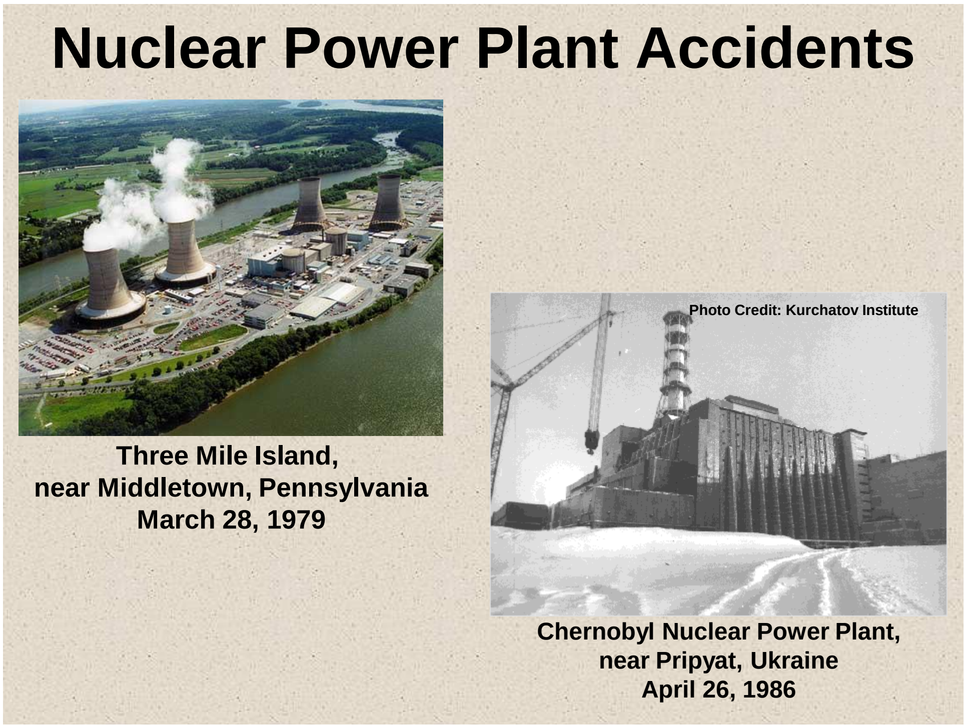
NUCLEAR POWER



Nuclear Power Plant Accidents

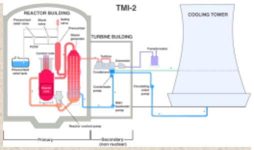
Three Mile Island,
near Middletown, Pennsylvania
March 28, 1979

Photo Credit: Kurchatov Institute

Chernobyl Nuclear Power Plant,
near Pripyat, Ukraine
April 26, 1986

Three Mile Island

near Middletown, Pennsylvania



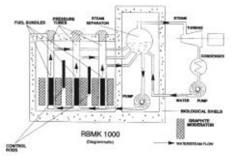
- Accident on March 28, 1979
  - Most serious in U.S. commercial nuclear power plant history
  - Equipment malfunction, design-related problems, and worker errors led to partial meltdown of the TMI-2 reactor core and very small off-site releases of radioactivity
  - No deaths or injuries to plant workers or members of nearby community
    - (avg radiation dose from accident: ~1 millirem; full set of chest X-rays ~6 millirem; background natural radiation does of area: ~100-125 millirem)
  - Led to **sweeping** changes in plant operations
  - The TMI-2 reactor is permanently shut down and defueled, with the reactor coolant system drained, the radioactive water decontaminated and evaporated, radioactive waste shipped off-site to an appropriate disposal site, reactor fuel and core debris shipped off-site to a Department of Energy facility, and the remainder of the site being monitored. The owner says it will keep the facility in long-term, monitored storage until the operating license for the TMI-1 plant expires at which time both plants will be decommissioned.

Some major changes made since the Three Mile Island accident:

- Upgrading and strengthening of plant design and equipment requirements, including fire protection, piping systems, auxiliary feedwater systems, containment building isolation, reliability of individual components (pressure relief valves and electrical circuit breakers), and the ability of plants to shut down automatically;
- Identifying human performance as a critical part of plant safety, revamping operator training and staffing requirements, followed by improved instrumentation and controls for operating the plant, and establishment of fitness-for-duty programs for plant workers to guard against alcohol or drug abuse;
- Improved instruction to avoid the confusing signals that plagued operations during the accident;
- Enhancement of emergency preparedness: immediate NRC notification requirements for plant events and an NRC operations center which is now staffed 24 hours a day. Drills and response plans are now tested by licensees several times a year, and state and local agencies participate in drills with FEMA and NRC;
- Establishment of a program to integrate NRC observations, findings, and conclusions about licensee performance and management effectiveness into a periodic, public report;
- Regular analysis of plant performance by senior NRC managers who identify those plants needing additional regulatory attention;
- Expansion of NRC's resident inspector program: at least two inspectors live nearby and work exclusively at each plant in the U.S to provide daily surveillance of licensee adherence to NRC regulations;
- Expansion of performance-oriented as well as safety-oriented inspections, and the use of risk assessment to identify vulnerabilities of any plant to severe accidents;
- Strengthening and reorganization of enforcement as a separate office within the NRC;
- Establishment of the Institute of Nuclear Power Operations (INPO), the industry's own "policing" group, and formation of what is now the Nuclear Energy Institute to provide a unified industry approach to generic nuclear regulatory issues, and interaction with NRC and other government agencies;
- The installing of additional equipment by licensees to mitigate accident conditions, and monitor radiation levels and plant status;
- Employment of major initiatives by licensees in early identification of important safety-related problems, and in collecting and assessing relevant data so lessons of experience can be shared and quickly acted upon;
- Expansion of NRC's international activities to share enhanced knowledge of nuclear safety with other countries in a number of important technical areas.

Chernobyl Plant

near Pripyat, Ukraine



- Accident on April 26, 1986
  - Most serious in global nuclear power plant history
  - Plant not properly designed & could only be run with very specific instructions;
    - Operators failed to follow instructions
    - Scientists were trying to determine how long turbines would spin and supply power following loss of main electrical power supply – risky experiment b/c reactors were known to be unstable at low power settings (removed safety and cooling equipment for experiment)
    - Fuel elements ruptured, explosive steam pressure blew cover plate from reactor emitting molten uranium, burning graphite, radioactive ash into atmosphere
      - NOT a nuclear explosion but amount of material released was 10 times that caused by US atomic bombing of Hiroshima

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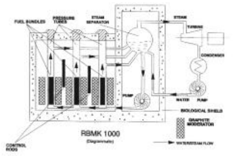
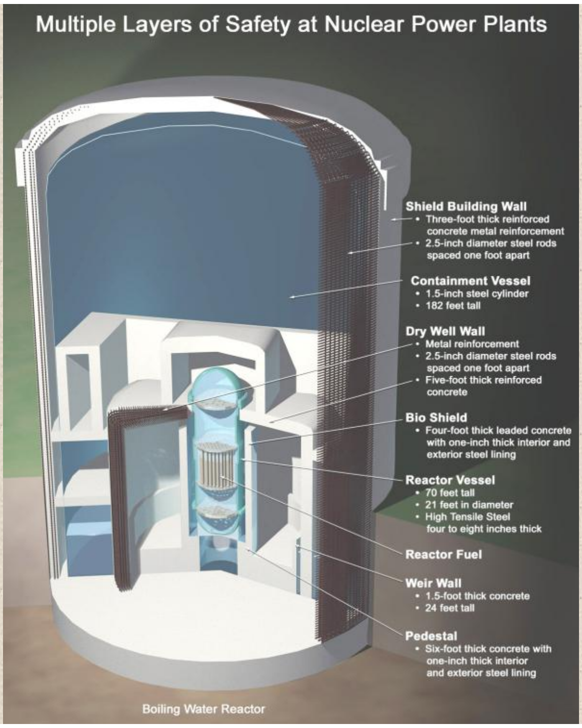
Chernobyl Plant

near Pripyat, Ukraine



- Accident on April 26, 1986
  - 135,000 people evacuated; 30-km exclusion zone created, later extended to cover 4300 km^2
    - 30-31 people died in accident and immediate aftermath from radiation exposure (most in fighting fires); 209 on site and involved in clean up were treated for acute radiation poisoning (19 of these later died from effects)
      - Radiation doses were up to 20,0000 millisieverts
    - Estimates vary on delayed health effects, and published reports range from negligible to extensive
      - At least 9 children died from thyroid cancer related to radiation
  - Reactor type is RBMK: high-power, pressure-tube reactors
    - These reactors are NOT used in the U.S. because of safety concerns

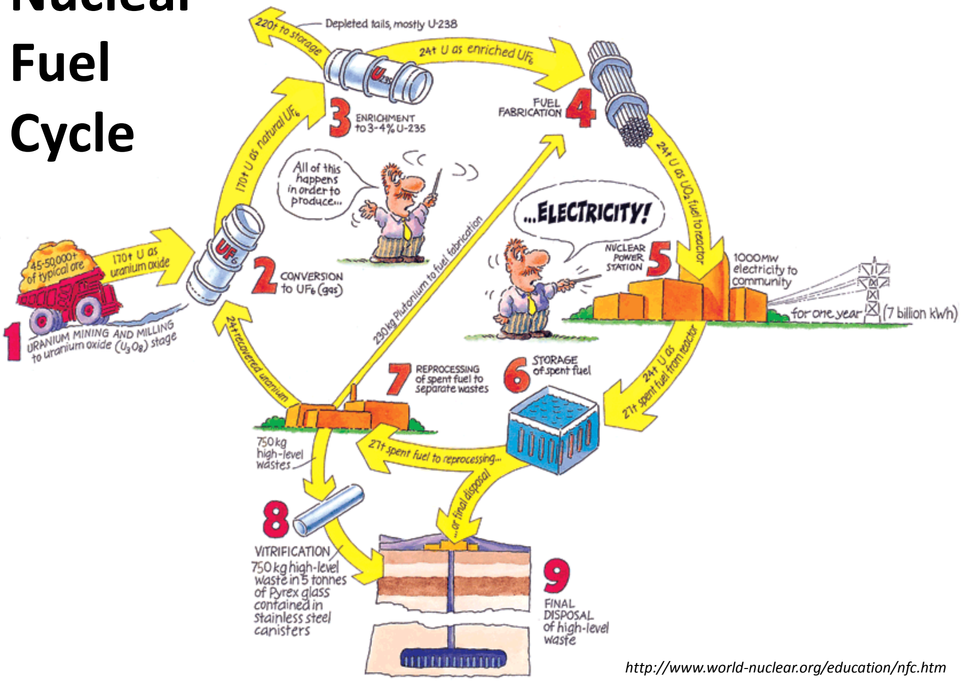
Safety


Multiple Layers of Safety at Nuclear Power Plants
Shield Building Wall
• Three-foot thick reinforced concrete metal reinforcement
• 2.5-inch diameter steel rods spaced one foot apart
Containment Vessel
• 1.5-inch steel cylinder
• 182 feet tall
Dry Well Wall
• Metal reinforcement
• 2.5-inch diameter steel rods spaced one foot apart
• Five-foot thick reinforced concrete
Bio Shield
• Four-foot thick leaded concrete with one-inch thick interior and exterior steel lining
Reactor Vessel
• 70 feet tall
• 21 feet in diameter
• High Tensile Steel four to eight inches thick
Reactor Fuel
Weir Wall
• 1.5-foot thick concrete
• 24 feet tall
Pedestal
• Six-foot thick concrete with one-inch thick interior and exterior steel lining
Boiling Water Reactor

See:

http://en.wikipedia.org/wiki/Nuclear_reactor
for cool images &
future/developing technologies

Nuclear Fuel Cycle

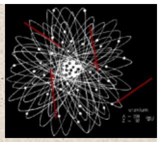


http://www.world-nuclear.org/education/nfc.htm

Quatities & Cost

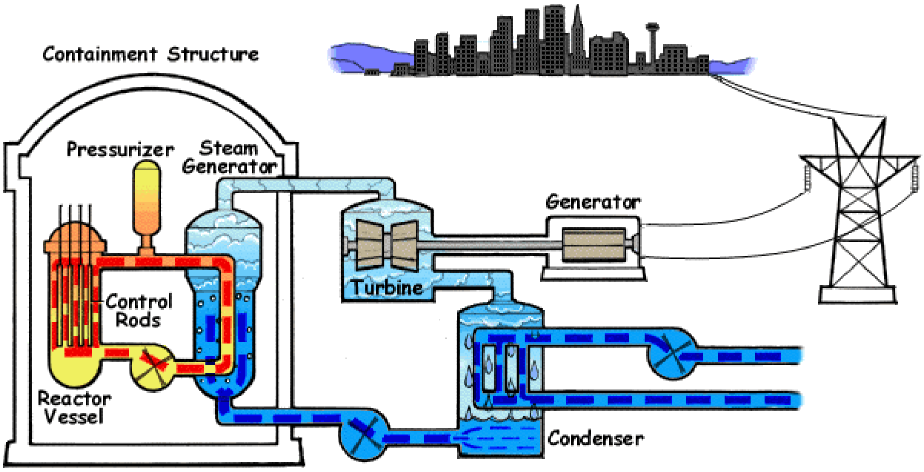
- In the diagram above it can be seen that about 200 tonnes U_3O_8 containing 170 tU gives rise to 24 tonnes of uranium in enriched UO_2 fuel, via conversion and enrichment stages. So, to get 1 kg of enriched uranium in fuel you need about 8 kg of mine product, now @ US$ 90/kg or a bit more, hence US$ 720. (In fact the utility often buys this material, then gets it converted to UF_6, then enriched, then fabricated, rather than buying the finished product.)
- 1 kg of enriched fuel (@3.5% U-235) will need an input of 4.8 SWU (see glossary) @ US$ 122/SWU, hence $ 586.
- But before this the uranium conversion will cost US$ 12/kg U, so for about 7 kg U it costs about $85.
- Total cost is thus about US$ 1393 for 1 kg enriched fuel, plus about $240 for actual fuel fabrication. This will yield about 3900 GJ thermal energy at modern burn-up rates, or about 360,000 kWh of electricity (at 33% thermal efficiency), and does the same job as about 160 tonnes of steaming coal for a total cost of 0.45 cents/kWh (US$) - a bit more at lower burn-up.

Uranium



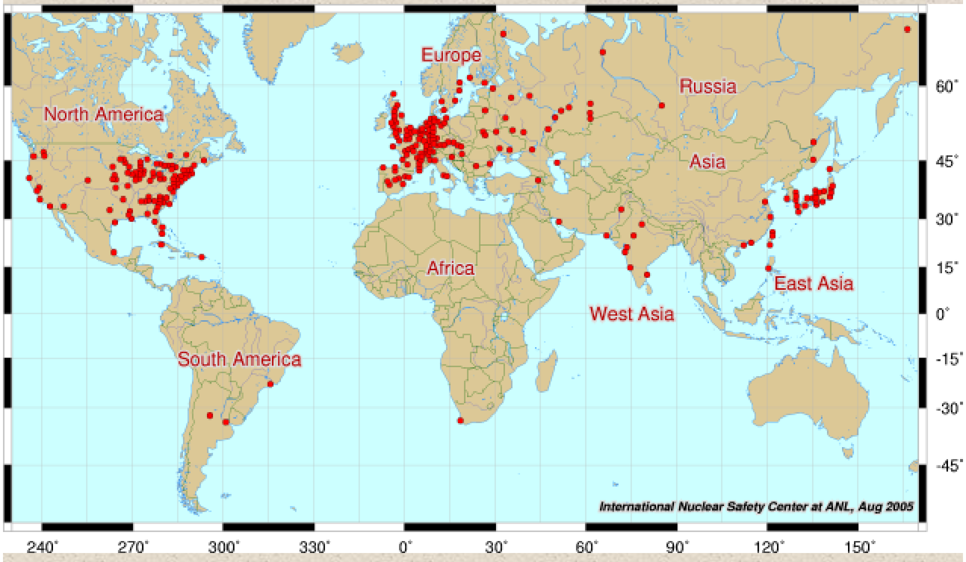
- Heaviest natural element (92 protons)
- 2 ppm in earth's crust
  - To be mined, must be at least 100 ppm of the rock it is in
  - Wyoming and Four Corners region produce most U.S. uranium
  - DOE estimates that U.S. has proven uranium reserves of at least 300 million lbs; Power plants use over 40 million lbs/year
- 1 lb of uranium has as much energy as 3,000,000 lbs of coal

Nuclear Power Plant Operations



Animation from the Nuclear Regulatory Commission Students' Corner
http://www.nrc.gov/reading-rm/basic-ref/students.html

Global Nuclear Energy

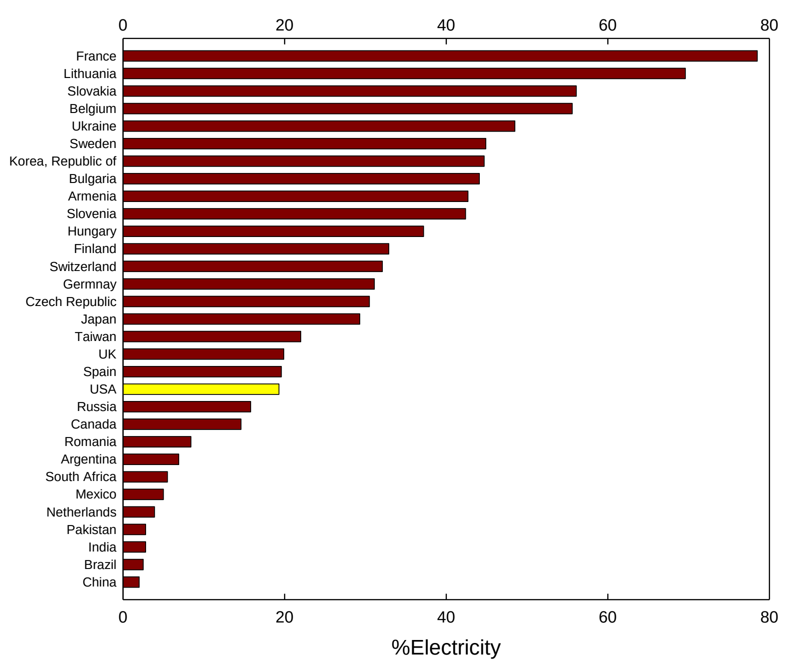


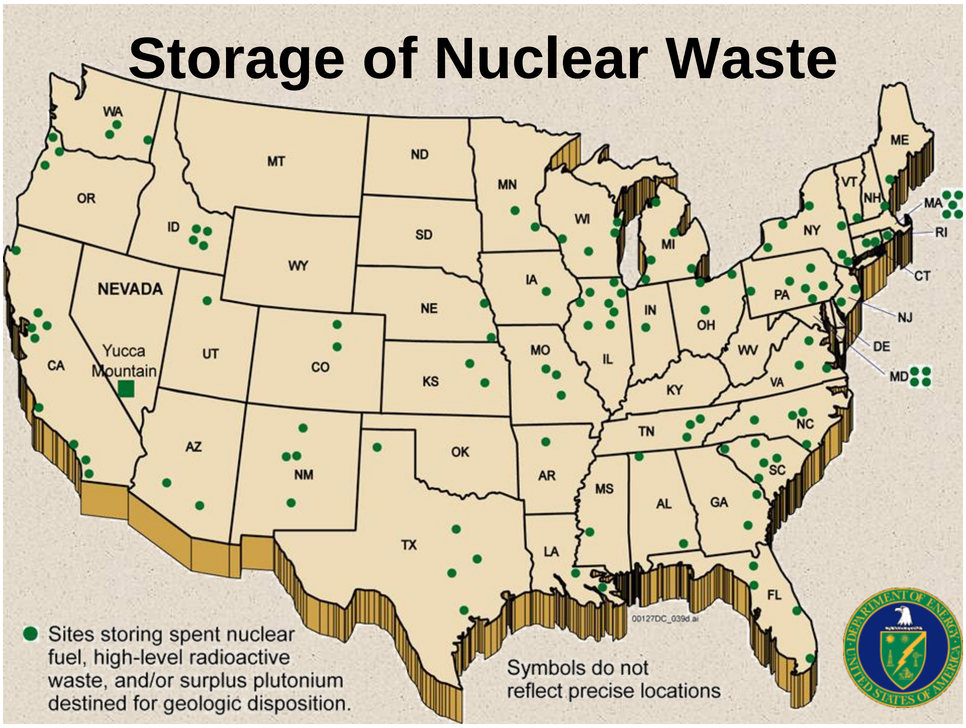
International Nuclear Safety Center at ANL, Aug 2005

108 Nuclear Power Plants in the U.S.

Accounts for **~19%** of the total net electricity generated in the U.S.; about as much electricity as is used in CA, TX and NY combined.

%Electricity Generated from Nuclear Power

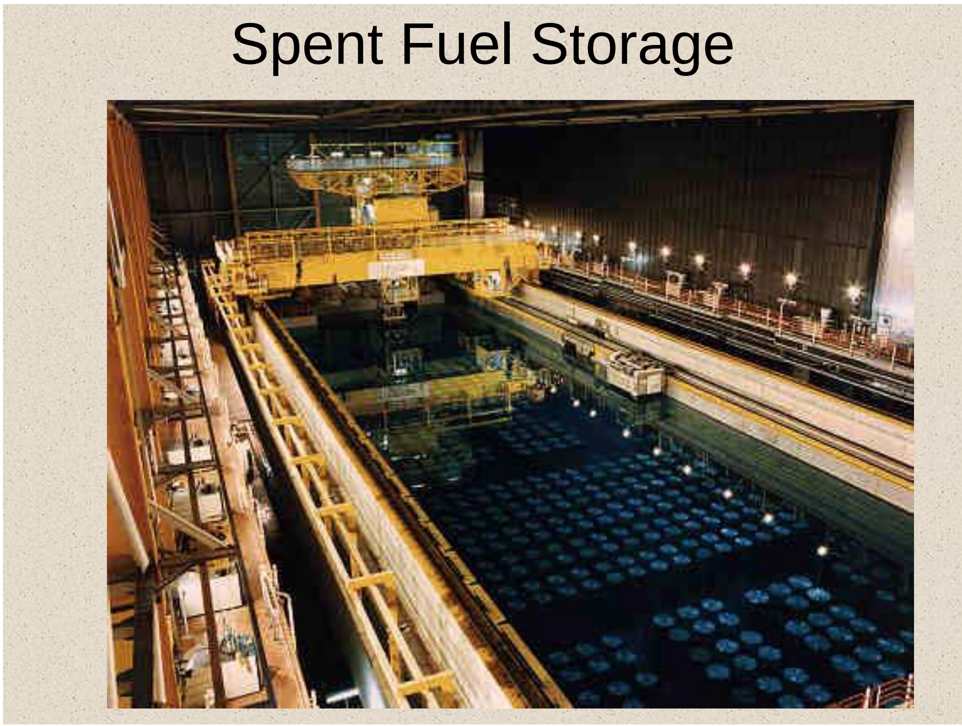




Storage of Nuclear Waste

● Sites storing spent nuclear fuel, high-level radioactive waste, and/or surplus plutonium destined for geologic disposition.

Symbols do not reflect precise locations



Spent Fuel Storage

Temporary Storage

Fuel Rod storage pools

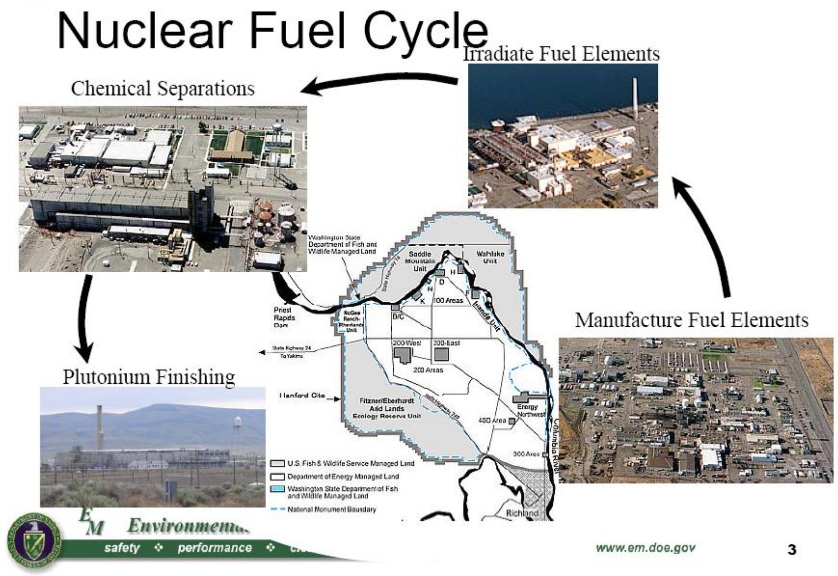
Dry storage containers

Storage pool for spent fuel at UK reprocessing plant

Loading silos with canisters containing vitrified high-level waste in UK, each disc on the floor covers a silo holding ten canisters

http://www.uow.edu.au/eng/phys/nukeweb/fuel_disposal.html

Hanford Site, Washington



Nuclear Fuel Cycle

Irradiate Fuel Elements

Chemical Separations

Manufacture Fuel Elements

Plutonium Finishing

www.em.doe.gov

3

http://www.em.doe.gov/pdfs/12_Thompson_Peterson -FINAL NAS GW Overview Oct 31_2007Presentation.pdf

New research could spearhead permanent nuclear waste storage

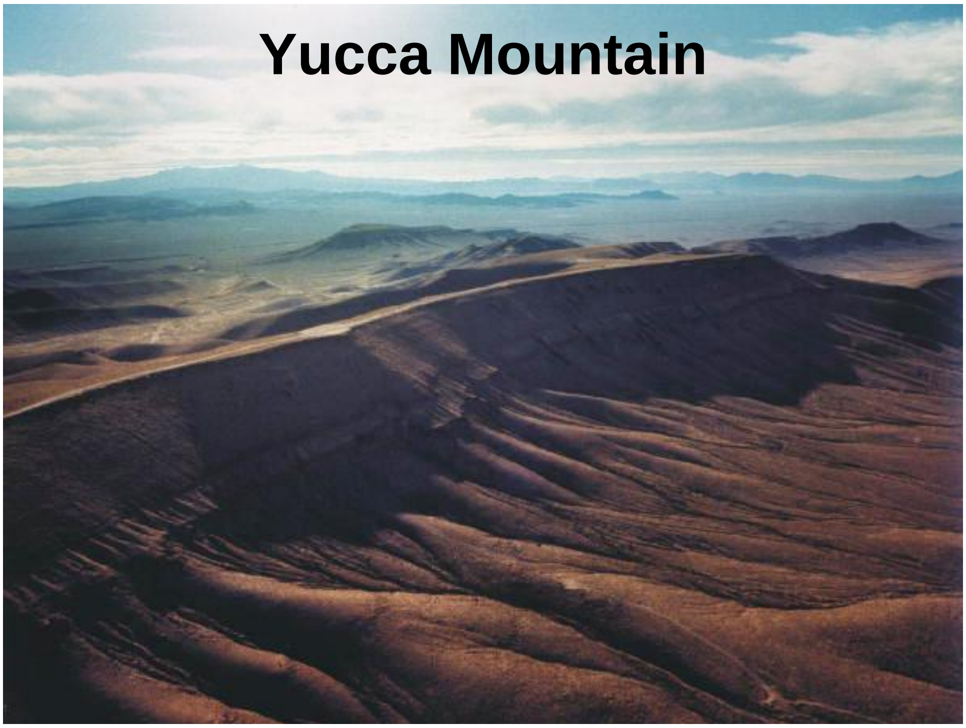
May 6, 2002

- Radioactive waste is primarily a combination of fuel rods and caustic solutions added to storage takes to break down rods => unknown chemistry
- Need to decrease the waste volume
- Studies underway to better understand the chemistry of the waste and how it reacts in different environments

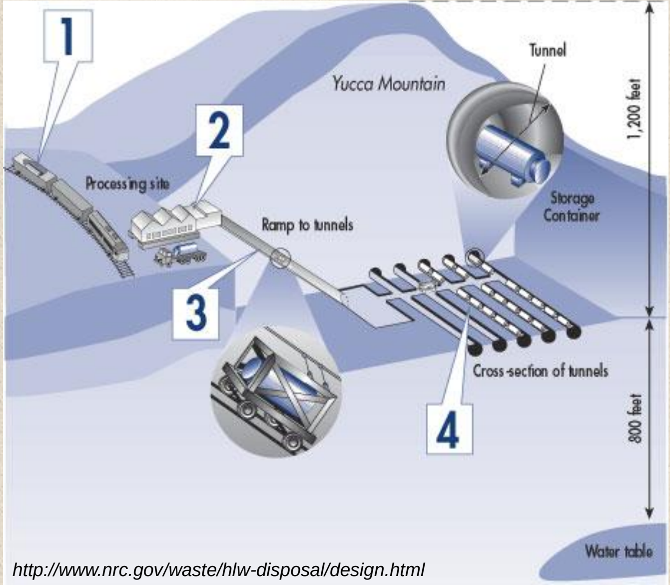
Permanent Storage

- Radioactive Waste must be dealt with for the next 10,000 to 1,000,000 years
- Long-term storage requires stabilization of waste into a form that will not react or degrade for extended periods of time.
  - Vitrification (high-level waste)
    - Evaporate water and de-nitrate fission products
    - Added to molten glass matrix, poured into stainless steel cylinders and sealed
    - Stored in underground repository
  - Ion exchange (medium active waste - NPP)
    - Concentrate radioactivity into small volume through ion exchange
    - Mix resulting sludge with cement (fly ash, blast furnace slag, or portland cement) in metal drum for storage
  - Synroc
    - Currently being developed for U.S. military waste
    - Synthetic rock is created from waste, developed at Australian National University

Yucca Mountain



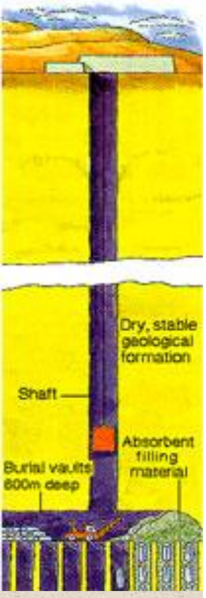
Conceptual Design of Yucca Mountain Disposal Plan



http://www.nrc.gov/waste/hlw-disposal/design.html

1. Canisters of waste, sealed in special casks, are shipped to the site by truck or train.
2. Shipping casks are removed, and the inner tube with the waste is placed in a steel, multilayered storage container.
3. An automated system sends storage containers underground to the tunnels.
4. Containers are stored along the tunnels, on their side.

Yucca Mountain



Nuclear Fuel Recycling

Nuclear Fuel Recycling

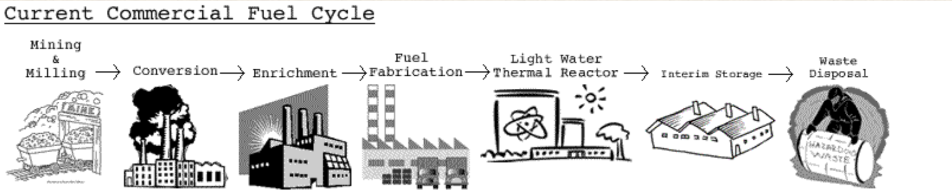
- Fuel rods are neutron emitters that, in close proximity to each other, begin a self-sustaining chain reaction – releasing energy and producing new elements by fission of uranium and producing plutonium (^{239}Pu) by nuclear chain reactions.

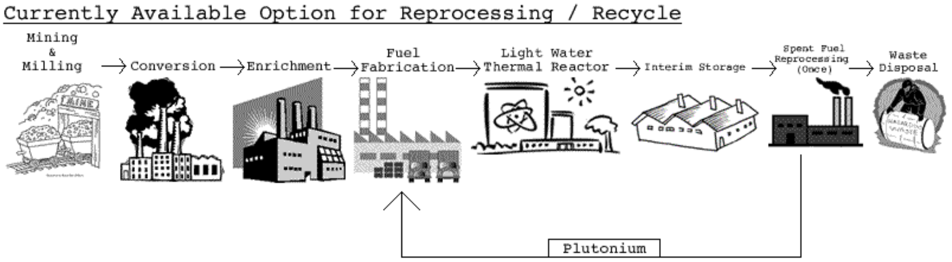
Nuclear Fuel Recycling

- Nuclear fuel is uranium oxide is enriched to 3-4%; ^{235}U is fabricated into pellets, and then inserted into fuel rods
- Fuel rods can supply energy for 1-3 years.
- Spent fuel has a considerable amount of ^{235}U but has also generated significant ^{239}Pu.
- After 3 years in a reactor, 1,000 lbs of 3.3-percent-enriched uranium (967 lb of ^{238}U and 33 lbs of ^{235}U) contains
  - 8 lbs of ^{235}U and 8.9 lbs of plutonium
  - Separating these two from the other components greatly reduces the radioactivity of the residue
  - Purified ^{235}U can be used as reactor fuel.

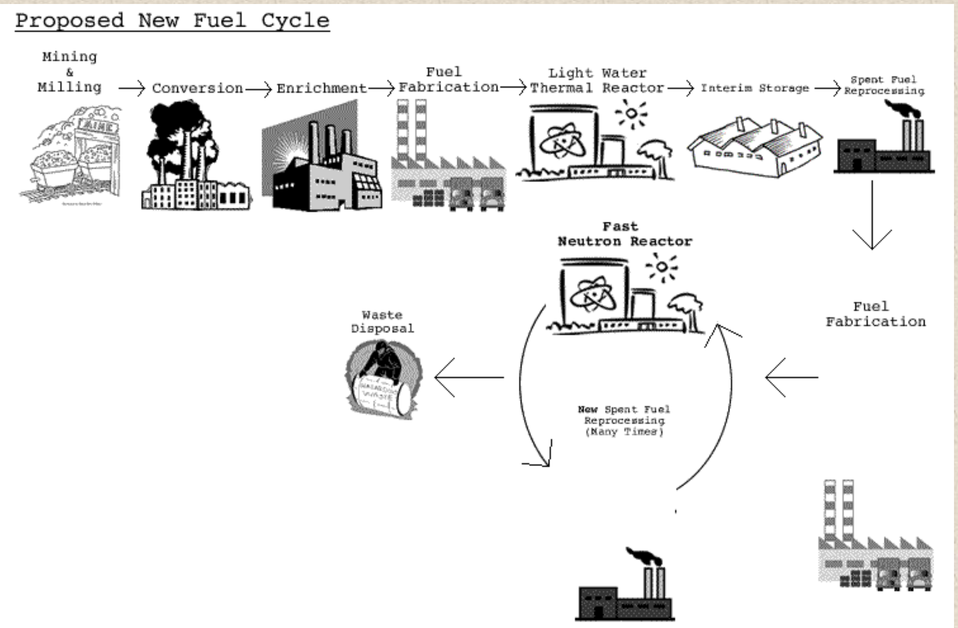
Nuclear Fuel Recycling

- U.S. doesn’t reprocess spent fuel, although it was planned at one time.
- France has been reprocessing power plant spent fuel rods at the COGEMA LaHague site since 1966.
- Problems with fuel recycling: theft of plutonium
- Safety records of current recycling plants are not good





http://www.fas.org/programs/ssp/nukes/nuclear_power_and_fuel_cycle/index.html



http://www.fas.org/programs/ssp/nukes/nuclear_power_and_fuel_cycle/index.html

Long-Term Availability of Raw Uranium Supply

How much uranium is there?

- Uranium is one of the world's most abundant metals and **can provide fuel for the world's commercial nuclear plants for generations to come**. The price of uranium has increased significantly since 2000, spurring uranium exploration and mining. (*http://www.nei.org/howitworks/nuclearpowerplantfuel/*)

OR

- There is enough uranium to maintain 1000 new reactors for their 40-year lifetime. (MIT, "The Future of Nuclear Power")

Mini Nuclear Power Plants

Mini Nuclear Power Plant

- Each one could Power 20,000 Homes
- Goal: Generate Electricity for 10 cents/Watt
- Cost: $25 million each
- Assembled quickly & transported by truck, rail, ship to remote locations, even if they do not currently have electricity

Mini Nuclear Power Plant

- Never need to be opened on site.
  - Very small amount of enclosed fuel
  - “impossible” to go supercritical or ‘melt down’
  - Buried underground; guarded by security detail
  - Not appropriate for proliferation (can’t enrich)
  - Refuel every 7-10 years
  - Total waste = size of softball & candidate for fuel recycling
- Nuclear Regulatory Commission (NRC) has no plans to review the Hyperion design in the near future
  - Very little testing information available
  - NRC expects it will take significant time to ensure safety requirements
  - Technical reports to support pre-application review will be submitted to NRC in late FY 2009.

Prospects for Nuclear Power

See report:

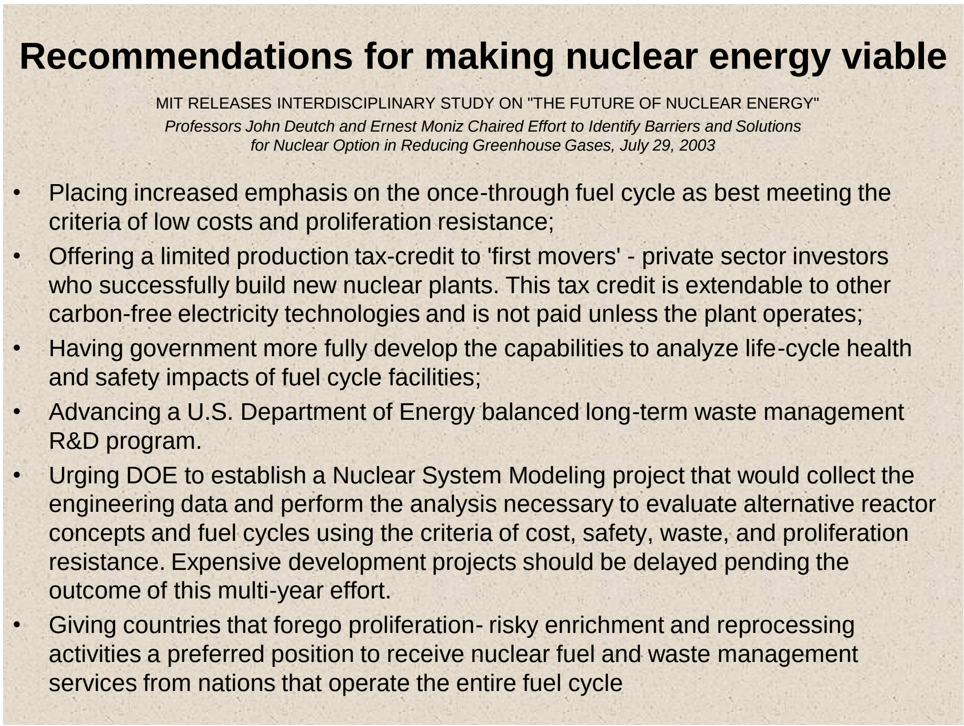
"THE FUTURE OF NUCLEAR ENERGY"
Professors John Deutch and Ernest Moniz Chaired Effort to Identify Barriers and Solutions

for Nuclear Option in Reducing Greenhouse Gases, July 29, 2003

Prospects for Nuclear Power Limited

MIT RELEASES INTERDISCIPLINARY STUDY ON "THE FUTURE OF NUCLEAR ENERGY"
Professors John Deutch and Ernest Moniz Chaired Effort to Identify Barriers and Solutions
for Nuclear Option in Reducing Greenhouse Gases, July 29, 2003

- High relative costs
- Perceived adverse safety, environmental, and health effects
- Potential security risks stemming from proliferation
- Unresolved challenges in long-term management of nuclear wastes



Recommendations for making nuclear energy viable

MIT RELEASES INTERDISCIPLINARY STUDY ON "THE FUTURE OF NUCLEAR ENERGY"

Professors John Deutch and Ernest Moniz Chaired Effort to Identify Barriers and Solutions for Nuclear Option in Reducing Greenhouse Gases, July 29, 2003

- Placing increased emphasis on the once-through fuel cycle as best meeting the criteria of low costs and proliferation resistance;
- Offering a limited production tax-credit to 'first movers' - private sector investors who successfully build new nuclear plants. This tax credit is extendable to other carbon-free electricity technologies and is not paid unless the plant operates;
- Having government more fully develop the capabilities to analyze life-cycle health and safety impacts of fuel cycle facilities;
- Advancing a U.S. Department of Energy balanced long-term waste management R&D program.
- Urging DOE to establish a Nuclear System Modeling project that would collect the engineering data and perform the analysis necessary to evaluate alternative reactor concepts and fuel cycles using the criteria of cost, safety, waste, and proliferation resistance. Expensive development projects should be delayed pending the outcome of this multi-year effort.
- Giving countries that forego proliferation- risky enrichment and reprocessing activities a preferred position to receive nuclear fuel and waste management services from nations that operate the entire fuel cycle