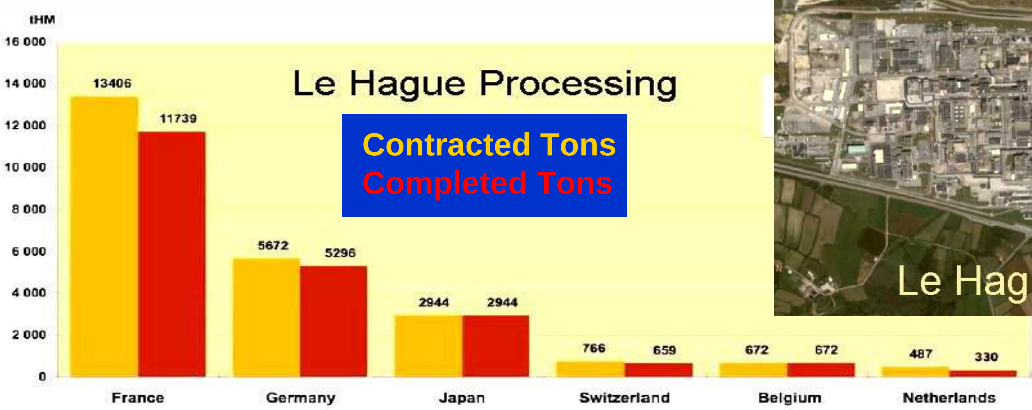


Stored Tons

Quantities in storage (tons heavy metal)	1987	1997	2000	2010	2020
Spent LEU fuel (~1% plutonium)	3,050	9,020	10,350	11,250	10,850
Spent MOX fuel (4-6% plutonium)	0	195	520	1,300	2,350
Spent re-enriched reprocessed uranium fuel (1% plutonium)	0	0	150	350	700
Reprocessed uranium	~7,500	~12,000	16,000	20,000	25,000
Separated plutonium	2.5	38	48	~48	~48
Availability of reactors (years)	25 to 35	15 to 25	10 to 20	2 to 12	0 to 2

Notes: The availability of reactors is the calculated expected number of remaining operating years, as an average for the 28 reactors of 900 MWe in which EDF theoretically could pursue the use of re-enriched reprocessed uranium fuel or MOX. These reactors were started-up between 1977 and 1987, with a planned lifetime of 30 years, recently extended by the operator to 40 years. However, the extension has yet to be approved by the Nuclear Safety Authority on a case-by-case basis. The low and high values respectively correspond to 30 and 40 years of operation.

Source: WISE-Paris estimates based on CDP (2000), ANDRA (2006).



Thorium Schedule & Benefits

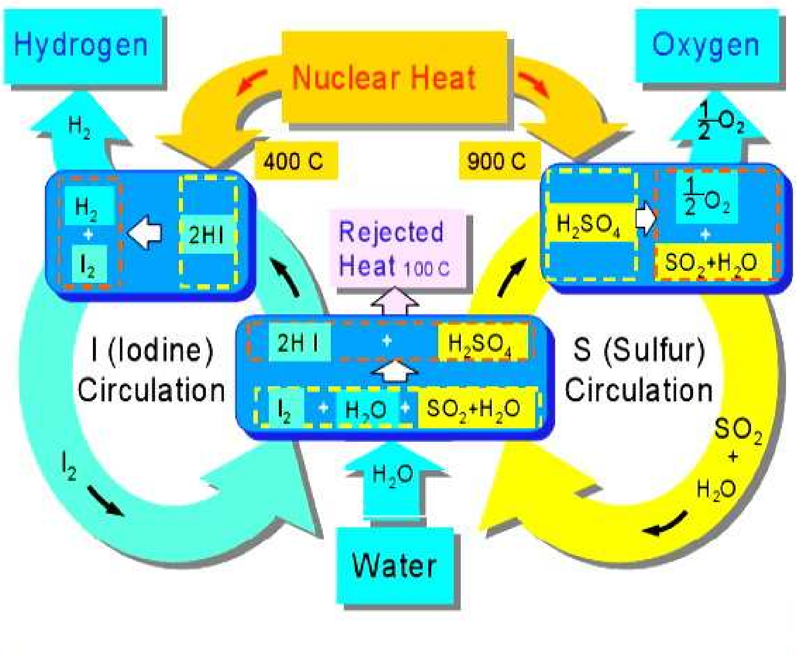
A Thorium LFTR could be working in 5 years…

$ 1 B	$ 5 B	$ 70 B per year industry	
Develop	Scale up	Produce	Export
2010	2015	2020	One LFTR per day
	Commercialize		

Rickover's Shippingport was built in <u>32 months</u>. (1954)
Weinberg-engineered Oak Ridge X-10 was built in <u>9 months</u>.

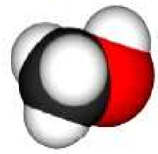
LFTR can make products beyond water desalinization, but we <u>still don't want to burn hydrocarbons</u>, if we can avoid it, and Nitrogen fertilizers must be used with care…

Dissociate water at 900°C to make hydrogen: sulfur-iodine process.

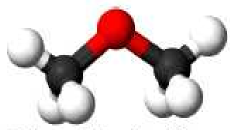


http://wwwtest.iri.tudelft.nl/~klooster/reports/hydro_slides_2003.pdf

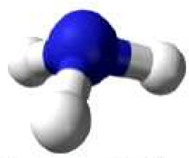
$CO_2 + 3 H_2 \rightarrow CH_3OH + H_2O$



Methanol for gasoline



Dimethyl ether for diesel



Ammonia for fertilizer