# Nuclear Energy

Lecture 11

Energy Law & Policy

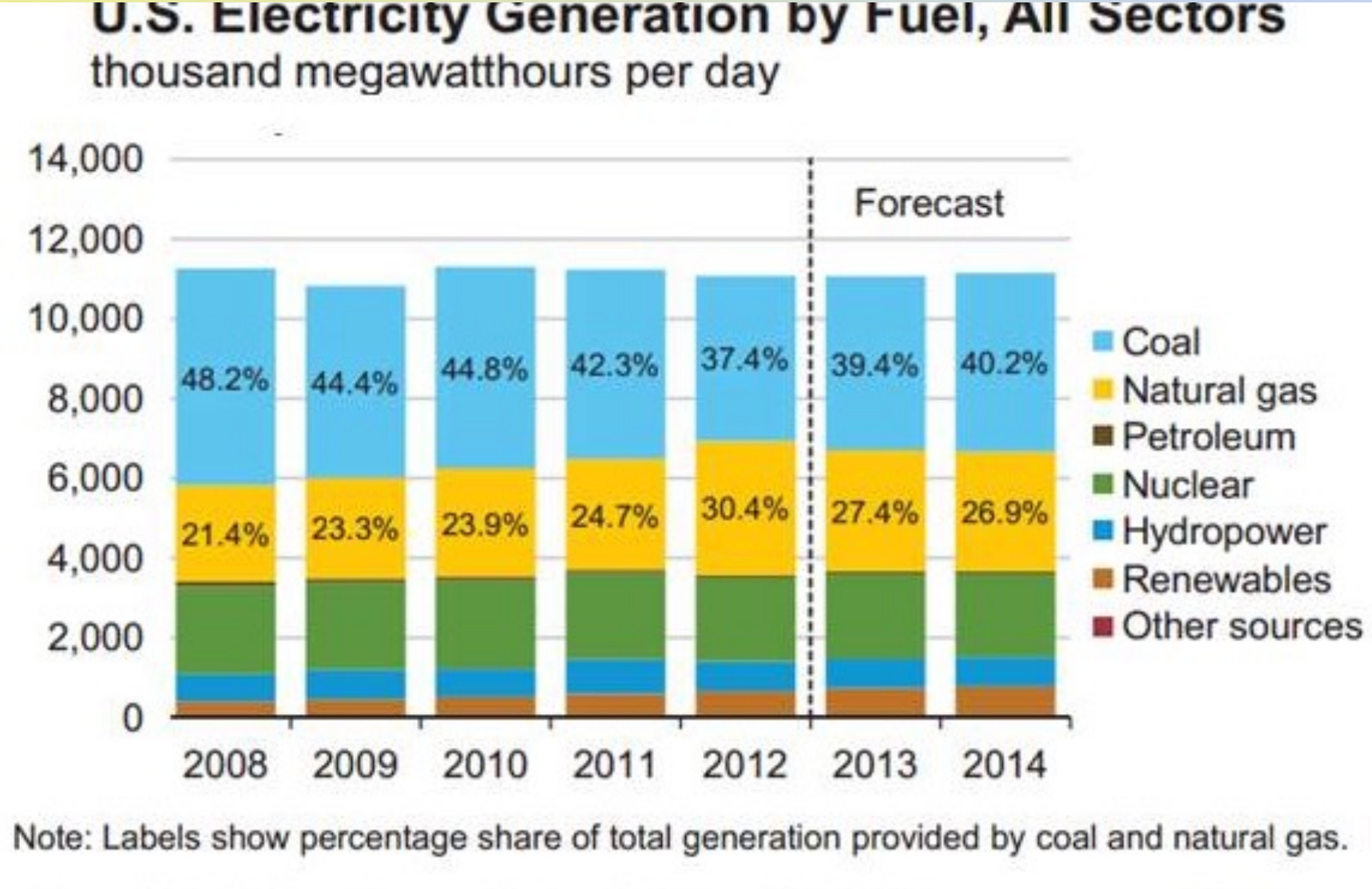
Fall 2013

# A Renaissance for Nuclear Power?

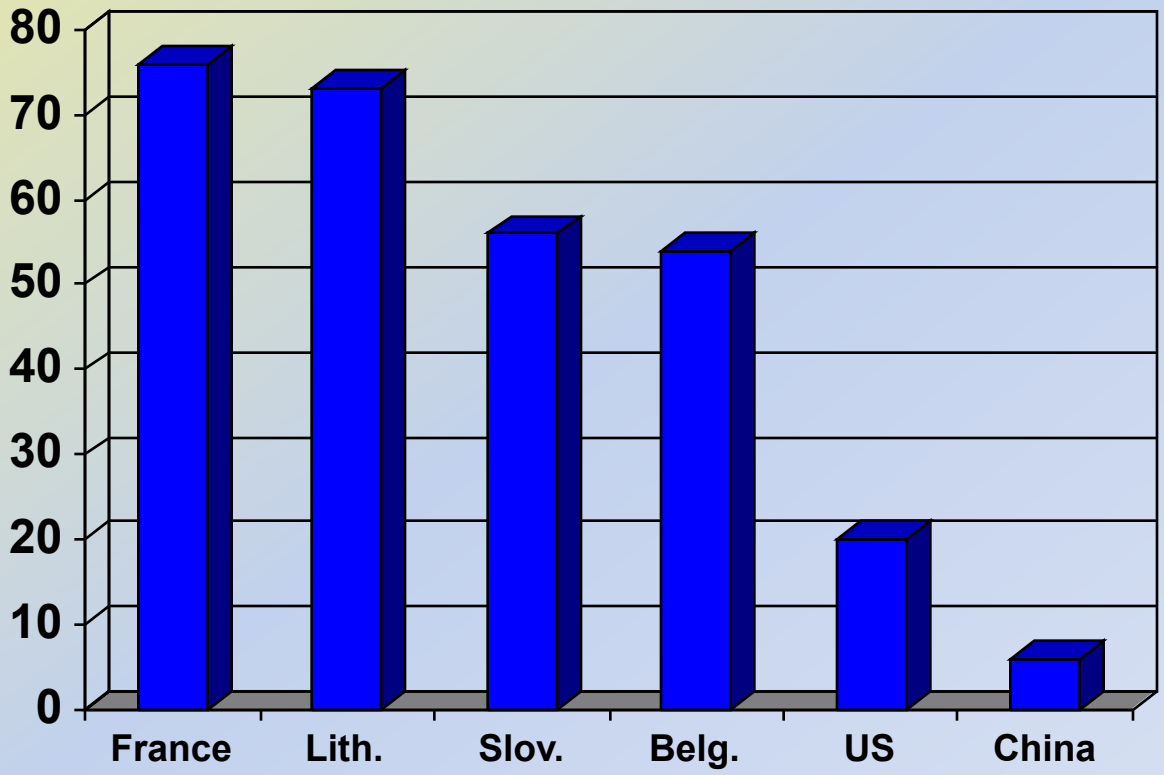
## Pre-Fukushima Nuclear Power

- Status of nuclear power in America:
  - Legacy of cost overruns
  - Three Mile Island – 1979 – Americans no longer assumed Nuclear Power was safe.
  - Chernoble – 1986 – more serious incident – turned most of Europe against nuclear power.
  - *No new power plant built in US since TMI*.

# Nuclear Holding Steady



# Countries Generating Significant Amounts of Nuclear Energy




15 Countries Derive >25% Electricity From Nuclear Energy

# Future of Nuclear Power?

- The world is clearly not waiting for the US to make any decisions regarding nuclear power.
- By 2030 - if US intends to maintain 20% share of electricity production nuclear – we will need to have constructed 30 new reactors.
- Many more required if we wish to replace coal plants to reduce greenhouse gas and SOX and NOX emissions.

# Revival?

- Recognition of large role in electricity generation.
- Role of nuclear in carbon reduction.
- Support from GOP
- Lack of major safety incident in past twenty five years -- *until Fukushima*.
- "New Economics" of nuclear.
  - Plants paid for – currently very profitable

# But are “New Economics” real?

- IEA says capital costs of $2000/kw – borderline economical
- Still produces toxic waste – not accounted for
- Fissile materials generated create security risk.
- $2000/kw price is reached only with “breathtaking” subsidies.

# What are the subsidies?

- Price Anderson Act
  - Passed 1957 – with 10 year sunset
  - 2005 – extended 20 more years
  - Caps exposure at around 10 billion
    - Chernobyl cost estimated $350 B
    - Estimates of around 2.5 cents/kW
- Subsidies to Legacy Plants
  - With restructuring, nuclear power costs were still too high, so “stranded costs” were passed through to ratepayers.
  - Around 7 cents/kW

# Other Subsidies

- Special tax breaks
  - Accelerated depreciation
  - Depletion allowance
- Subsidized federal loans
- Waste Management – deferring costs, federal subsidies for Yucca Mountain
- Decommissioning – federal government has determined that ¼ of trust funds are insufficient to cover costs

# Still Not Viable Without Subsidies

*"Other energy technologies would be able to compete with nuclear power far more effectively if the government focused on creating an energy-neutral playing field rather than picking technology winners and losers."*

Union of Concerned Scientists

February 2011

# What Is Happening Now?

- Plumer article (Nuclear Option:  An Atomic Bargain with the GOP):
  - GOP seeks to put nuclear power "into overdrive."
  - GOP critical to breaking deadlock on climate change
  - Result:  democrats were ready to make a deal to get greenhouse gas legislation passed.

# The Failure of Climate Change Legislation

- Constellation $9 Billion Calvert Cliffs nuclear project at Chesapeake Bay is on hold.
  - Failure of climate change legislation blamed.
  - Other reasons cited:
    - Regulatory uncertainty
    - Recession
- Florida's NextEra Energy: "There's a lot of capital sitting on the sidelines just waiting for more regulatory clarity."

# Fukushima – March 2011

- Radioactive Fallout
  - Meltdown of nuclear reactor
    - Radioactive release about 20% of Chernobyl
  - Still not contained -- radioactive water being leaked into Pacific Ocean
- Political Fallout
  - “I wonder if human beings can really control nuclear energy. I have now become an advocate calling for zero nuclear plants.”
    - Former Japanese Prime Minister Junichiro Koizumi

# What Happened

- Tsunami strike causes equipment failures, leading to loss of coolant and meltdown.
- No short term fatalities recorded from meltdown.
  - 18,500 killed by earthquake and tsunami
  - Uncertain long term health problems
- Leak of radioactive water in ocean discovered in July 2013

# Lessons Learned

- Need better seawalls in tsunami zones
  - 14 foot seawalls were insufficient for major earthquake
- Back up batteries and diesel generation to power cooling, hydrogen recombiners are now standard.
- *But are lessons learned enough?*

# Problem of Proliferation

- A 1 GW reactor produces 250 kg of plutonium per year.
  - About 175 kg of this is in the form of plutonium isotopes that can be reprocessed to replace 175 kg of Uranium 235 in a nuclear reactor.
- But: same 175 kg of plutonium isotopes can be used to make 25 nuclear warheads.
  - Albright, Annual Review of Energy (1988)

# The Weinberg Dilemma

- Alvin Weinberg -- “abundant energy and nuclear proliferation may create a Malthusian vice.”
- *1971: “The risk of CO2 accumulation inherent in the widespread use of coal is analogous to the risk of nuclear proliferation: both problems are global, uncertain, and could pose profound challenges to man's future.”*

# Can Reprocessed Fuel Be Used to Create Weapons?

- Frank N. Von Hippel of Princeton University
  - Reprocessing spent nuclear fuel is too dangerous because it leads to the inevitable proliferation of nuclear weapons
- Alexander De Volpi – Argonne National Lab -- cannot make weapons from reprocessed plutonium.

# Lovins -- Proliferation, Climate Change and Oil

- “Policy still rests on the fatally contradictory assumption that nuclear power is economical, necessary, and experiencing a revival. This makes the proliferation problem insoluble.”
- “[P]roposals to expand nuclear subsidies -- whether to buy Senate climate-bill votes, or motivated by a sincere but mistaken belief that nuclear expansion will help protect climate -- will amount to lose-lose scenarios; that approach will only prop up a failed climate non-solution that also makes proliferation unstoppable. “

# Response to Lovins

- “Because Lovins renders no substantive academic or acquired nuclear credentials, the analyses he presents ought to be held to a strict standard of scientific credibility, such as that described by the Daubert U.S. Supreme Court decision.”
  - Alexander De Volpi

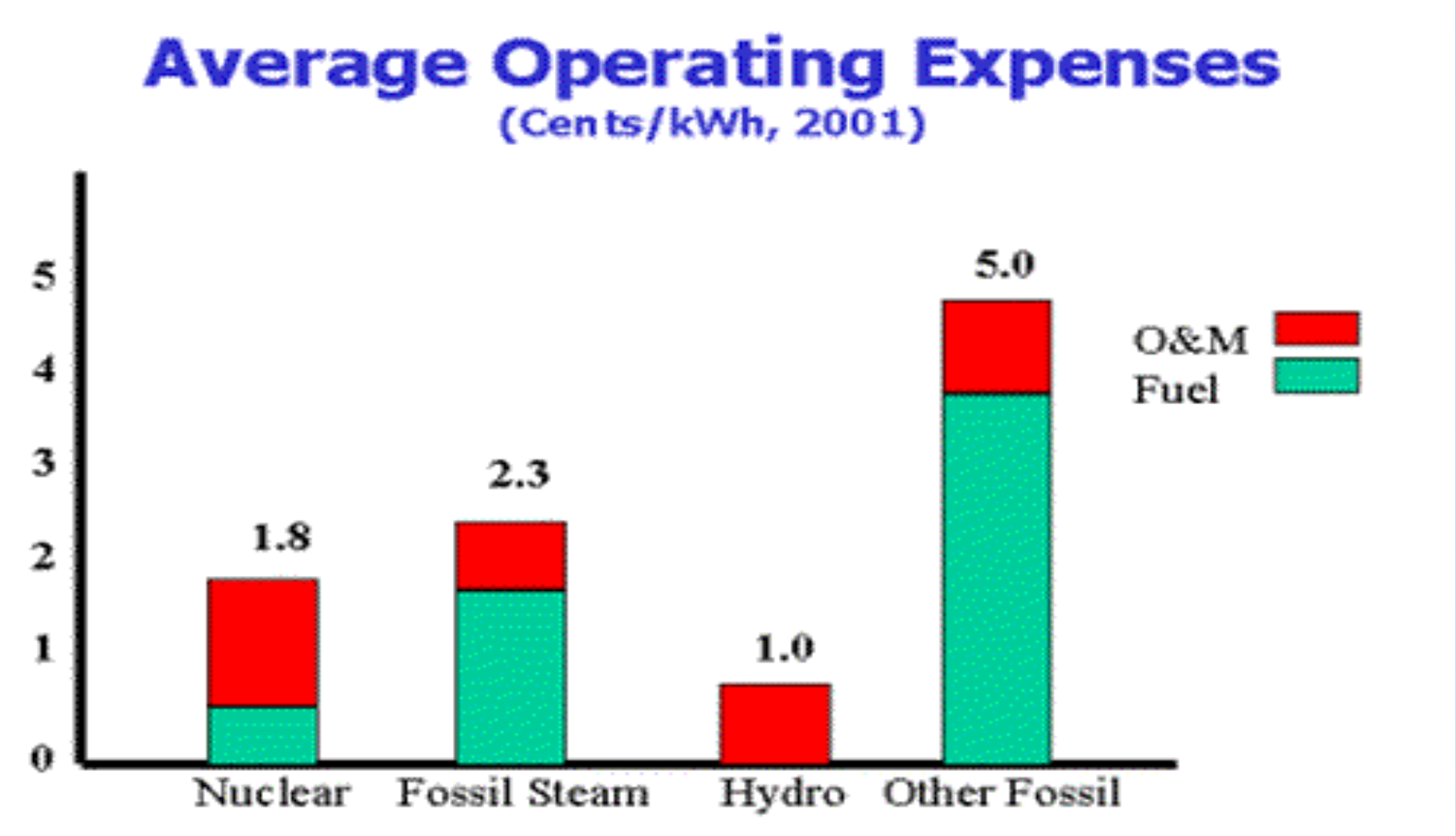
# Other Problems of Nuclear Solution

- Nuclear Energy is more cost effective at large scales.
  - This solution runs counter to the trend towards distributed generation.
  - Requires continued reinvestment into the grid.
    - e.g. First Energy proposed $3 B transmission upgrade

# US Commercial Reactor Statistics

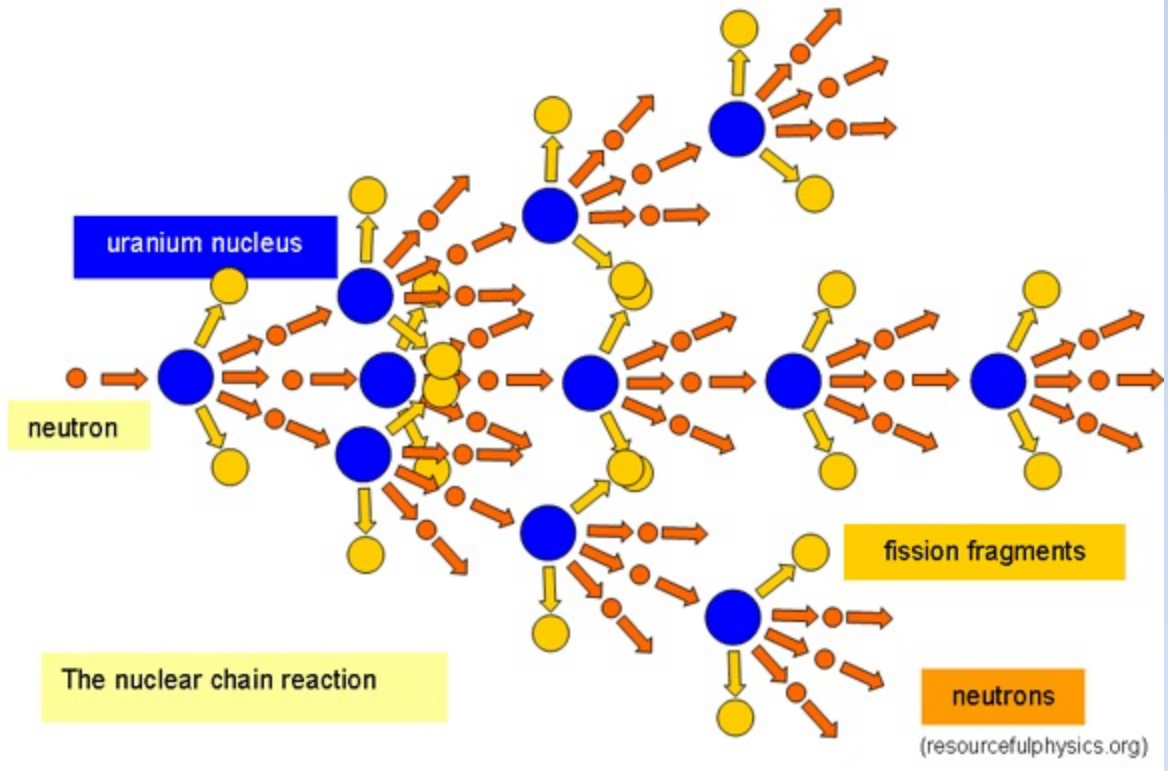
- 104 Operating Reactors
  - 9 Reactors Built Since 1968
  - 60 Year Operating Life (extended licenses)
- > 90% Capacity Factor
  (Coal – 71%, Wind – 21%, Solar – 15%)
- 12% of US Generating Capacity
- 20% of US Electricity supplied By Nuclear
- Estimate $5.0 Billion Capital Cost

# US Average Operating Cost Comparison

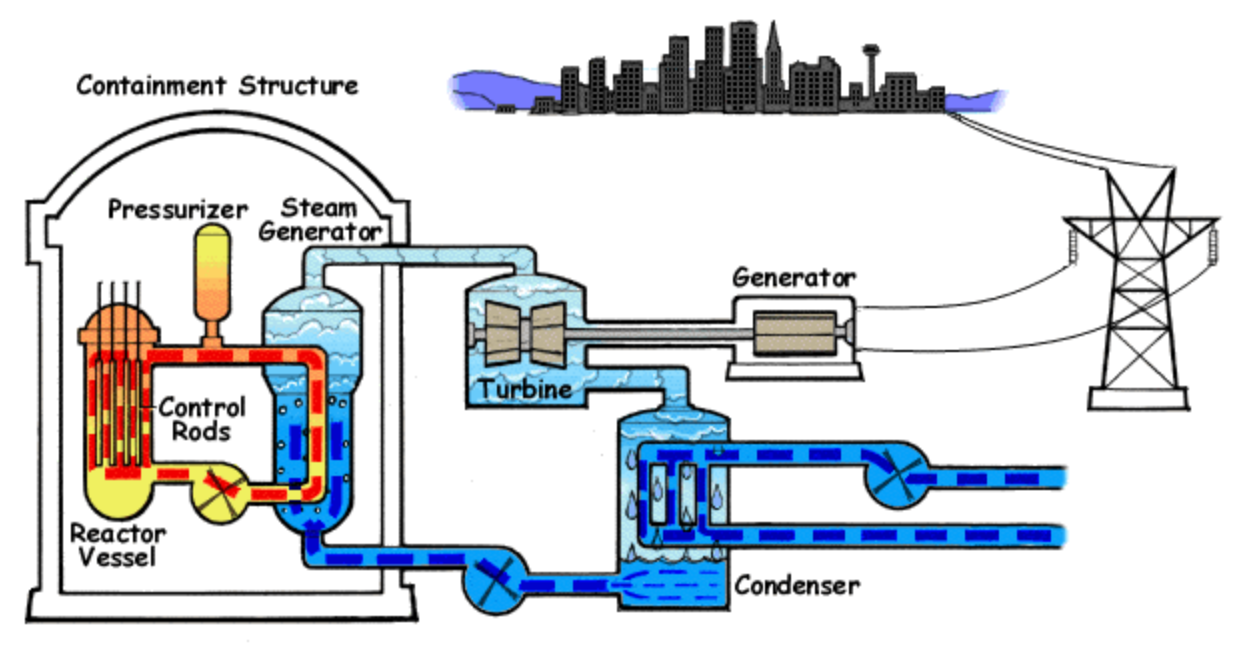


# Nuclear Fission Process

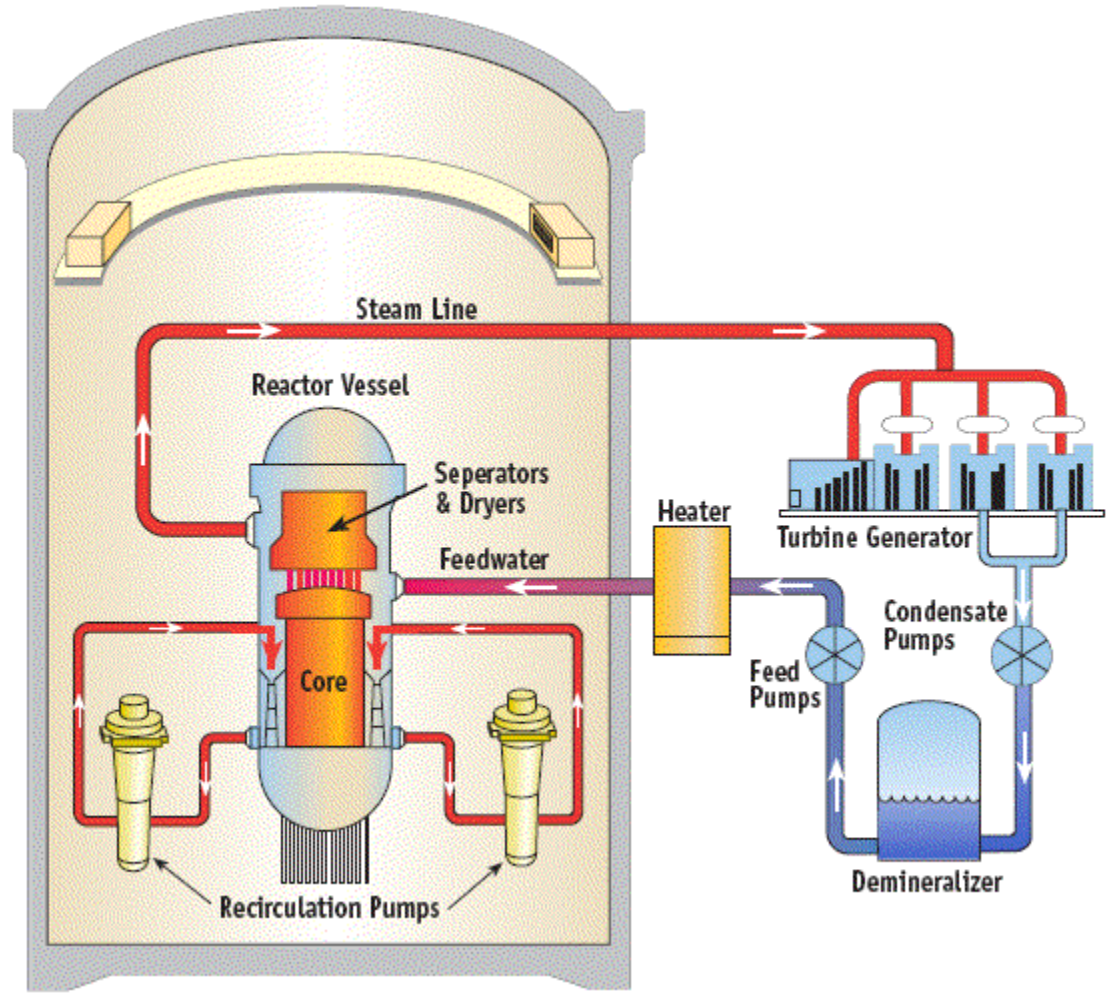
- Fissile Material (U-235, Pu-239) Absorbs Neutron
  - Splits into Fission Products, 2.43 neutrons, energy



# Pressurized Water Reactors – 69



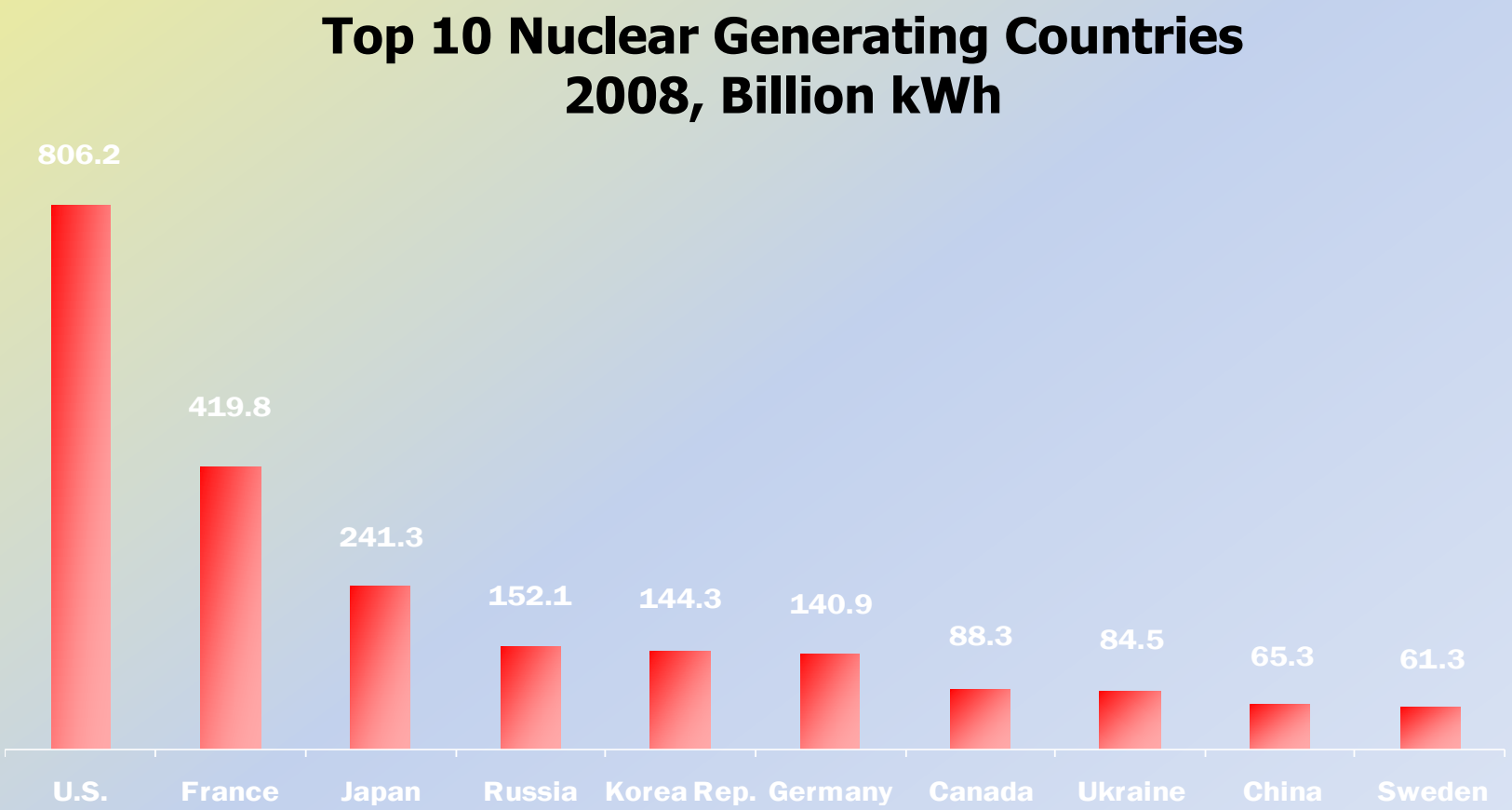
# Boiling Water Reactors – 35 operating



# Nuclear Fuel

- For Self Sustaining Chain Reaction Require Enriched Uranium – 235
  - 3-4 % Pressurized Water Reactor
  - 7-10% Boiling Water Reactor
  - Enrichment Much Too Low For Nuclear Explosion
  - 181,000 Pounds Uranium Oxide in Reactor Core
    - 5,430 Pounds of U-235
- Refuel every 2 years, 1/3 fuel replaced
  - Only 1% U-235 Expended – 1,207 Pounds of U-235 Remain in Each 1/3 Expended Fuel Block.

# World Wide Nuclear Energy Factoids



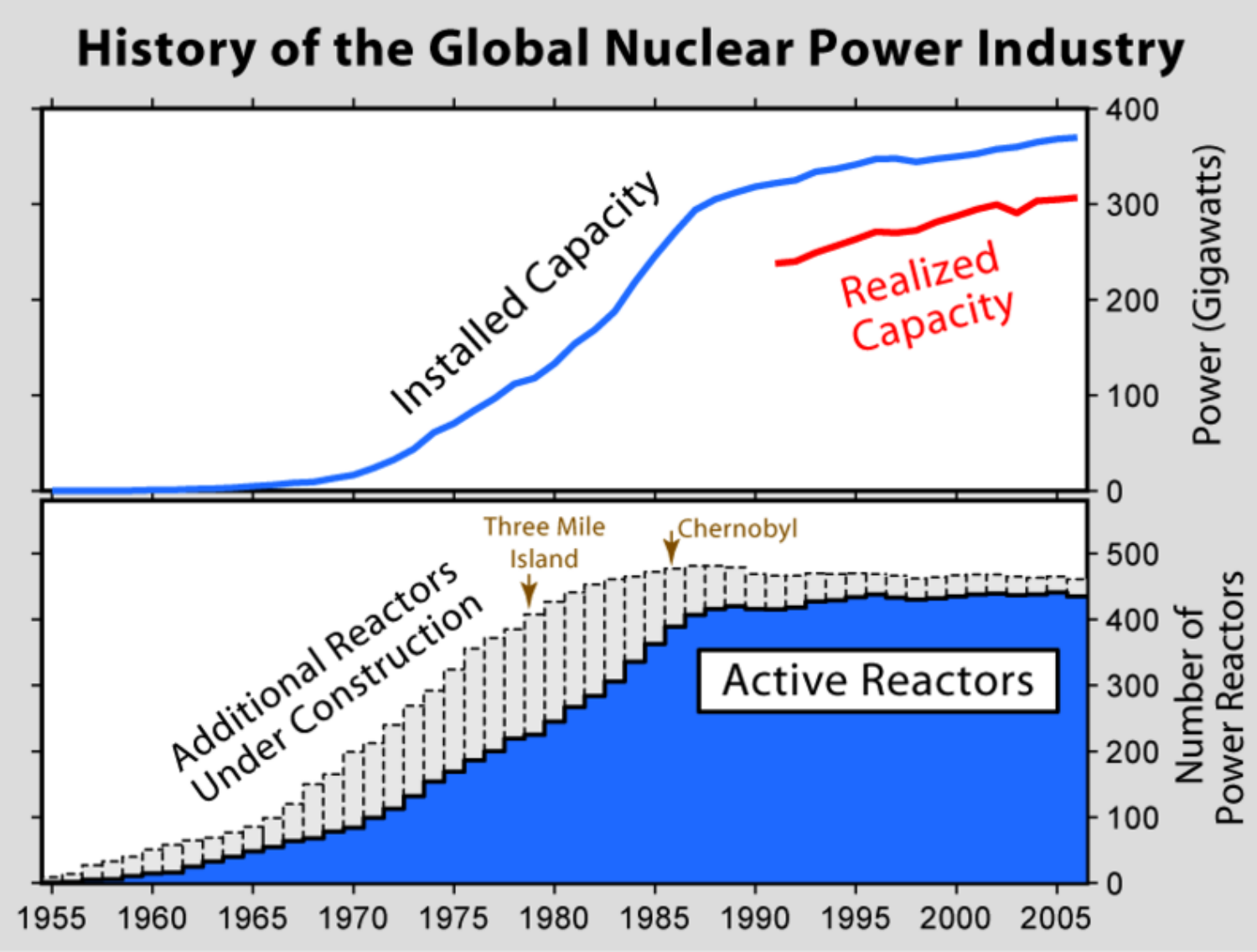

Source: International Atomic Energy Agency, U.S. is from Energy Information Administration

Updated: 9/09

# Reactor Types

- 437 Operating Reactors, 56 Under Construction
  - China – 21; Russia – 9; S. Korea – 6; India – 5
    56 total worldwide
- Other Reactor Types
  - Heavy Water Reactors
  - Breeder Reactors – 2 Operating
  - RBMK – Soviet Design (Chernobyl)
    - Graphite moderator - flammable
    - Water cooled – presence of water slows reaction
    - No Containment

# Nuclear History



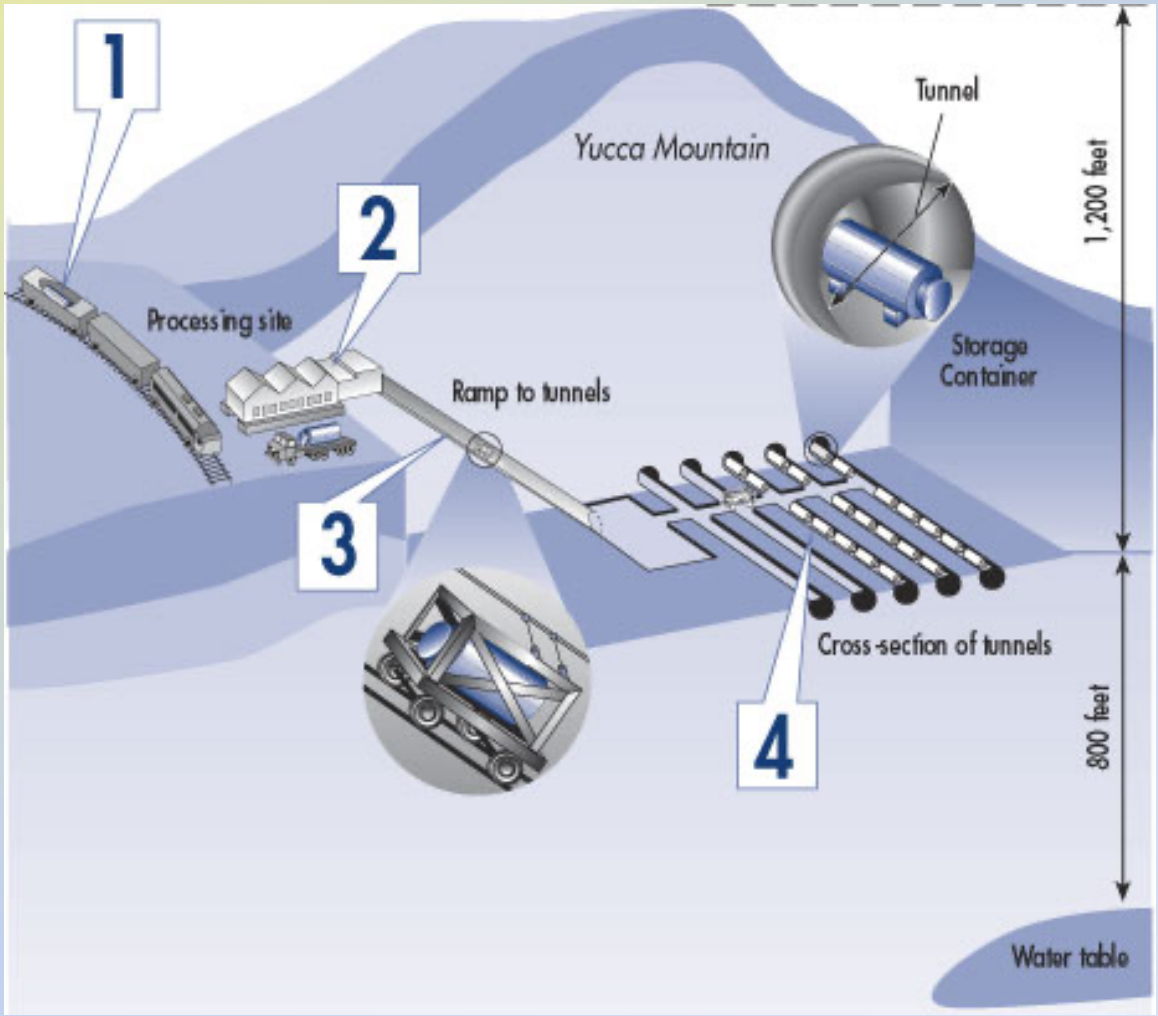
# Nuclear Waste

- Currently US Generated High Level Waste Inventory is around 40,000 metric tons.
  - Occupies volume of 140 ft X 140 ft X 100 feet
- Each reactor generates about 100 metric tons of fuel related (U-235, U-238, Pu-239,fission products)  waste per refueling.
  - If all fuel assemblies discharged by all the operating reactors from now until 2030 were placed in one area they would occupy about 1 city block.

# Yucca Mountain

- Nuclear Waste Policy Act 1982 Establishes Fund and Assigns DOE Responsibility for Providing A Central Site
  - $35 Billion Paid In By Utilities Thus Far
- Yucca Mountain On Hold - no funding in 2011/12
  - 20 years, $8 Billion Spent To Date
  - EPA Standards – 15 mrem/yr for first 10,000 years and 100 mr/year out to 1 million years

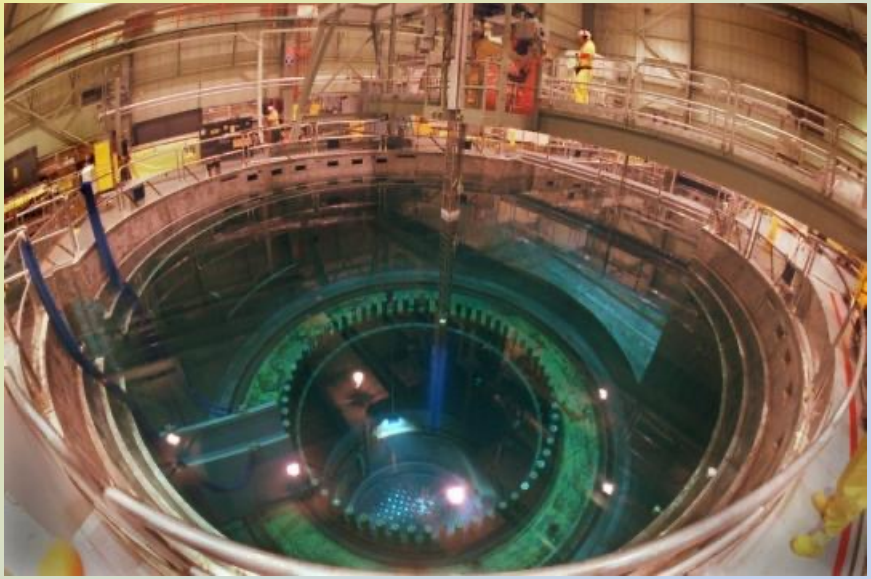
# Yucca Mountain Concept

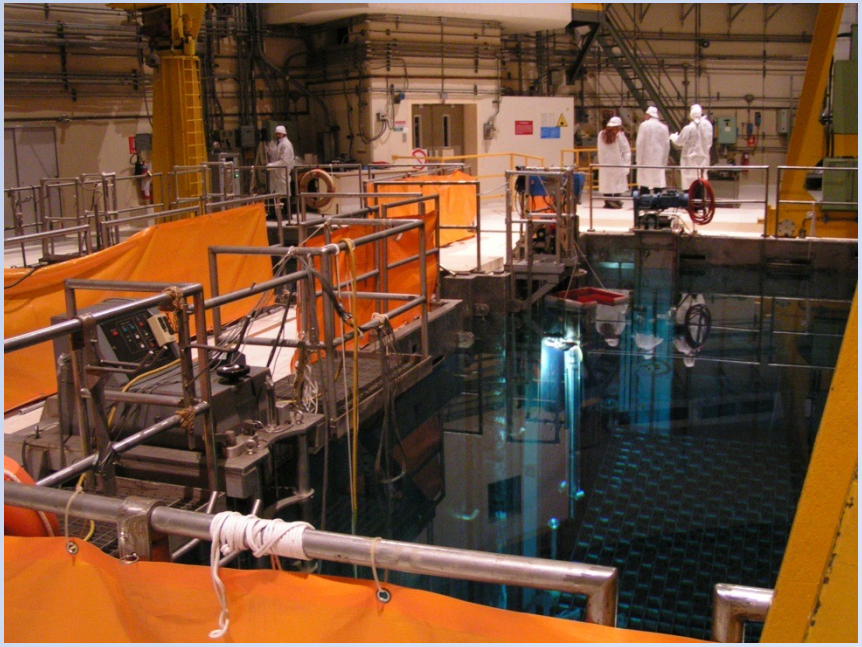


# Interim Fuel Storage

- 70 Sites In US approved for interim storage of spent fuel.
- First 10 years in spent fuel pools.
- After decay heat has decayed off dry storage casks are used.
- NRC Risk Analysis finds no significant impact of on site storage including assessment of terrorist threat.

# Spent Fuel Storage





# Issues Associated With Discharged Fuel

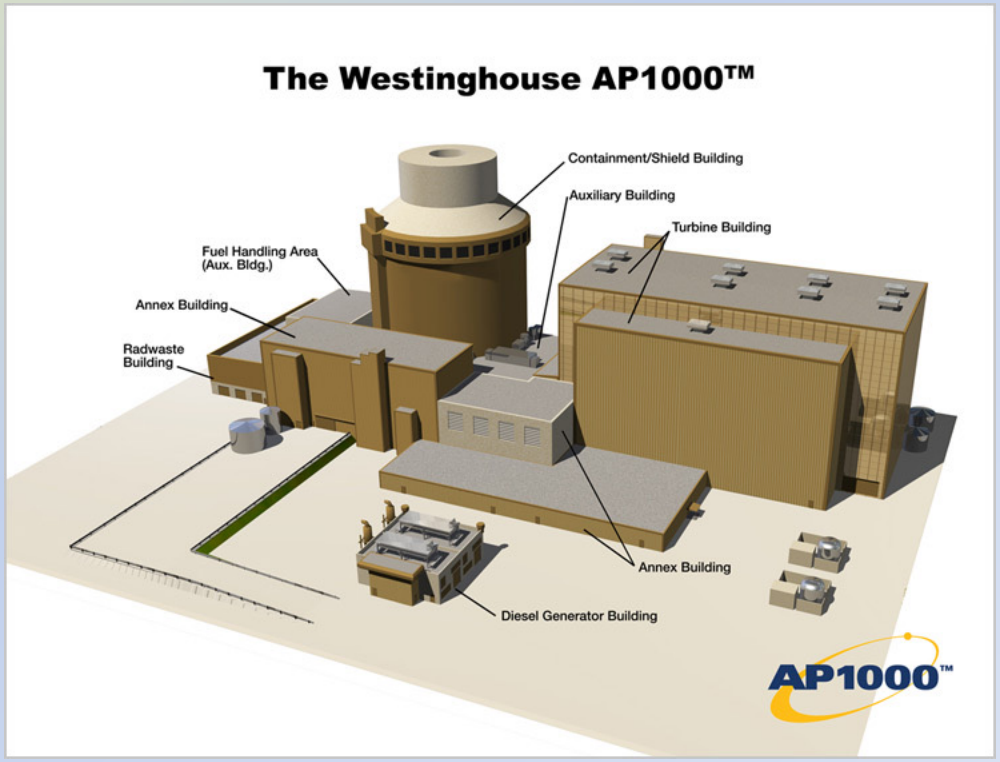
- Very High Radiation Doses
  - Gamma Radiation From Fission Products
- Thermal Heat Generation
  - Referred To as Reactor Decay Heat
- Initially Stored In Spent Fuel Discharge Pools for Around 10 Years.
- Dry Storage Thereafter
- Note: NOT A Criticality/Nuclear Explosion Risk.

# US Nuclear Power From The Past To The Future

- 1979 Three Mile Island Accident
  - Partial Core Meltdown due to loss of coolant
    - No Fatalities, No Injuries
- Shoreham - $6.0 Billion – Never Operated
- Non-Standard Plant Design Added To cost
- Cumbersome Licensing Process – driven by opposition to nuclear power – constant change
- 50% Nuclear Plant Availability
- By Late 1980s all nuclear plant orders cancelled due to huge construction costs, plant delays, poor plant performance.

# Westinghouse Advanced Light Water Design – AP1000

- Passive Safety Systems
- Standard Pre-Approved, Licensed Design
- Detailed computer aided, modularized  design and construction planning greatly reduces construction costs



# New Plant Construction Status

- China Has Ordered 4 AP1000 Plants – 2 in actual construction
- China Negotiating To Build 12 more AP1000s.
- Worldwide 56 new reactor orders in some stage of processing.

# Cost Considerations

- Best Guess For A New Construction AP1000 is $5.0 Billion.
- Financing Construction is the major issue confronting utilities.
- Waste Management Costs Are Not Trivial – Estimate for Central Waste Storage is >$100 Billion and counting.

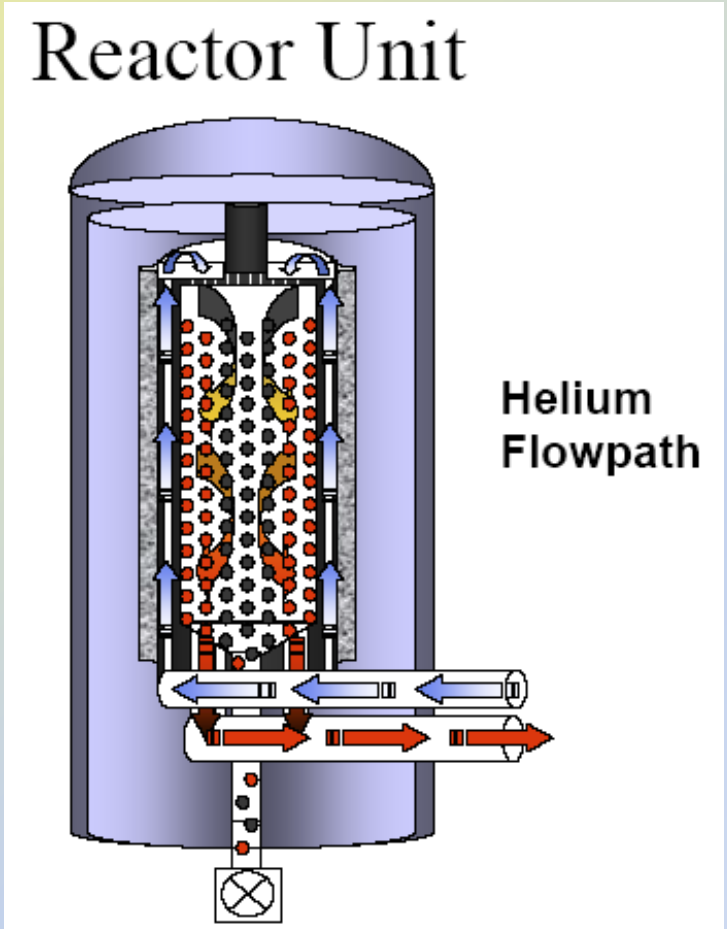
# Hydrogen Generation Ties To Nuclear Power

- Current Generation Reactors Only Produce Hydrogen Through Electrolysis.
- Next Generation Reactors (2020) Using Metal Cooling or Gas Cooling Will Operate At High Enough Temperatures to Support ThermoChemical Production of Hydrogen.
  - Pebble Bed Reactors Under Development – Inherently Safe Helium Cooled Reactor Operates at 1,600$^{o}$C.

# Not Too Bright A Future

- Of 17 new plant applications – only one has received loan guarantees.
- Exelon Corp. has abandoned plans for 2 reactors in Texas. – Nat Gas $ cited
- Constellation Energy Turned Down Loan Guarantee of $7.8 Billion.
- Finland – project estimated at 3 Bil Euro now at 6 Bil Euro, with no end in sight.
- Progress Energy 2 Reactor Site Estimated at $22 Bil.

# Next Generation: Pebble Reactors




- 360,000 pebbles in core
- 3,000 pebbles handled daily
- 350 pebbles discharged daily

Source: mit.edu

# Summary

- 106 Operating US Reactor Plants Seem To Have Solved Operational Issues.
- Waste Management Requires Great Improvements In Approach and Cost.
- Cost Of New Plant Construction Is a Major Barrier For the Technology.
  - Need new break through in technology to reduce costs
  - Need to develop DG plants

# Future of New Nuclear Power

- No nuclear power plant ever
  - been built on time and on budget
  - produced power to its original specifications
- Barring an extraordinary technology breakthrough nuclear energy is likely to be too costly to matter.

# CSU Energy Policy Center

Thank you!