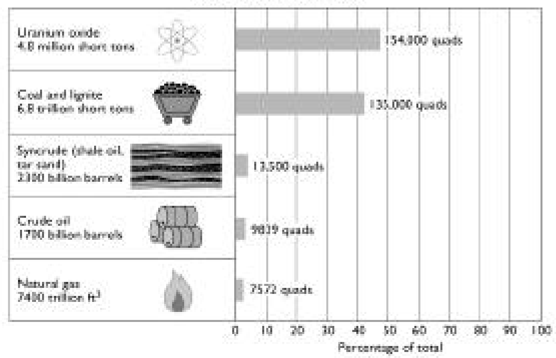
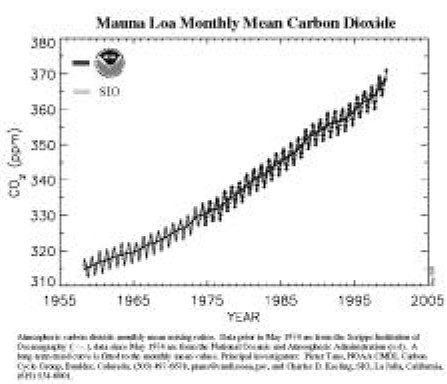
Radioactive Waste

Why Tuff?

World Energy Resources



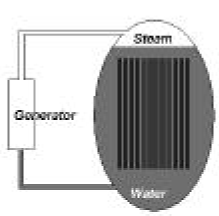


Nuclear - ^{235}U fission

- *^{235}U is less than 1% of natural Uranium.*
- *Can be enriched to 3.3%.*
- *US light-water reactors use water as moderator and coolant.*
- *Produces about ~16% of US electricity and about 7% of total energy consumed.*
- *No new reactors.*
- *Size of energy resource is larger than coal.*

^{235} U Fission

- *US light-water reactor*
- *Water is both moderator and heat transfer agent.*
- *Moderator slows neutrons for capture.*
- *Fuel is UO_2 enriched to 3.3% ^{235}U.*
- *Fuel produces 3 million times as much energy per gram as fossil fuel.*
- *Zero CO_2 emission*



^{235}U Nuclear- Other

- *Canadian (Deuterium moderated)*
  - *Unenriched U fuel*
- *High Temperature Gas-Cooled*
  - *Graphite moderated*
  - *Highly enriched fuel (weapons-grade)*
  - *Chernobyl & Fort St. Vrain*
  - *France, Germany*

Radioactive Waste

- About half of ^{235}U is consumed.
- Spent fuel rods contain ^{90}Sr and ^{137}Cs plus trans-uranics (Np, Pu, Am, Cm, etc).
- Cs and Sr have 30 year half-lives.
- TUs have up to 24,000 year half lives.
- Spent fuel still produces ~900 W/Ton of power after 10 years.

Fission Product hl > 10yr

Isotope	HalfLife	g/asby 1YR	g/asby 10YR	Ci/asby 10yr
^{85}Kr	10y	78	40	1100
^{90}Sr	29y	190	170	13,000
^{93}Zr	10^6	810	810	0.6
^{99}Tc	$2x10^5$	200	200	3.4
^{107}Pd	$7x10^6$	340	340	0.03
^{126}Sn	10^5	12	12	0.2
^{129}I	$2x10^7$	62	62	0.01
^{135}Cs	$2x10^6$	350	350	0.5
^{137}Cs	30	330	270	22,000
^{151}Sm	93	190	185	31

Spent Fuel Heat Production W/MT

- 90d 27,000
- 1y 9,200
- 10y 860
- 100y 190
- 1000y 38
- 3000y 19

(25,000 MWd/MT @ 25MW/MT power)

Geologic Host Rocks

- Salt (Germany, France, WIPP)
  - High Thermal conductivity
  - Self-sealing (flows plastically)
- Granite (Sweden)
  - Good thermal conductivity
  - Stable craton environment
- Tuff (Yucca Mountain, Nevada)
  - It's in Nevada.
  - It's already contaminated.

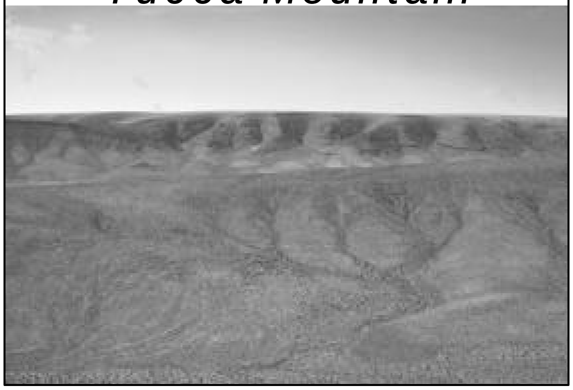
Thermal Conductivities

- Salt 6 W/mK
- Quartz 6 W/mK
- Granite 3 W/mK
- Shale 1-2 W/mK
- Welded Tuff 2 W/mK
- Nonwelded 0.5 W/mK
- Pumice 0.02 W/mK

Yucca Mountain

Yucca Mountain

Yucca Mountain



Tuff

- Tuff is rhyolite volcanic ash.
- It is highly variable in physical properties (density, thermal conductivity etc).
- It starts as compacted tiny fragments of glass
- It may weld (compact)
- Welded tuff may devitrify (crystallize)
- Non welded tuff may alter to zeolite

Rhyolite Eruptions

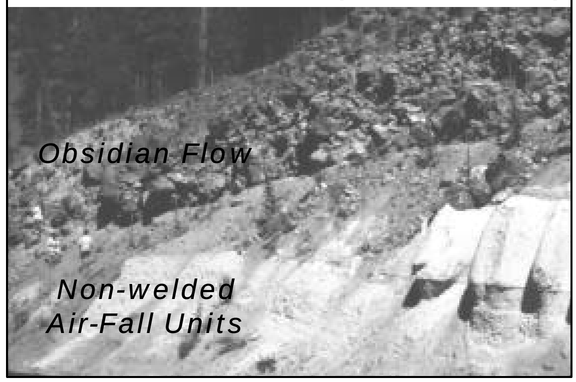
- Very high viscosity
- Low temperature (600 - 800ºC)
- Massive Pyroclastic eruptions
  - Air fall (pumice)
  - Ash Flow (Nuée Ardente) Tuff
  - Obsidian Flows
- Edifice
  - Caldera (5 - 25 km)
  - Resurgent dome

Rhyolite Eruptions

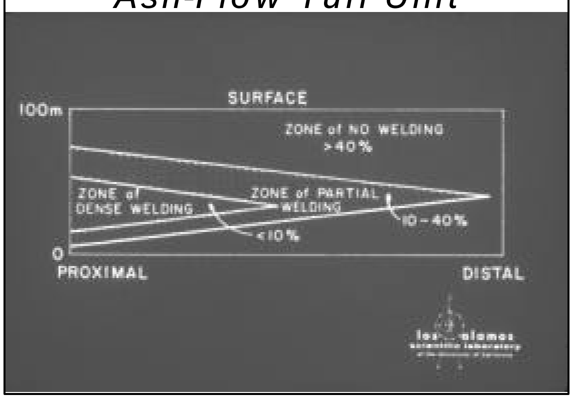
- Associated Phenomena
  - Hot Springs
  - Geysers
  - Fumaroles
- Geologic Setting
  - Continental Margins and Interiors
  - Subduction Zones

Pumice = Glass foam

Silicic Tuff Units (Jemez, NM)



Ash-Flow Tuff Unit

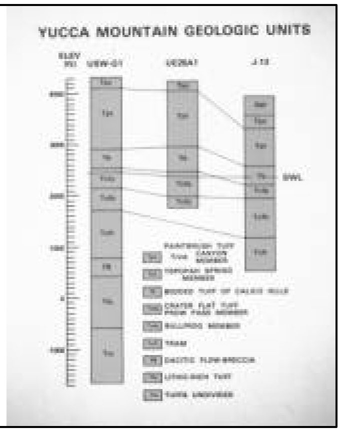


Ash-Flow Tuff Cooling Unit

Ash-Flow Tuff with Air-Fall Units (pumice)

Topopah Springs Tuff

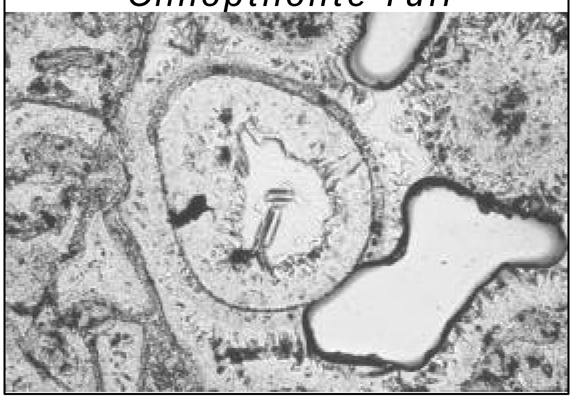
Yucca Mountain Units



Zeolite Alteration

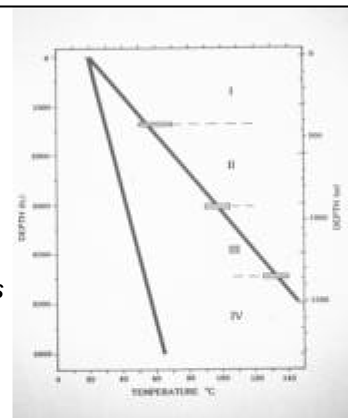
- Zeolites are framework silicates with hydrated interstitial cations.
- Glass alters to zeolites in several zones that reflect alteration temperatures.
  - Zone I — Opal/Cristobalite
  - Zone II — Clinoptilolite
  - Zone III — Analcime
  - Zone IV — Albite

Clinoptilolite Tuff



Zeolite Zones

Indicate higher temperatures in the past



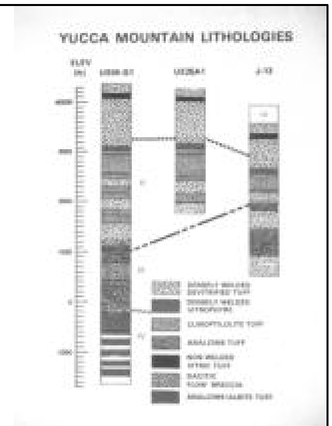
G-Tunnel, NTS

Zeolites in veins indicate upward movement of aqueous fluids

Zeolite Stability

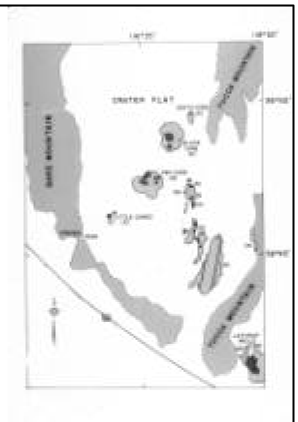
- *Zeolites form from glass*
- *Zeolite zone boundaries start at 65º*
- *Cannot emplace heat generating wastes in zeolite horizons (below SWL)*
- *Zeolites in veins indicate upward high temperature water flow in past.*

Yucca Mountain Lithology



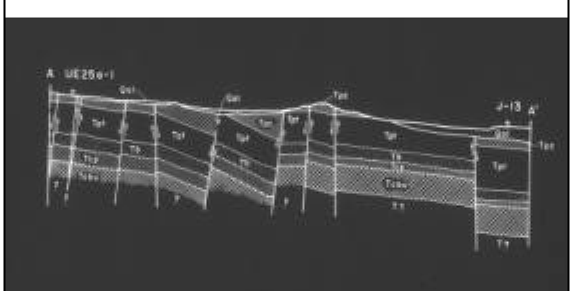
Recent Volcanism:

Obvious problem



Recent Volcanism

Faulting



Tuff (Yucca Mountain)

- *Advantages*
  - *Deep unsaturated Zone*
  - *Zeolites in groundwater flow path*
  - *Easy to mine*
  - *Remote from population centers (other than Las Vegas).*
- *Disadvantages*
  - *Low thermal conductivity*
  - *Geologically active (young cinder cones)*
  - *Faulted medium*
  - *Variable physical properties*

Tuff Technical Difficulties

- *Thermal Conductivity*
  - *Highly variable*
  - *Pumice units may not be recovered in core*
  - *Thermal models are questionable*
- *Recent volcanism*
  - *Very obvious*
- *Hydrology*
  - *Very difficult to model (Faulting & Physical properties)*
  - *Evidence of hot springs and upward movement of heated fluids not considered*

Geologic Host Rocks: Hanford