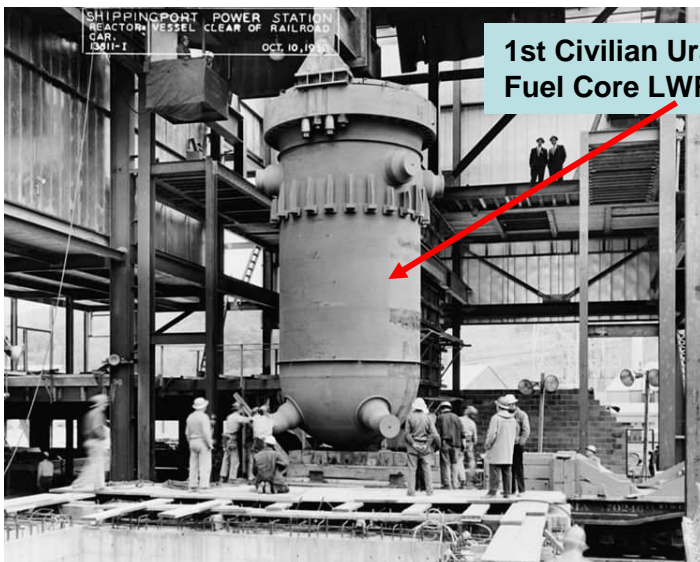
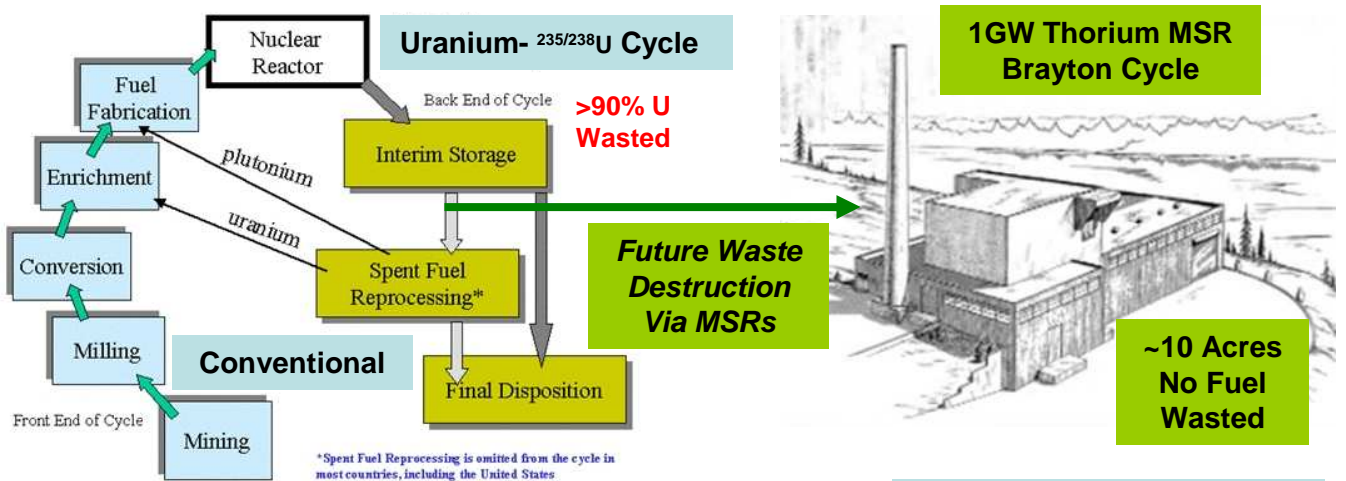


Thorium-Based Molten-Salt Reactors

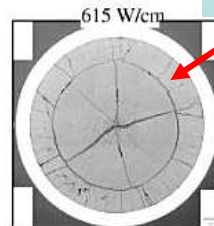
- Thorium is far more common & cheaper than Uranium...
 - No ‘enrichment’ energy wasted – ^{232}Th is just a metal common in “rare-earth” ores.
 - **All Thorium is consumed** – no ‘spent’ fuel (>90% of BWR/PWR Uranium is unused).
- Thorium-Fluoride (ThF_4) salt is the ‘fertile fuel’ input (ThF MSR, or LFTR)...
 - Exceedingly stable salt, of **no weapons value**.
 - Totally consumed, with **no refuelling shutdowns** needed, **no excess fuel** in core.
 - ^{232}Th is neutron-bred in core to $^{233}\text{Uranium}$ within the molten salt – **no external fissiles**.
 - ^{233}U fissions better than higher U isotopes, so **less waste, all with modest half lives**.
- MSRs automatically throttle via thermal expansion...
 - As thermal load changes, **fission rate tracks salt density**.
 - **No runaway or ‘meltdown’ possibility** -- salts are radiation stable.
- MSRs have higher temp & power density so ~30% better thermal efficiency
 - De-commissioned BWRs/PWRs can become >3x more potent MSRs.
 - Air (Brayton) or steam-turbine cycles possible, eliminating water for cooling.
- MSRs can consume existing BWR/PWR fissile wastes on site...
 - Typical wastes from a 1GW ThF_4 MSR, over 30 years, is under 80lbs.
 - A 1GW LFTR makes 1/1000 the Plutonium of a BWR/PWR & can consume it.
 - Further **reduction of wastes onsite**, down to whatever low level is desired.
- MSRs have no expensive control/containment/emergency systems.
 - **TFTR (Thorium LFTR) cost ~\$3/Watt** (much less than current ^{235}U BWR/LWRs).
 - **Scalable** from 1MW to multiple GW – siting anywhere on Earth or in space.
 - Initial working MSR was for the 1960s DoD Atomic Plane – had to be **small**.

3/10/2011, Dr. A. Cannara, 650-400-3071, cannara@sbcglobal.net



1st Civilian Uranium Solid-Fuel Core LWR, 60MW

Normal Solid-Fuel Pellet Damage In <2 Years, Cladding Must Hold Unused Fuel + Wastes For Millennia



~10mm Dia.

Equivalent 60MW Thorium MSR Core

Equal Scales



Thorium- ²³³U Fission Refs

<http://tinyurl.com/yb2qgex>
www.thoriumenergyalliance.com (note 2010 TEAC2 Conference link to presentations)
<http://thoriumenergy.blogspot.com/2006/04/brief-history-of-liquid-fluoride.html>
www.energyfromthorium.com/pdf (ORNL archives)
<http://thoriumenergy.blogspot.com/>
<http://cavendishscience.org/bks/nuc/thrupdat.htm>
www.world-nuclear.org/info/inf62.html
<http://thoriumenergy.blogspot.com/2008/04/long-lived-fission-products.html>
www.tpub.com/content/doe/h1017v2/css/h1017v2_67.htm
<http://newenergyandfuel.com/http://newenergyandfuel.com/2007/09/10/thorium-reactor-possibilities/>
www.youtube.com/watch?v=AZR0UKxNPh8&NR=1
www.cosmosmagazine.com/features/print/348/new-age-nuclear?page=0%2C3
www.theregister.co.uk/2011/02/01/china_thorium_bet/ (China jumps ahead again)
<http://energyfromthorium.com/2011/01/30/china-initiates-tmsr/#comments>
www.telegraph.co.uk/finance/comment/ambroseevans_pritchard/8393984/Safe-nuclear-does-exist-and-China-is-leading-the-way-with-thorium.html

President's 2010 Commission & ORNL
<http://sites.google.com/site/rethinkingnuclearpower/aimhigh>
http://brc.gov/Reactor_Fuel_Cycle_Technology_SC/RFC_TSC_08_30_10mtginfo.html
Hargraves & Sorenson are from the Thorium Alliance and Rothrock is a VC.
https://www.ornl.gov/fhr/documents/FHR_Workshop_Summary.pdf (Fall 2010 Report)

US Government...
<http://energyfromthorium.com/pdf/CivilianNuclearPower.pdf> (1962 report to JFK)
www.ornl.gov/info/ridgelines/mov12/msre.htm
www.reddit.com/r/politics/shirt/aijbb/give_the_world_the_best_christmas_present_of_all/
<http://tinyurl.com/ye27k98>

Thorium-232 (Th232) absorbs a neutron, becoming Th233, which has a half-life of only 22 minutes. Th233 decays into Protactinium (Pa233) through beta decay (electron emission). Pa233 has a half-life of 27 days and beta decays into U233. Alternatively, Th232 can absorb a proton and move directly to U233 (the Japanese use this approach via a common proton accelerator).

U233 Fission...
<http://en.wikipedia.org/wiki/Uranium-233>
 Relative yields of Sr89, Sr91, Ba139, Ba140 & La141 are about equal (10%) for U233 fission. For U239, Sr is attenuated to 0.3 - 0.4...
<http://article.pubs.nrc-cnrc.gc.ca/ppv/RPViewDoc?issn=1480-3291&volume=37&issue=4&startPage=660>
 U233 fission-product masses: 91, 141, 143, 144, 147, 149, 151, 153 & 156

When used in a reactor to breed ²³³U for fission, Thorium has so high an energy density that 12 grams (about 4 pennies) provides enough energy to supply a typical American's needs for a decade. That much Thorium can be found in about any cubic meter of rock on Earth, Moon or Mars. **DoE has a 3200-ton stockpile – enough for years of all US energy needs without mining.** Mining of 'rare earths' typically yields abundant Thorium as a byproduct – a free fuel!



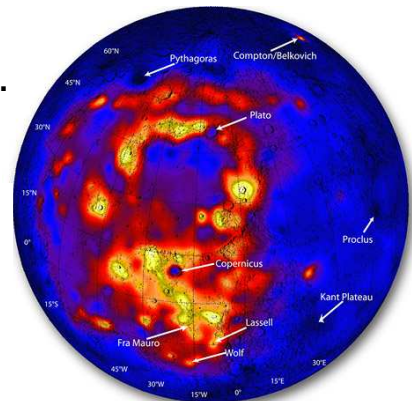
Courtesy US DoE



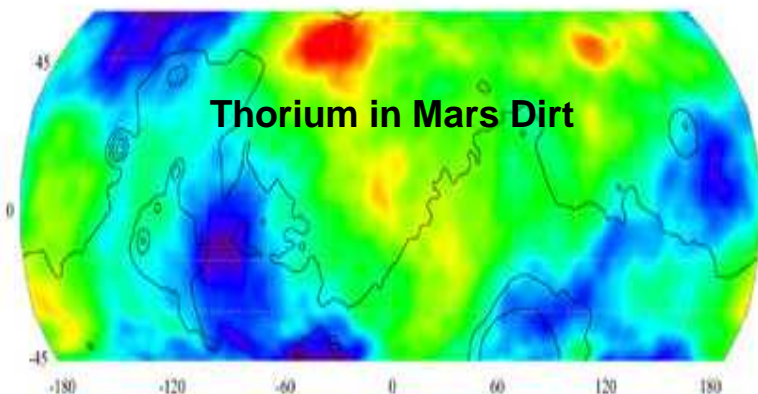
Thorium in Moon Dirt...



Monazite (>4% Th)
www.ornl.gov



17
 0
 Thorium (parts per million)



Thorium in Mars Dirt



1/2 Oz. Thorium runs 1 American's life for 1 decade

Safe Nuclear Power

- 20% of US generation now, >70% of French (reprocessing):
 - China, India, Japan, UK, Germany, Norway...
- High power density (>60MW/acre), 24-hour source
 - **Every GW of nuclear capacity avoids releasing 1.5 million tons of CO₂ per year versus getting that GW from burning natural gas – coal even worse.**
 - Fission is only realistic choice today:
 - Fusion's Tritium-breeding efficiency problem unsolved (but MSR can solve it*)
 - **Safest is MSR: no meltdown, no weapons, low waste, low cost**
 - Current Uranium cycle in PWR/BWR wasteful & expensive
 - Solid fuel creates fabrication, operation & cleanup problems
 - Liquid-salt fuel becomes an easier, safer chemistry problem
 - **No explosive potential** (steam or nuclear)
 - *Lithium-6/7 salt inclusion makes Tritium & Helium3 for fusion research & medicine
- Safest fission begins at the lowest fissile nucleus: ²³³U
 - ²³³U doesn't occur in nature because of its ~160k-year half life
 - ²³³U is easily created (bred) from Thorium via slow neutrons or protons
 - Thorium & Uranium can easily be converted to salts
 - **Salts are extremely stable** in high radiation & temperature
 - Molten salt is an ideal reactor material because:
 - After startup, **Load throttles reaction-rate** via natural salt expansion with temp
 - ~30% **better thermal efficiency** than best PWR/BWR plant
 - ~10% better than most combustion plants

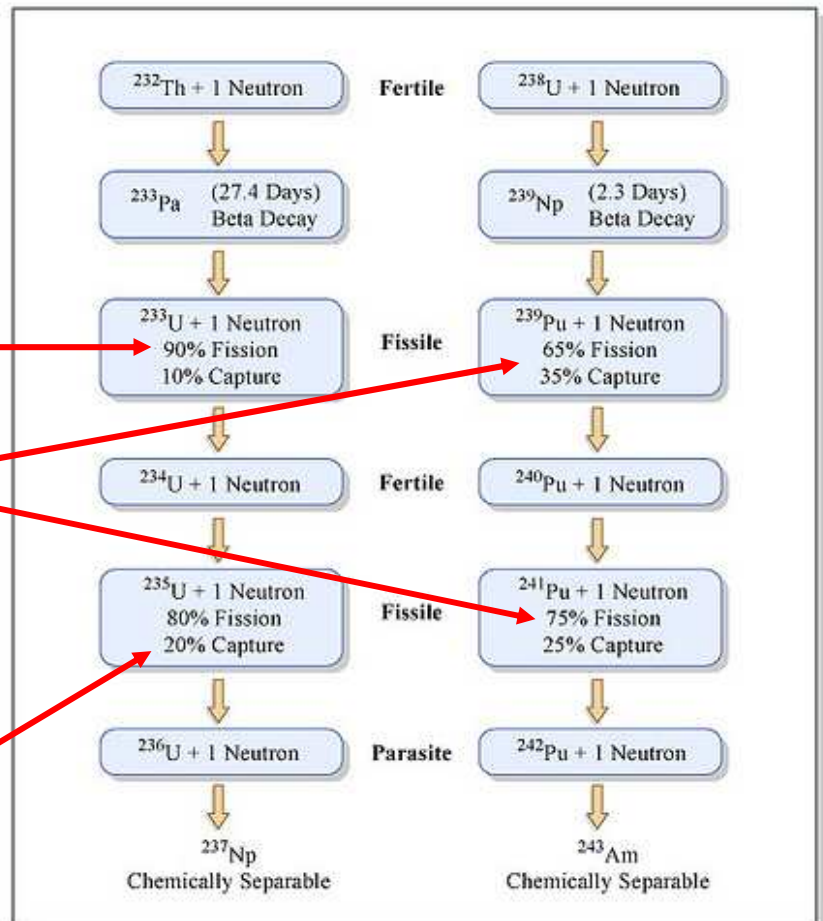
Starting fission with Thorium vs ²³⁸Uranium

Thorium bred to ²³³U with a neutron (via Protactinium decay), or via proton-beam spallation

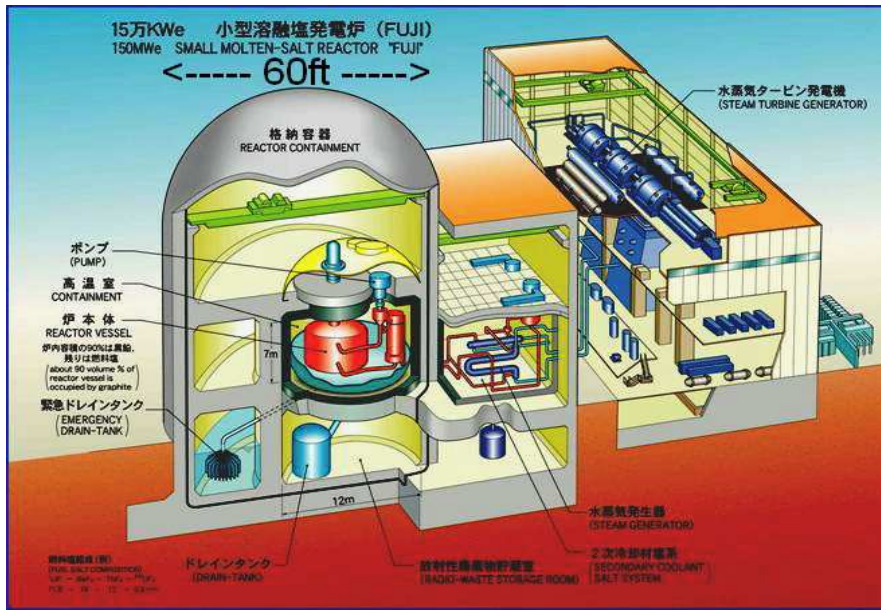
Next neutron hitting ²³³U has a very high probability of causing fission & releasing energy, but ²³⁸U bred to Plutonium is much less likely to fission, thus building up higher-mass Pu & waste, all of which has bomb-making potential

Because Thorium starts at mass 232 & neutron captures rarely exceed 236 (< 20% of 10% = 2%), ²³⁸U & Pu are rarely produced, but are consumed if fissile

Graphics Courtesy of Wikipedia

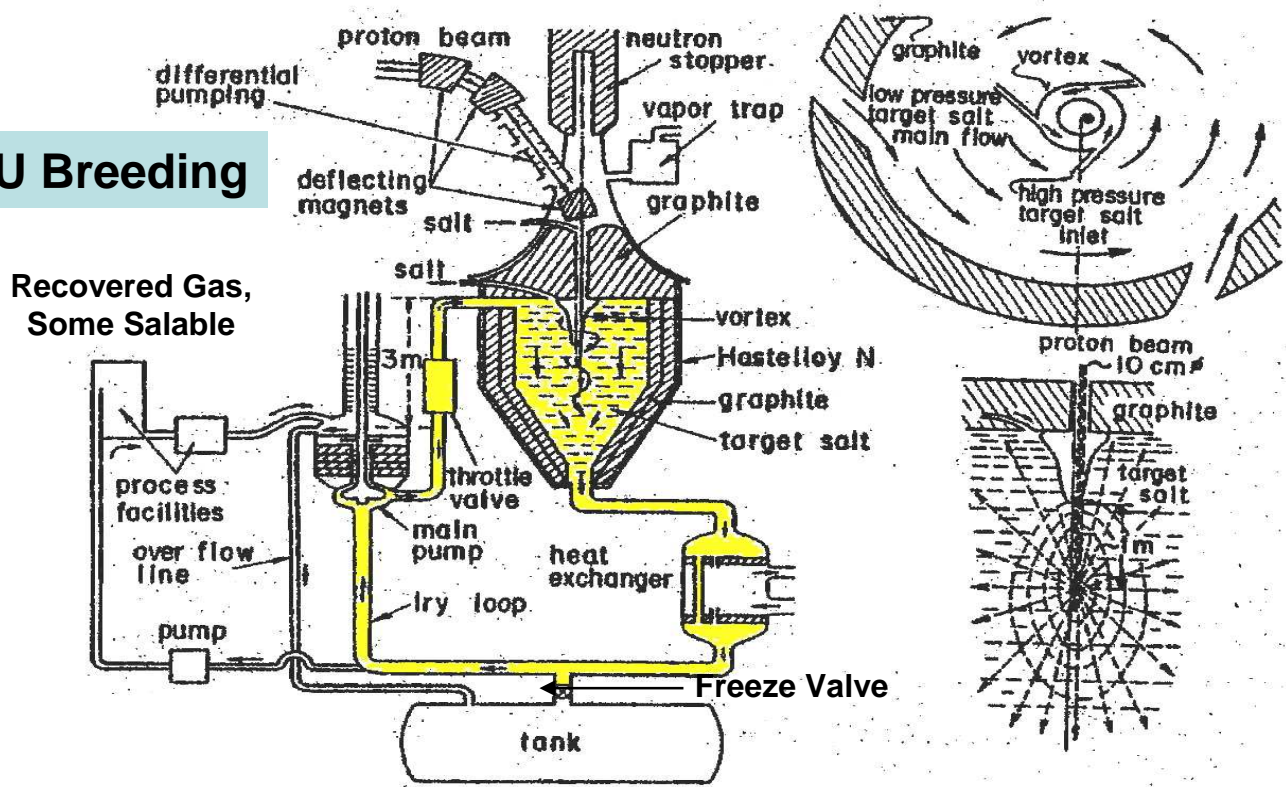


Japanese Thorium MSR Design



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 %

²³³U Breeding

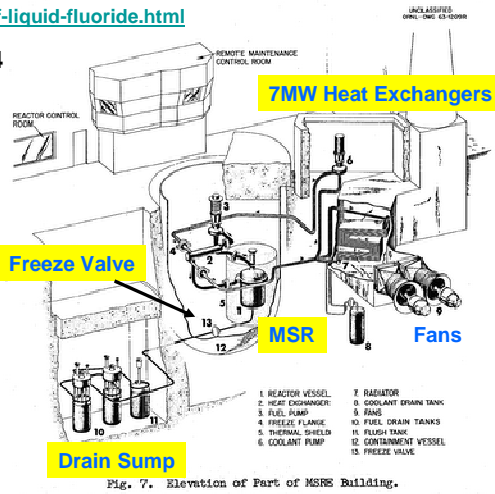
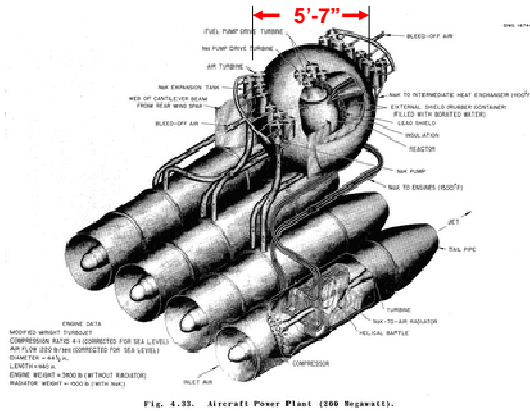


US MSR History

thoriumenergy.blogspot.com/2006/04/brief-history-of-liquid-fluoride.html

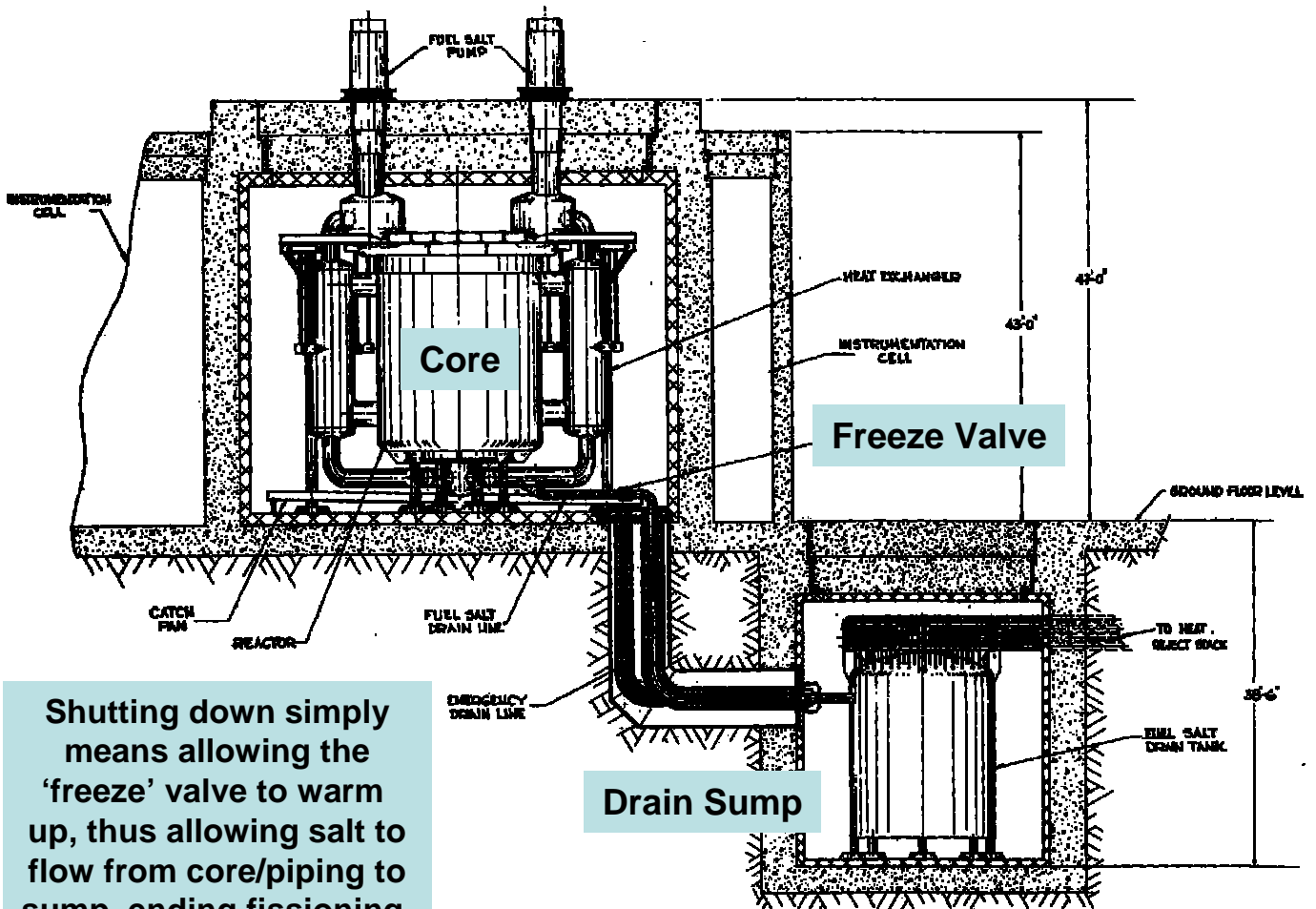
Work began in 1954 & continued to 1974
(MSRE ran 4 years, >17,000 hours)

200MW "Fireball" Test Aircraft Reactor & Turbines



MSRE Test-Reactor Building

Molten-Salt Reactor & Shutdown Sump Structure...



Shutting down simply means allowing the 'freeze' valve to warm up, thus allowing salt to flow from core/piping to sump, ending fissioning.