Status of Nuclear Energy

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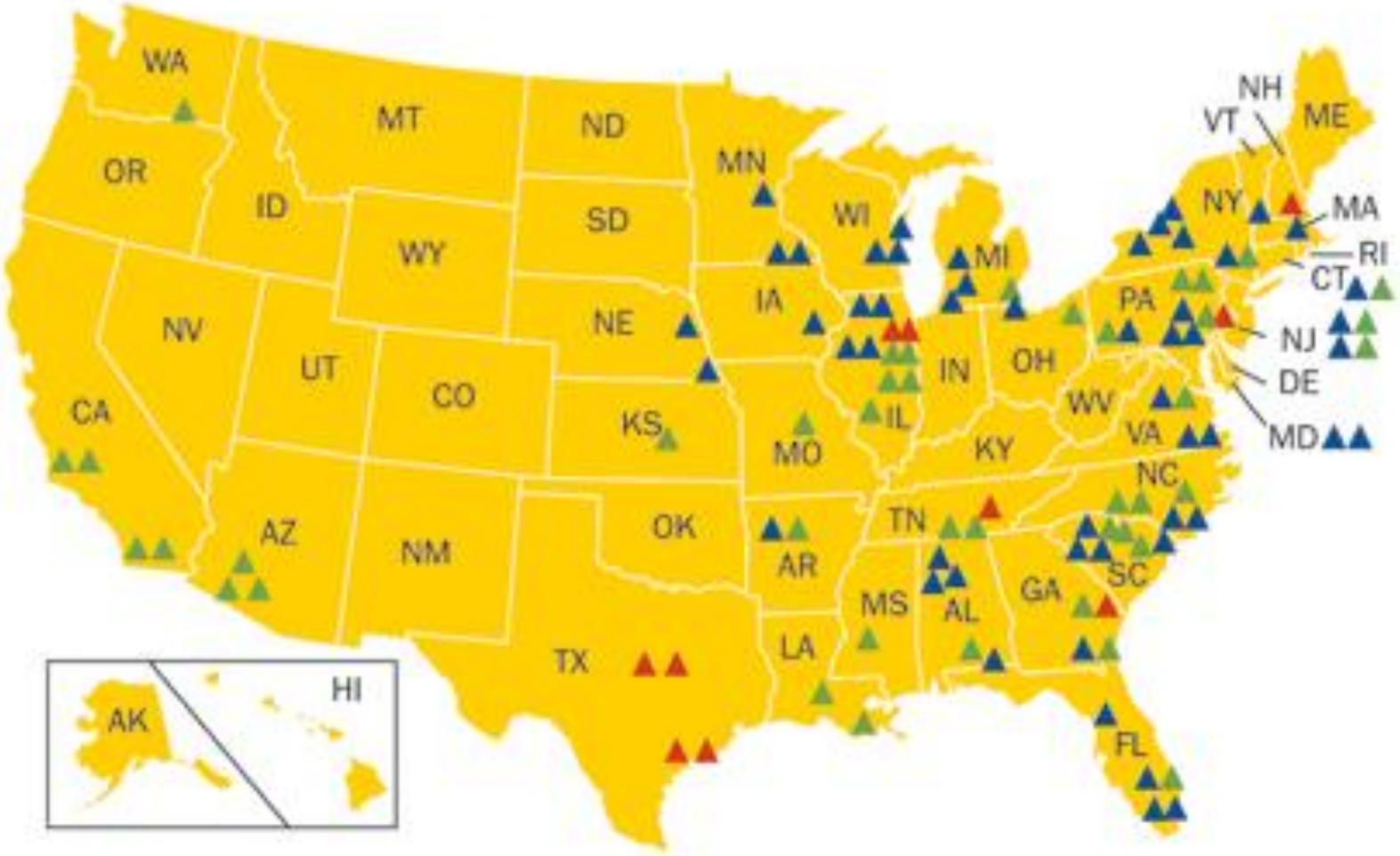
Outline

- Brief History
- Basic Technology
- Current Reactors
  - Up-rates
  - License Renewals
- Next Generation Reactors
- Generation IV Reactors
- Small Modular Reactors
- New Construction
- Issues
  - Waste
  - Safety
  - Cost
  - Resources

History

- First US commercial reactors in 1957 (60 MWe)
- 17 reactors built in 60s
- 109 have been built since
- 22 have been shut down
- 104 currently running (104 GWe)
- 2/3 PWR, 1/3 BWR
- About 20% of US electricity is from nuclear

U.S. Commercial Nuclear Power Reactors—Years of Operation

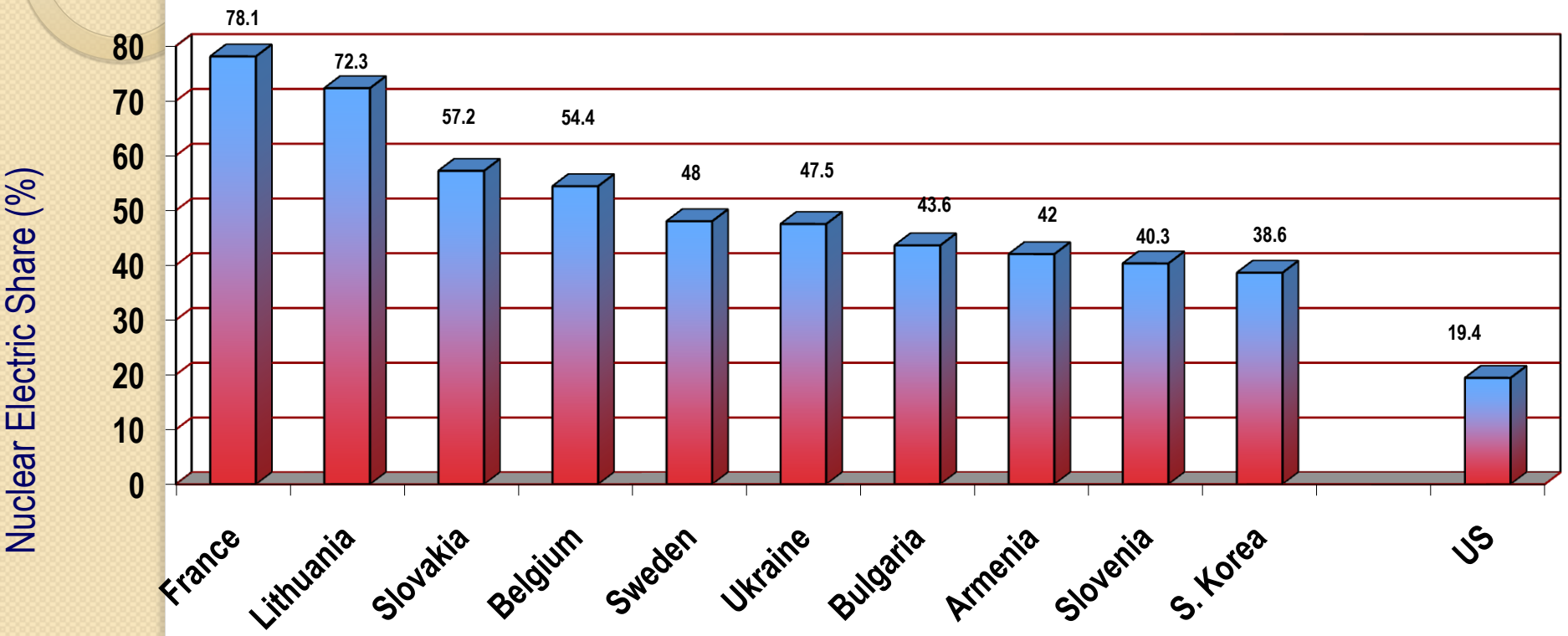


Years of Commercial Operation	Number of Reactors
△ 0-9	0
▲ 10-19	10
▲ 20-29	42
▲ 30-39	52

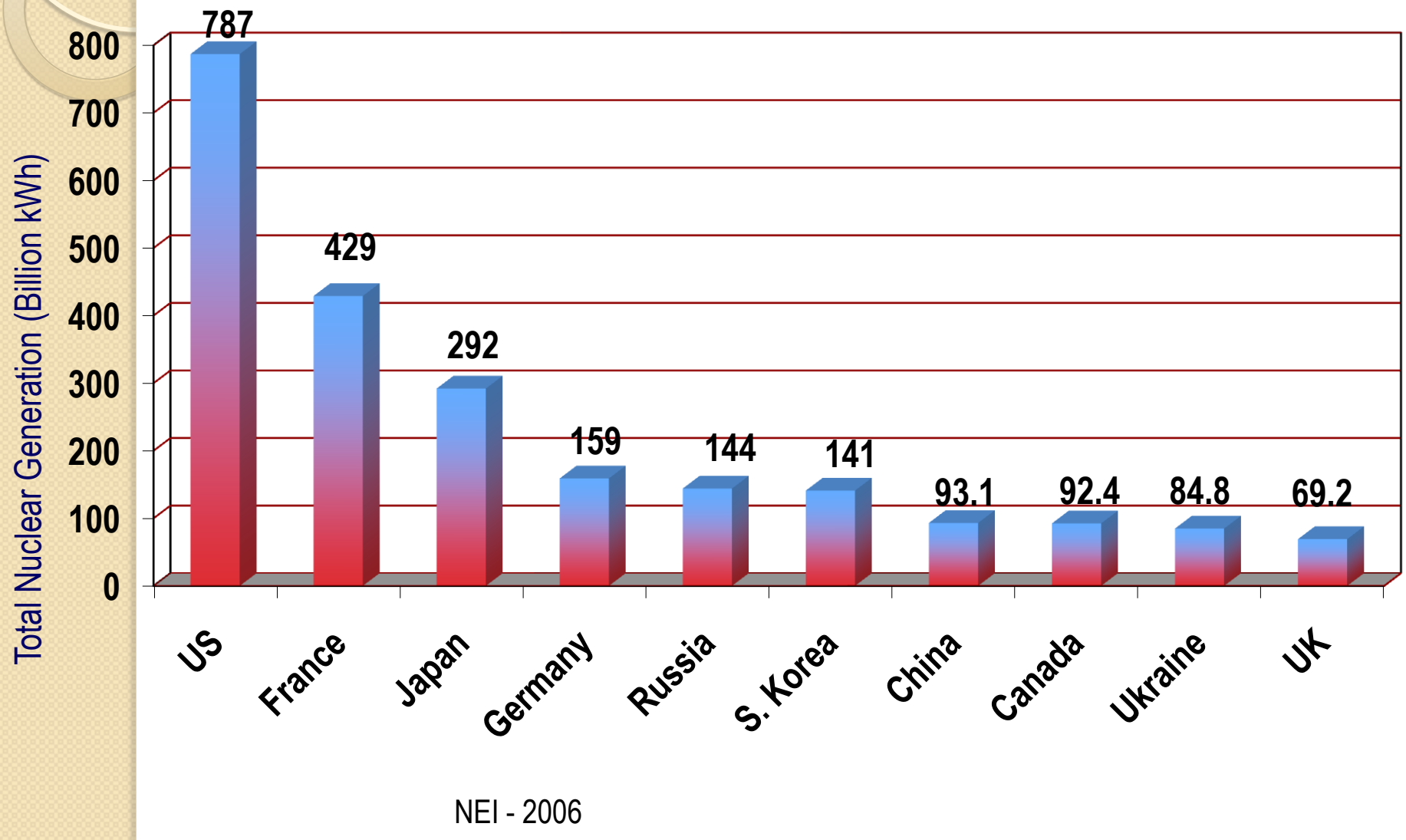
Source: U.S. Nuclear Regulatory Commission

Who uses nuclear energy?

17% of world's electricity production (2006)

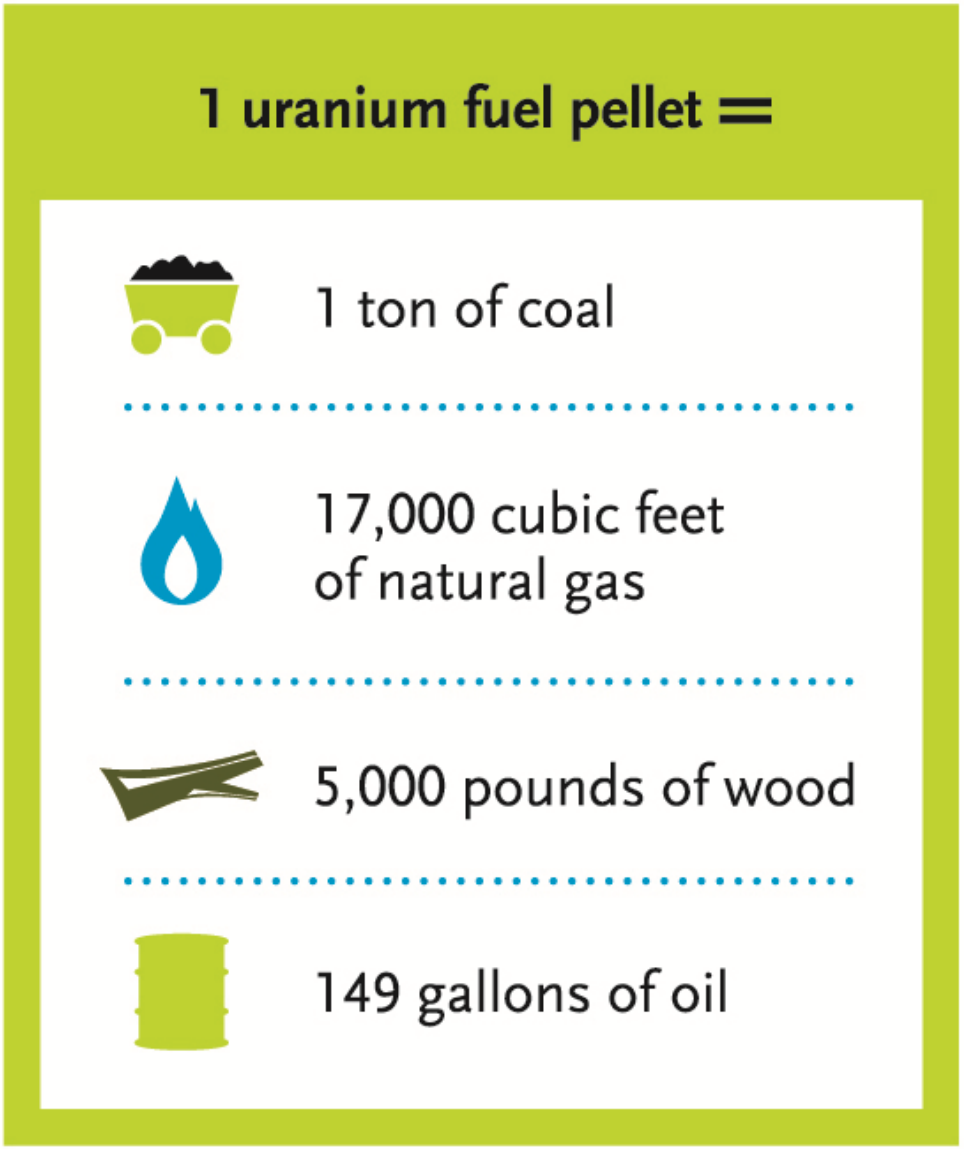


Who uses nuclear energy?



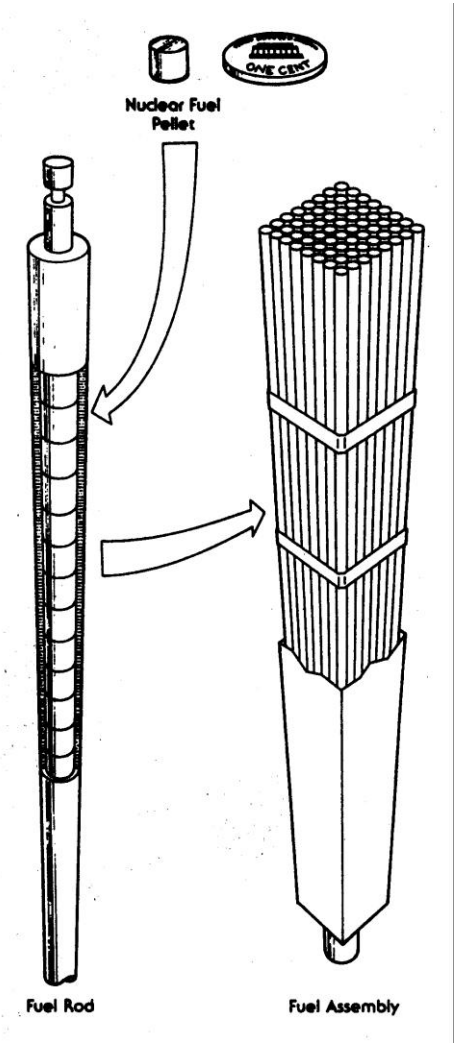
NEI - 2006

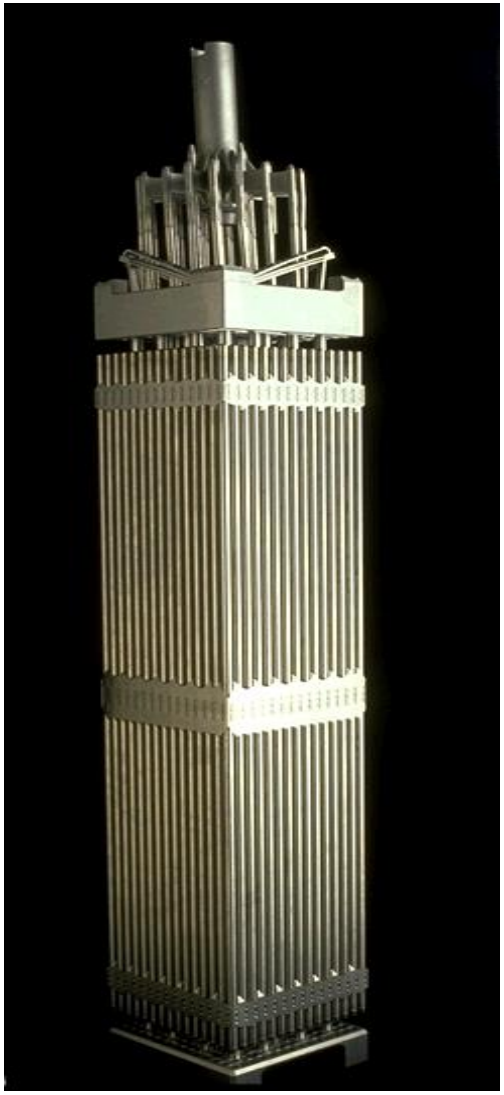
Power Production Equivalents



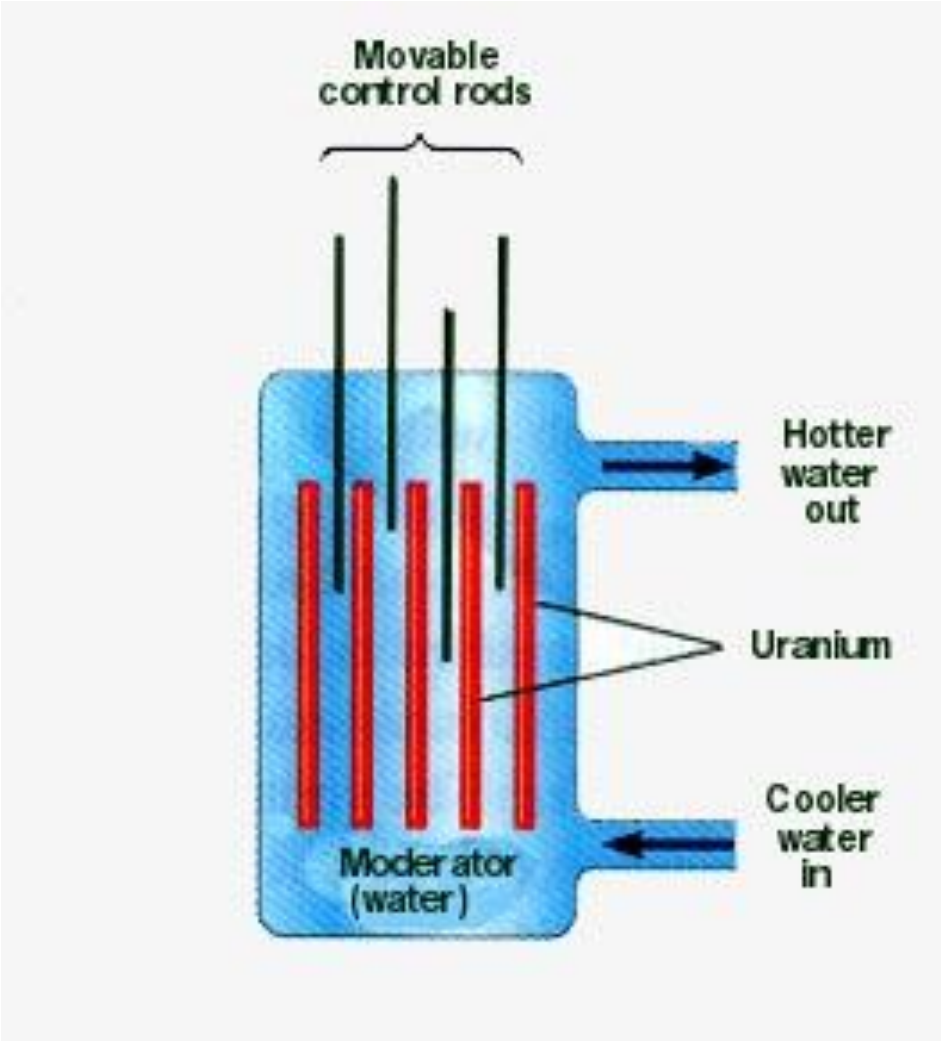
Source: Nuclear Energy Institute

Fuel Assemblies

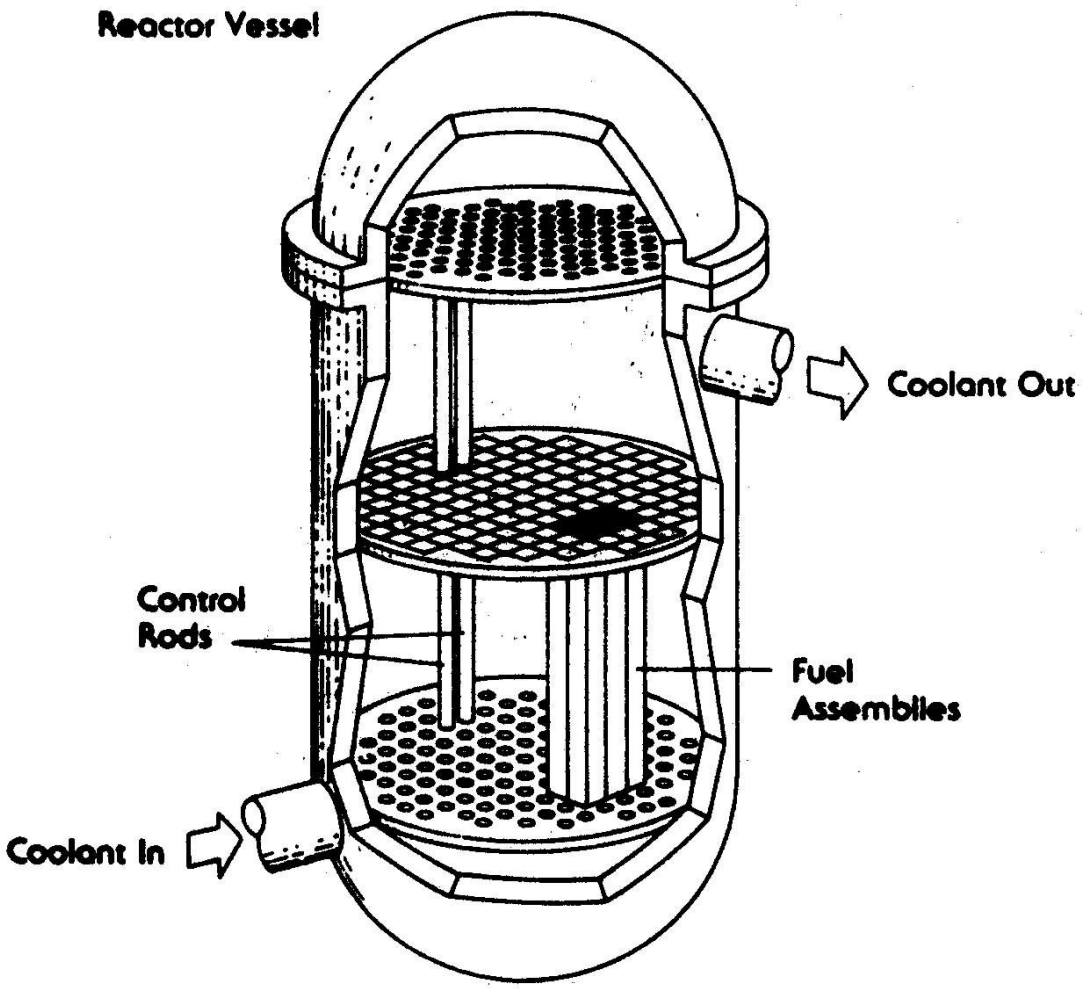




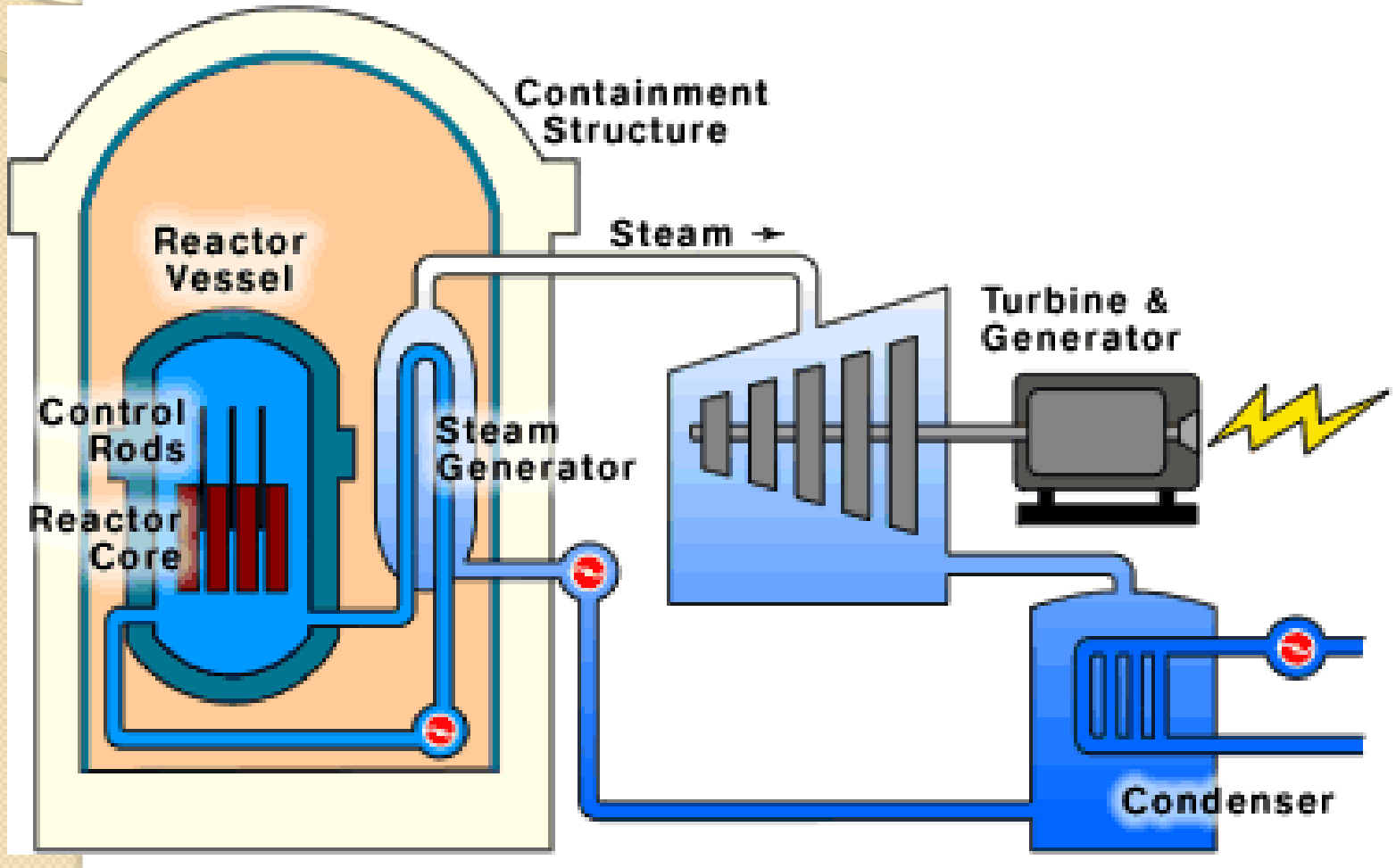
Reactor Schematic



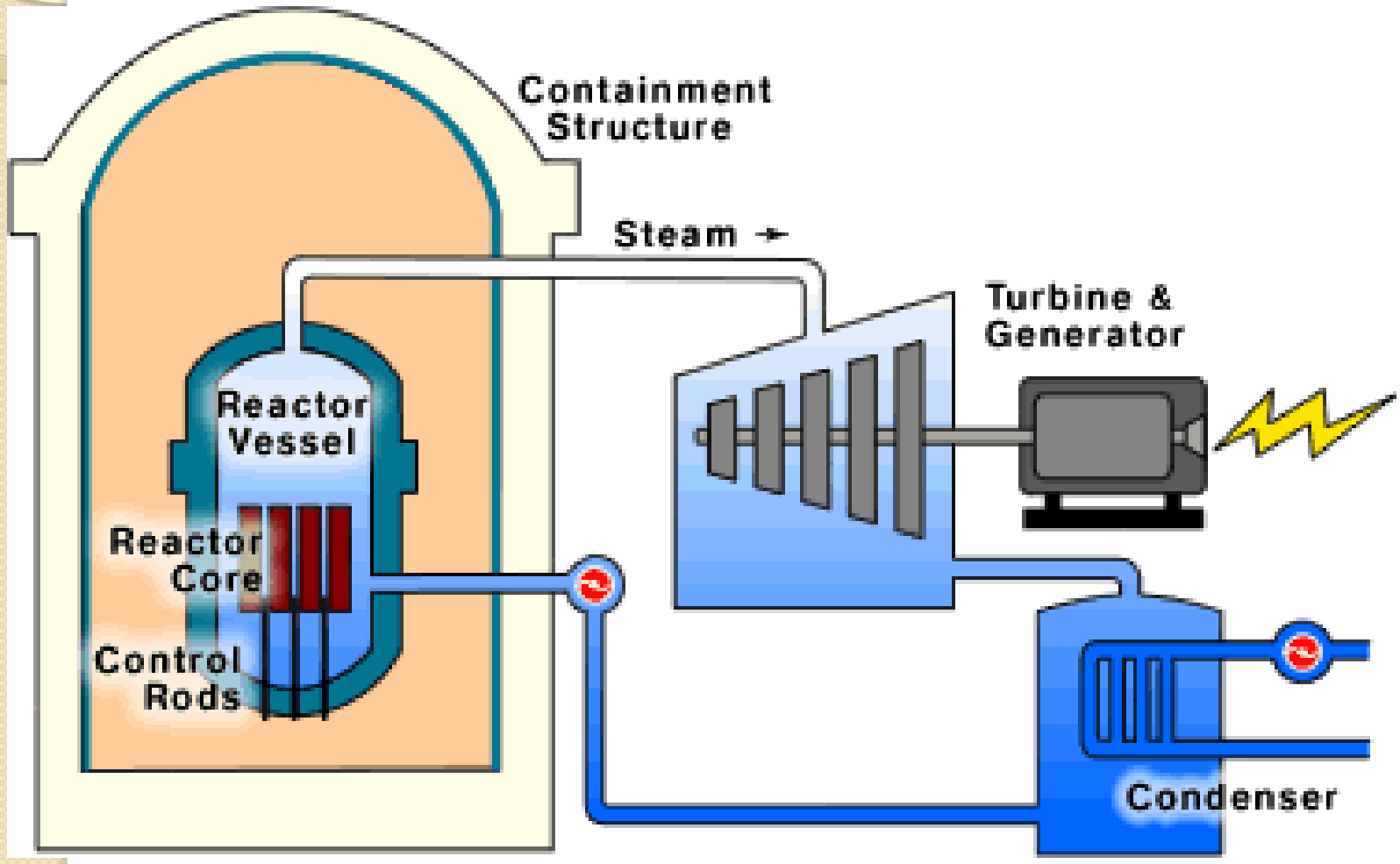
Reactor Pressure Vessel



Pressurized Water Reactor

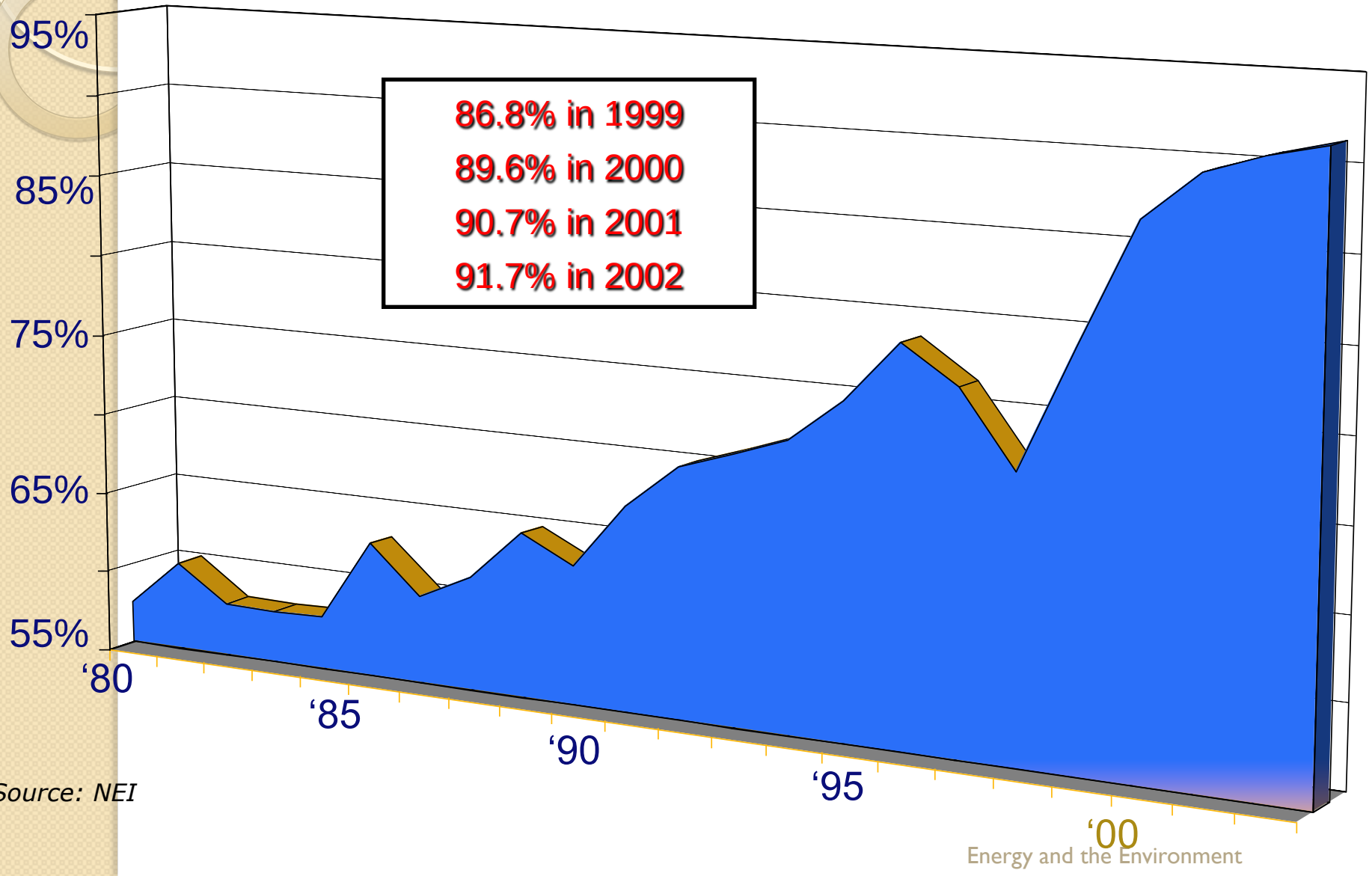


Boiling Water Reactor



A Typical Power Plant

Capacity Factors Improve

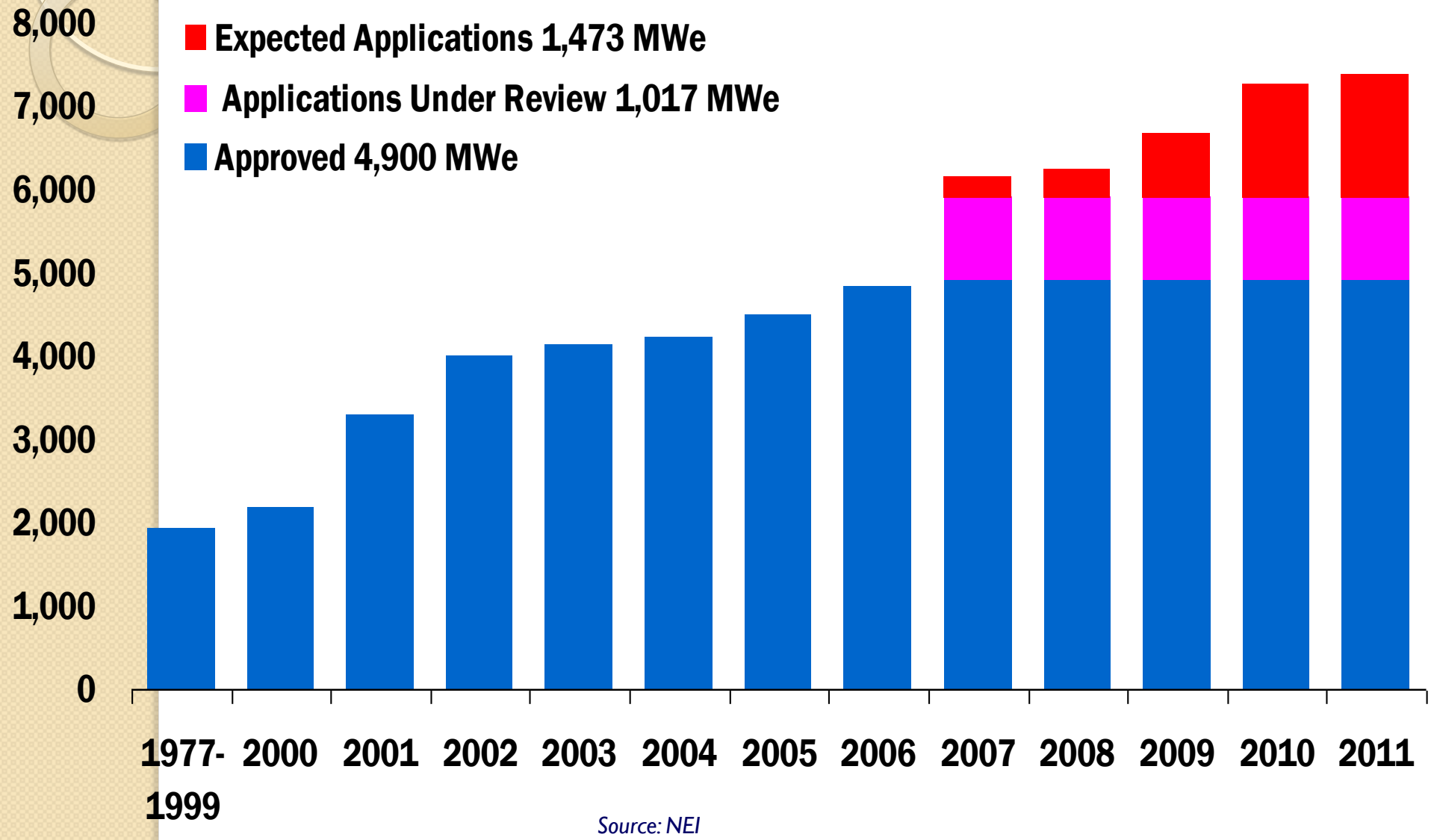


Source: NEI

Uprates

- US Plants have been permitted uprates totaling 6 GWe
  - Measurement uncertainty recapture power uprates (< 2% - enhanced techniques for calculating reactor power - state-of-the-art feedwater flow measurement)
  - Stretch power uprates (typically up to 7 - usually involve changes to instrumentation setpoints)
  - Extended power uprates (up to 20% - require significant modifications to major balance-of-plant equipment)

Extending Assets: Power Uprates



Source: NEI

License Renewal

- Plants were given 40 year licenses
- They can apply for extensions up to 20 additional years
- 59 Plants have asked for and been awarded extensions (none have been turned down to date)
- 19 more have applied for extensions and 20 are expected to apply

Evolution of Nuclear Power

Generation I

Early Prototypes

- Shippingport
- Dresden
- Magnox

Generation II

Commercial Power

- PWRs
- BWRs
- CANDU

Generation III

Advanced LWRs

- CANDU 6
- System 80+
- AP600

Generation III+

Evolutionary Designs

- ABWR
- ACR1000
- AP1000
- APWR
- EPR
- ESBWR

Generation IV

Revolutionary Designs

- Safer
- Sustainable
- Economical
- More Proliferation Resistant and Physically Secure

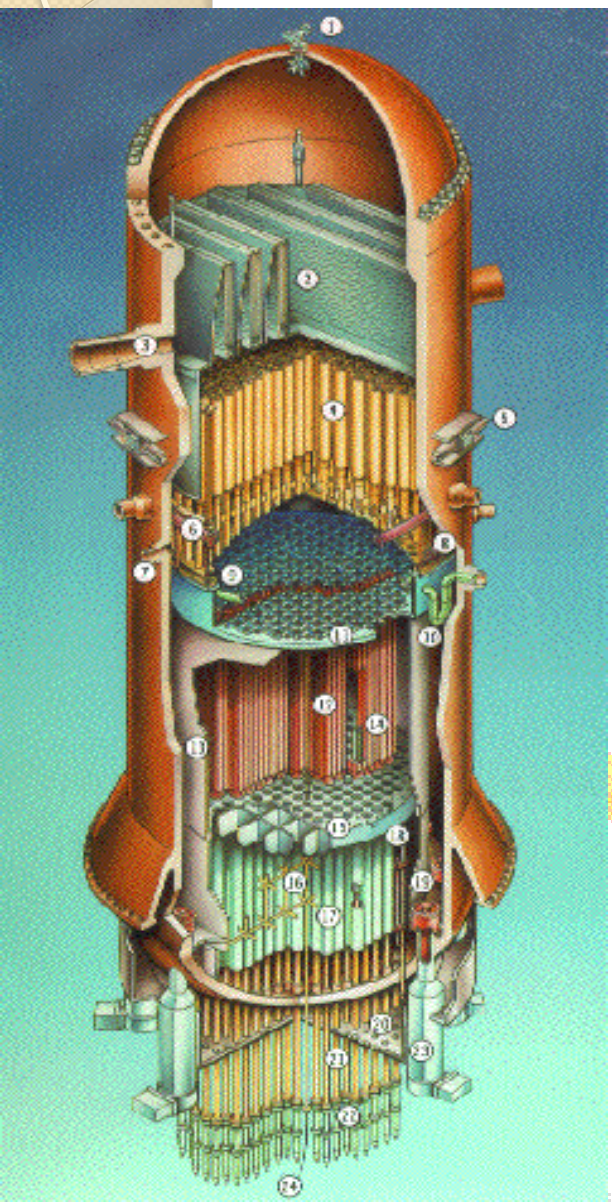
1950 1960 1970 1980 1990 2000 2010 2020 2030

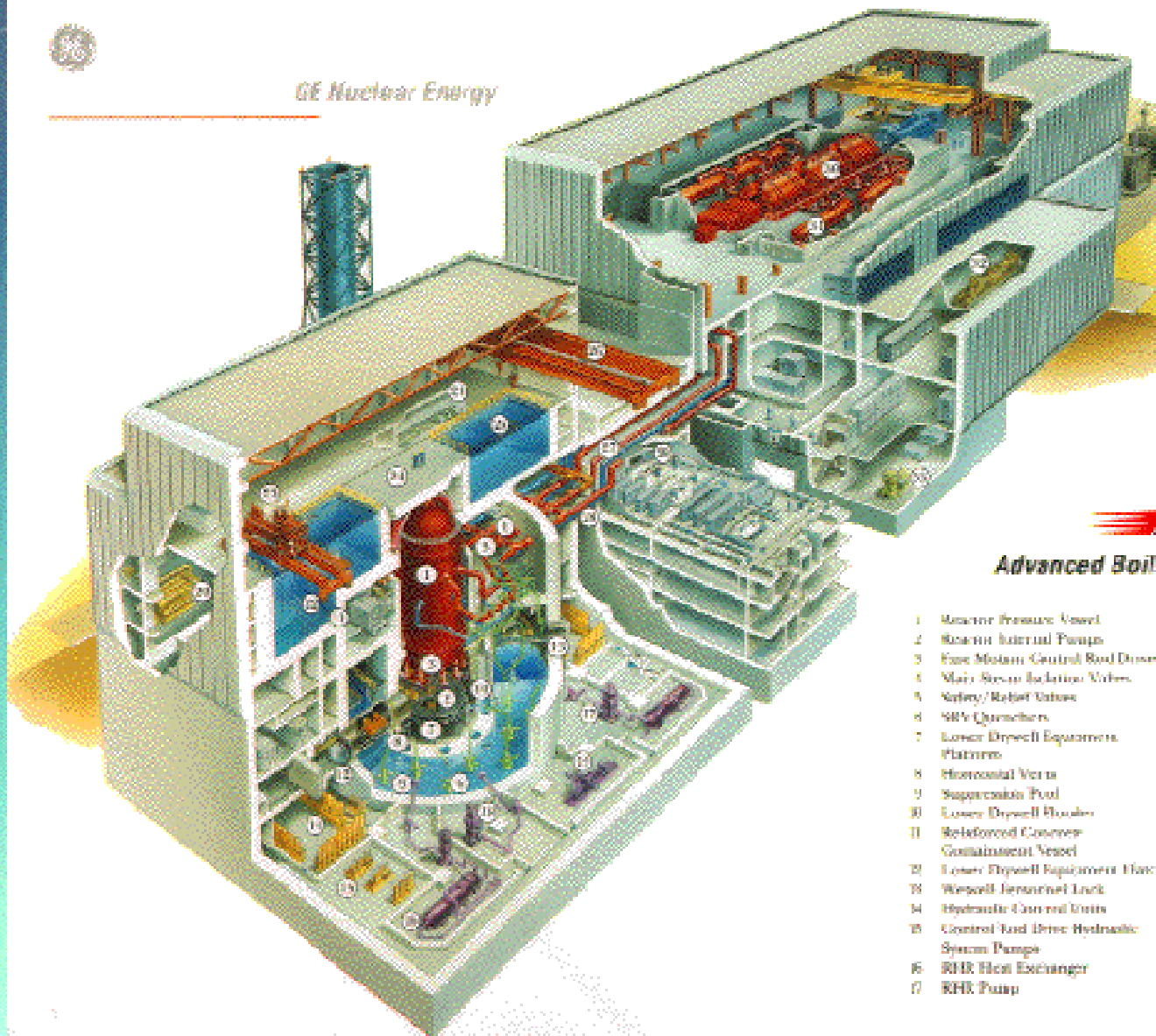
Gen I | Gen II | Gen III | Gen III+ | Gen IV

Next Generation – Gen III

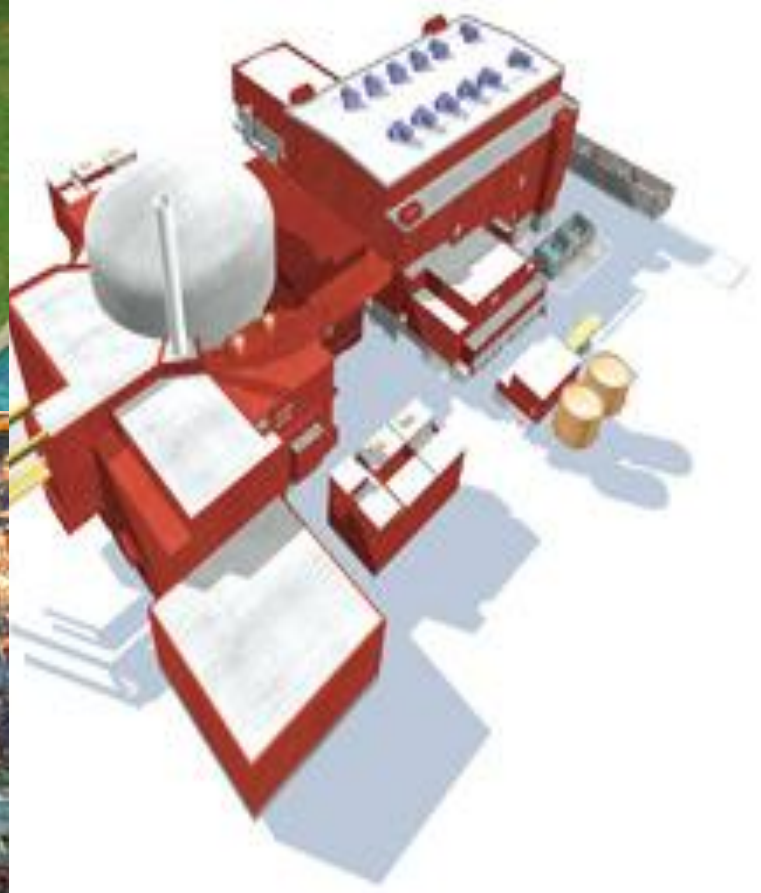
- Standardized designs
- ABWR and APWR
- Longer life (60-120 years)
- Improved safety
- Fewer parts
- Higher burnup
- None built in US (yet) – several built or under construction in Japan, South Korea, Europe, Russia

Advanced LWR: ABWR

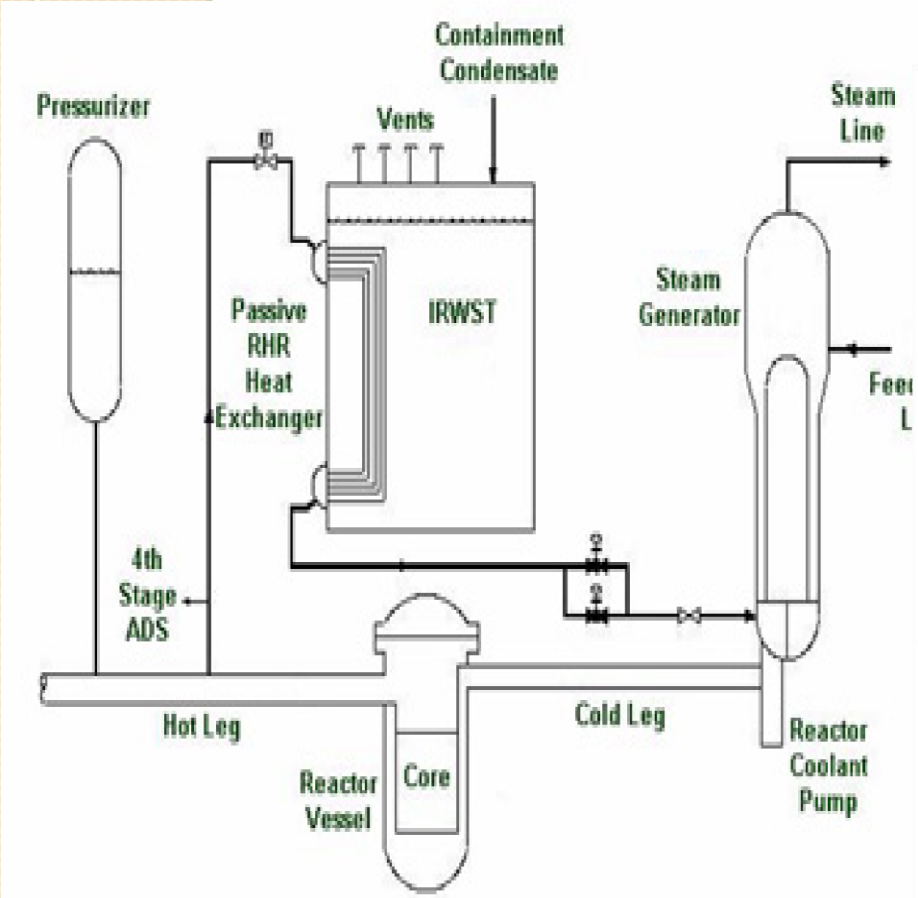


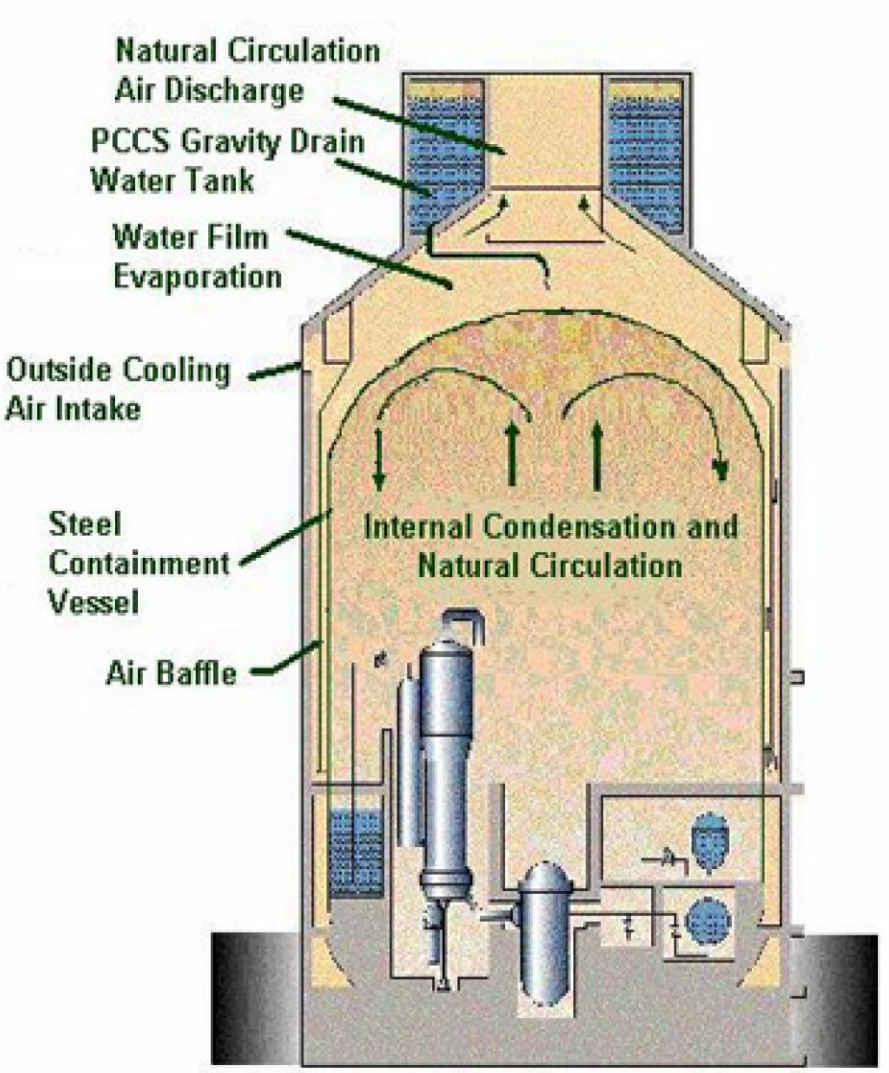


Advanced LWR: EPR

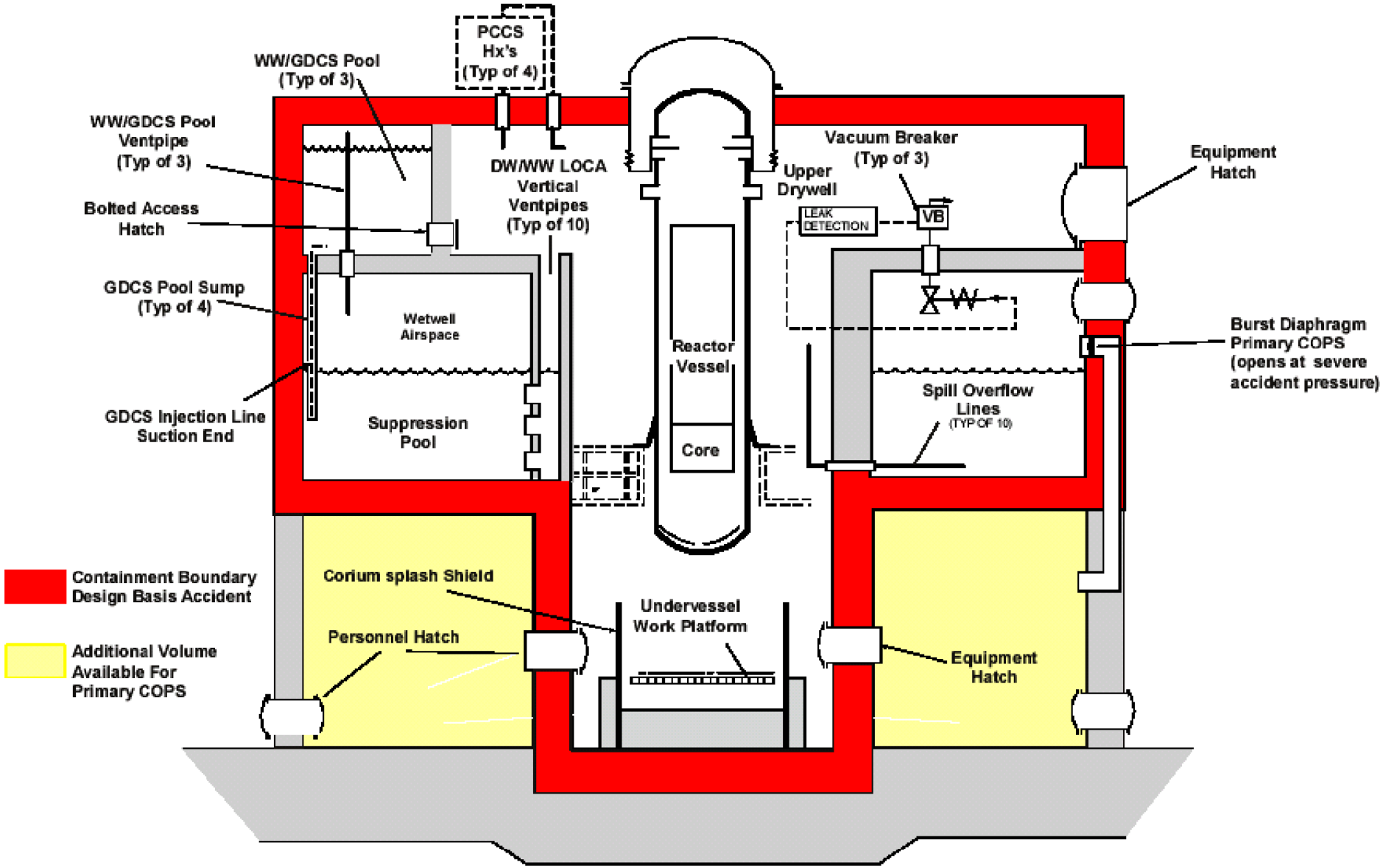


Advanced LWR: AP-1000

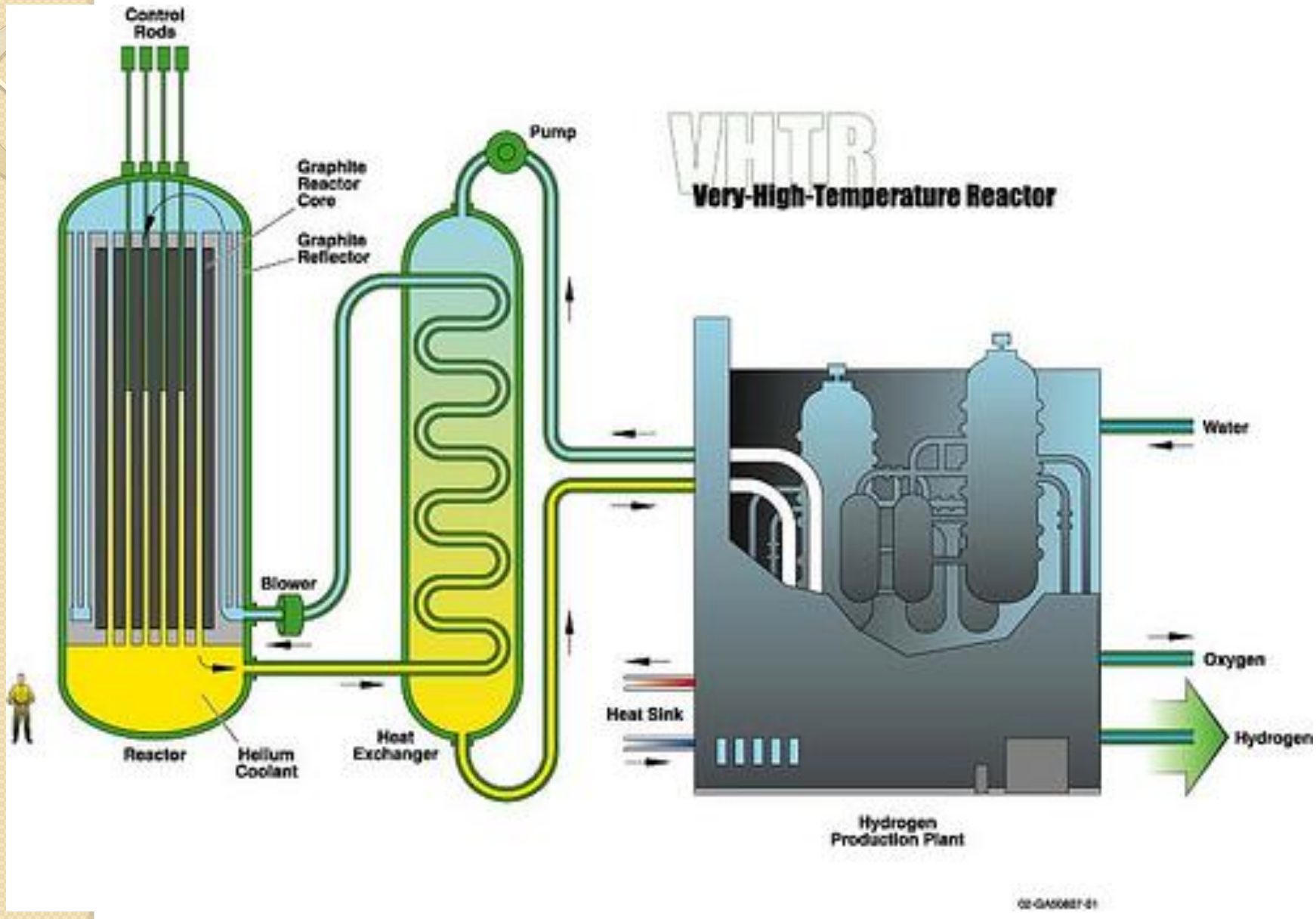


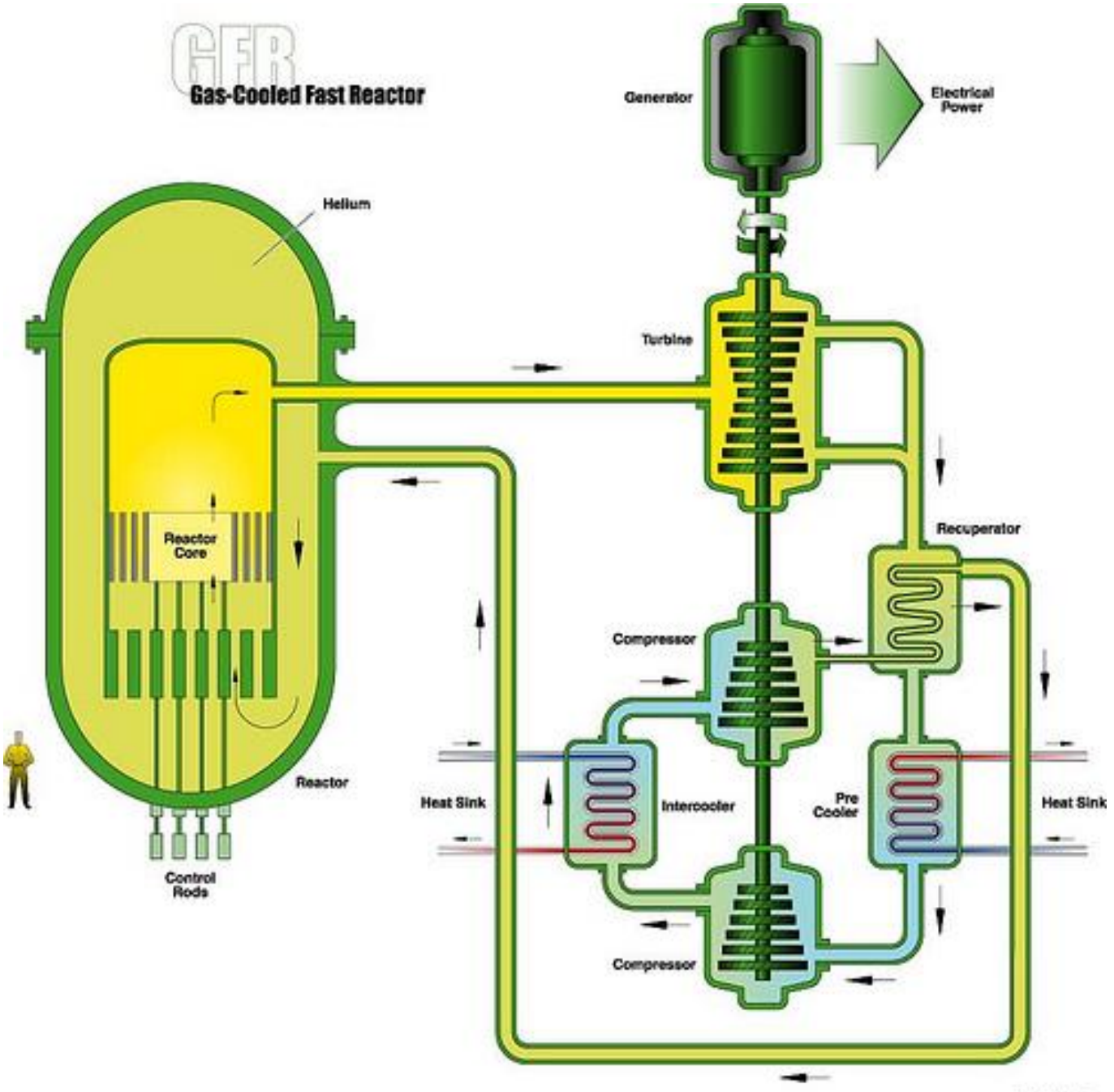


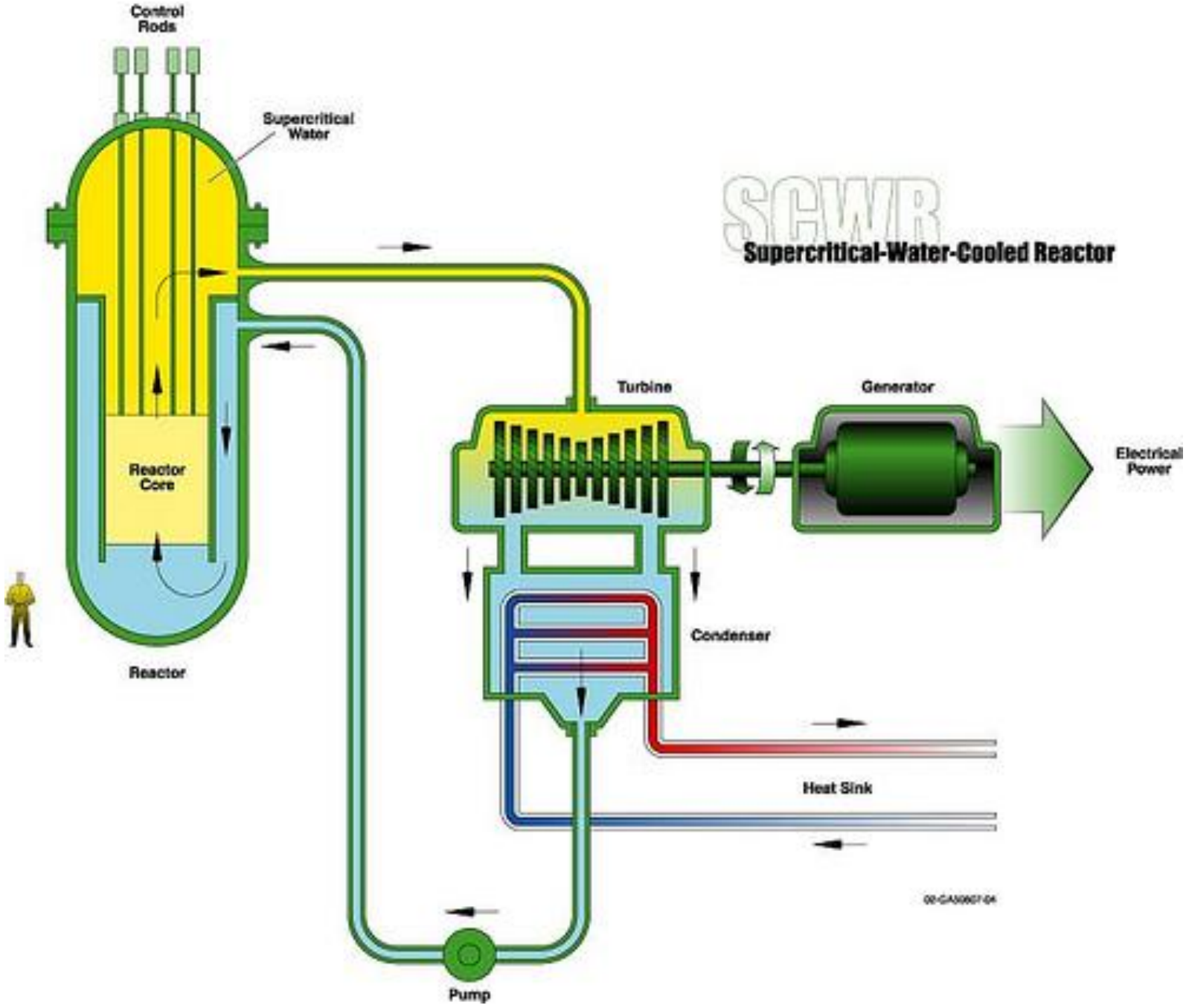
Advanced LWR: ESBWR

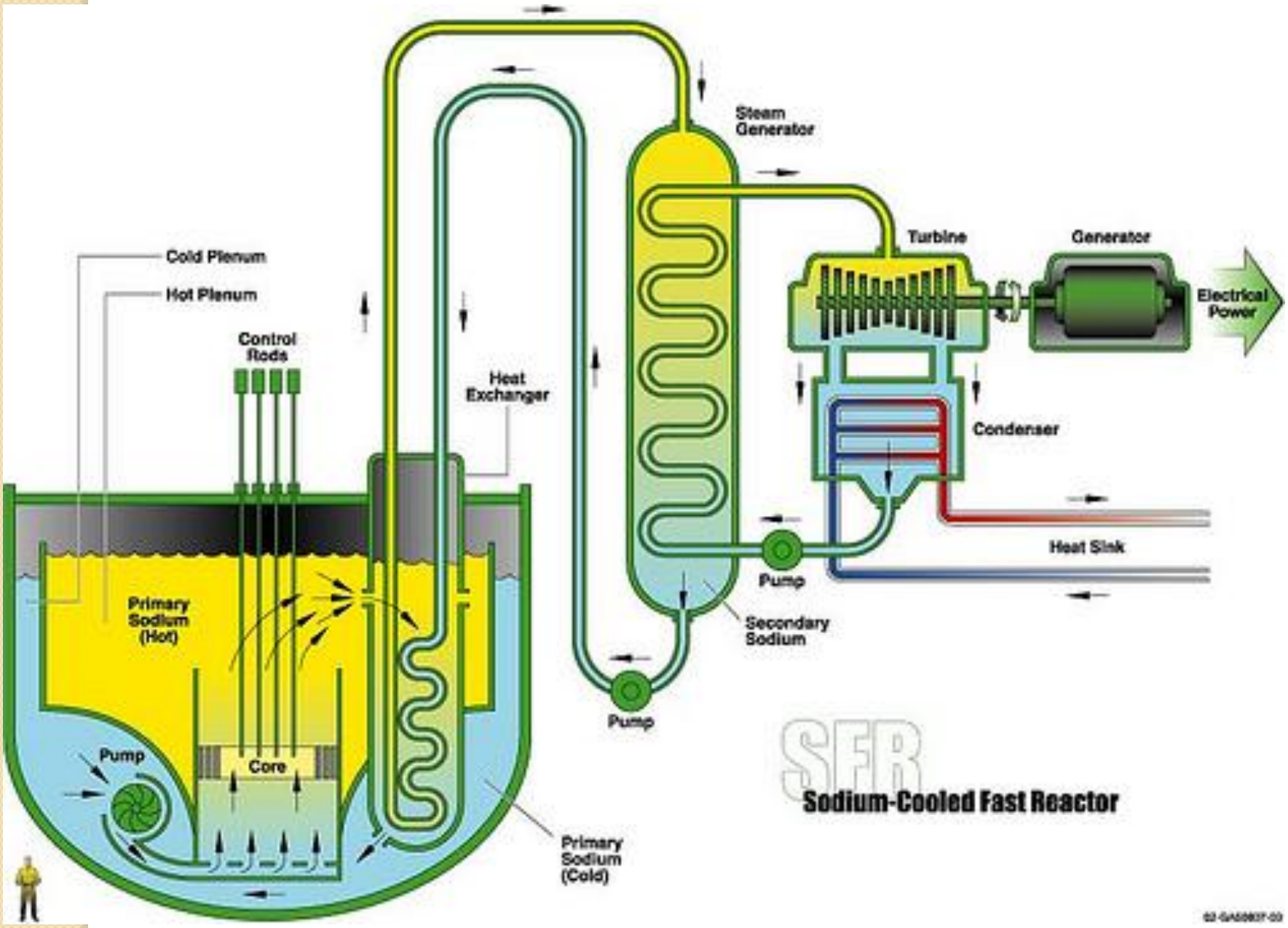


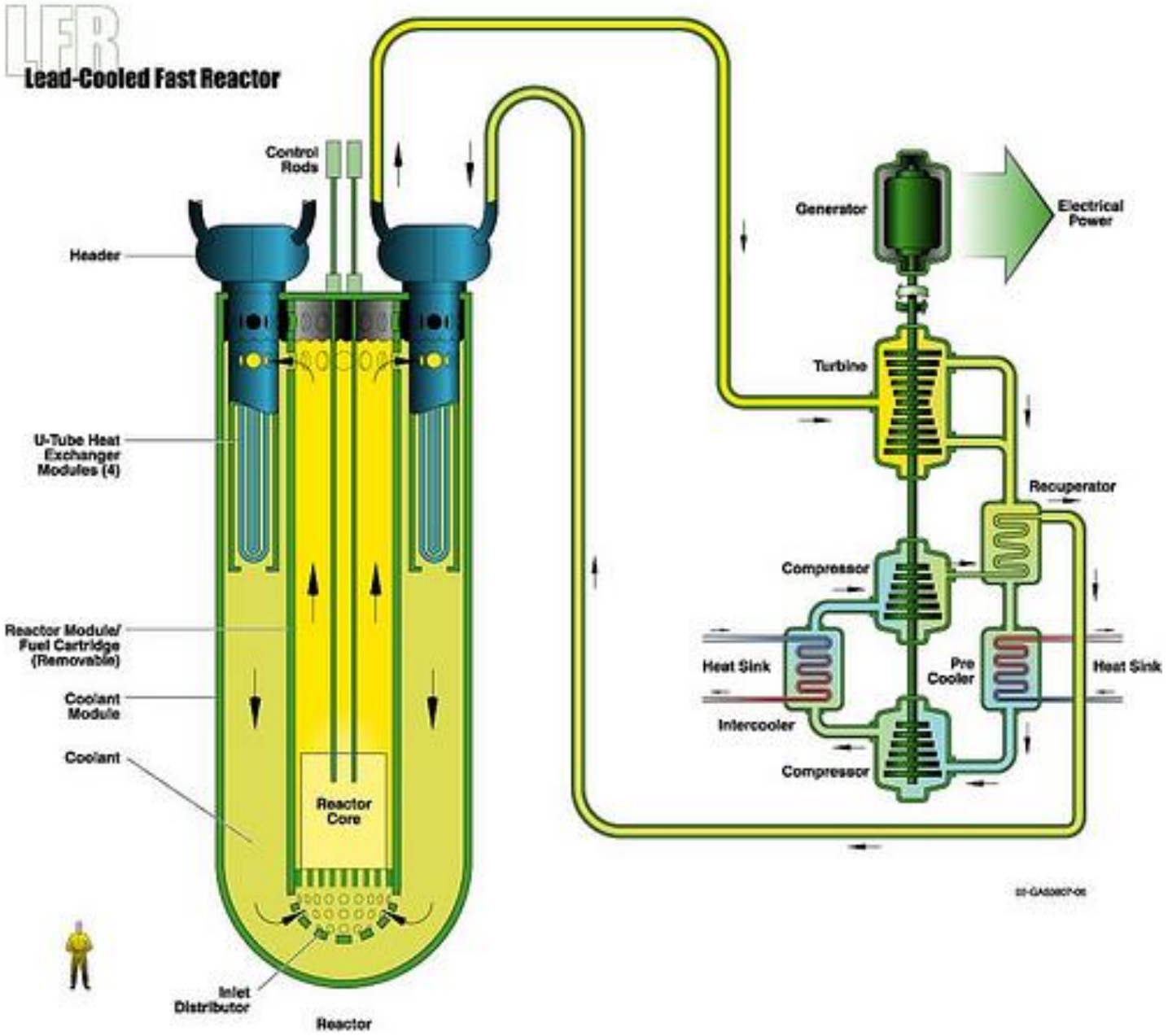
Generation IV Designs

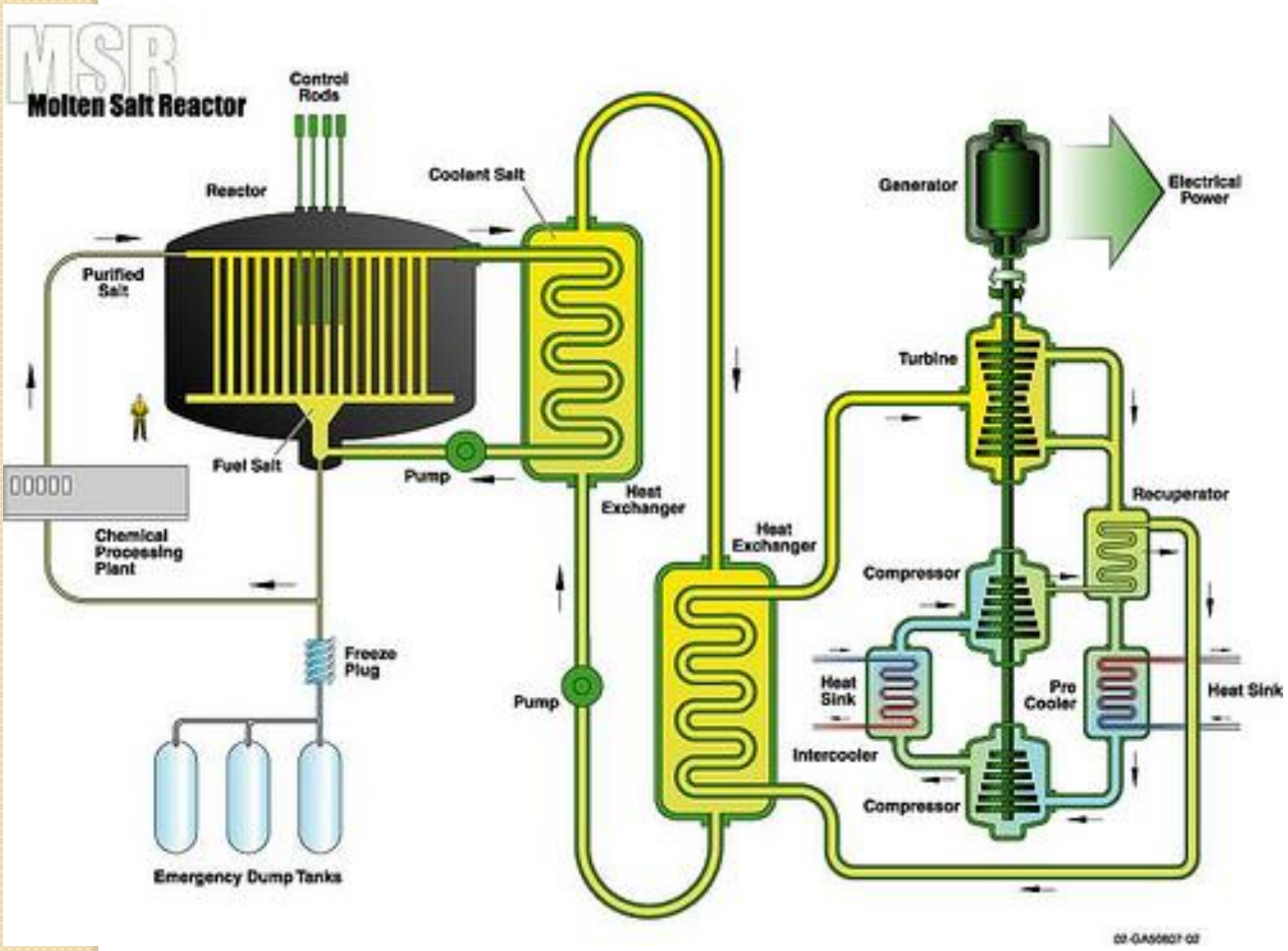



GFR
Gas-Cooled Fast Reactor
Generator
Electrical Power
Helium
Turbine
Recuperator
Reactor Core
Compressor
Reactor
Heat Sink
Intercooler
Pre Cooler
Heat Sink
Control Rods
Compressor


Control Rods
Supercritical Water
SCWR
Supercritical-Water-Cooled Reactor
Turbine
Generator
Electrical Power
Reactor Core
Reactor
Condenser
Heat Sink
Pump


Steam Generator
Turbine
Generator
Electrical Power
Cold Plenum
Hot Plenum
Control Rods
Heat Exchanger
Condenser
Heat Sink
Pump
Secondary Sodium
Primary Sodium (Hot)
Pump
Core
Primary Sodium (Cold)
SFR
Sodium-Cooled Fast Reactor


LFR
Lead-Cooled Fast Reactor
Control Rods
Header
U-Tube Heat Exchanger Modules (4)
Reactor Module/ Fuel Cartridge (Removable)
Coolant Module
Coolant
Reactor Core
Inlet Distributor
Reactor
Generator
Electrical Power
Turbine
Recuperator
Compressor
Heat Sink
Pre Cooler
Heat Sink
Intercooler
Compressor

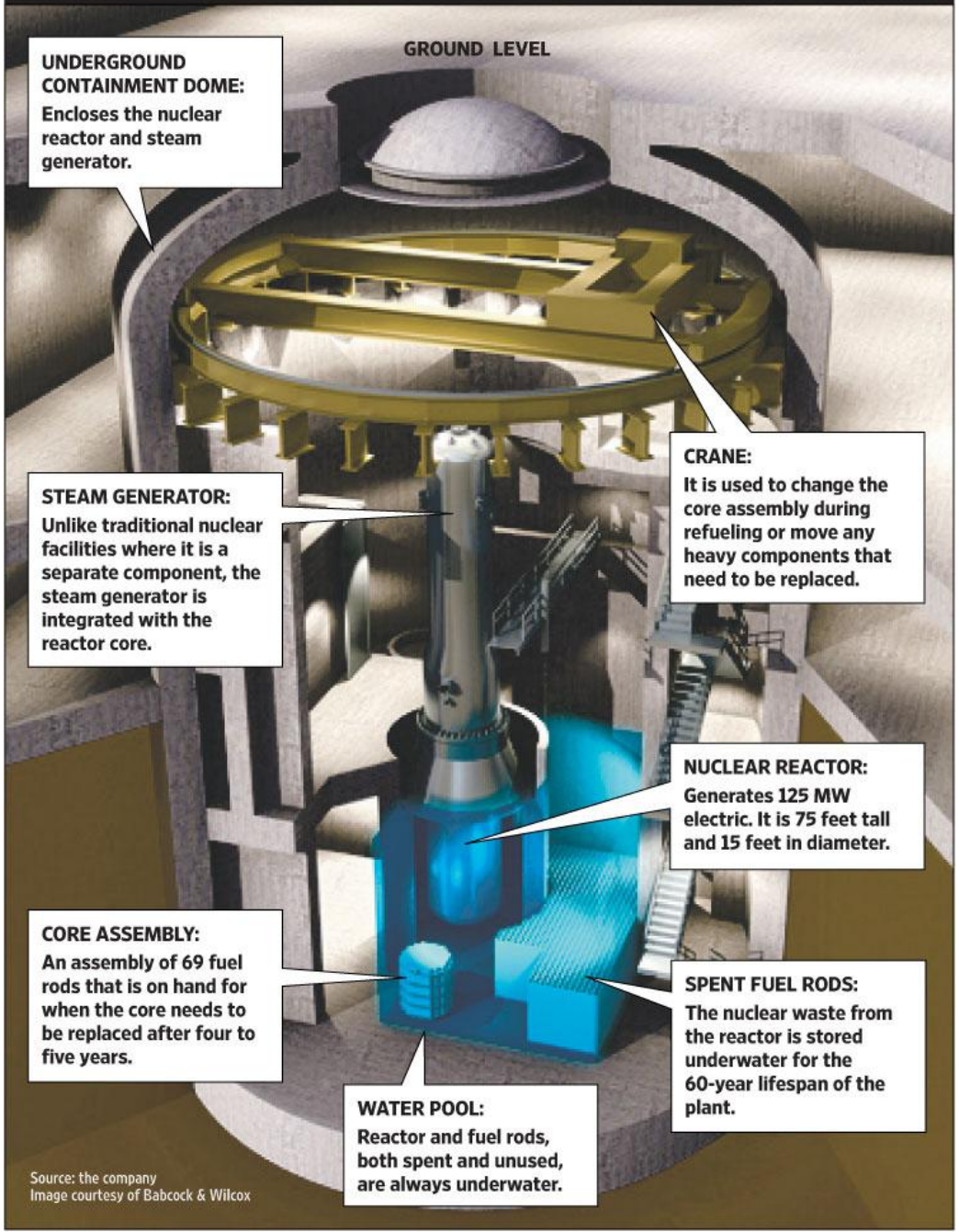

MSR
Molten Salt Reactor
Control Rods
Reactor
Coolant Salt
Purified Salt
Fuel Salt
Pump
Heat Exchanger
Chemical Processing Plant
Freeze Plug
Emergency Dump Tanks
Pump
Heat Exchanger
Generator
Electrical Power
Turbine
Recuperator
Compressor
Heat Sink
Pre Cooler
Heat Sink
Intercooler
Compressor

Small Modular Reactors

- There is recent interest in small reactors
  - 40-300 MWe
  - Reduced capital cost and construction time
  - Some require no refueling
  - Reactor, energy conversion, and waste storage in one module (for 60 year life)
- Galena, AK spends 28 cents/kWh on diesel generated power – Toshiba offering SMR

Compact Power

Babcock & Wilcox's reactor design is significantly smaller than that of existing nuclear plants.

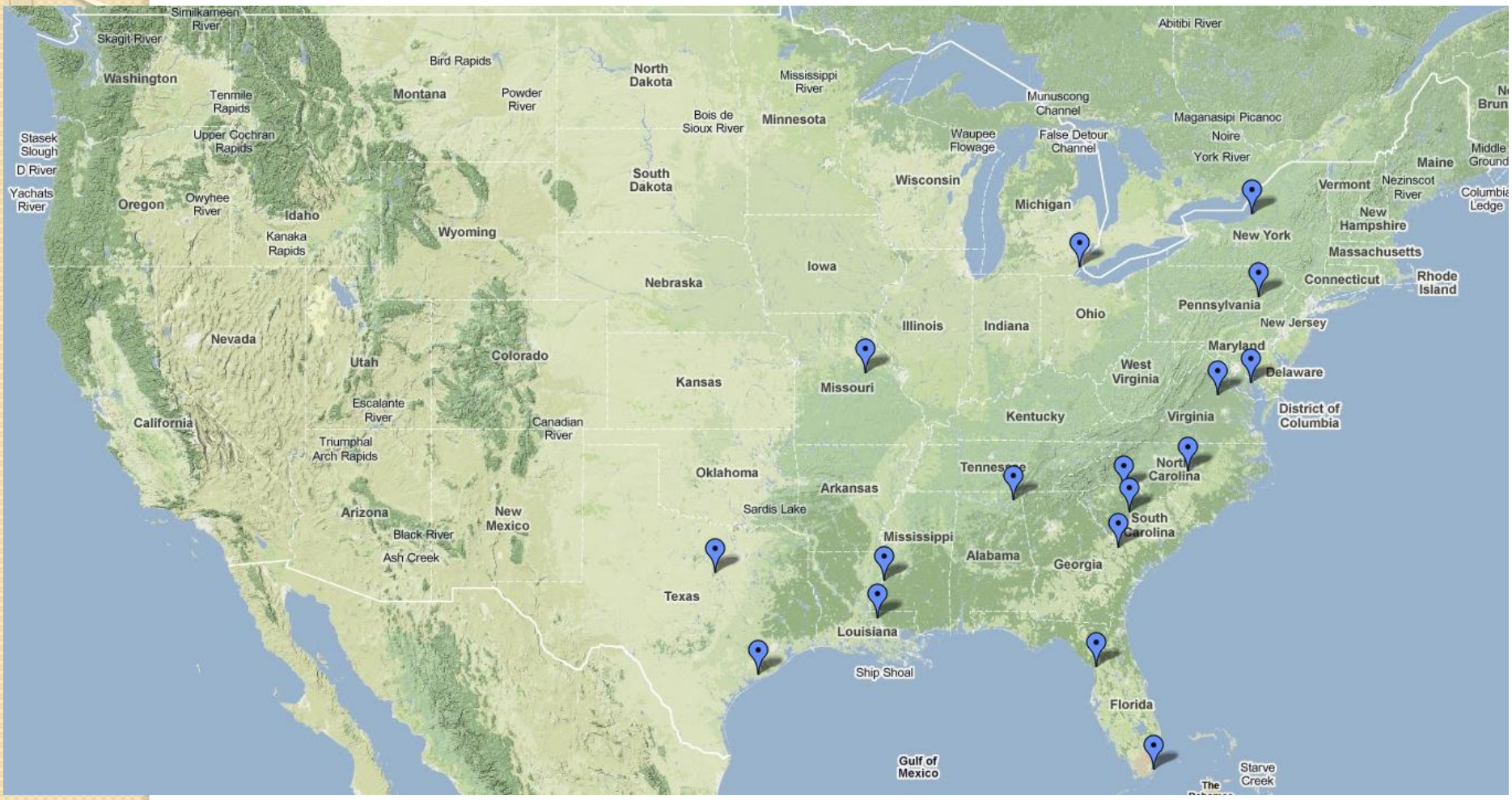


Source: the company
Image courtesy of Babcock & Wilcox

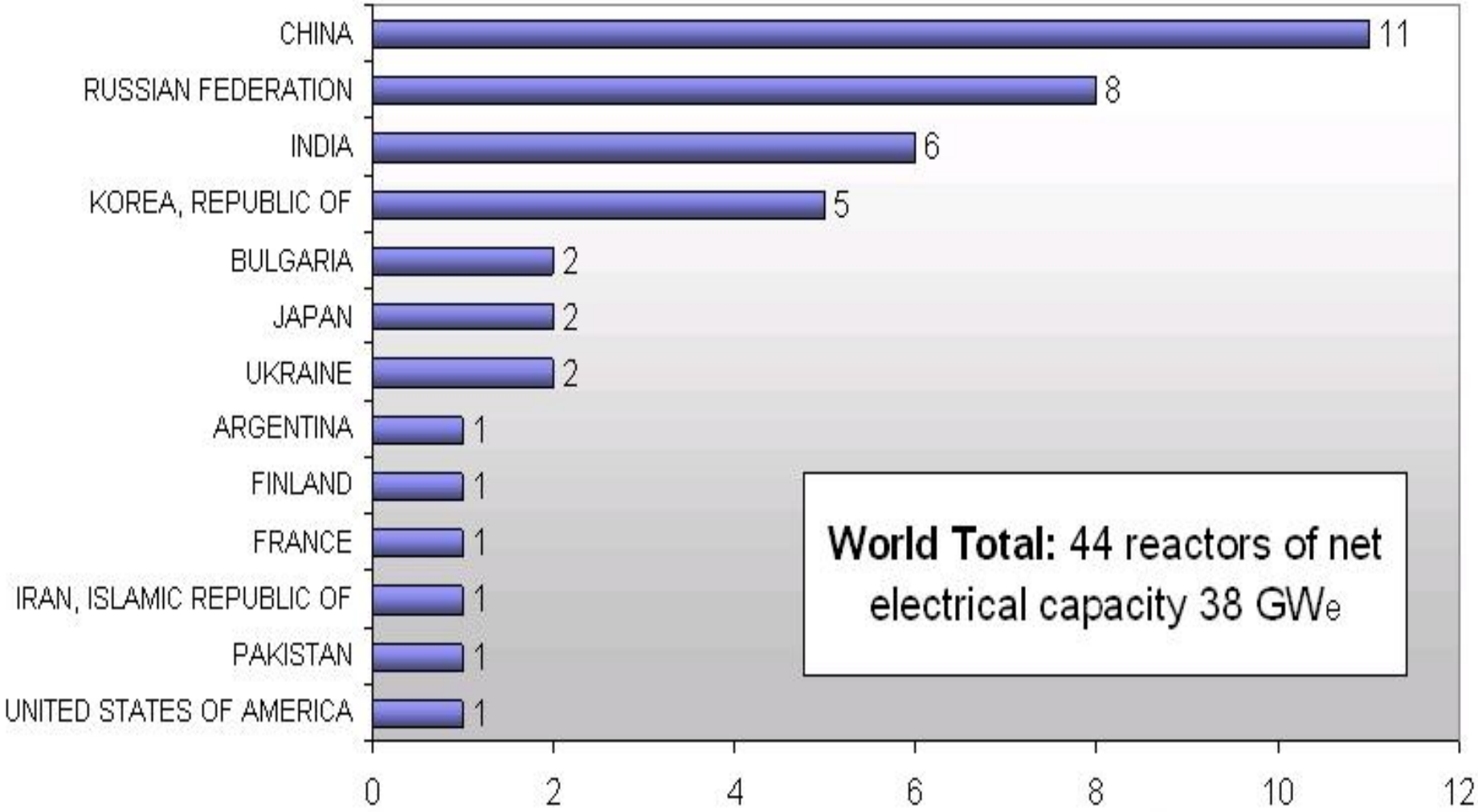
New Construction

- 15 applicants (17 sites) have expressed interest in building new reactors
- Southern Nuclear (Vogtle in GA) has started digging [but does not yet have construction/operating license (COL)]
- Several COLs targeted for 2012
- Florida PSL disallowed putting construction in rate base

US Proposed Construction



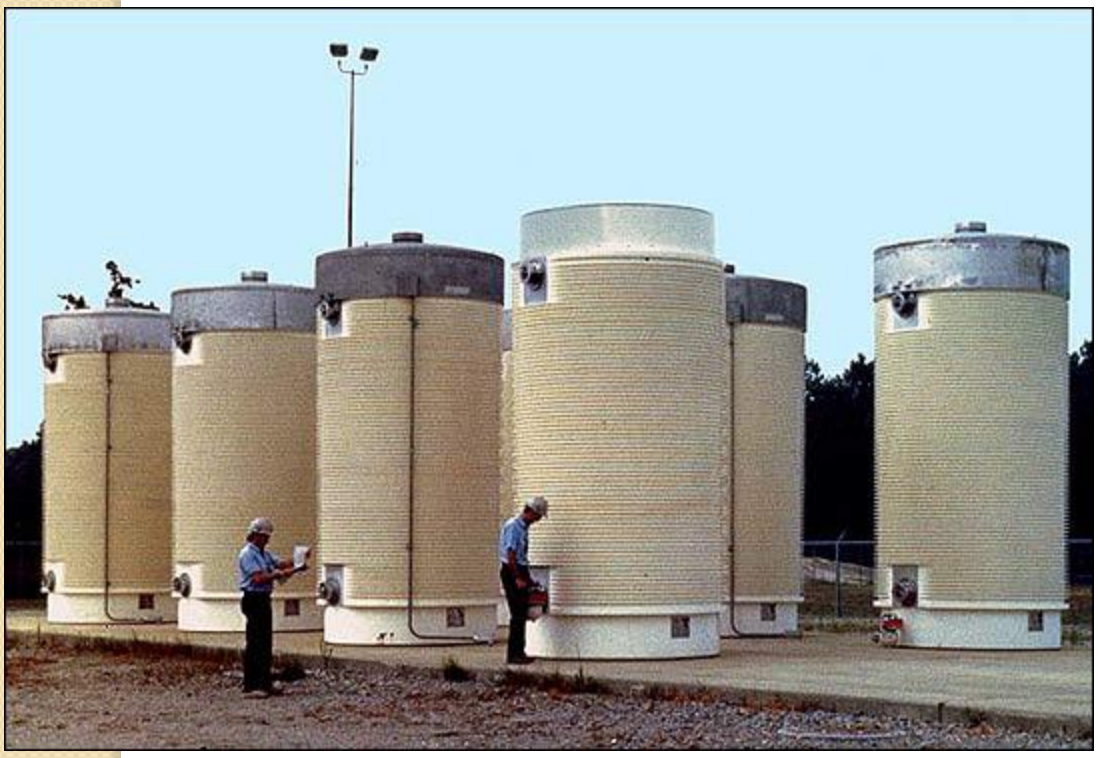
Number of Reactors under Construction Worldwide

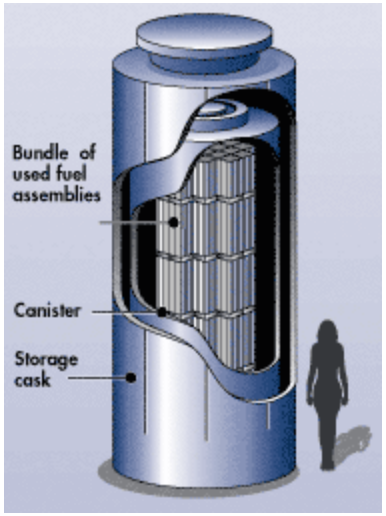


Note: The World Total includes also 2 reactors under construction in Taiwan, China.

Issues - Waste

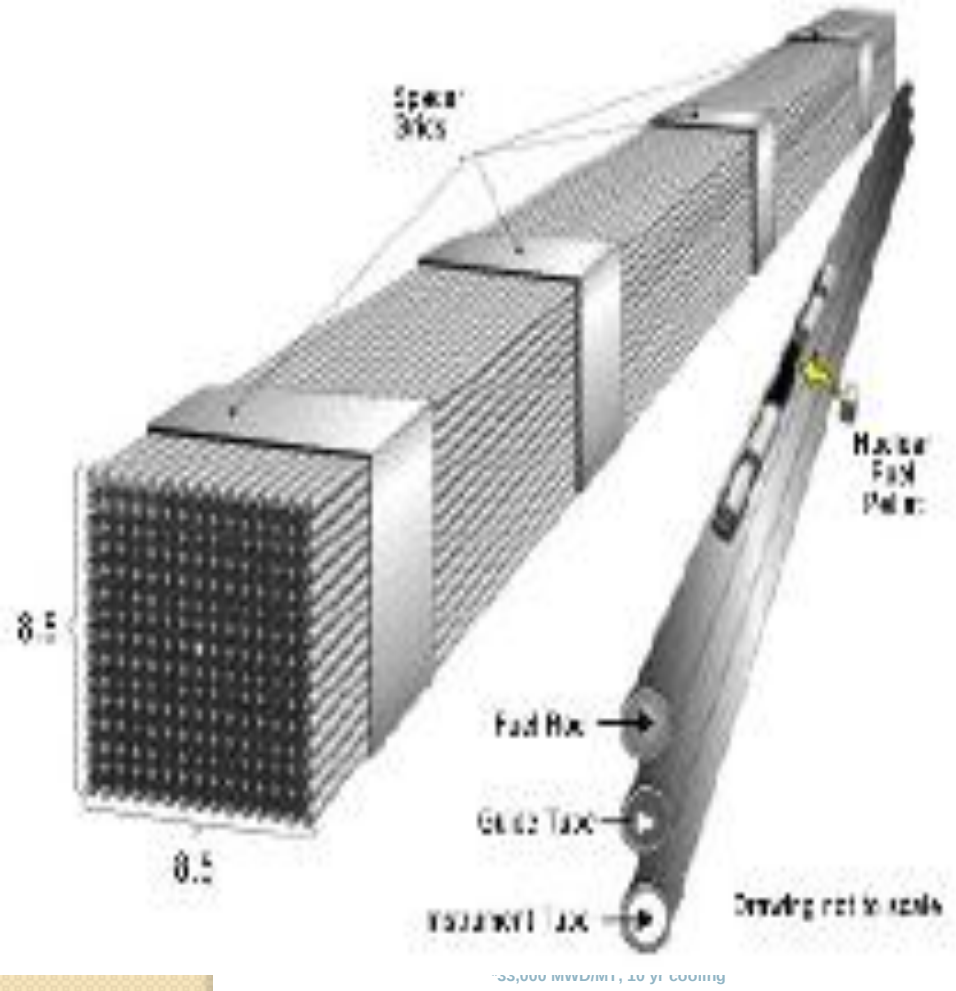
- Nuclear reactors produce a small volume of high level waste that lasts for centuries
- Reactors are re-fueled every 18-24 months and 1/3 of the core is replaced
- Currently, waste is stored in an on-site pool upon removal from core
- After cooling, it can be placed in dry cask storage (as pool fills)



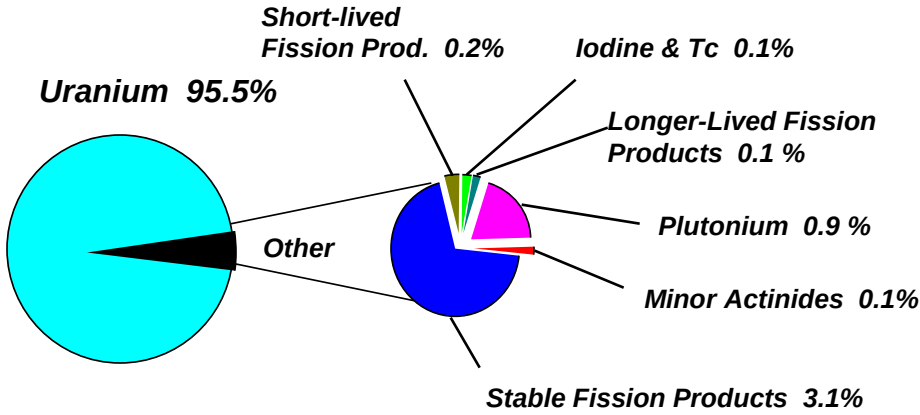


- Well-Shielded
- Cooled by Natural Convection
- Steel canister, concrete shield

Spent Nuclear



- ***Most is U and Pu, which can be recycled and 'burned'***
- ***Most heat produced by fission products decays in 100 yr***
- ***Most radiotoxicity is in the actinides (TRU) could be transmuted and/or disposed in much smaller packages***



Commercial Spent Fuel in Storage at the End of 2009

	Metric tons	Assemblies	Dry casks
Reactor pool storage	48,818	169,732	
Independent (mostly dry) storage	13,865	49,121	1,232
Total	**62,683**	**218,853**	**1,232**

Yucca Mountain

- The Federal Government was supposed to begin taking high level waste from commercial plants in 1998
- 10 sites selected in 1984 – narrowed to 5 (Utah, Mississippi, Washington, Texas, and Nevada) selected for further study – then narrowed to 3 (Washington, Texas, and Nevada) - Yucca selected in 1987
- Utilities have paid ~ $30 billion into the waste fund to design, build, and operate this facility ($9 billion spent)

Potentially Acceptable Sites for the First Repository

Source: DOE Office of Civilian Radioactive Waste Management. Adapted by CRS.

Proposed potentially acceptable sites and candidate areas for second repository

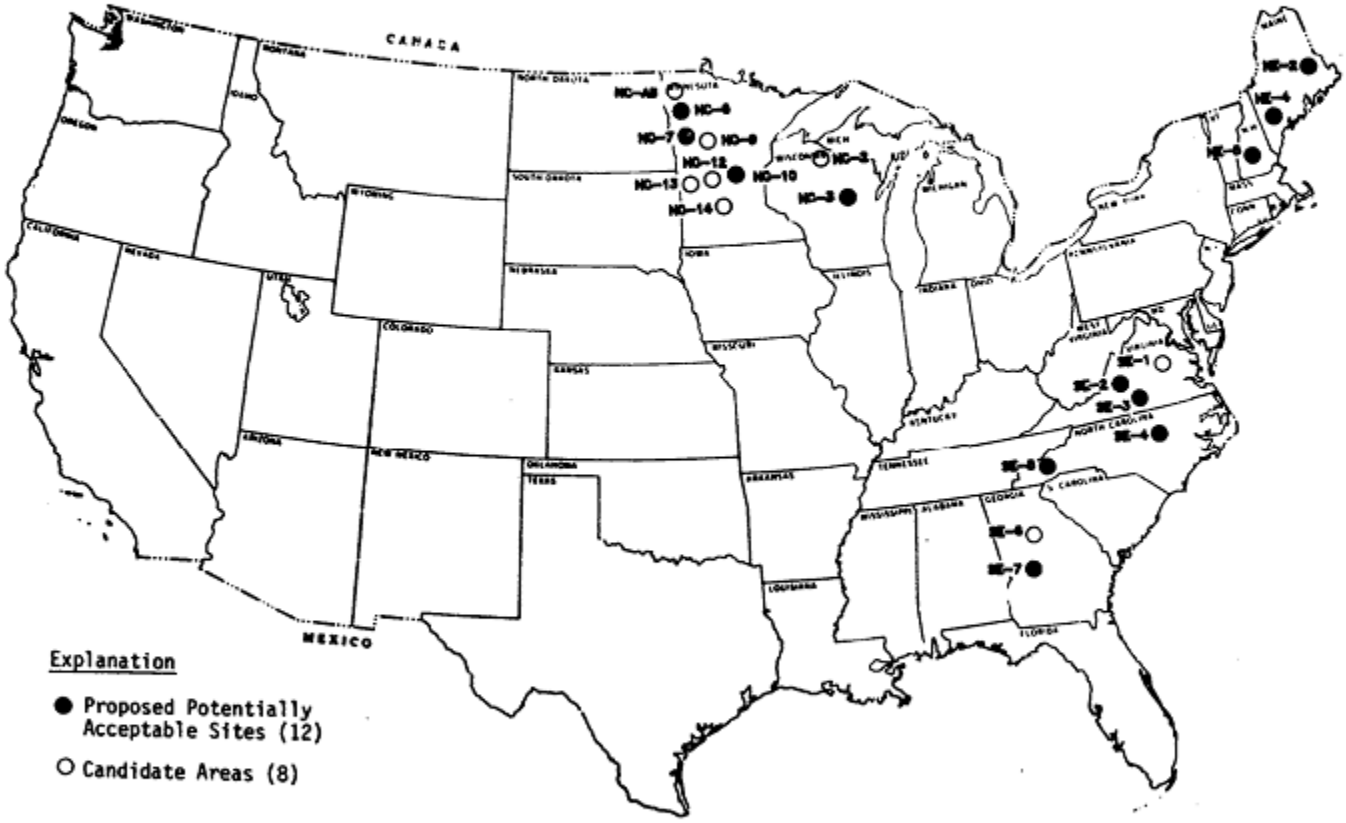


Figure 4. Proposed Potentially Acceptable Sites and Candidate Areas for the Second Repository

14

DISTRIBUTION CATEG

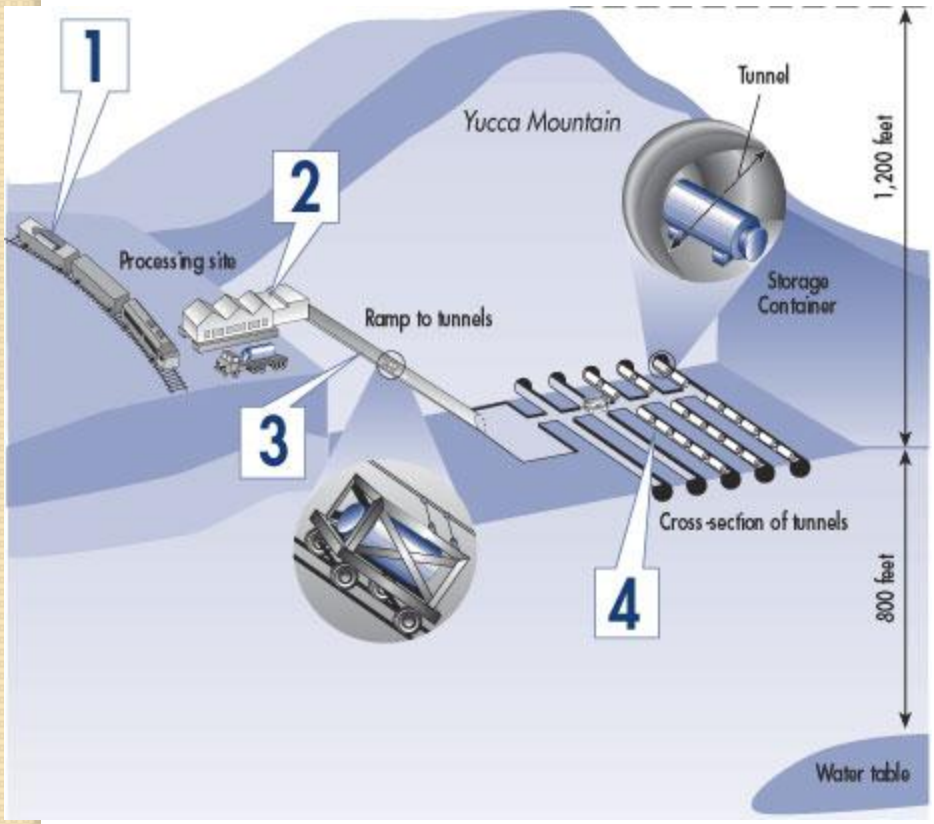
DRAFT

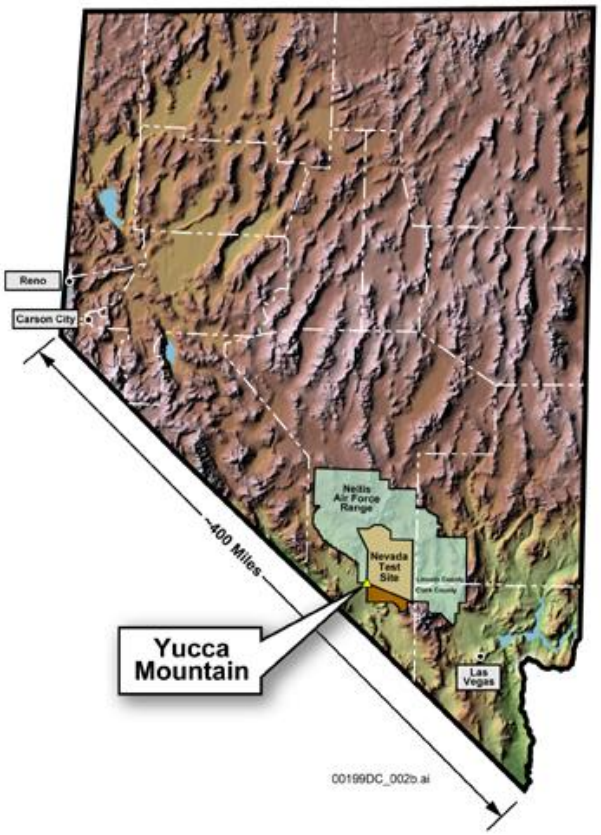
A RECOMMENDATION REPORT
CRYSTALLINE REPOSITORY PROJECT

OVERVIEW

JANUARY 1986

PARTMENT OF ENERGY
RADIOACTIVE WASTE MANAGEMENT
REPOSITORY PROJECT OFFICE


1
2
3
4
Yucca Mountain
Tunnel
Processing site
Ramp to tunnels
Storage Container
Cross-section of tunnels
1,200 feet
800 feet
Water table

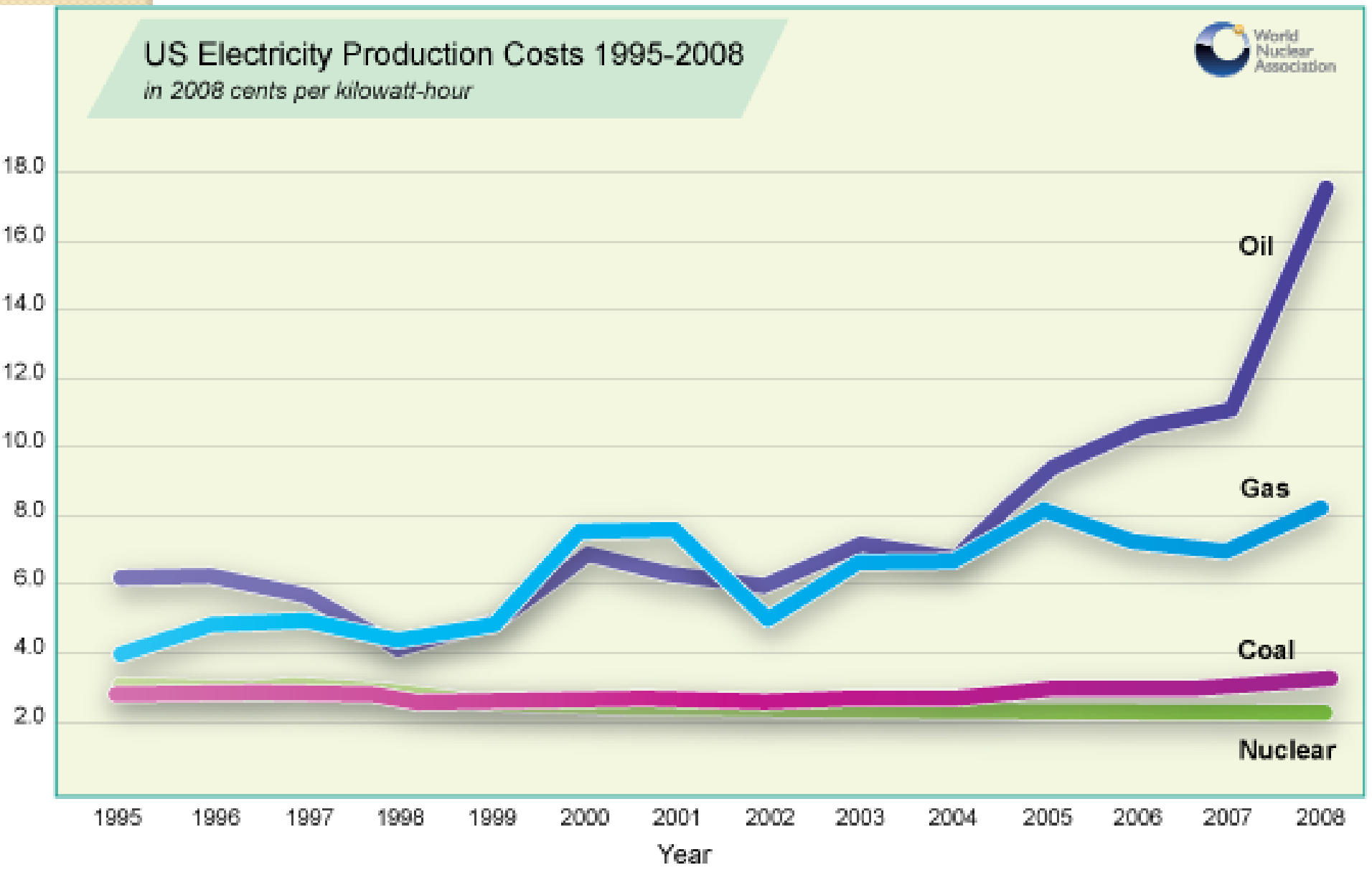

Reno
Carson City
Nellis Air Force Range
Nevada Test Site
400 Miles
Yucca Mountain
Las Vegas
C0199DC_002b.ai

Yucca Mountain

- 2002 - House Joint Resolution 87 moves process ahead
- Mid-2008 – DOE submits license application to NRC
- Late 2008 – Congress defunds project
- 2010 – DOE attempts to withdraw license application

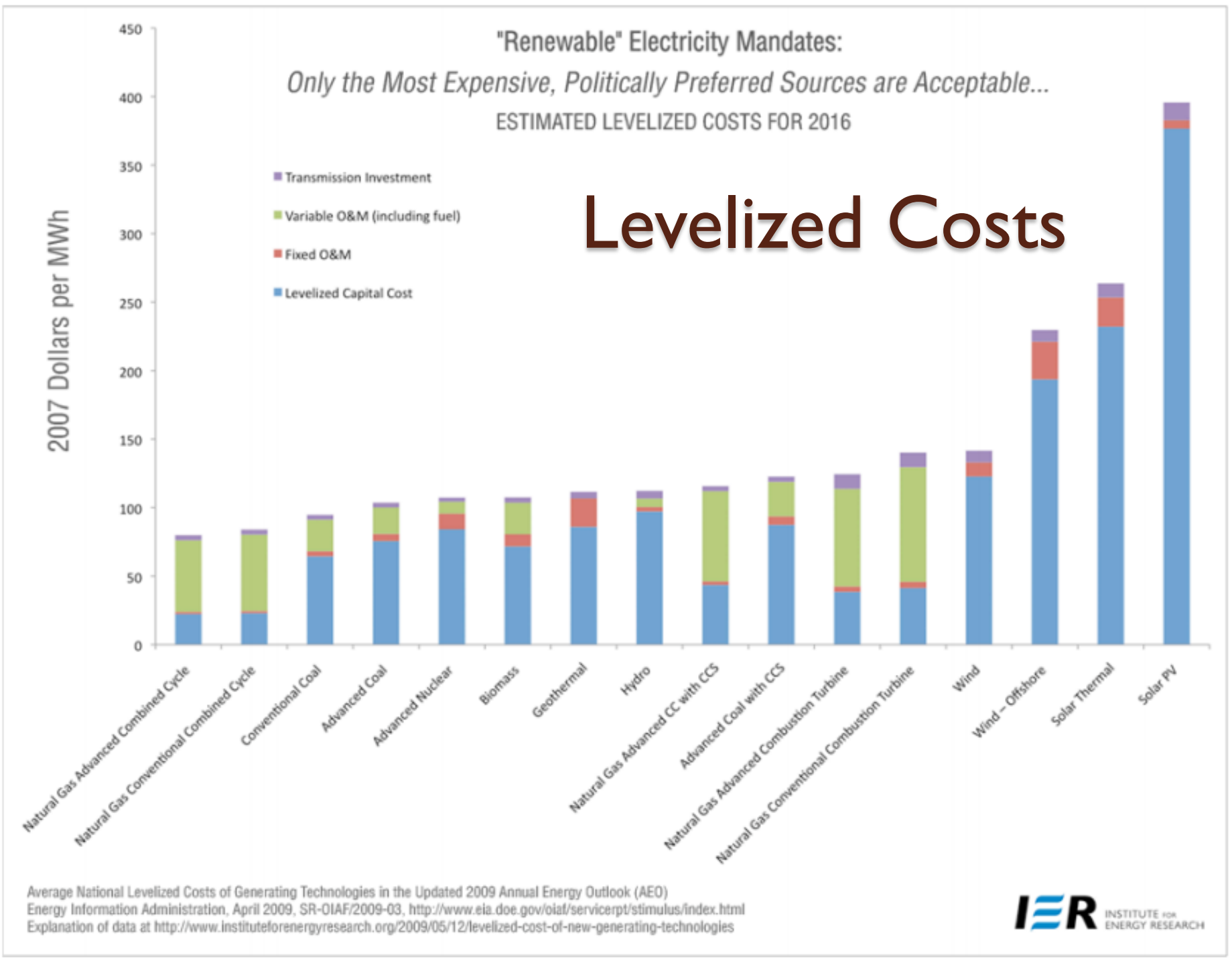
Electricity Costs

- Nuclear Reactors are capital intensive, but fuel is relatively inexpensive
- Current reactors are paid for, so electricity is inexpensive
- Projected costs for new construction indicate future costs will be reasonable



Production Costs = Operations & Maintenance + Fuel. Production costs do not include indirect costs or capital.

Source: *Ventyx Velocity Suite, via NEI*



Average National Levelized Costs of Generating Technologies in the Updated 2009 Annual Energy Outlook (AEO)
Energy Information Administration, April 2009, SR-OIAF/2009-03, http://www.eia.doe.gov/oiaf/servicerpt/stimulus/index.html
Explanation of data at http://www.instituteforenergyresearch.org/2009/05/12/levelized-cost-of-new-generating-technologies

IER INSTITUTE FOR ENERGY RESEARCH

Resources

- Uranium is mined in Australia, Canada, Africa, Kazakhstan, USA, etc.
- Natural uranium is 0.7% U-235 by weight
- We enrich to 3-5% for commercial reactors (Canadian reactors require less enrichment)
- Only a fraction of uranium is burned
- Estimates indicate fuel resources exhausted this century
- Reprocessing will extend this by several centuries
- We don't reprocess currently (cost, prolif.)

Conclusions

- Fission is coming back
- Things to look for
  - Resolution of Yucca Mountain license
  - Report from Nuclear Waste Commission
  - Progress on new construction
    - Opposition?
    - Time-to-completion