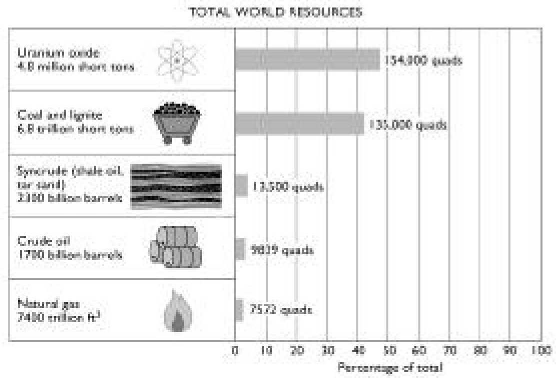
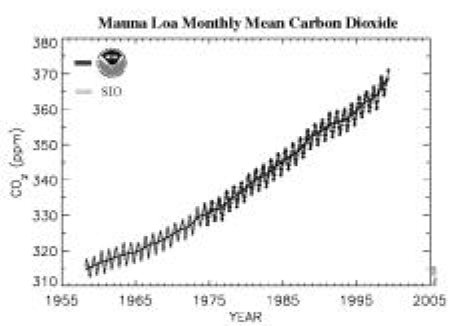
Radioactive Waste

Why Tuff?

World Energy Resources



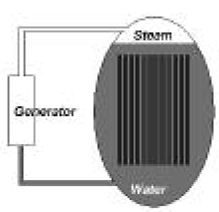


Nuclear - ^{235}U fission

- *^{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.*

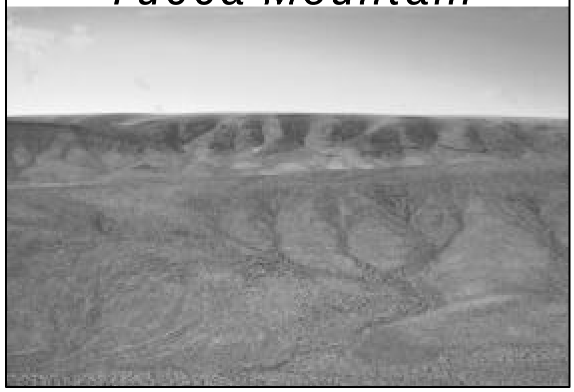
Thermal Conductivities

- *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

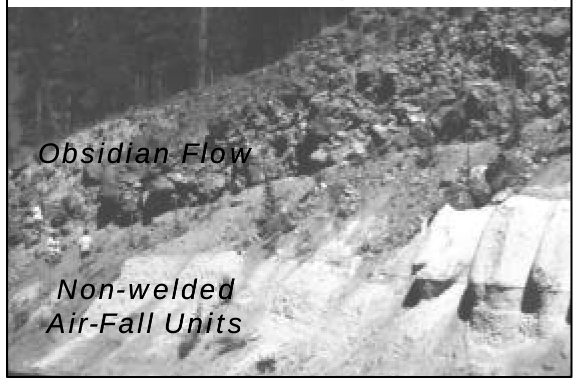
- Very high viscosity
- Low temperature (600 - 800ºC)
- Massive Pyroclastic eruptions
  - Air fall (pumice)
  - Ash Flow (Nuée Ardente) Tuff
  - Obsidian Flows
- Edifice
  - Caldera (5 - 25 km)
  - Resurgent dome

Rhyolite Eruptions

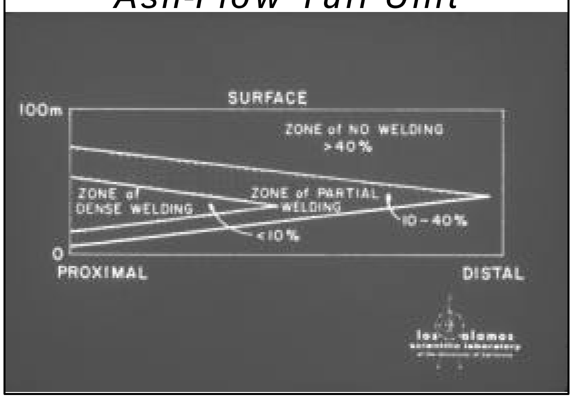
- Associated Phenomena
  - Hot Springs
  - Geysers
  - Fumaroles
- Geologic Setting
  - Continental Margins and Interiors
  - Subduction Zones

Pumice = Glass foam

Silicic Tuff Units (Jemez, NM)



Ash-Flow Tuff Unit



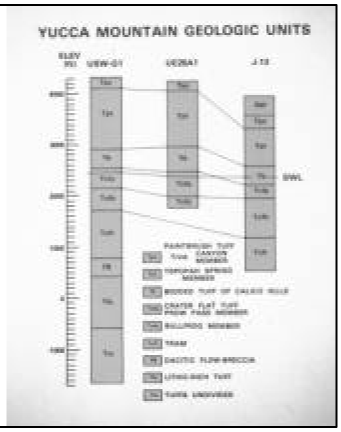
Ash-Flow Tuff Cooling Unit

Ash-Flow Tuff

with Air-Fall Units (pumice)

Topopah Springs Tuff

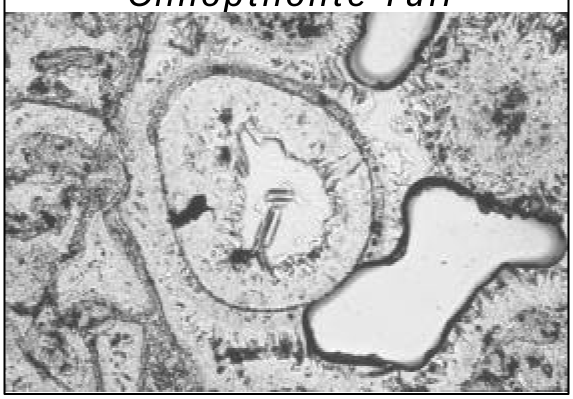
Yucca Mountain Units



Zeolite Alteration

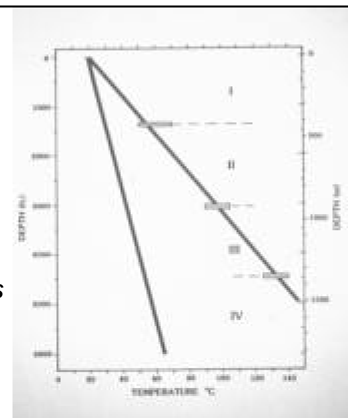
- Zeolites are framework silicates with hydrated interstitial cations.
- Glass alters to zeolites in several zones that reflect alteration temperatures.
  - Zone I Opal/Cristobalite
  - Zone II Clinoptilolite
  - Zone III Analcime
  - Zone IV Albite

Clinoptilolite Tuff



Zeolite Zones

Indicate higher temperatures in the past



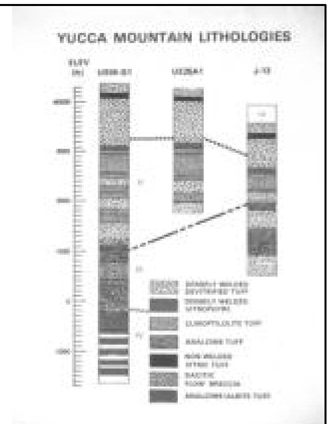
G-Tunnel, NTS

Zeolites in veins indicate upward movement of aqueous fluids

Zeolite Stability

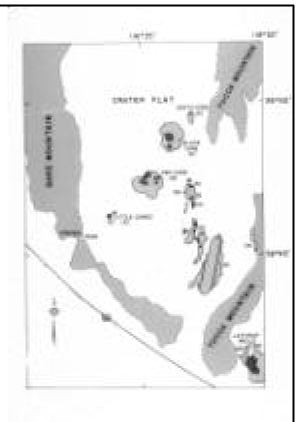
- Zeolites form from glass
- Zeolite zone boundaries start at 65º
- Cannot emplace heat generating wastes in zeolite horizons (below SWL)
- Zeolites in veins indicate upward high temperature water flow in past.

Yucca Mountain Lithology



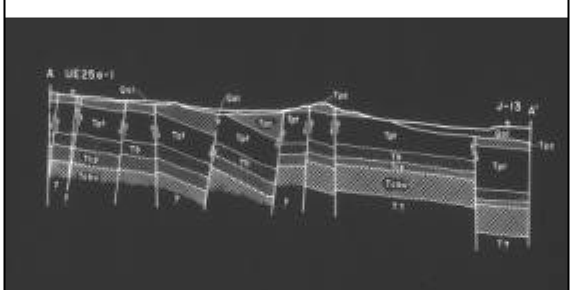
Recent Volcanism:

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