NUCLEAR POWER:

PROSPECTS for the 21st CENTURY

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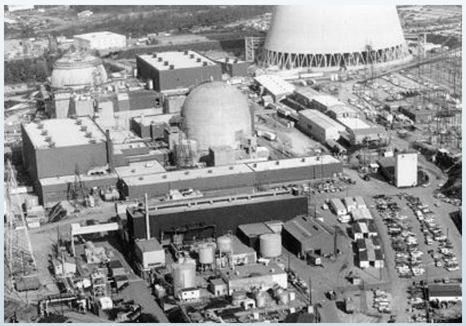
Historical Perspective for Nuclear Energy

- One of the first technology/engineering fields that encompassed systems from the microscopic world to the macroscopic world (atoms => devices)
- A major contributor to the public welfare via power, human health and security
  - major source of electricity (nationally ~ 20%)
  - enabling technology in the medical sciences
  - underlying technology for our national security

Evolution of Nuclear Power Systems

Generation I

Early Prototype Reactors



- Shippingport
- Dresden,Fermi-I
- Magnox

Gen I

1950 1960 1970 1980 1990 2000 2010 2020 2030

Nuclear Power for Electricity

- What is the current status of nuclear electricity?
- How is nuclear energy used to make electricity?
- What is a nuclear reactor and how does it operate?
- What are issues that could its affect future use?
  - What are the effects of radiation on health?
  - Are nuclear power plants safe enough?
  - How is spent fuel and the nuclear waste handled?
- What are the new technologies being developed?

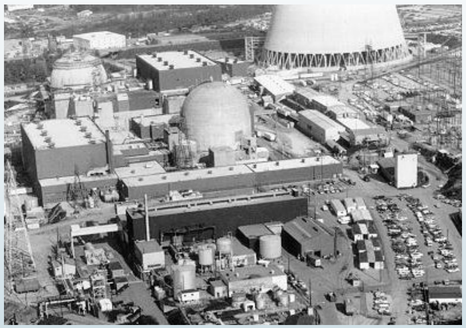
Evolution of Nuclear Power Systems

Generation I

Early Prototype Reactors

Generation II

Commercial Power Reactors



- Shippingport
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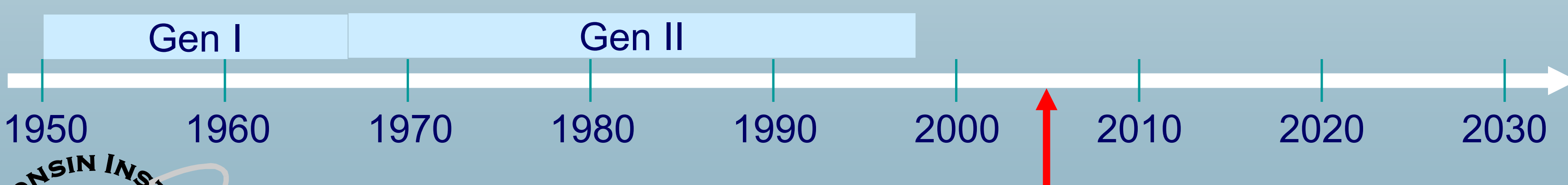
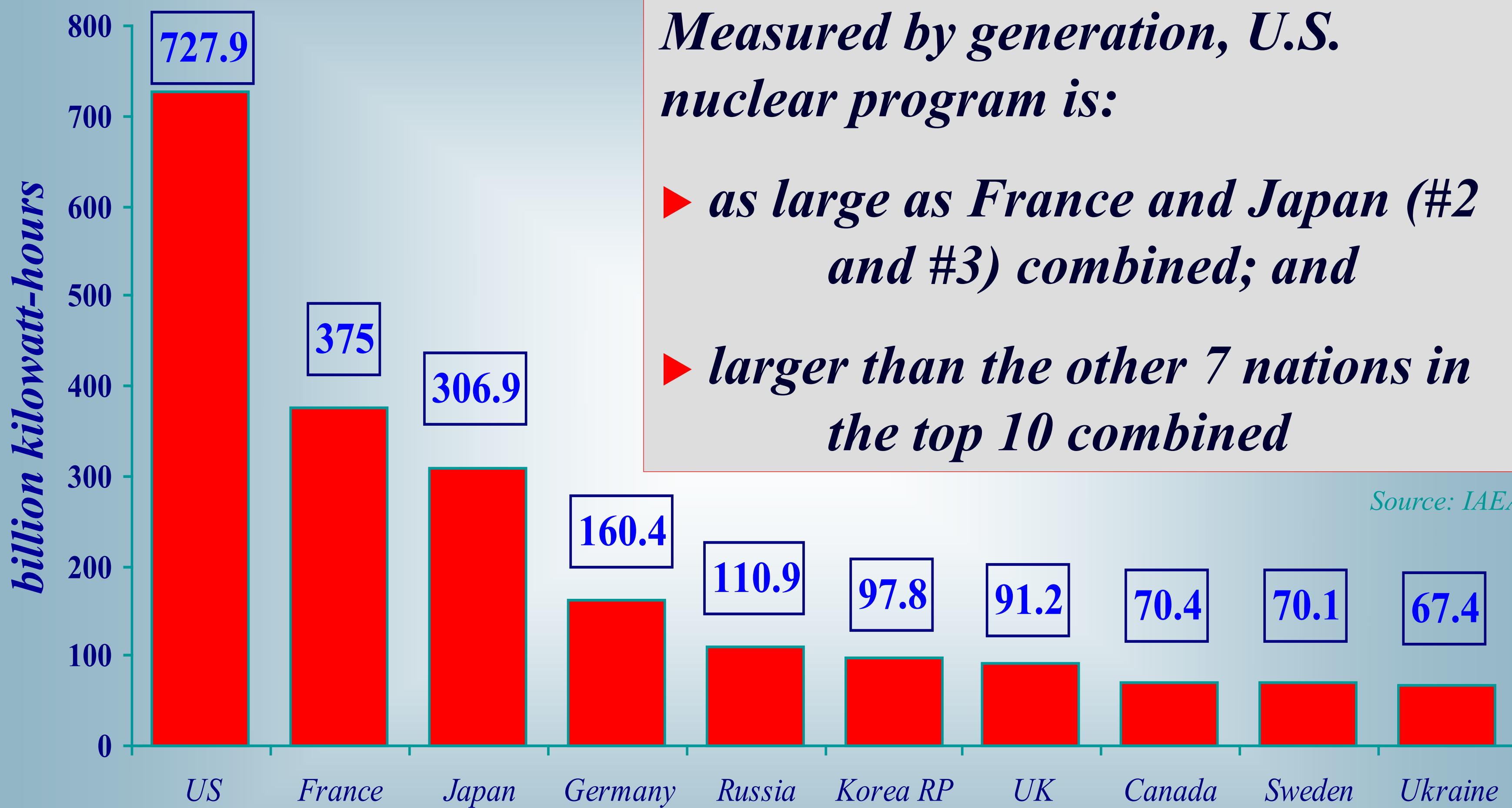
- LWR: PWR/BWR
- CANDU
- VVER/RBMK



Top 10 Nuclear Countries (2000)

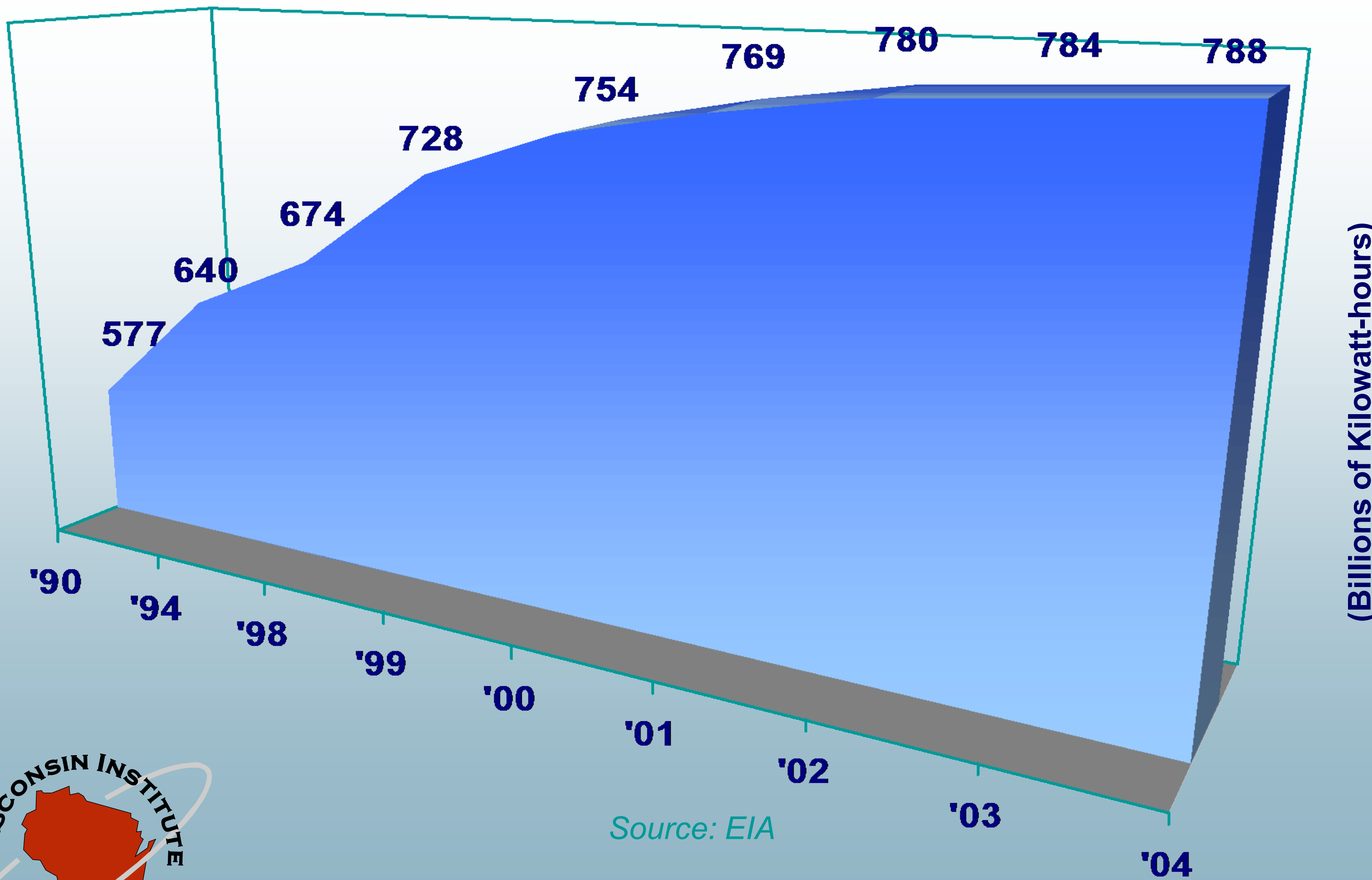


Measured by generation, U.S. nuclear program is:

- ***as large as France and Japan (#2 and #3) combined; and***
- ***larger than the other 7 nations in the top 10 combined***

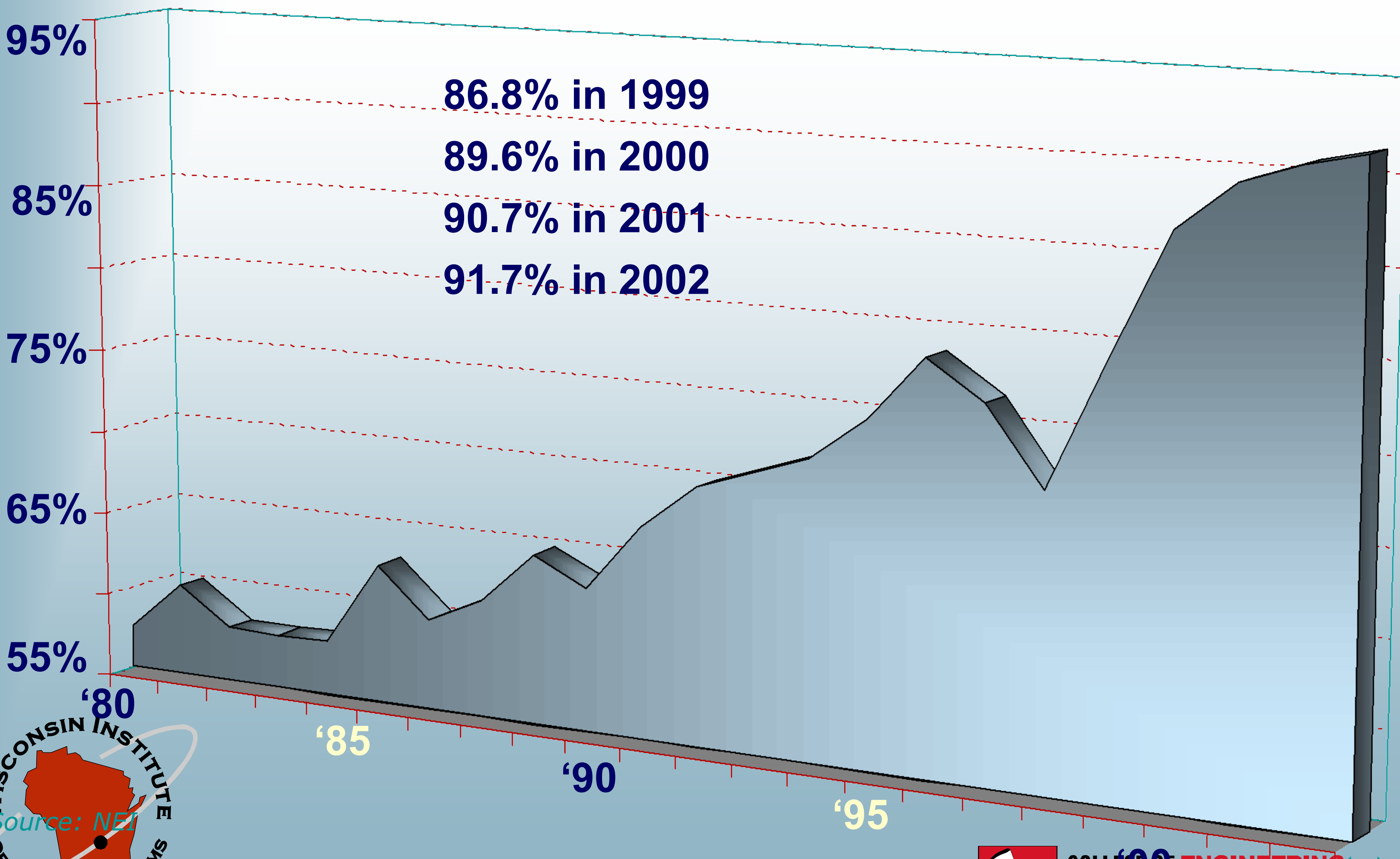
Source: IAEA

Record U.S.Nuclear Electricity Production



Source: EIA

Capacity Factors Improvement



Source: NEI

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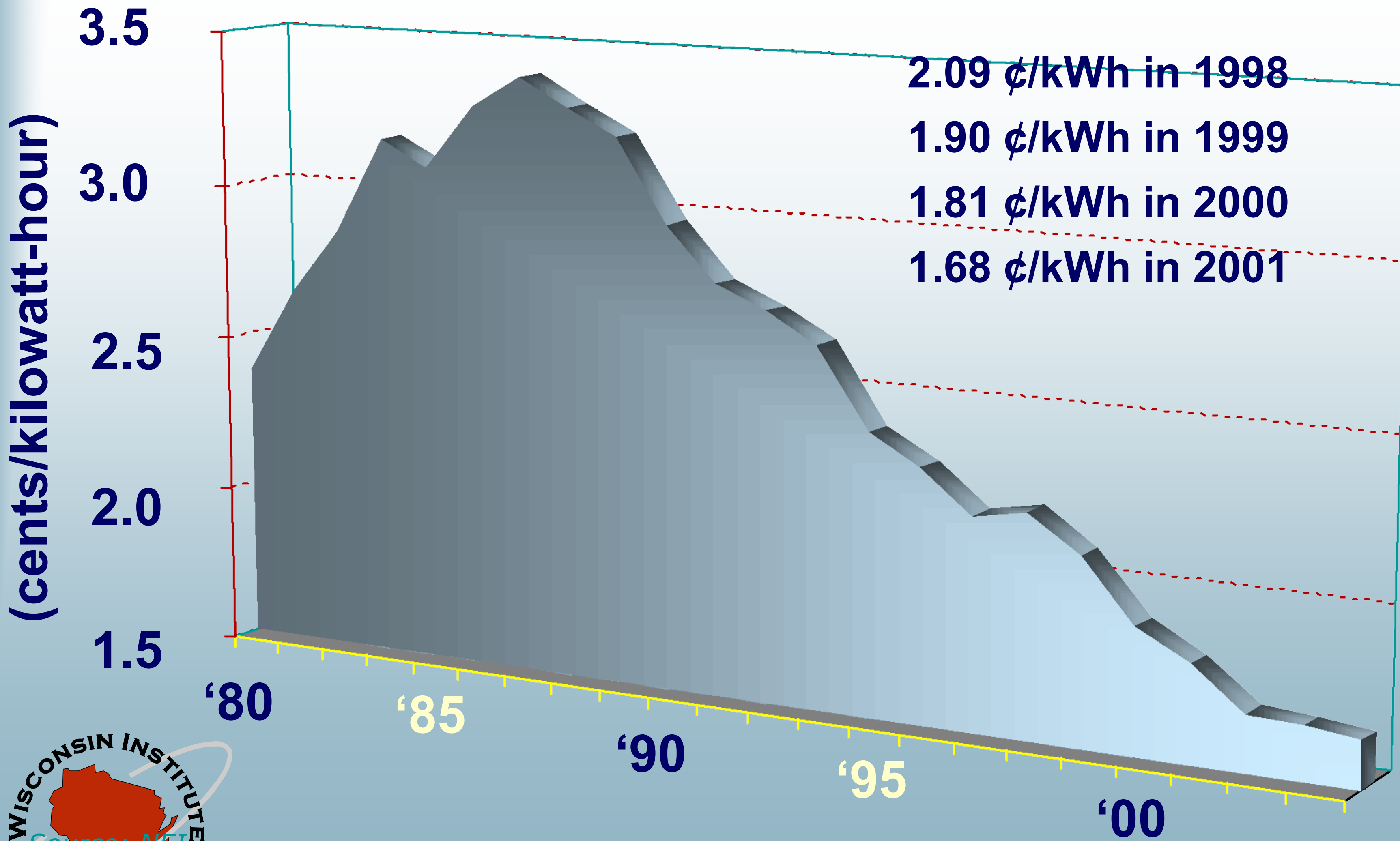
Lowest Electricity Production Costs



Source: NEI

License Renewal:Extends Value

44 NPP Extended   34 NPP Applied   22 NPP In-process

Nuclear Units Under Construction Worldwide

Country	Units	Total MWe
Argentina	1	692
Bulgaria	2	1,906
China	4	3,610
China, Taiwan	2	2,600
Finland	1	1,600
India	7	3,112
Iran	1	915
Japan	1	866
Pakistan	1	300
Romania	1	655
Russia	4	3,775
Ukraine	2	1,900
Total	**27**	**21,931**

Source: International Atomic Energy Agency PRIS database

Updated: 6/06

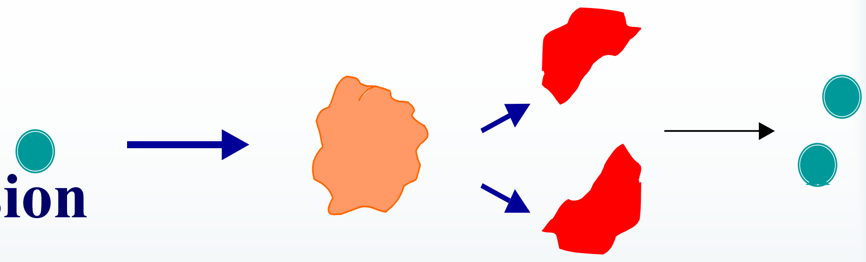
NEI

Nuclear Power Plants: US Potential Orders

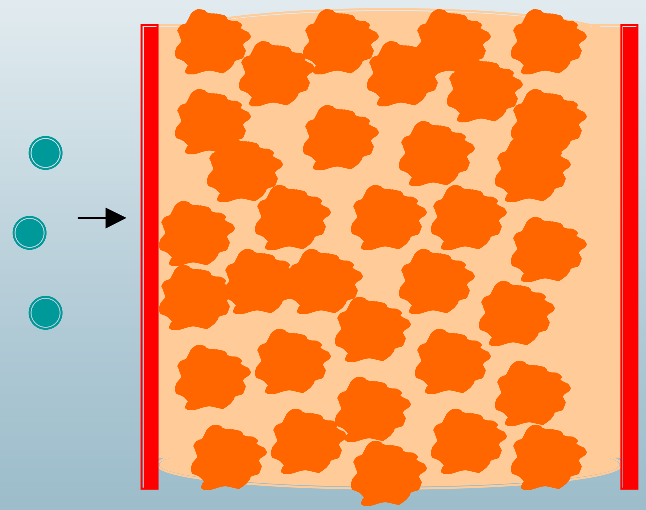
Company	Site(s)	Early Site Permit (ESP)	Design, # of units	Construction/Operating License Submittal Timeline
TVA (NuStart)	Bellefonte (TN)		W: AP1000 (2)	October 2007
South Carolina E & G	Summer (SC)		W: AP1000 (2)	October 2007
Duke	Cherokee County, SC		W: AP1000 (2)	October 2007
Progress Energy	Harris (NC) Florida (Site TBD)		W: AP1000 (2) TBD (2)	October 2007 July 2008
Constellation (UniStar)	Calvert Cliffs (MD) or Nine Mile Point (NY)	Will go to COL with early submittal of siting info	Areva: EPR (5)	4Q - 2007
Dominion	North Anna (VA)	Under review, approval expected 2007	GE: ESBWR (1)	November 2007
Entergy (NuStart)	Grand Gulf (MS)	Under review, approval expected 2007	GE: ESBWR (1)	November 2007
NRG Energy (STP)	South Texas Project (TX)		GE: ABWR (2)	Late 2007
Southern Company	Vogtle (GA)	Submitted August 2006, Approval expected early 2009	W: AP1000 (2)	March 2008
Entergy	River Bend (LA)		GE: ESBWR (1)	May 2008
Amarillo Power	Near Amarillo, TX	Under development for 4Q/07	GE: ABWR (2)	As soon as practicable after 2007
Texas Utilities	TBD	Straight to COL	TBD: 2-6 GWe	2008
Exelon	Clinton (IL)	Under review, approval expected 2007	TBD	TBD
Florida Power & Light	TBD		TBD	TBD
Duke	Davie County, NC	Under consideration		TBD
Duke	Oconee County, SC	Under consideration		TBD

Nuclear Fission produces Energy

A neutron is absorbed by a uranium atom, breaking into fission products & hi-speed neutrons



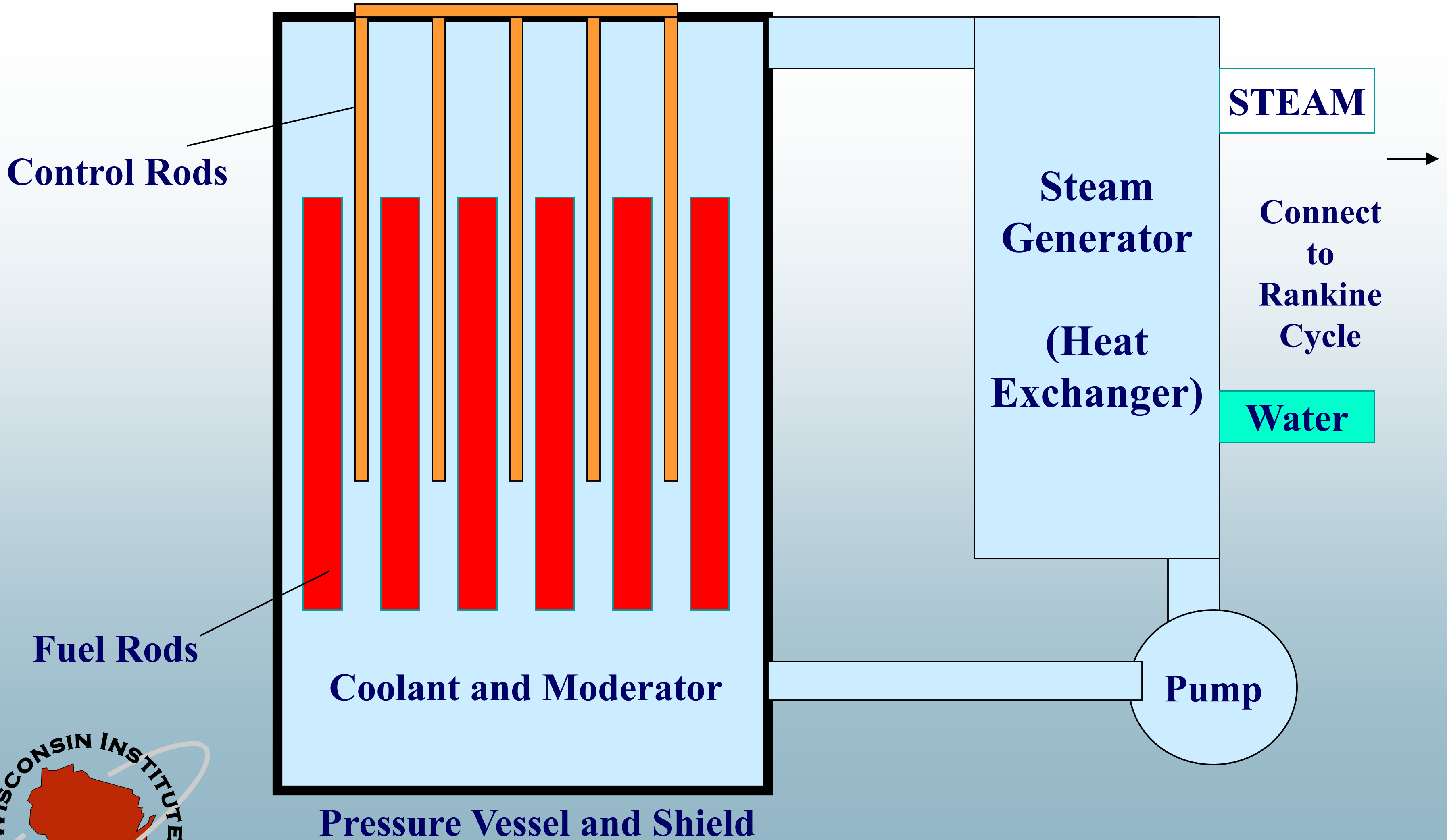
Energy released is over million times larger than any carbon fuel



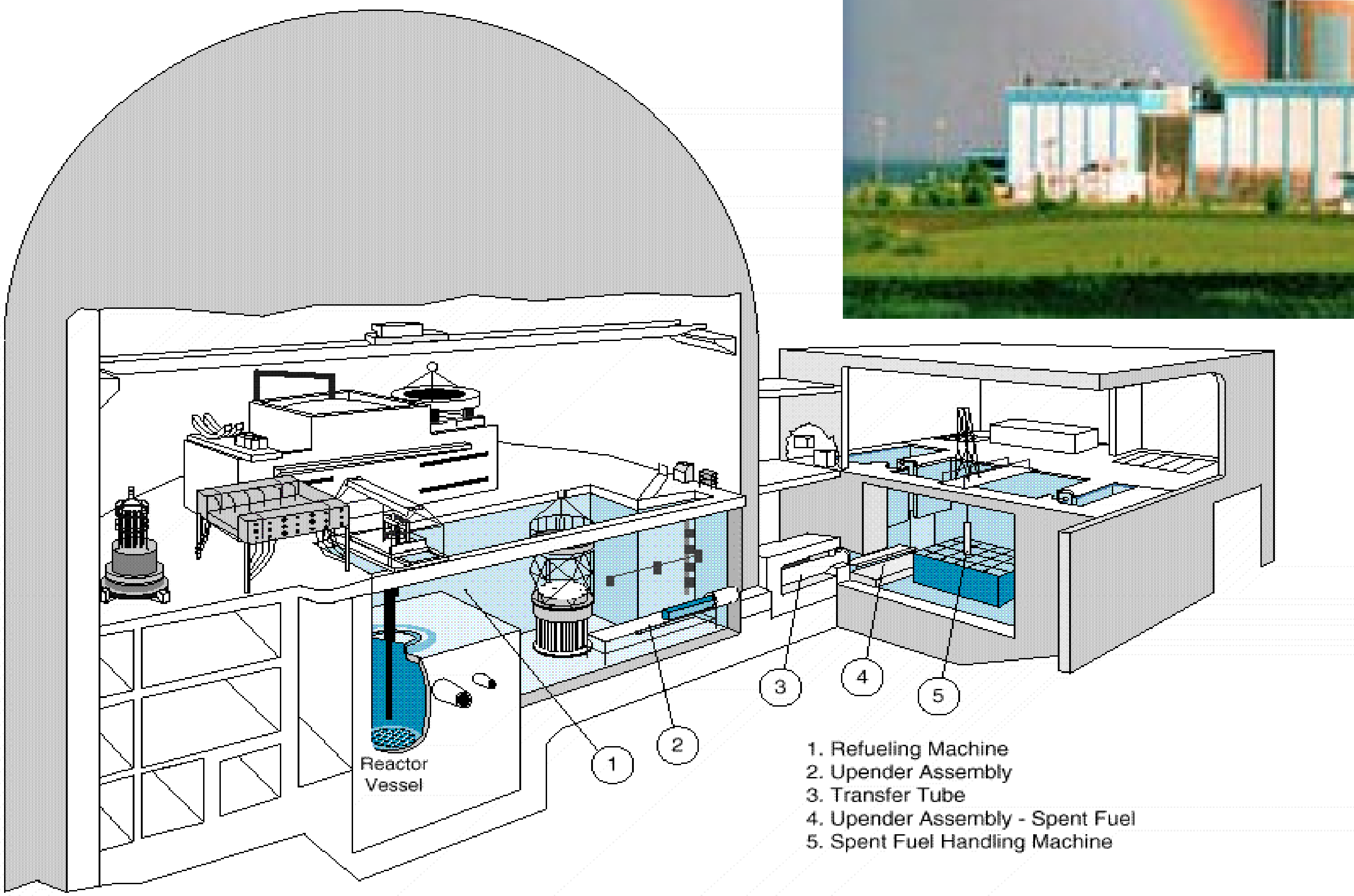
Energy from the fission products takes the form of local heating of the solid fuel rod

To continue the fission reaction, the hi-speed neutrons are moderated by water that is also used as a coolant

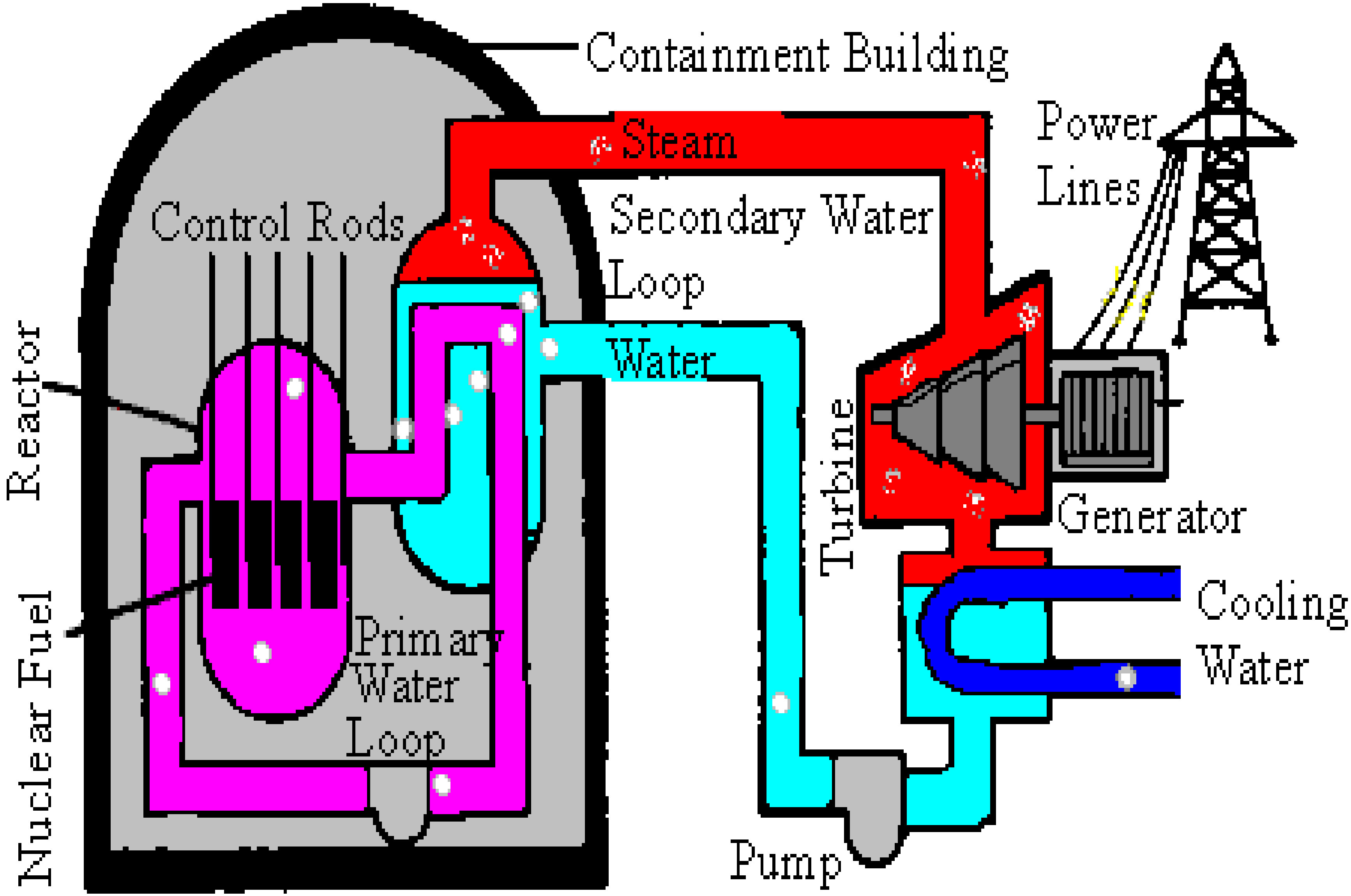
Fission controlled in a Nuclear Reactor



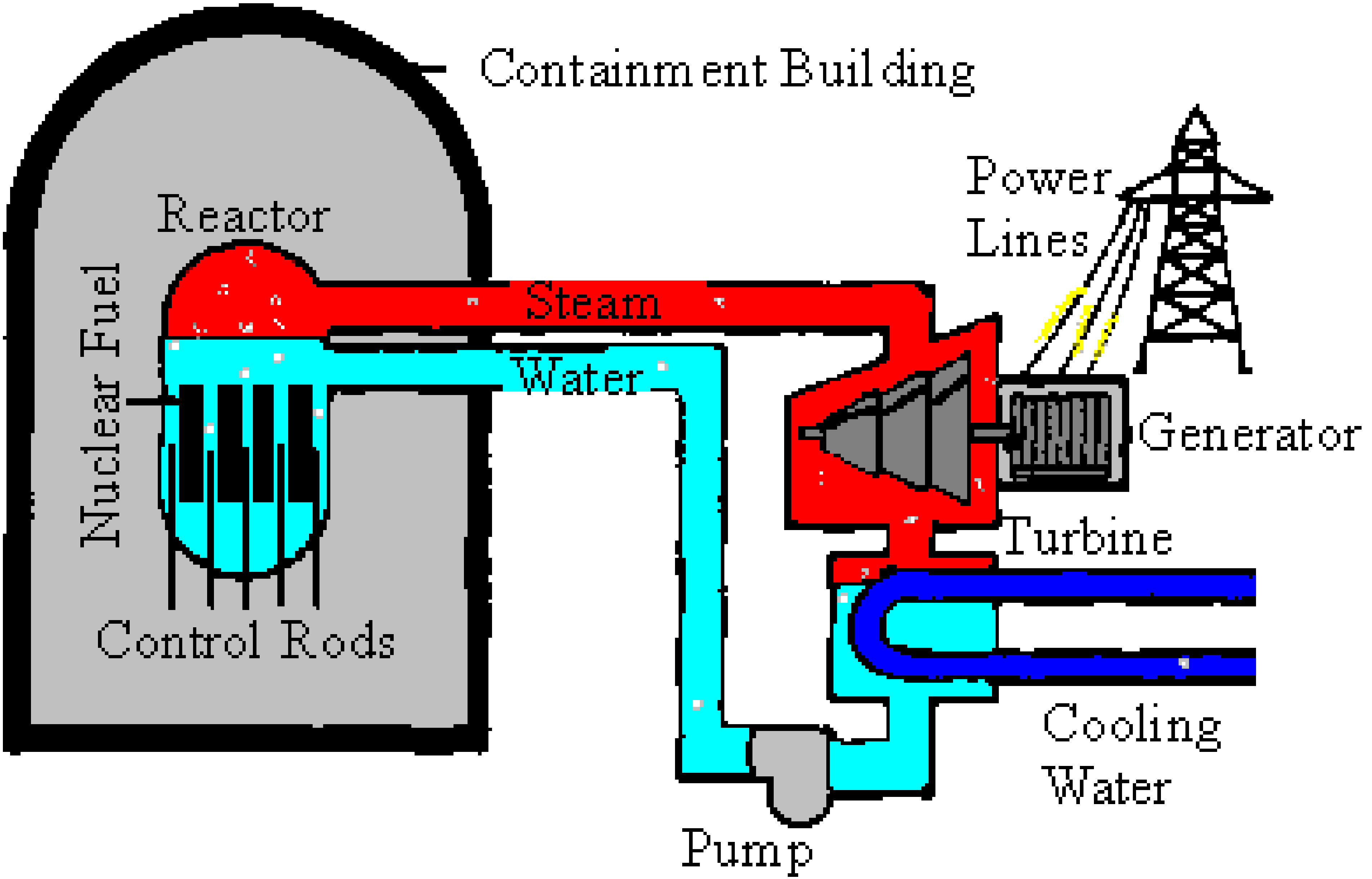
PWR Containment



Pressurized Water Reactor



Boiling Water Reactor



Radiation and Health Effects

- Radiation is a release of energy by unstable elements (He^+-alpha ray, electron-beta ray, EMR- gamma ray)
- Radiation at sufficient levels can effect health
  - ~2000 times natural background radiation is deadly
  - 20 times natural background allowed for rad workers
  - 2-3 times natural background allowed for general public
  - 4-5 X-rays are equivalent to annual natural background
  - Nuclear plant normally releases less than 0.01 natural background to the general public; the general public gets ~0.1 natural background from other man-made sources

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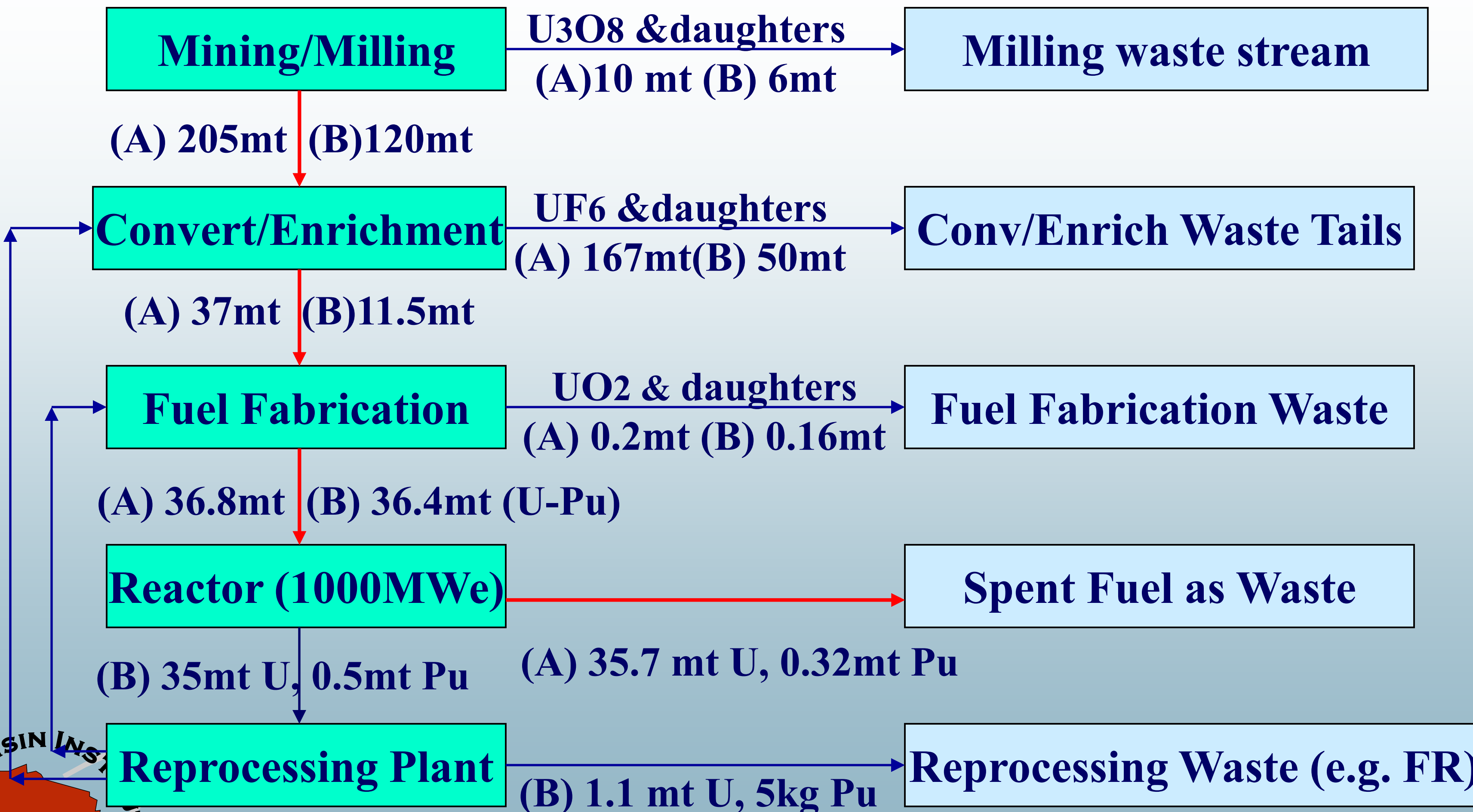
Nuclear Power Safety

- There has not been a loss of life in the US due to commercial nuclear plants (TMI released a small amount of radiation)
- Chernobyl accident - a terrible accident with a bad design
  - These plants are now closed or redesigned for operation
  - Russian nuclear plant operations are being assisted by IAEA
- Regional deregulation of the electricity industry can improve the safe management of nuclear power plants as a fleet.
  - - Upgrades of power plant equipment and reliable replacement schedule
  - - Risk-informed decision making by the industry and be cost-effective

=> New nuclear plants will be safer than current designs

Nuclear Power Fuel Cycle

[1995:IAEA - 1000 MWe-yr – (A) Once Thru (B) U-Pu recycle]

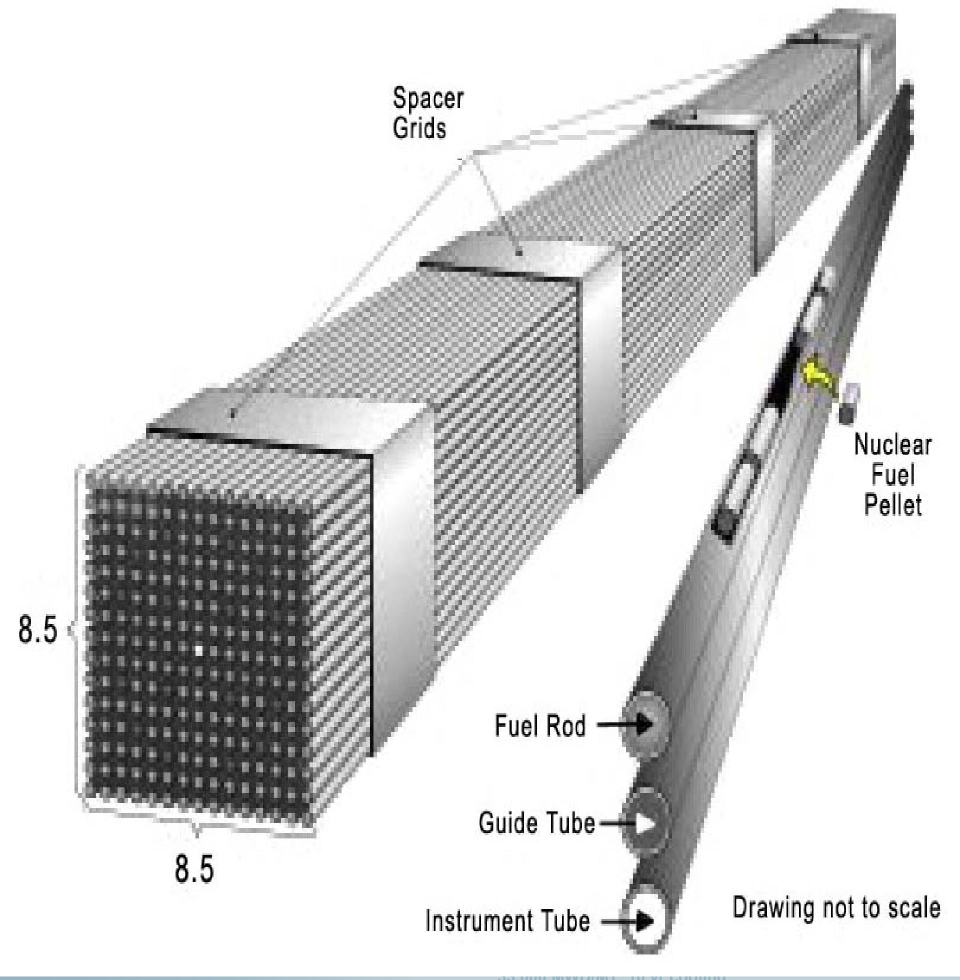


Advanced LWR Nuclear Fuel Cycles

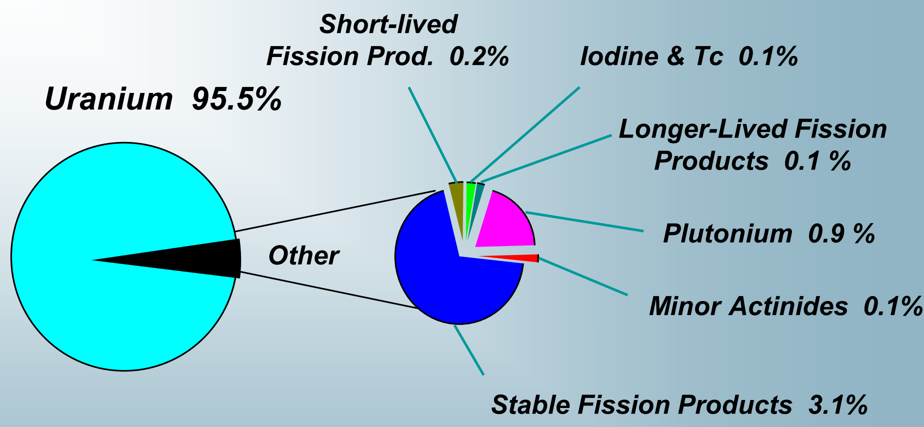
[LWR: 1000 MWe at 90% Capacity; 0.3% Tails; 3 Batch-cycle w 33% Thermal Eff.]*

ONCE-THRU CYCLE 50 GWd/mtHM 4.5 w/o U-235 18 mo cycle	**Mining/Milling**	**ONCE-THRU CYCLE** 100 GWd/mtHM 9.1% U-235 36 mo cycle (Note: 5+ Batch cycle decreases U-ore requirements by 10%)
204.4 mtHM	↓	214.5 mtHM
	Convert/Enrichment	
	Fuel Fabrication	
20 mtHM	↓	10 mtHM
Annual SNF Content 93.4% U ~1.0% U235 5.15% FP 1.33% Pu 0.12% M.Act	**Reactor (1000MWe)**	**Annual SNF Content** 87.43% U ~ 2.0% U235 10.3% FP 1.9% Pu 0.3% M.Act.
20 mtHM	↓	10 mtHM
	MRS or Repository	

Spent Nuclear Fuel



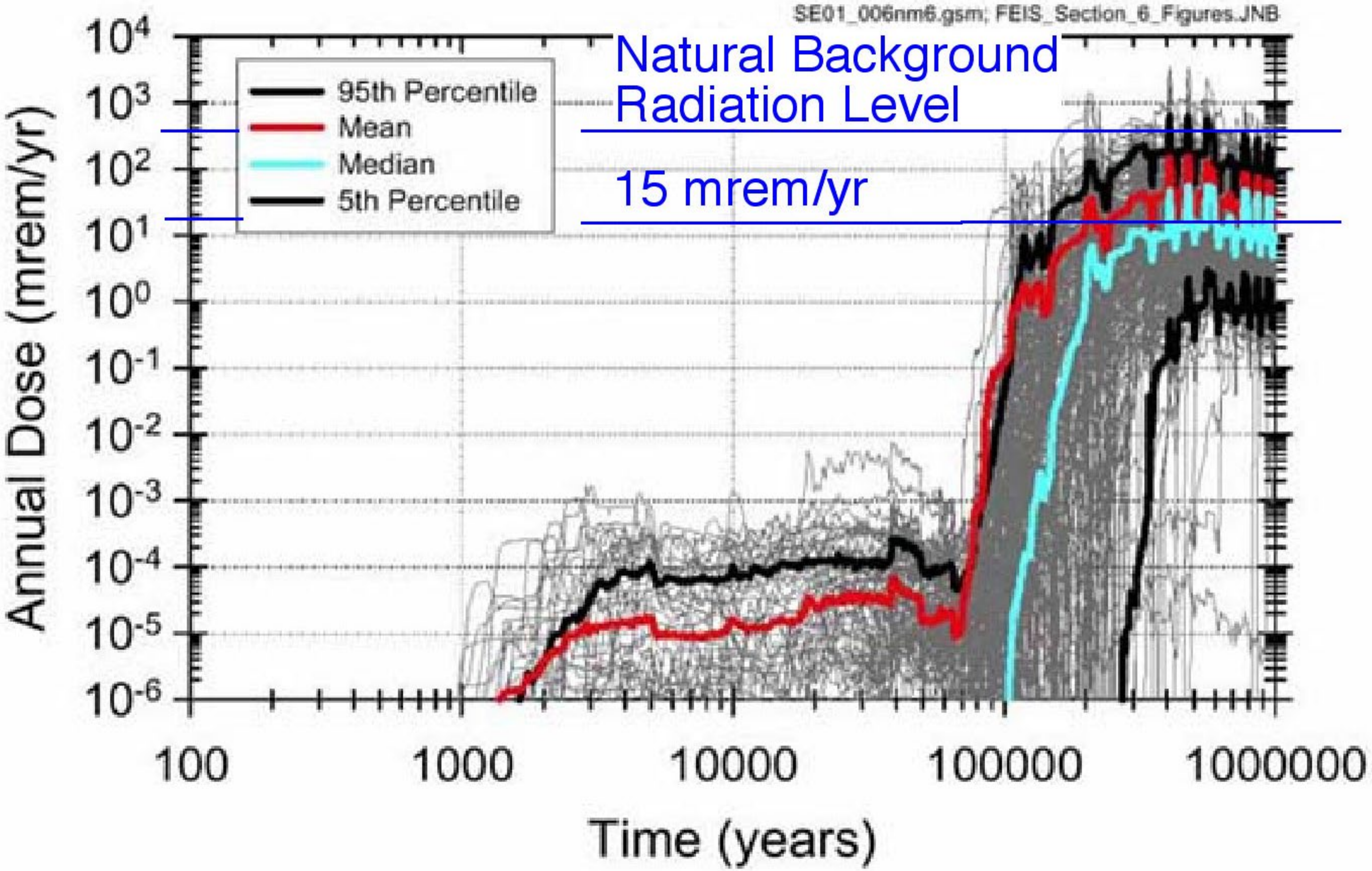
- *Most is U and Pu, which can be recycled and 'burned'*
- *Most heat produced by fission products decays in 100 yr*
- *Most radiotoxicity is in the actinides (TRU) could be transmuted and/or disposed in much smaller packages*



Nuclear Power High Level Waste (HLW)

- All nuclear fuel cycle waste (except HLW) has been safely and reliably disposed through DoE and NRC regulations; milling, enrichment, fabrication as LLW
- Since 1982, US law 'defines' spent nuclear fuel as HLW, since reprocessing has not occurred since 1976 (Japan & Europe is where reprocessing does occur)
- Spent fuel is currently stored at ~104 nuclear power plant sites (~ 2000 mt/yr; total ~50,000 mt) and planned to be stored/buried at one site in the US (Yucca Mtn)
- All nuclear electricity is taxed at 1mill/kwhre for a HLW fund (~ $0.8 billion/yr; total over ~ $20 billion)
- HLW radiation exposure at disposal site less than natural background radiation levels in that region

HLW Environmental Impact*



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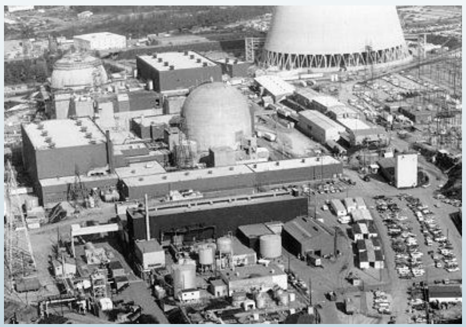

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Commercial Power Reactors

- LWR: PWR/BWR
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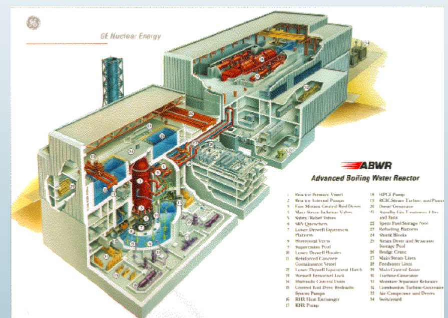
Generation III

Advanced LWRs



- System 80+
- AP1000
- ABWR, EPR
- ESBWR

Gen I | Gen II | Gen III

1950 1960 1970 1980 1990 2000 2010 2020 2030

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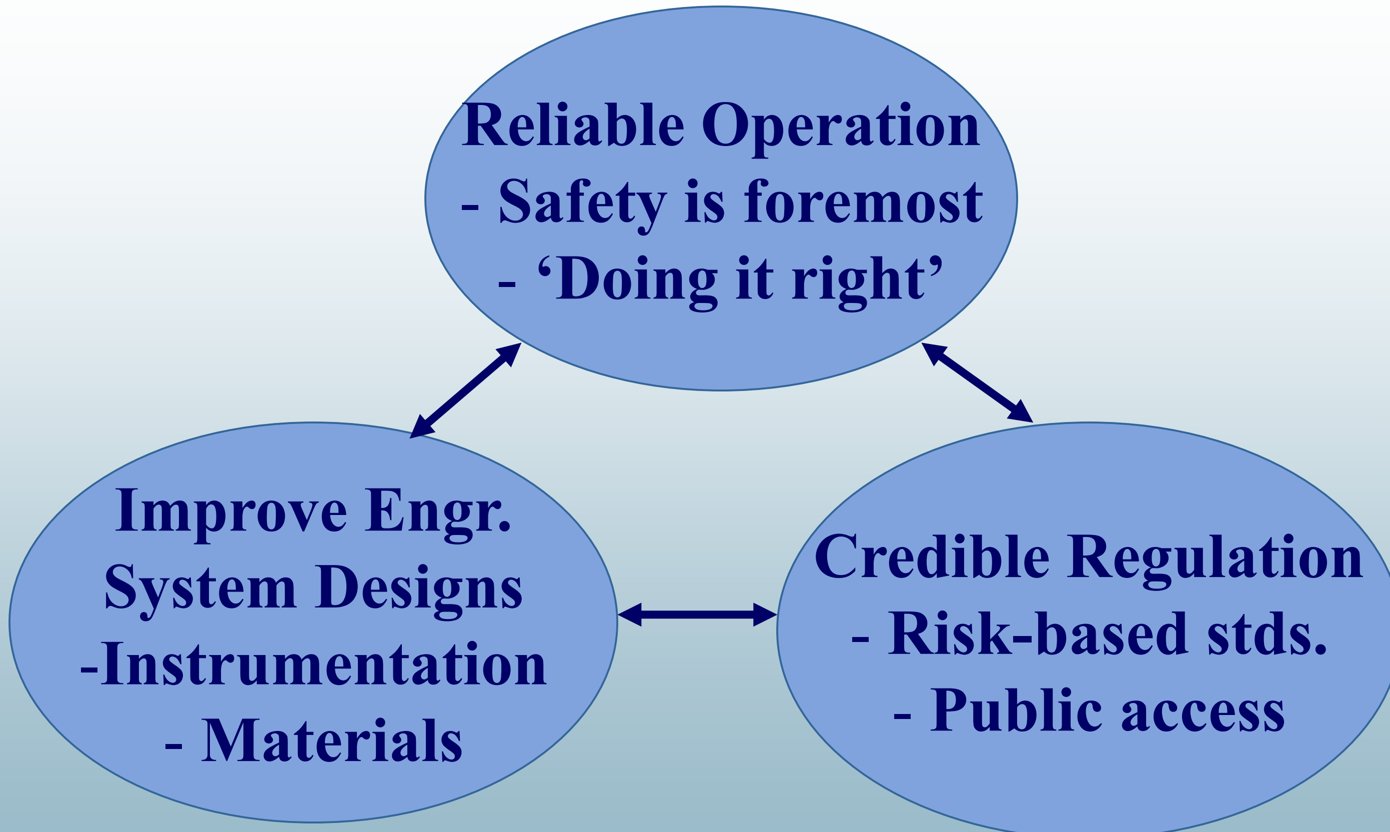
Nuclear Power Safety

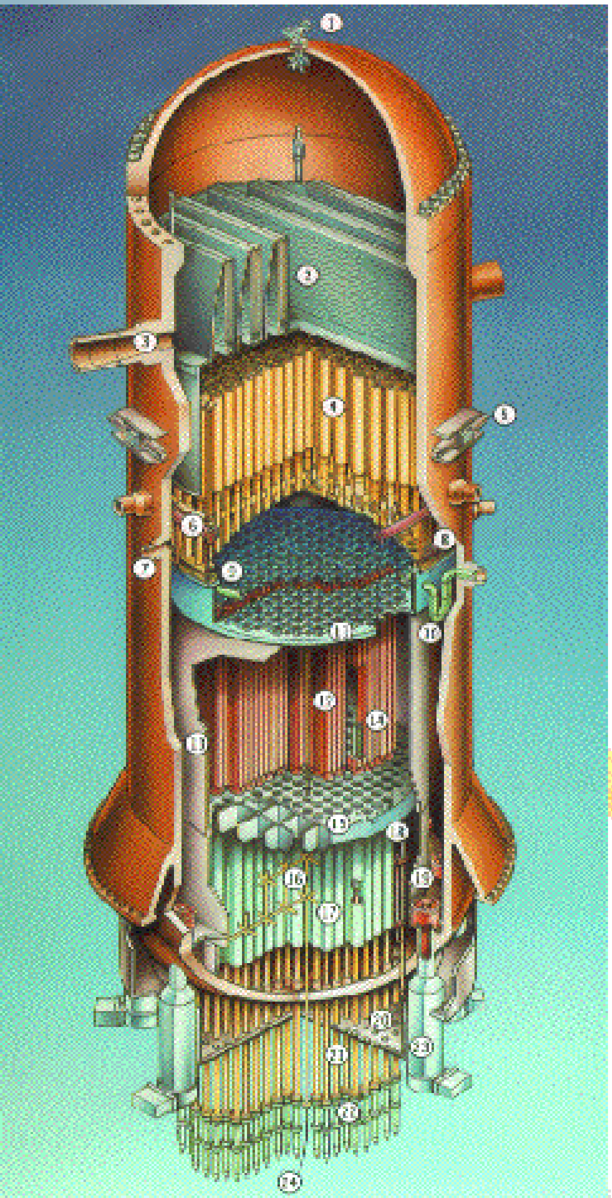
- Current nuclear power plants have high levels of safety: i.e., reliable operation, low occupational radioactivity dose to workers and with minimal risk and health effects from severe accidents.
- Future nuclear reactor system shall at least meet the expectations of current reactors (and more).
- As the number of nuclear plants increase worldwide, the level of safety must improve.
- Passive decay heat removal, minimize transients, less complexity; more time for operator actions are the keys to improved safety performance.

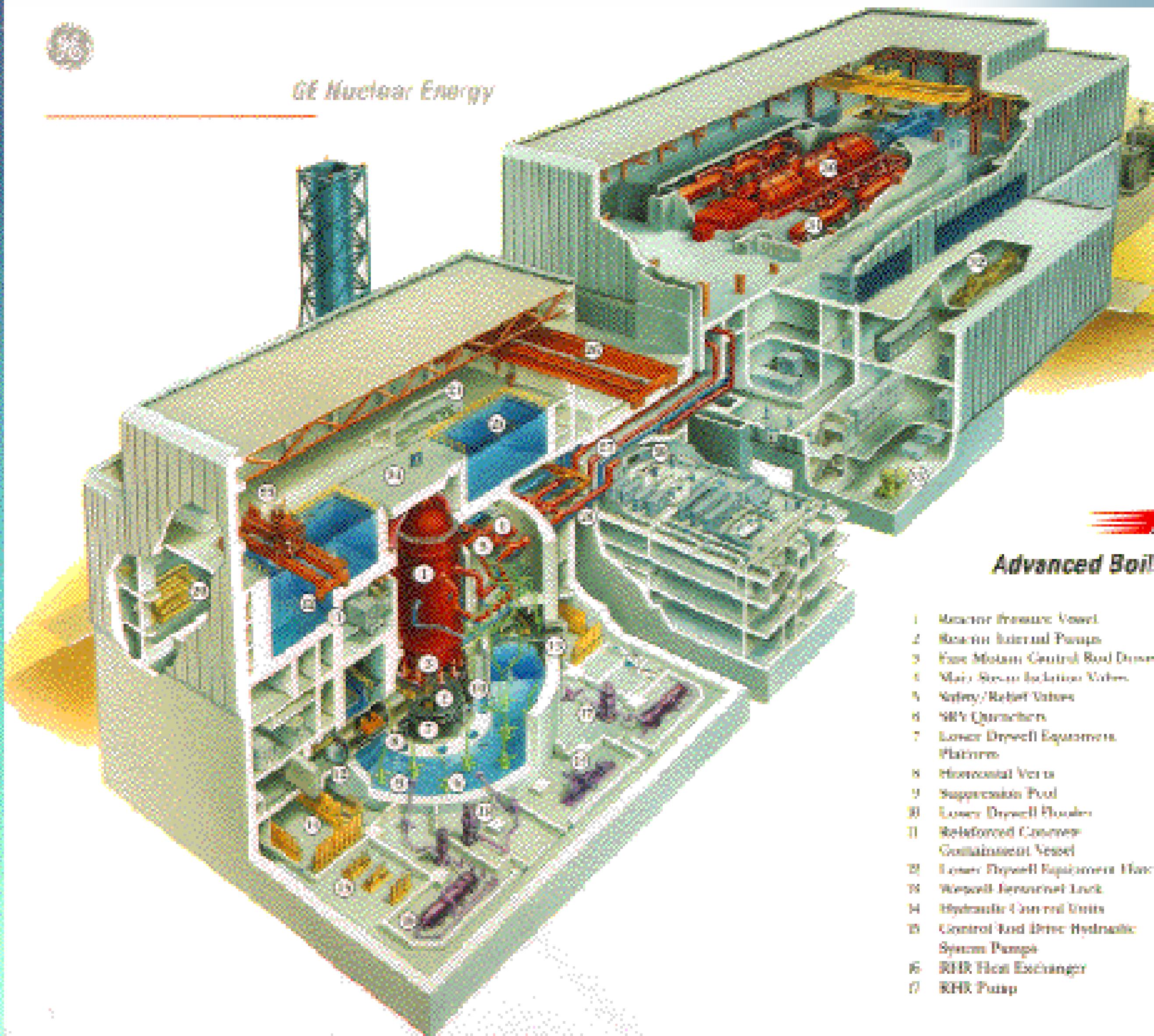
Nuclear Energy: Defense-in-Depth



Involve/train top-notch people for all sectors

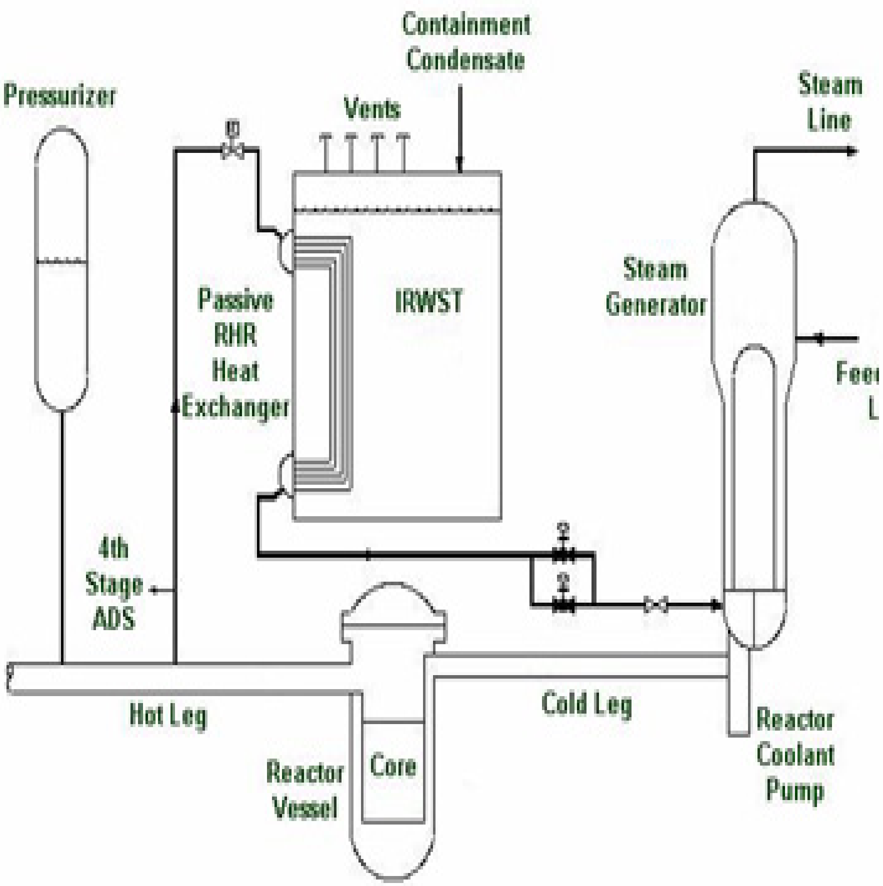
Advanced LWR: ABWR

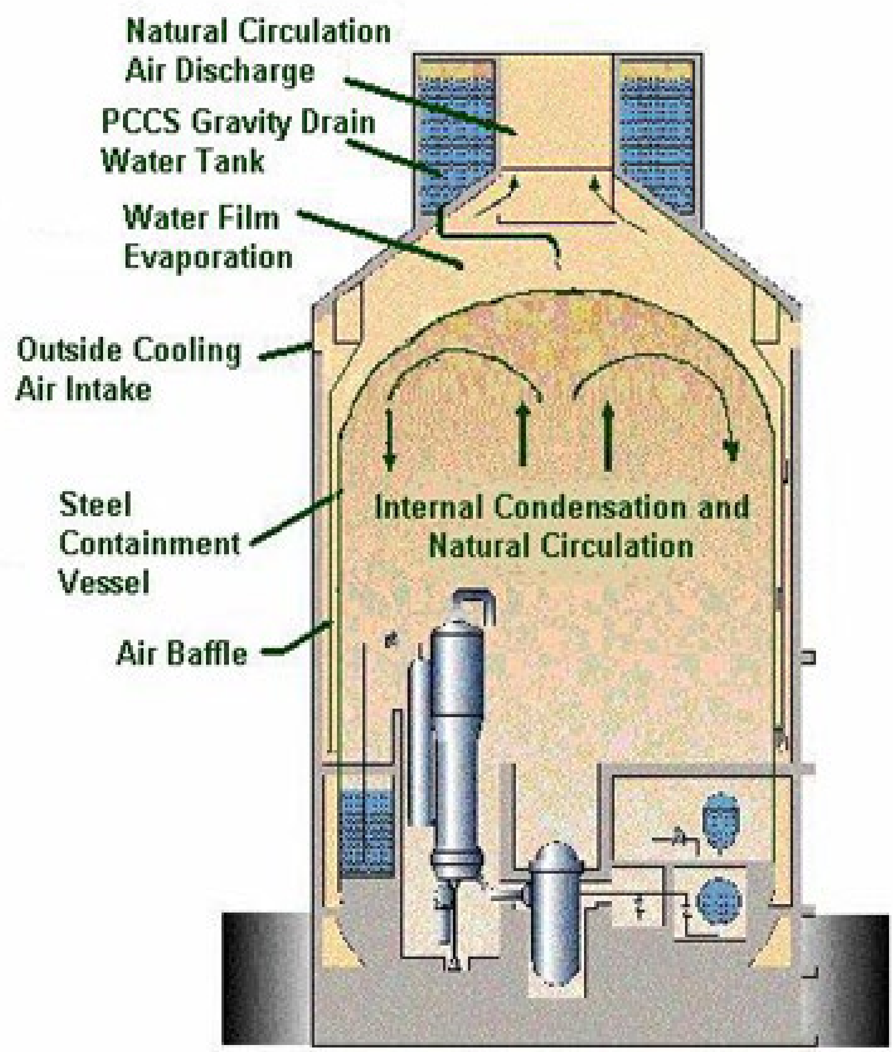




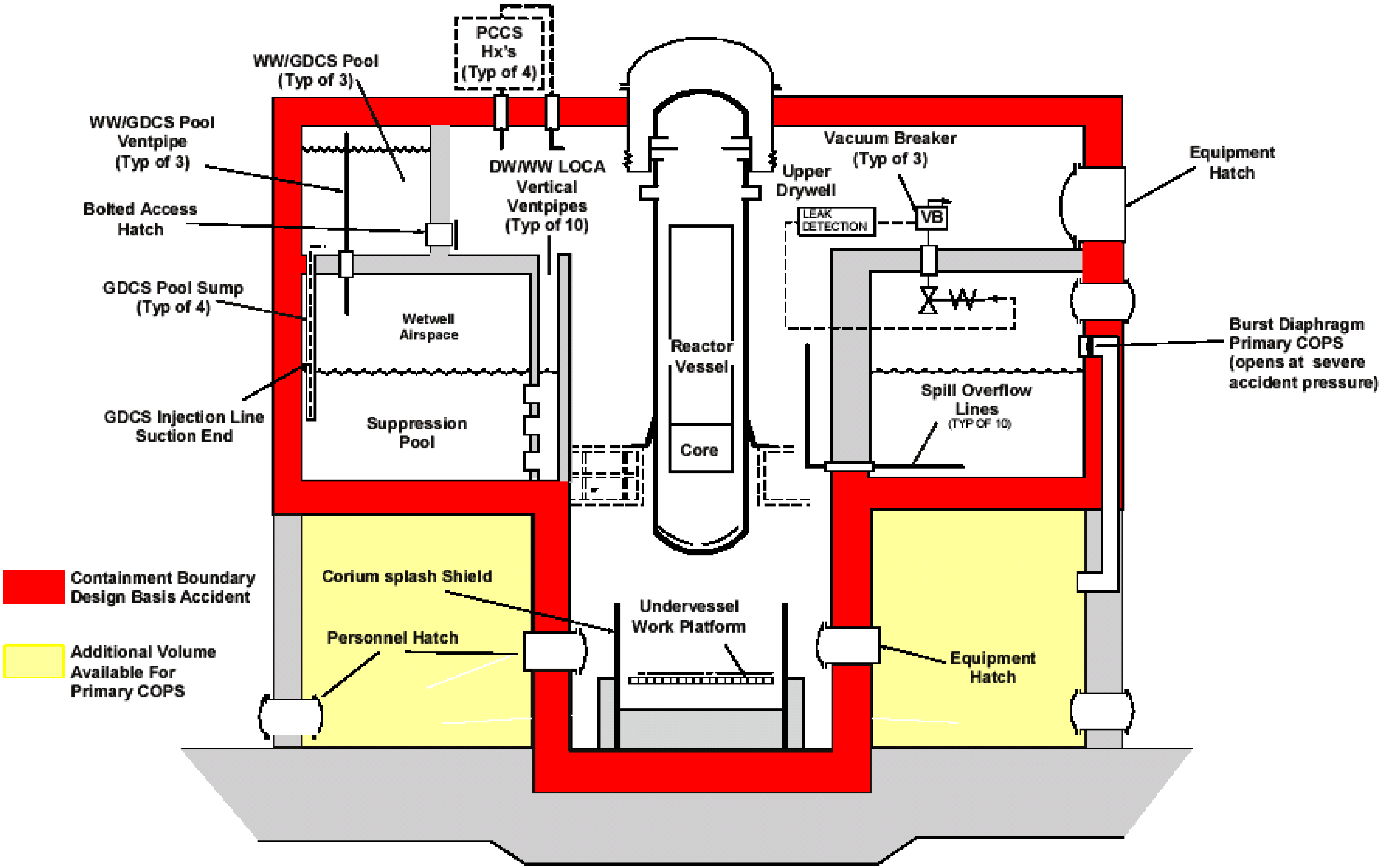
Advanced LWR: EPR

Advanced LWR: AP-1000





Advanced LWR: ESBWR



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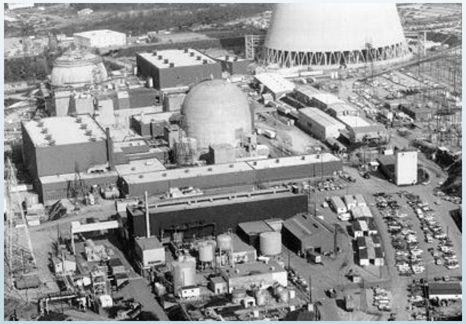

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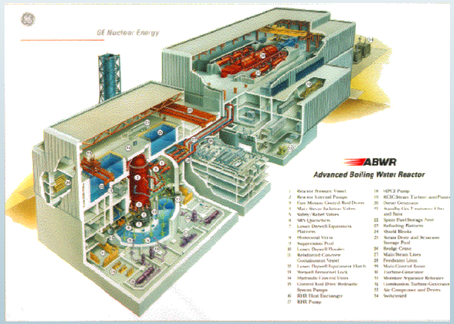

•System 80+ •AP1000
•ABWR, EPR •ESBWR

Generation IV

- Enhanced Safety
- Highly economical
- Minimized Wastes
- Proliferation Resistance

Gen I | Gen II | Gen III | Gen IV

1950 1960 1970 1980 1990 2000 2010 2020 2030

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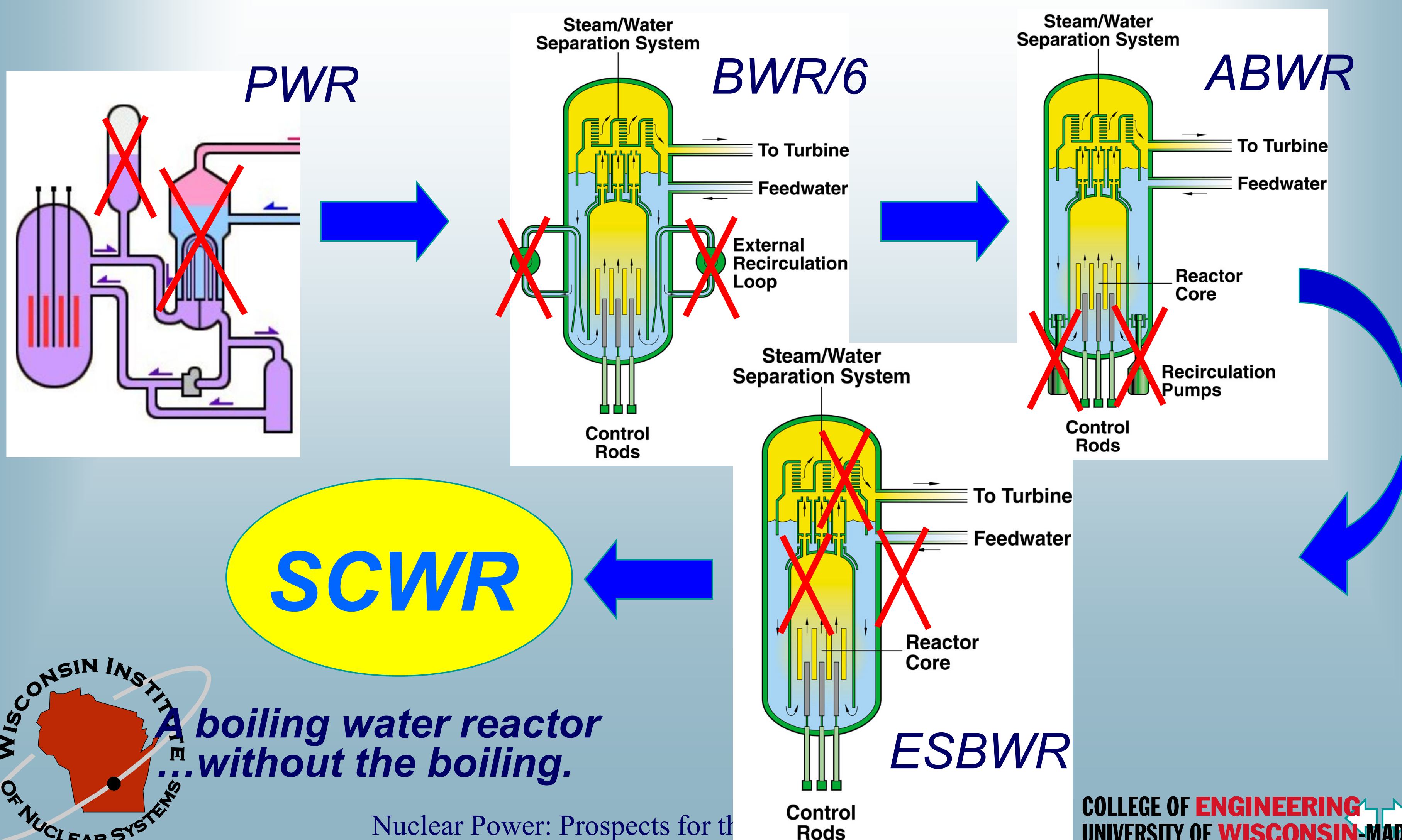
System Efficiency affects Cost

- Higher nuclear system efficiency reduces cost:
  - Higher efficiency reduces plant size (material used)
  - Higher efficiency reduces fuel consumed
  - Higher efficiency can allow for plant simplification
- Improved efficiency also has challenges:
  - Higher temperatures require robust materials
  - Modified materials require novel reactor designs

An Option: Japan - SCWR

The next step in path toward simplification

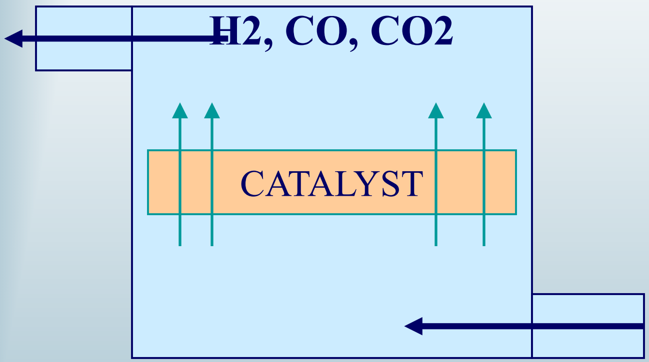


A boiling water reactor ...without the boiling.

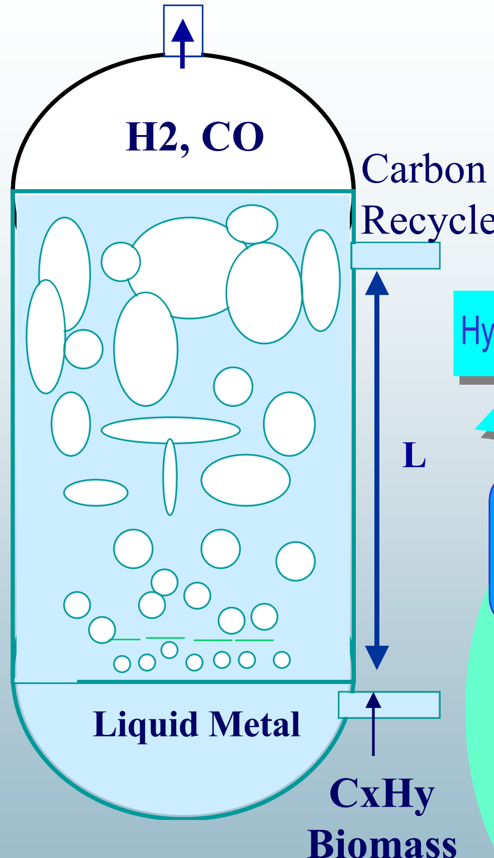
Process Heat for Synfuel Production

200 C ⟷ **1000 C**

Aqueous-phase Carbohydrate Reforming (ACR)

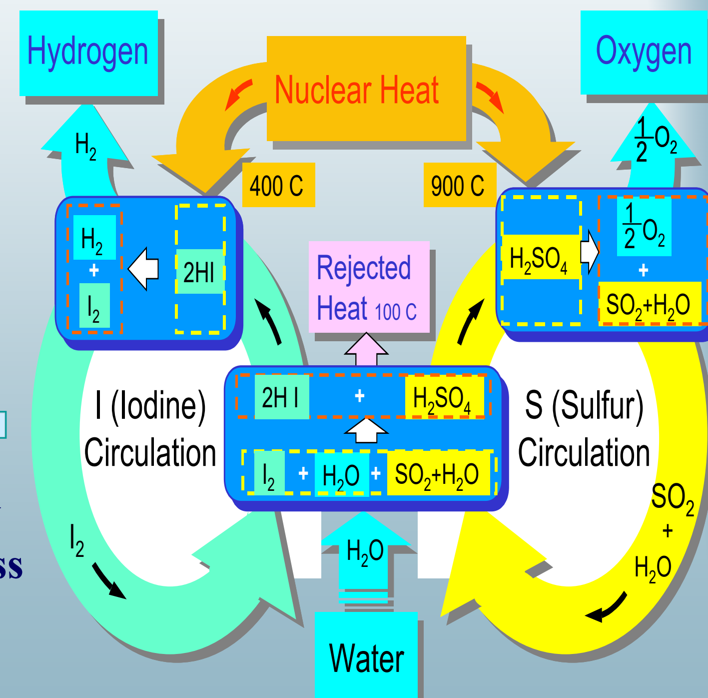


AQUEOUS CARBOHYDRATE



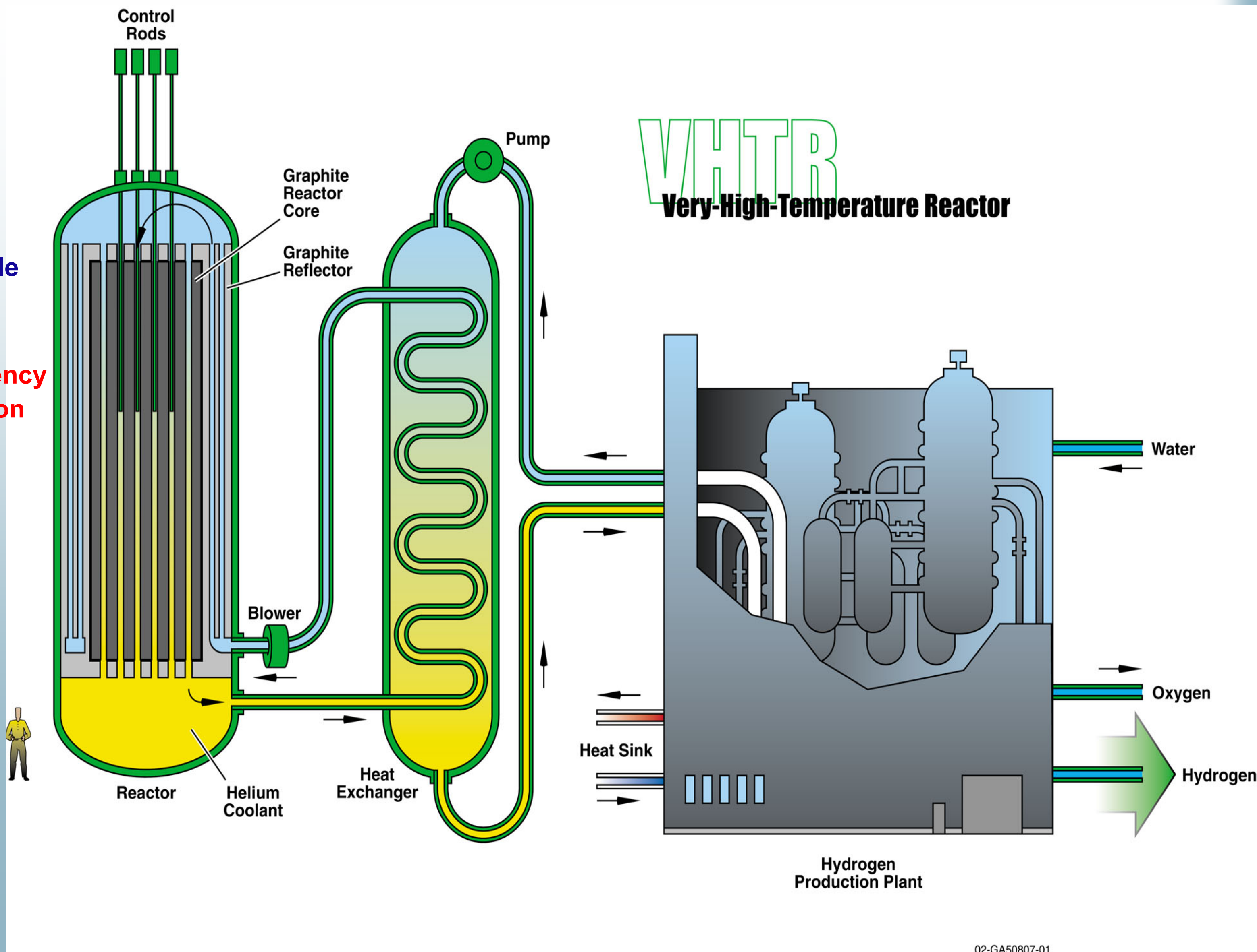
LM Condensed Phase Reforming (pyrolysis)

Thermochemical Processes

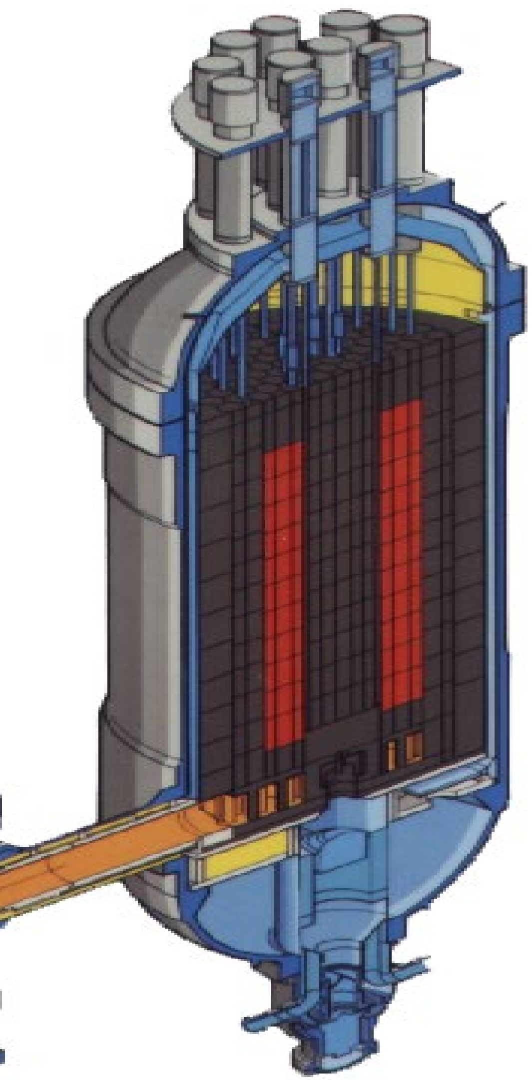


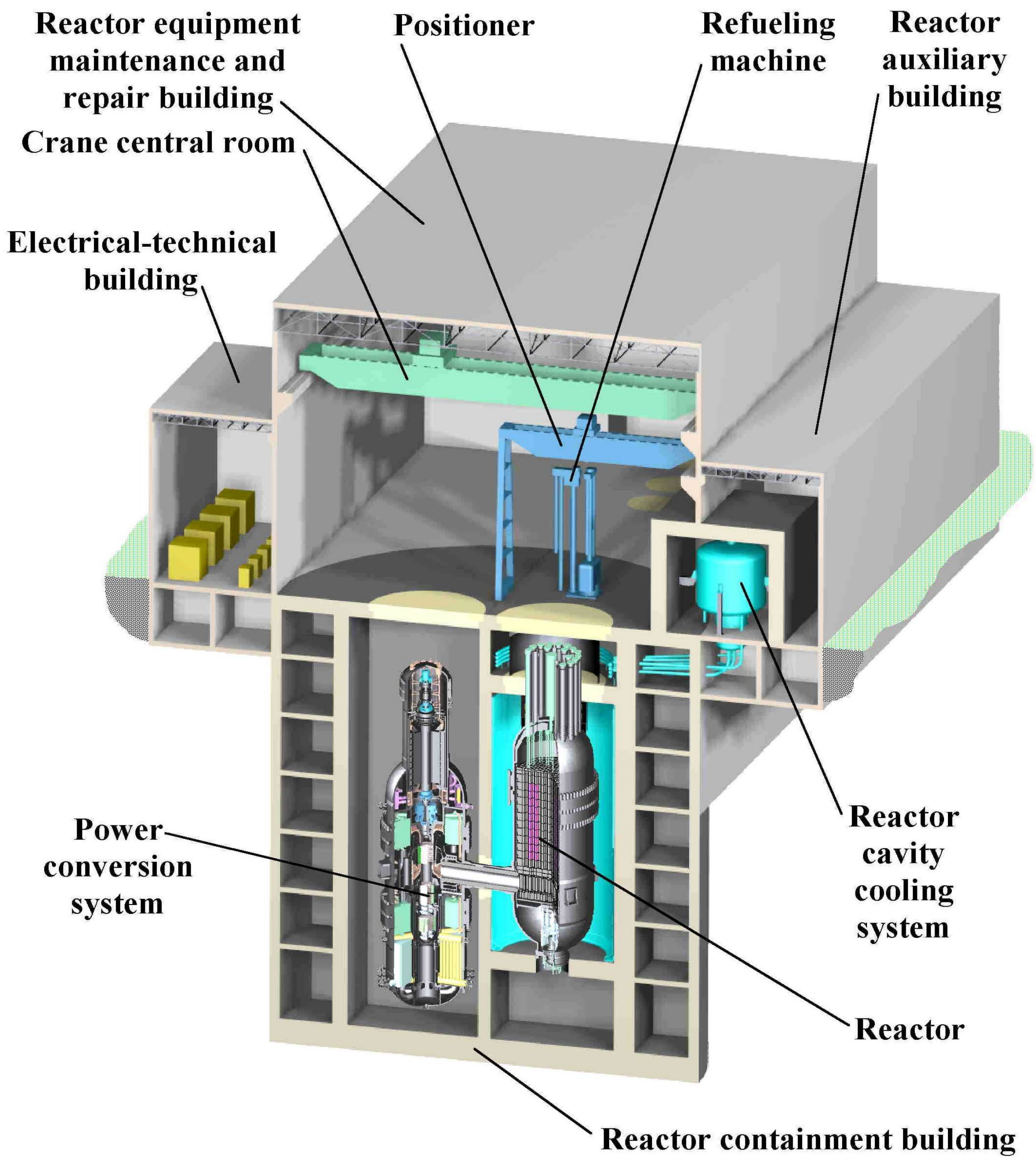
Very-High-Temperature Reactor (VHTR)

- Characteristics
  - Helium coolant
  - 1000°C outlet temp.
  - 600 MWth
  - Water-cracking cycle
- Key Benefit
  - High thermal efficiency
  - Hydrogen production by water-cracking



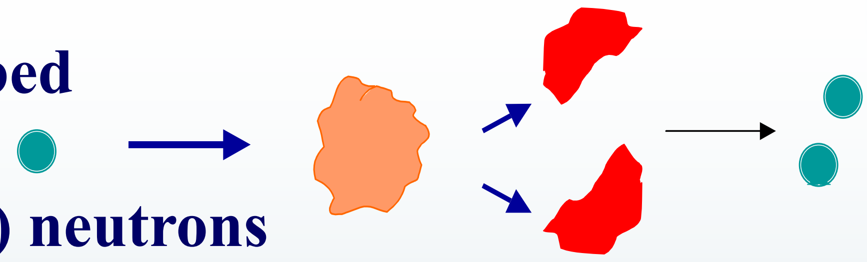
GAS-COOLED REACTOR



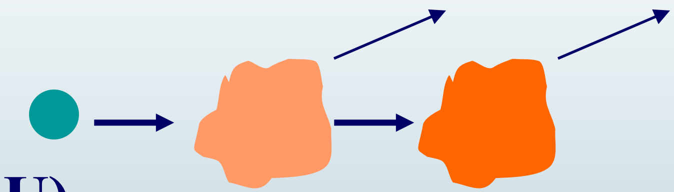


Nuclear Fission Transmutation

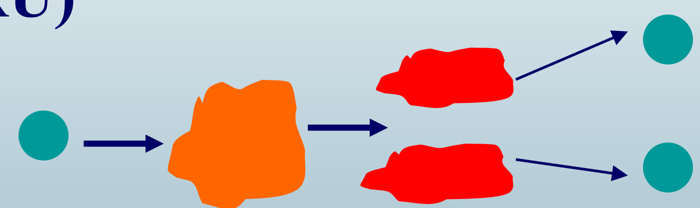
A thermal neutron (slow) is absorbed by U-235 (fissile fuel), fissions into fission products and hi-speed (fast) neutrons



A neutron (slow or fast) is absorbed by a U-238 atom, transmuting it into Pu-239 (fissile fuel) or transuranic elements (TRU)

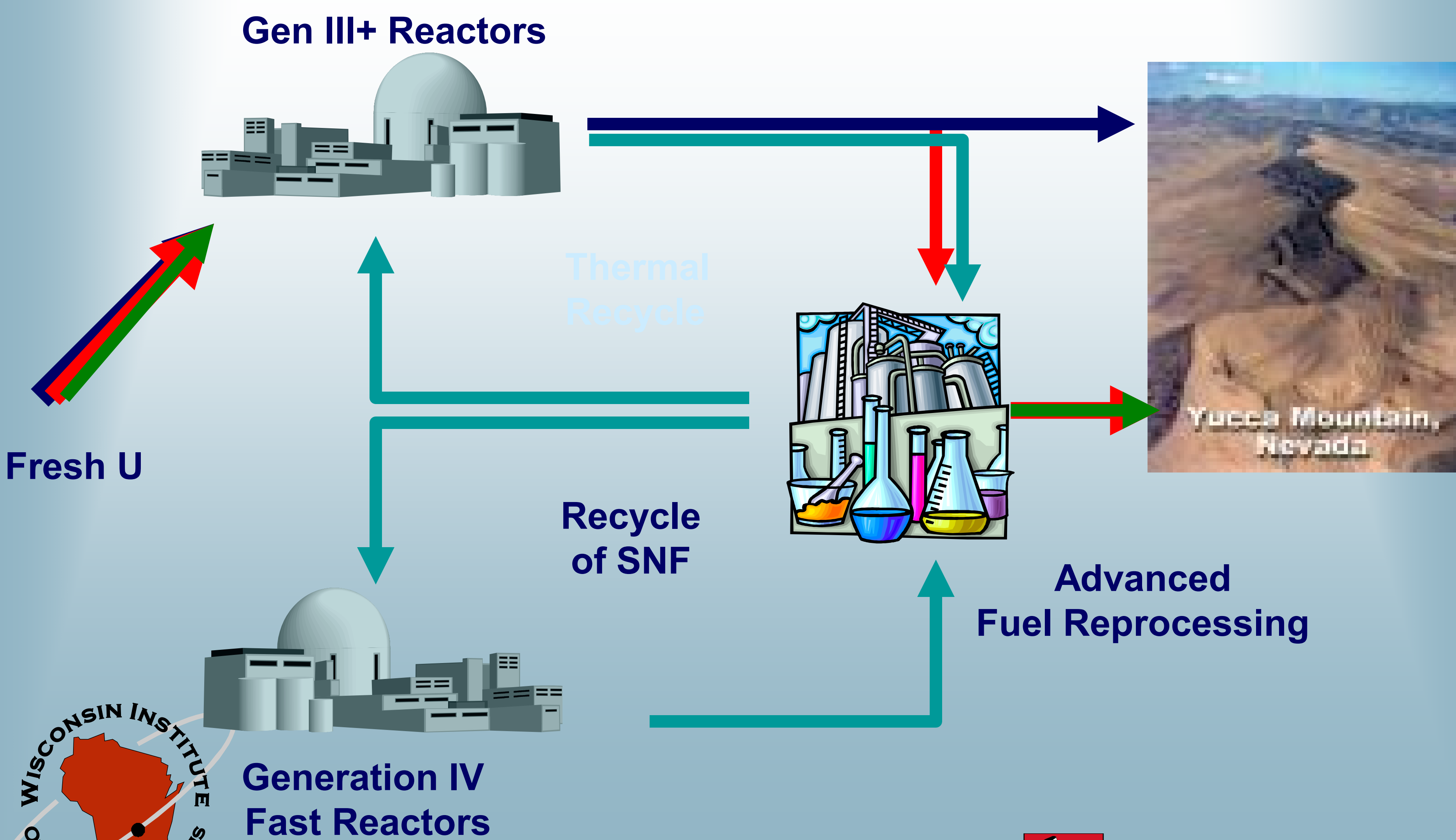


A neutron (fast) is absorbed by Pu-239 and TRU and fissions w fast neutrons



A fast reactor using hi-speed neutrons to both produce power and to fission Pu and transmute/fission TRU - thus reducing the amount of long-lived radioactive waste: Conversion Ratio (CR) is net amount fissile fuel produced

Advanced fuel cycles



Minimize Nuclear Waste

Nuclear Futures	Legal Limit	Extended License for Current Reactors	Continued Constant Energy Generation	Constant Market Share	Growing Market Share
Total Discharged Fuel by *2100*, MTHM	**63,000**	**120,000**	**240,000**	**600,000**	**1,300,000**
Current approach	**1**	**2**	**4**	**9**	**21**
Expanded capacity		**1**	**2**	**5**	**11**
Thermal Recycle			**1**	**2**	**5**
Full Recycle					**1**

Global Nuclear Energy Partnership