Recent Developments in Nuclear Energy

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Nuclear Energy Today

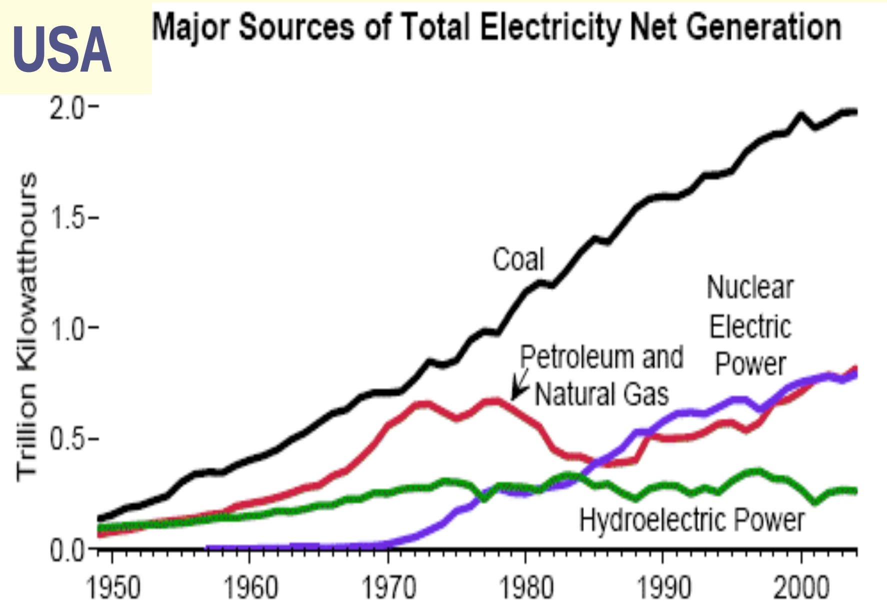
The largest non-fossil electricity source

- 104 US reactors, 442 World wide
- US: 100.5 GWe, 20% of production
- World: 367 GWe, 16% of production

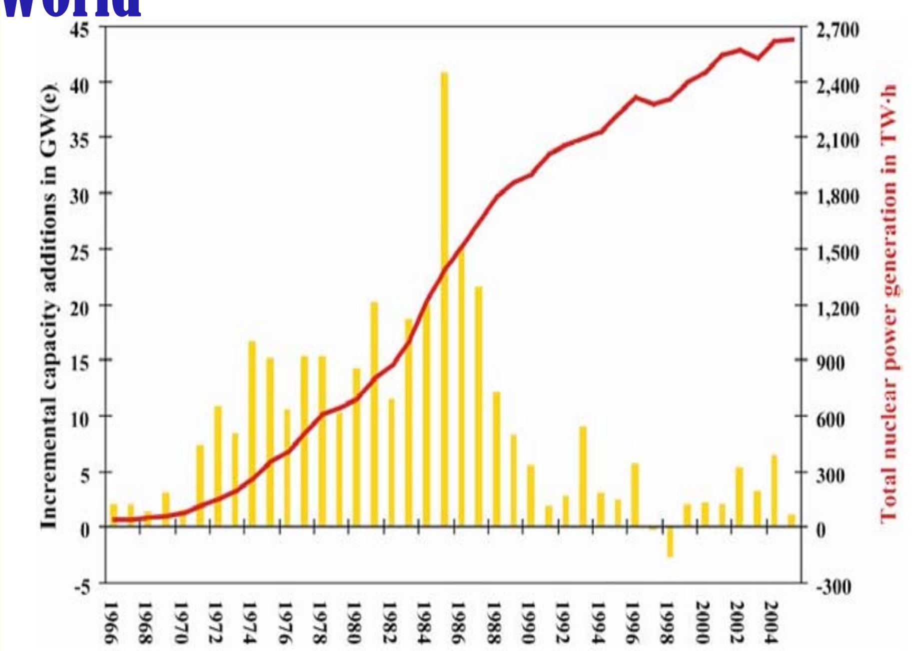
Nuclear energy production grew in spite of few plant additions in the last 15 years.

- Long fuel cycles & reduced refueling times led to 90% capacity factors
- Power uprates of existing plants were implemented.

USA



World

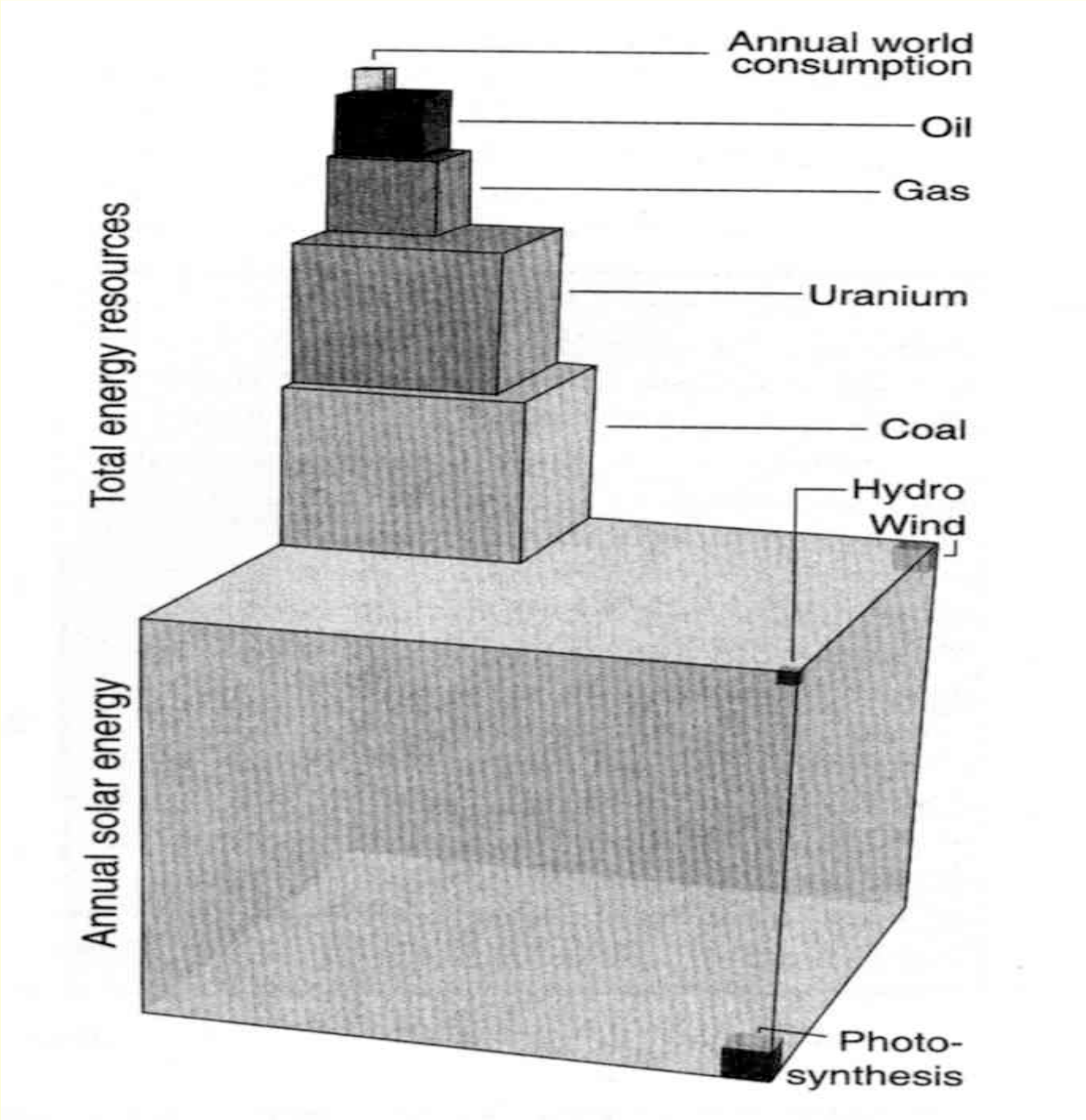


- 34 reactors are under construction around the world.
- US utilities declared plans for license applications for 30+ new light water reactors.
- China, India, Russia and South Korea have declared plans to add about 110 new reactors by 2030.
- Interest is growing in parts of the World that never used nuclear energy before, such as Turkey, Egypt and UAE.

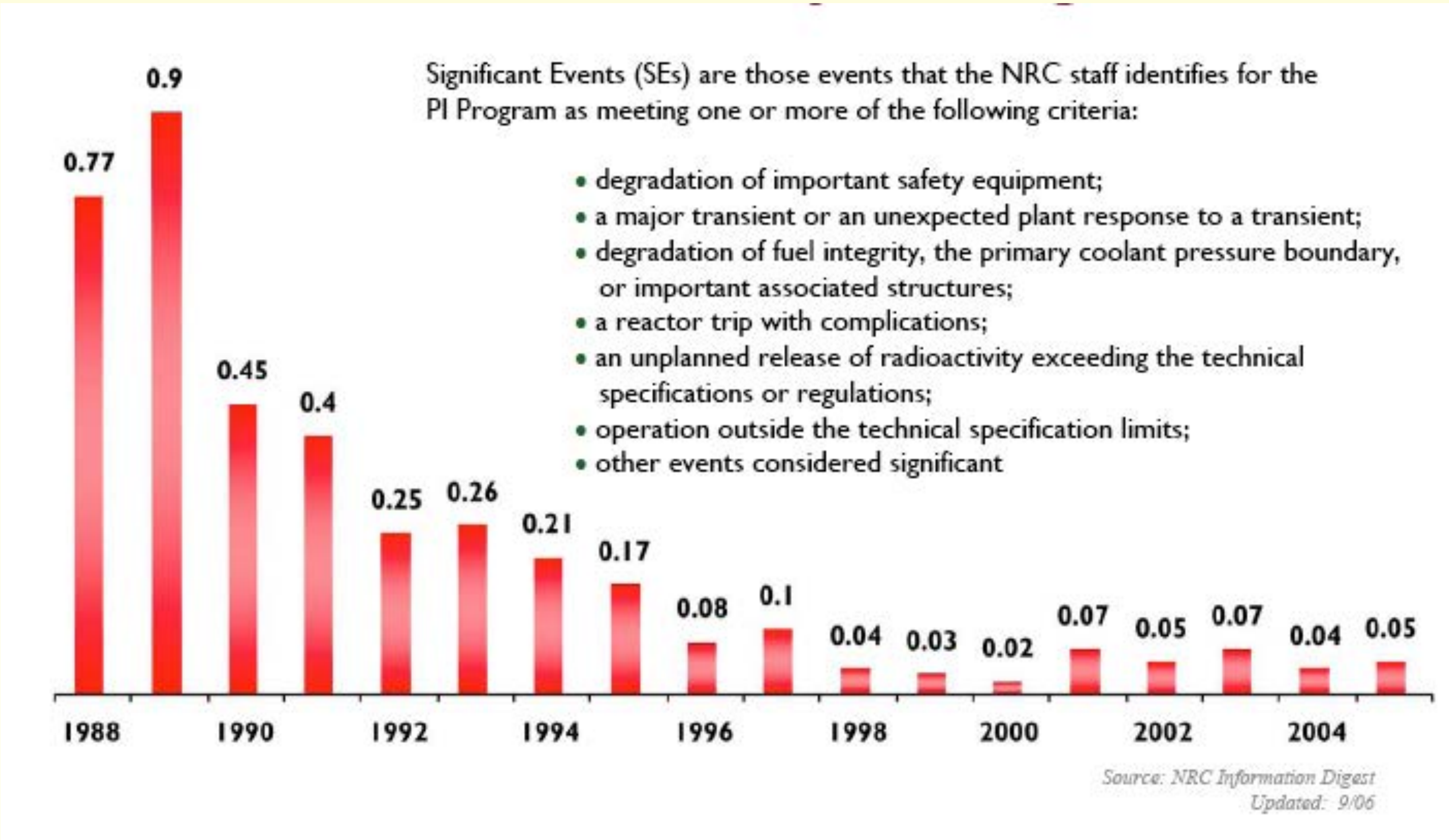
Reasons for renewed interest in nuclear energy

- Economic Stability:
  - Most of the cost of nuclear power is its plant. Once built, nuclear fuel cost fluctuations have little impact on cost of electricity. This is the opposite of oil and gas power plants.
  - Avoiding the potential cost of carbon taxes.
- Environmental Concerns: Avoiding CO_2 emissions leaves few alternatives:
  - CO_2 sequestration : may require decades to prove on wide scale
  - Hydro power: almost completely tapped
  - Wind and solar: intermittent energy and large land commitments
  - Efficiency in consumption: desirable but not sufficient
- Energy Security: Conventional oil and natural gas are finite resources; can coal, nuclear, biofuels, and other renewables provide fuel for transportation?
  - Current world consumption of U is 0.08 MT per year for 6% of total energy.
  - Current world proven U reserves are about 5.5 MT, but at least 10 times this inventory exists at lower concentrations, and 100 times as much exist in sea water.
- Excellent Operation Record for the last 15 year

Relative Fuel Resources

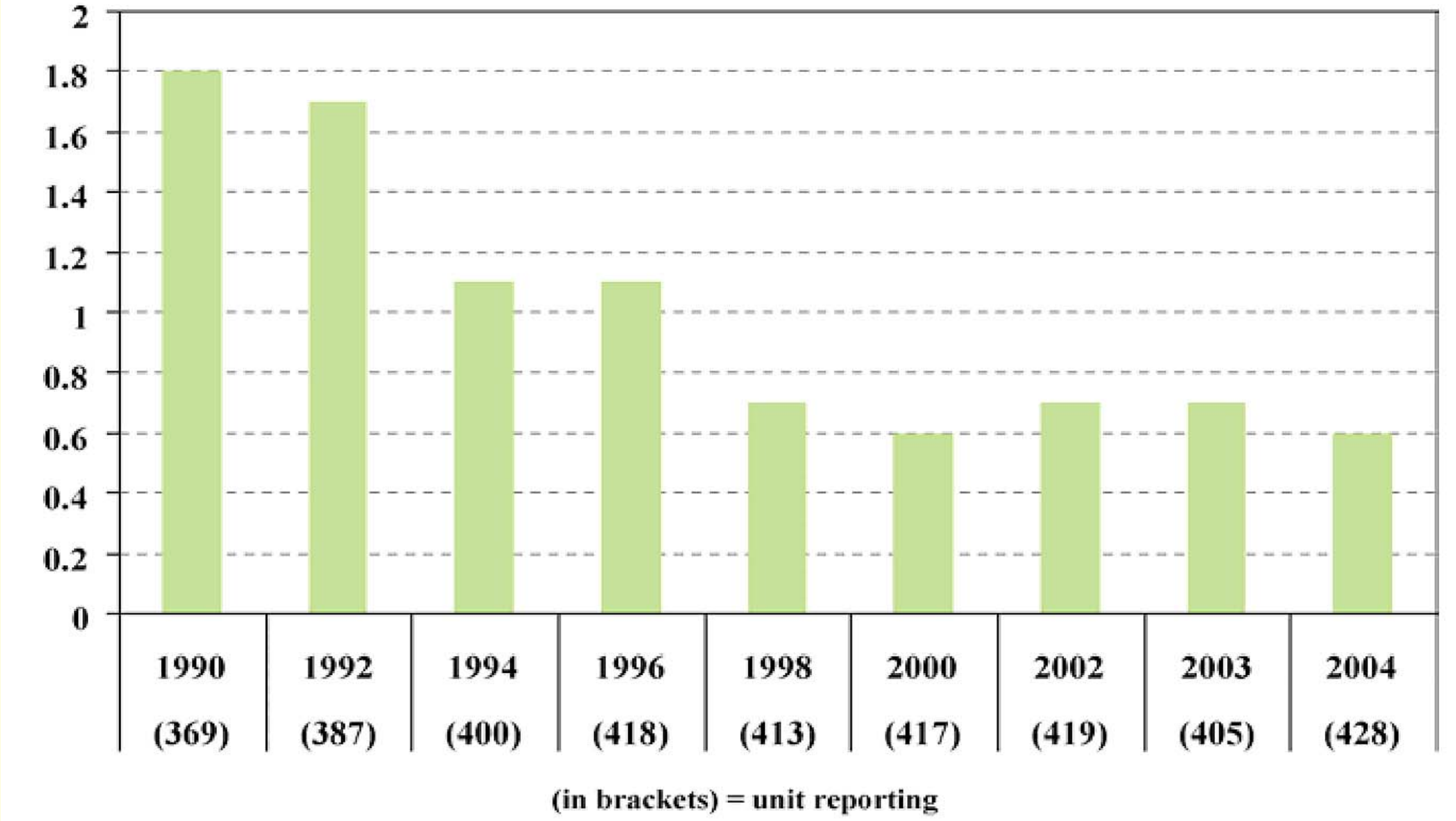


Nuclear Safety - Significant Events
Annual US Industry Average

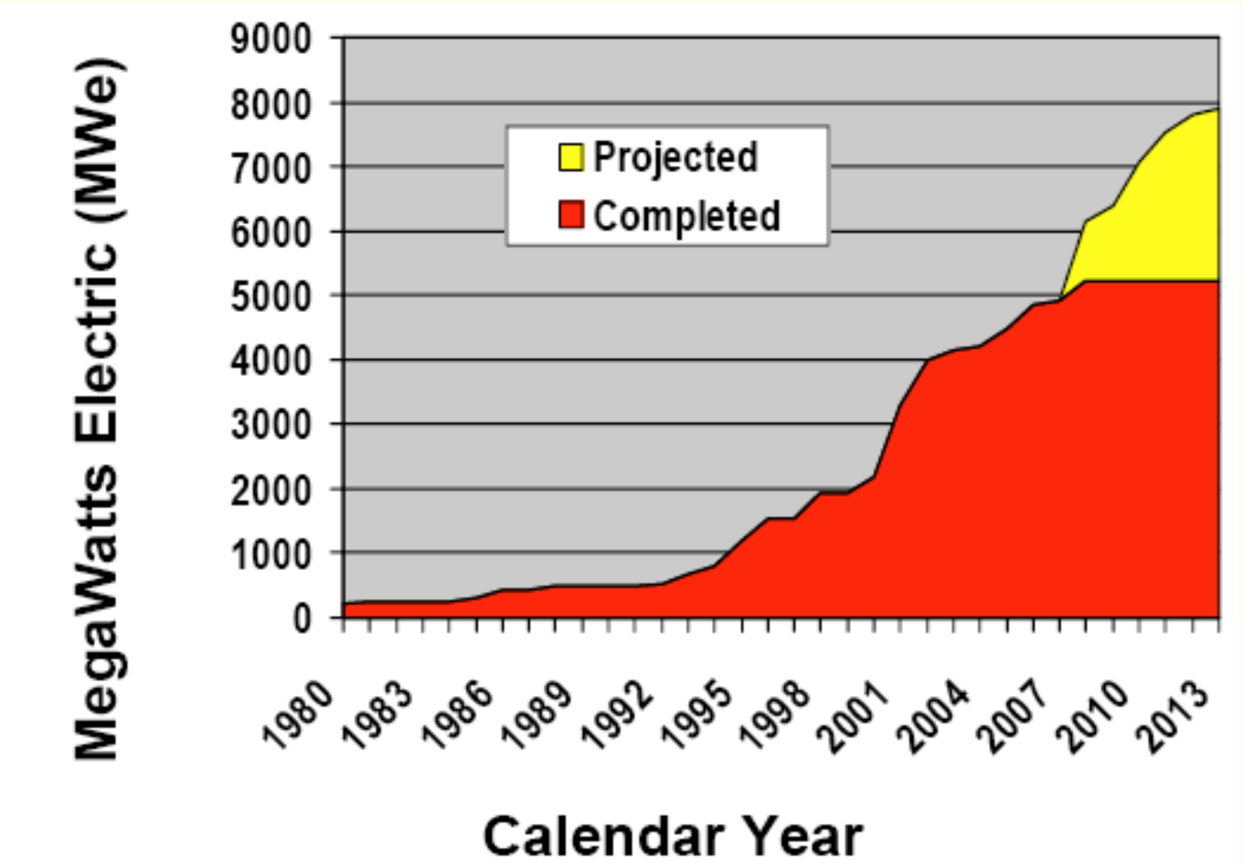


World Fleet Unplanned Safety-System Shutdowns per 7000 hours critical

WANO, 2004



Additional Power From Uprates

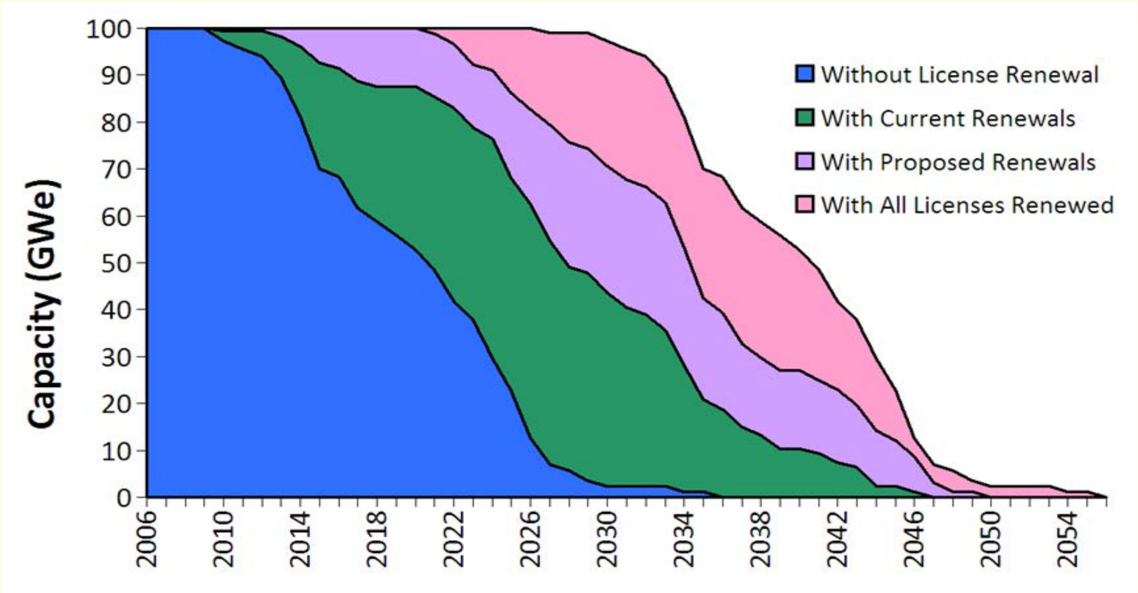


License Renewal

- Atomic Energy Act limits initial power reactor license terms to 40 years . NRC regulations allow renewals for up to an additional 20 years per extension

- Two parallel reviews are conducted by NRC: safety and environmental. Length of Review: 30 Months with hearing or 22 Months without hearing

- Status: Completed – 48 units, Under review – 15 units,
  41 remainder plants expected



U.S. New Nuclear Plant Status

17 companies working on license applications for as many as 31 reactors

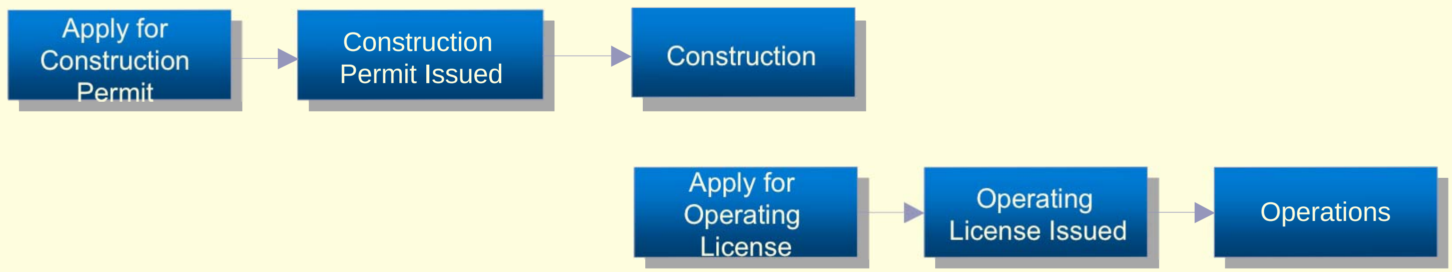
- Five other companies evaluating nuclear projects
- Six full license applications submitted
- Another nine applications possible this year

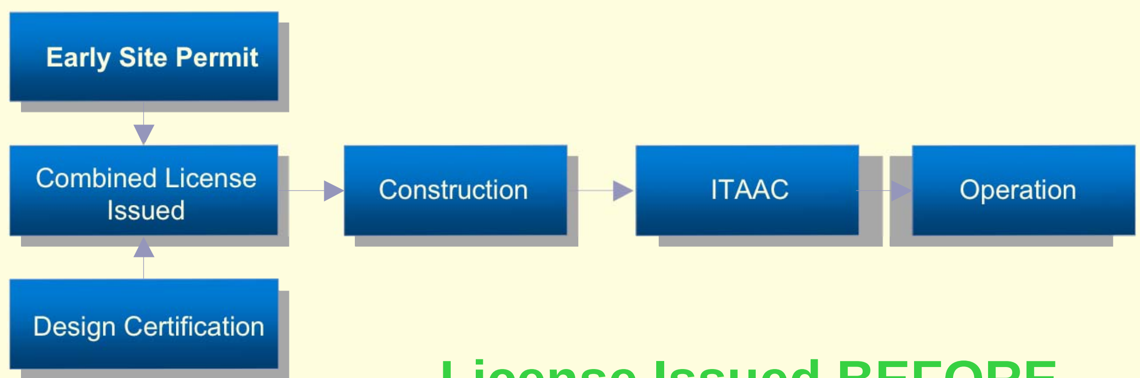
- 4 designs certified, three under review
  - Approval expected by 2011/12
- 3 early site permits issued, 1 under review, 6 companies considering applications
- Industry expenditure on new plants -$2+billion

NRC Licensing Process

OLD LICENSING PROCESS

License Issued AFTER Large Capital Investment





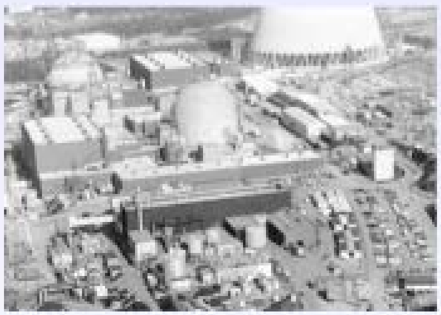
License Issued BEFORE Large Capital Investment

NEW LICENSING PROCESS

Evolution of Nuclear Power Systems

Generation I

Early Prototype Reactors



- Shippingport
- Dresden, Fermi-I
- Magnox

Generation II

Commercial Power Reactors

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

Generation III

Advanced LWRs

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

Generation IV

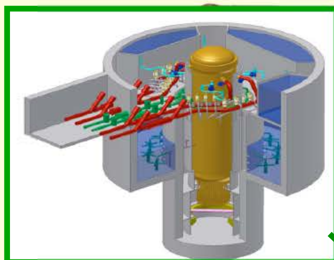
- Highly economical
- Enhanced Safety
- Minimized Wastes
- Proliferation Resistance

Gen I | Gen II | Gen III | Gen IV

1980 | 1990 | 2000 | 2010 | 2020 | 2030

Courtesy of Dept. of Energy

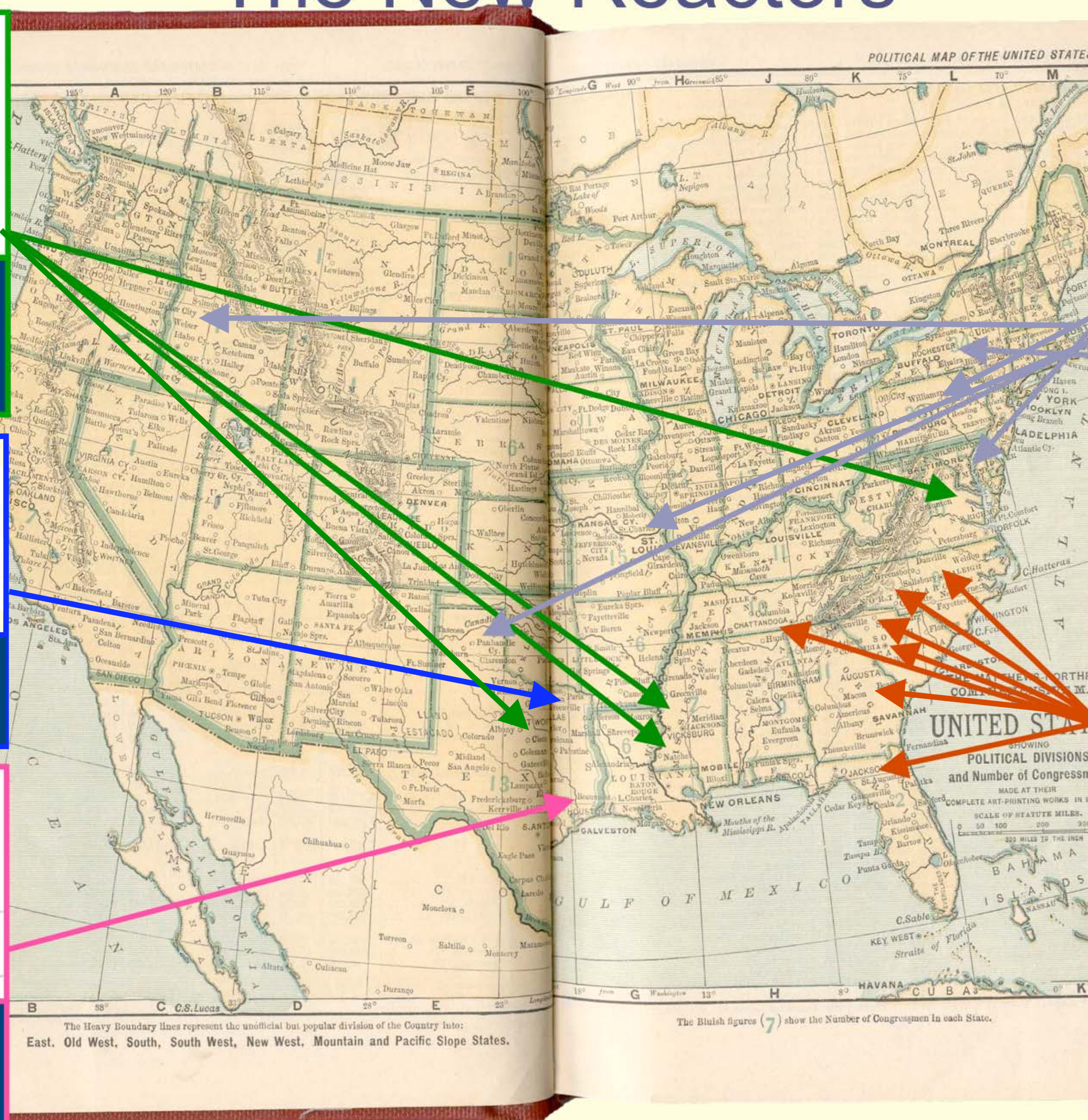
The New Reactors

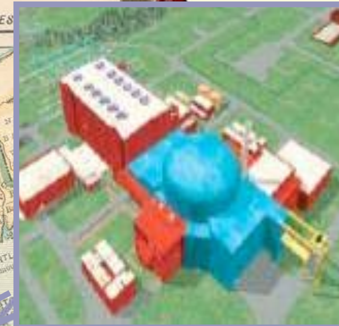


ESBWR
Dominion Entergy
Exelon

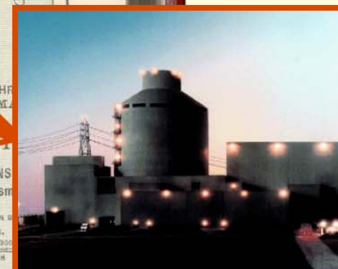
US APWR
TXU Power

US ABWR
NRG Energy





EPR
Amarillo Power
Ameren UE
UNISTAR
PPL Generation
Alternate Energy Holdings



AP1000
Duke
TVA
Progress
S.C. Electric & Gas
Southern Co.
Florida Power & Light

Challenges for quick build in nuclear energy

- Manufacturing Infrastructure:
  - Limited capacity for large forging of steel components
  - Nuclear quality is demanding, for example in welding of thick sections of steel. Now welding firms are refurbishing their capacities
- Skilled manpower:
  - Nuclear Engineers: universities had little interest in offering nuclear engineering courses.
  - Skilled labor for the construction according to nuclear standards
  - Operating labor for maintenance, with radiation protection knowledge
- Cost and Financing:
  - Construction delay risks lead to higher interest rates in open markets. Hence,
  - Time and duration of recovery of construction costs varies according to local conditions.
  - Large capital needs limit the capacity of many small electricity utilities to obtain loans.
- Geopolitical Issues of the nuclear power cycle - a longer term issue
  - Nonproliferation treaty governs support for new countries acquiring nuclear power plants
  - A global market for enriched uranium has ensured supplies from diverse sources
  - Technology for fuel cycle services should become part of a global order under the IAEA.
- Public Support could change
  - Nearly 65% support new plants. But this could change due to a serious event any where.
  - The number one public concern in the US is waste management. Progress is needed.

Improving Nuclear Energy Economics

Industry Solutions

- **Simplification**: W-AP1000 uses 2 not 4 loops & GE-ESBWR eliminates pumps
- **Standardization**: fixed design for multiple units
- **Large Capacity**: Several models at 1500 MWe
- **Construction time** through modularization, US may become similar to Japan and France

Government Solutions - Energy Act 2005

- **Pay 50% of cost of new applications (DOE 2010 program)**
- **Production credits** up to 6000 MWe
- Regulatory reform, and **Insurance for delays of the first 6 reactors**
- **Loan guarantees for non-emission**

Innovative Technology Solutions

- Increase reactor power density
  - New fuel design
  - Improved coolant properties - nanofluids
- Increase power conversion efficiency
  - High Temperature Gas Cooled Reactors

Nuclear Energy To reduce CO_2 Emissions

Near-term markets
- Fertilizers
- Oil Refining

Mid-term markets
- Coal Liquefaction
- Tar Sands

Long-term markets
- Remote Power
- Transportation

Nuclear Energy

•CO_2-free

•Efficient and cost-competitive

•Size/location to address the industry needs

→

Energy Products

Electricity

Heat

Hydrogen

Synthetic fuels

→

Services

Chemical Industry

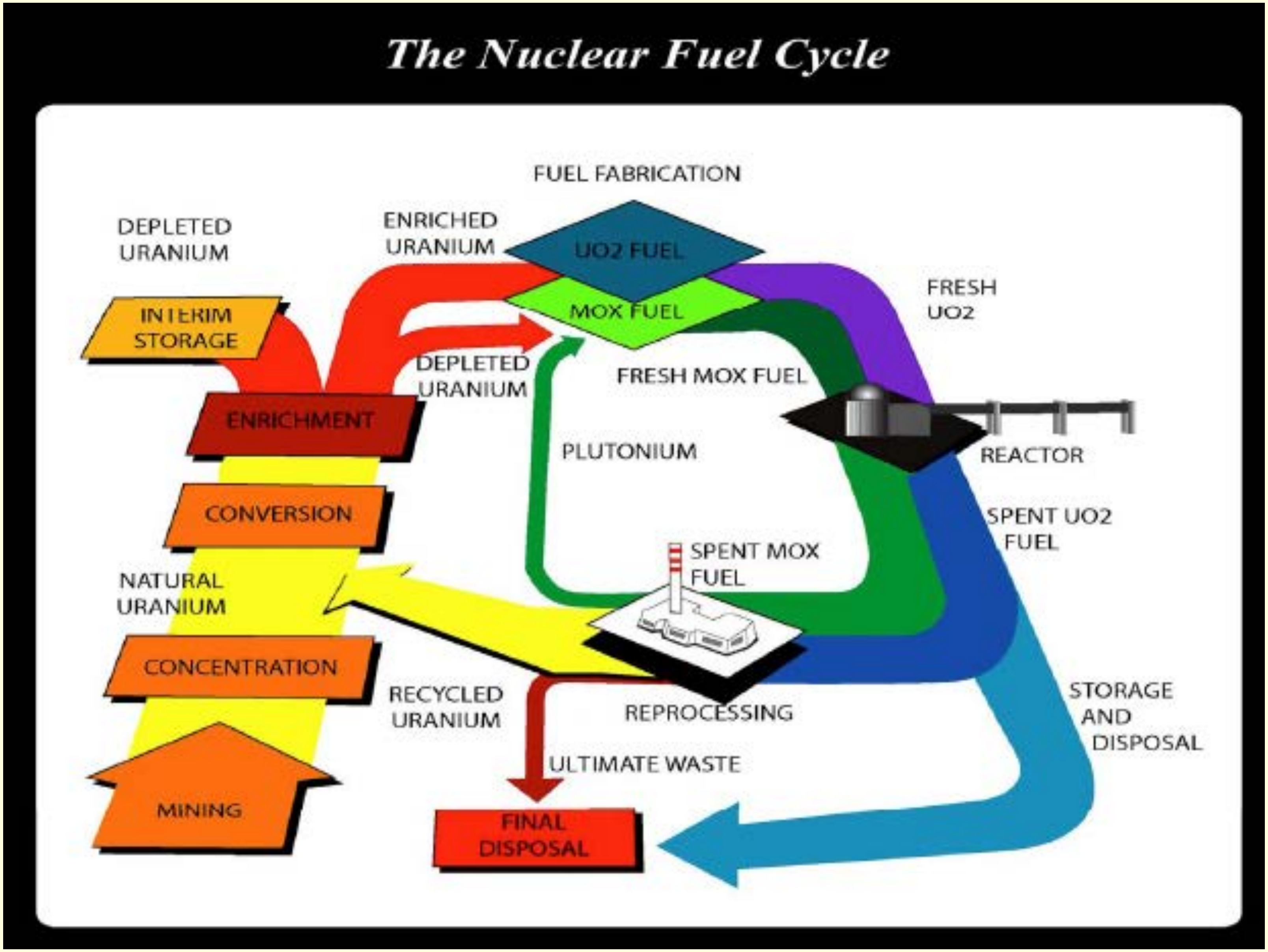
Transportation

Illumination

Heating …

The use of heat and/or hydrogen from nuclear energy in place of natural gas

- reduces carbon emissions,
- provides a hedge against natural gas price fluctuations,
- preserves fluid fuels and
- enables synthetic fluids in the future.

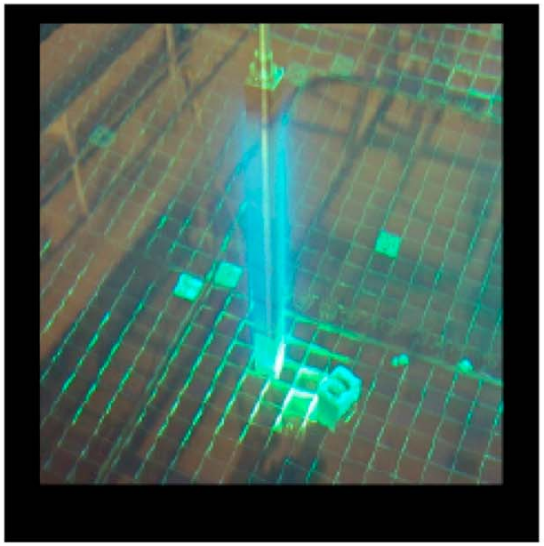

The Nuclear Fuel Cycle
FUEL FABRICATION
DEPLETED URANIUM
ENRICHED URANIUM
UO2 FUEL
MOX FUEL
FRESH UO2
INTERIM STORAGE
DEPLETED URANIUM
FRESH MOX FUEL
ENRICHMENT
REACTOR
PLUTONIUM
CONVERSION
SPENT UO2 FUEL
SPENT MOX FUEL
NATURAL URANIUM
CONCENTRATION
RECYCLED URANIUM
REPROCESSING
STORAGE AND DISPOSAL
ULTIMATE WASTE
MINING
FINAL DISPOSAL

Management of Spent Fuel

- ☆ Volumes are small: Energy content of uranium is a million times that of coal.
- ☆ Fission of 1.05 g of U^{235} generates 1 MWd of thermal energy, thus generating about 10 g of spent fuel per year per house consuming 200 kWhr/month.
- ☆ Spent fuel is mostly uranium (about 95%, at 0.5 to 0.8% ^{235}U) with:

  1% plutonium, 0.1% higher actinides, 3-5 % fission products.
- ☆ Worldwide, roughly 8000 tons/yr are discharged per year, or 2400 m^3.
- ☆ Spent fuel in the US, Korea, Spain,Sweden, and several other countries is stored at reactor sites, waiting for a geological repository planned by governments. This is called the once-through fuel cycle
- ☆ In France, England, Russia,and Japan spent fuel is processed for Pu recycling. Fission products and higher actinides emplaced in glass, destined to a geologic repository. This is called the closed fuel cycle.
- ☆ One recycle of Pu as mixed oxide (M) is planned in existing LWR reactors, then fuel is to be stored until it is needed for future fast reactors (which are even better at fissioning Pu and the higher actinides).
- ☆ Options to burn (transmute) Pu and higher actinides are being considered.

  - Mixed Oxide U-Pu or Inert Fuel in LWRs - Fast Reactor Burners or Breeders - Accelerators



http://www.nucleartourist.com/

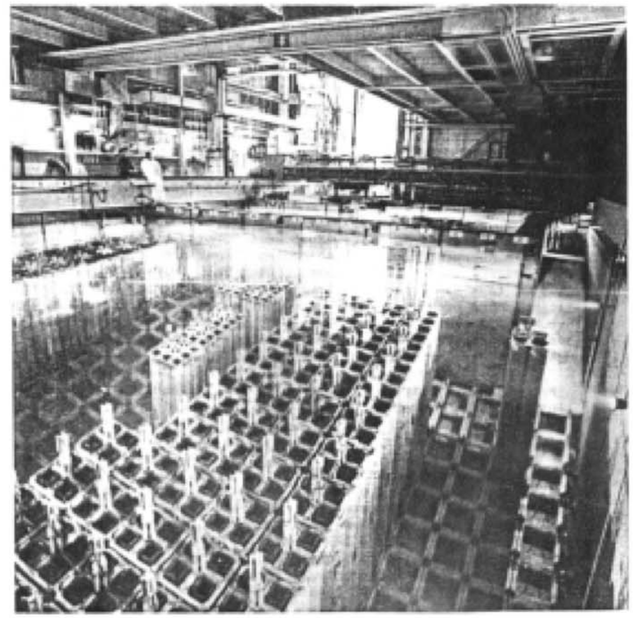


FIGURE II-A-1. G. E. Morris Operation — Fuel Pool. Water Depth is 8.7 m (28.5 ft).

Figure 2.2: Concrete storage casks at a U.S. nuclear power plant

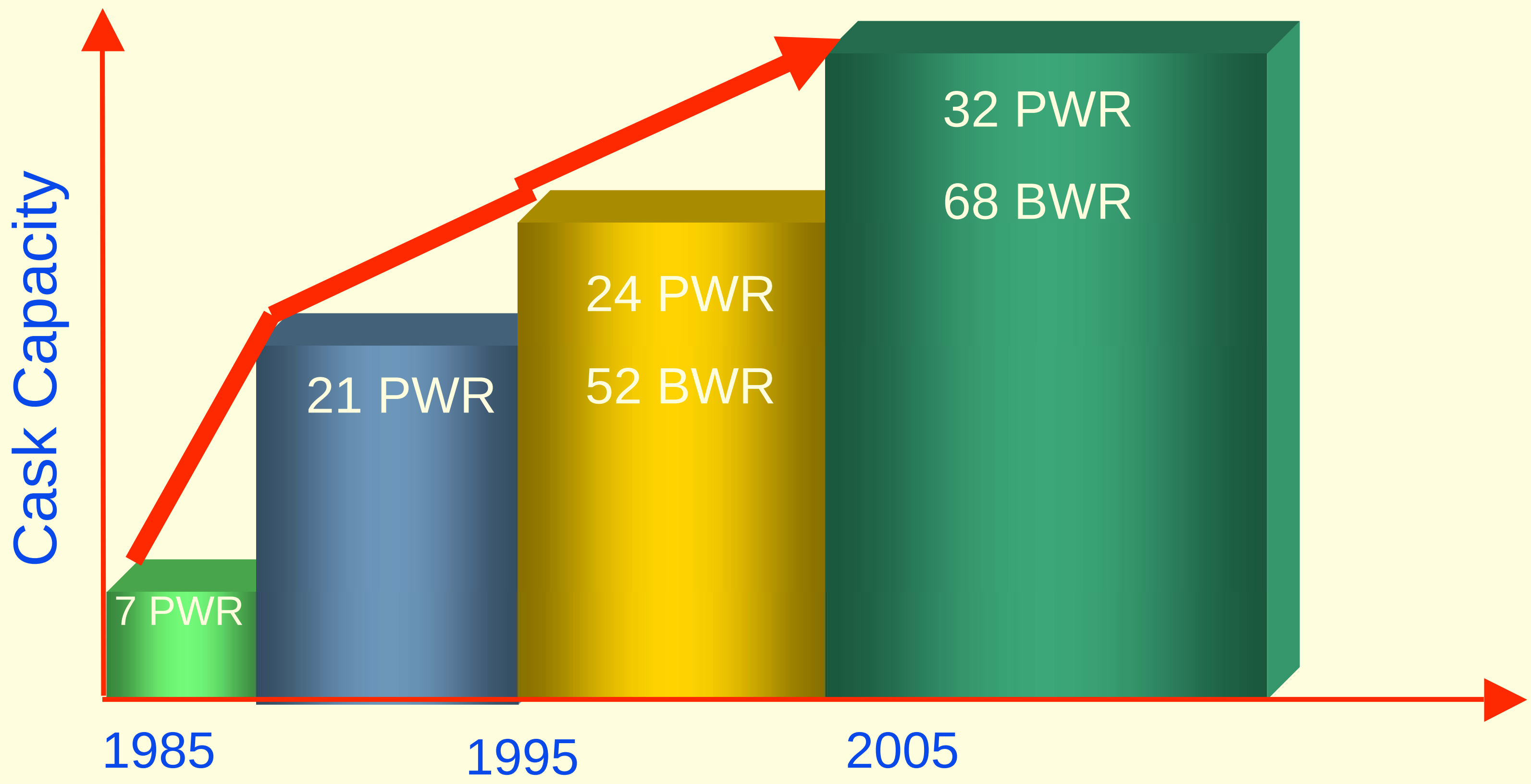
After 10 or more years, radiation and decay heat levels are low enough that the fuel assemblies may be stored in large casks cooled by air on the outside. Such casks hold 24 to 40 fuel assemblies.

The casks have double metal ring seals and are bolted to ensure no radioactive release will be ale to occur Helium is used inside the cask to promote heat removal from the fuel assemblies to the cask wall. Air on the outside removes the heat.

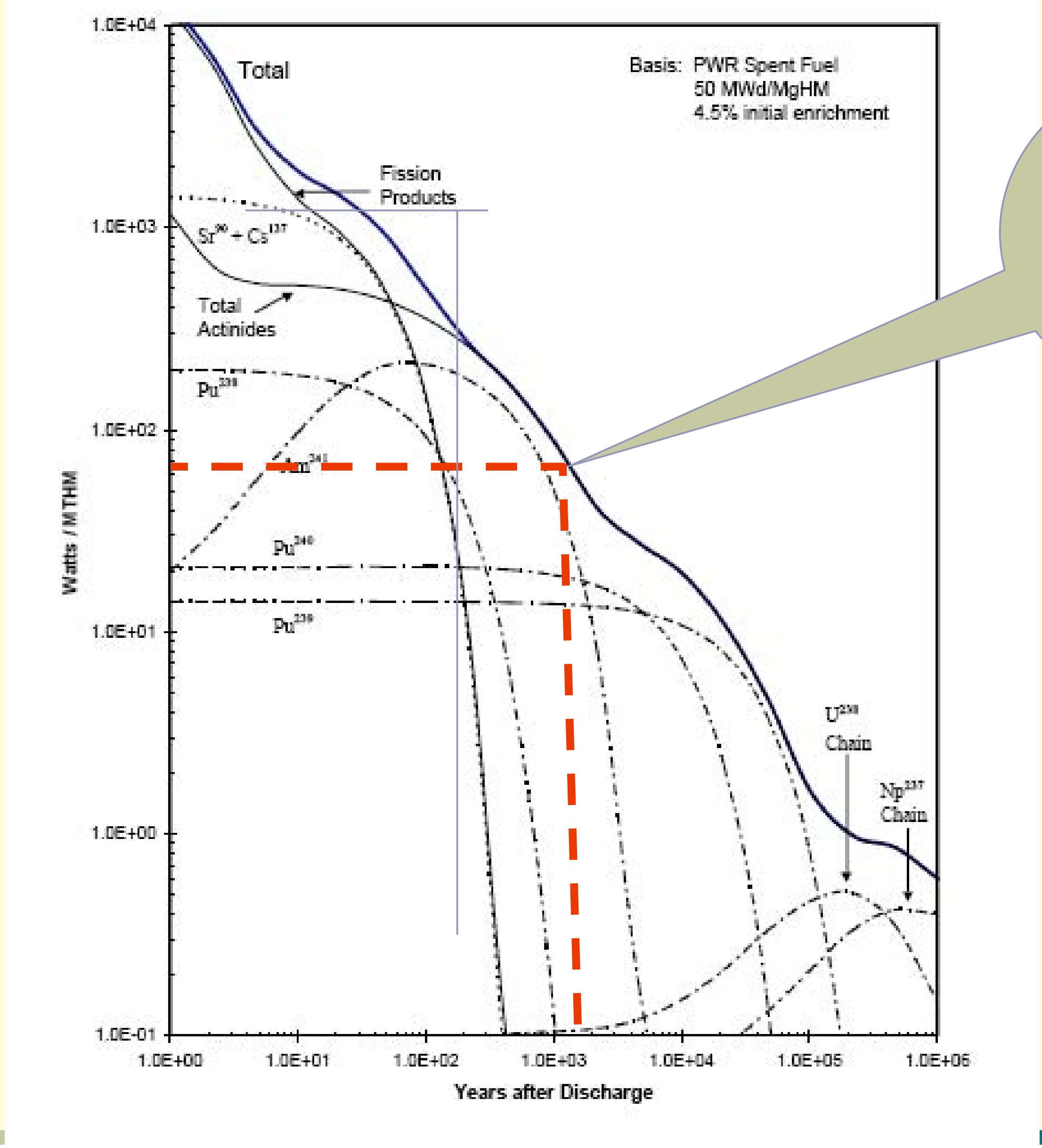
Pressure inside the cask and temperature on the outside are monitored.

Spent Fuel/Waste Volume is Not the Issue

- Economics drove casks to higher capacity for assemblies
- Balance capacity with shielding and decay heat
- The operation of a PWR for 40 years results in 80 casks



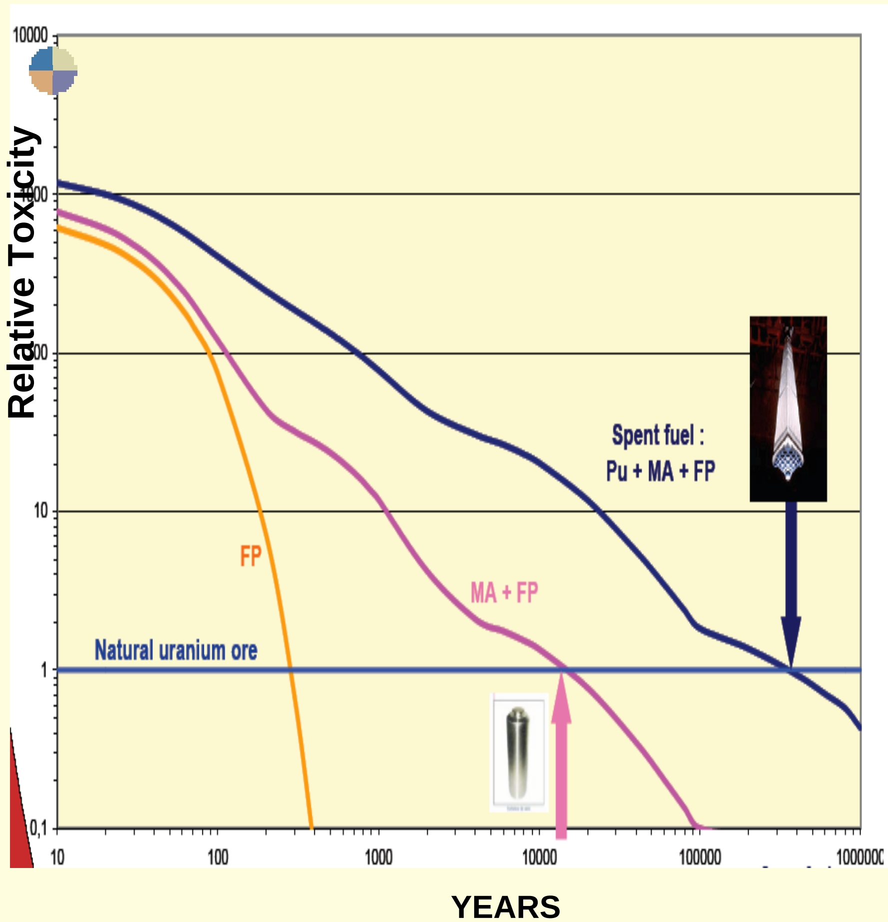
Decay behavior of spent fuel -- thermal power



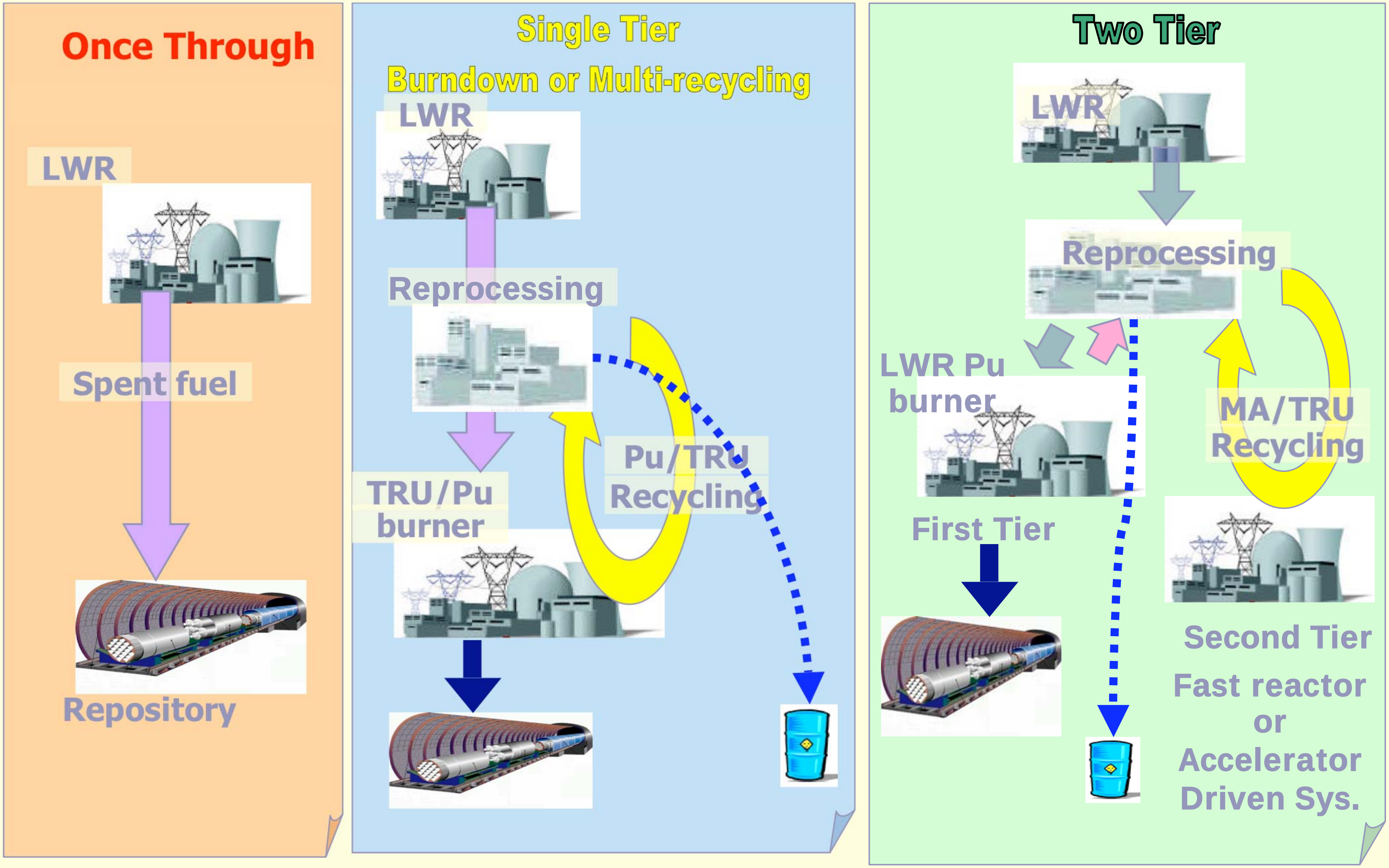
About 70 watts of heat (a light bulb) per spent fuel assembly after 1000 years

Radioactive Wastes Are Hazardous; But, the Hazard Decreases With Time

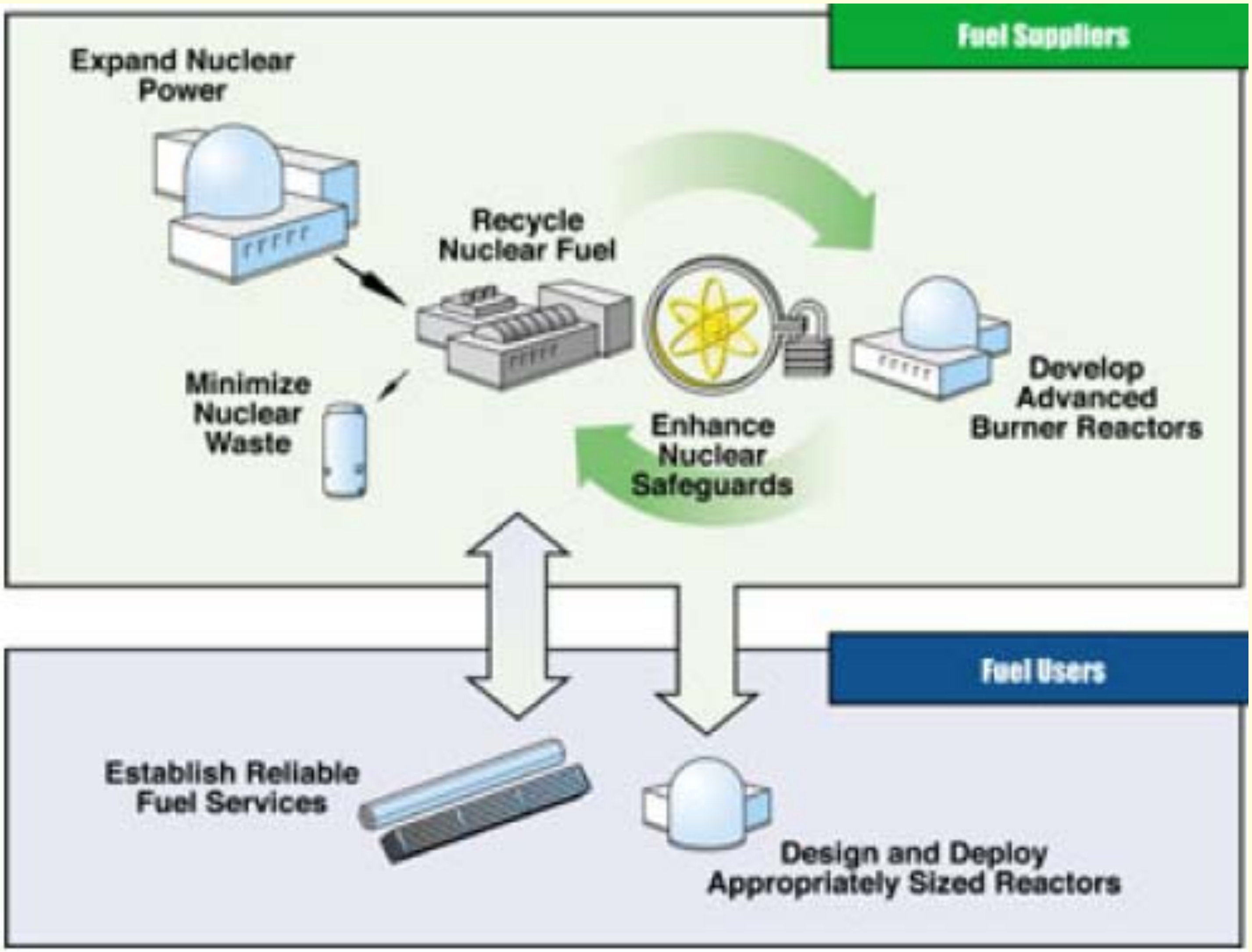
- Radionuclides decay away with time
- Safe disposal is isolation until most radionuclides decay away
- Need good storage location
- Limit of isolation: Uranium
  - Uranium is a radioactive heavy metal
  - Long half-lives
  - Chemical toxicity exceeds radiotoxicity



Fuel Cycle Options



Global Energy Partnership



Summary

Nuclear energy is one of a few options that can supply the world with the energy it needs while avoiding increased emissions of CO_2.

The nuclear option has accumulated a record of excellent reliability in the last two decades to bring confidence that wider nuclear deployment can be achieved while maintaining safety.

There are many possible advancements in reactors to improve cost of electricity and safety margins, and they need to keep improving to enhance competition.

The industrial capacity to build reactors in the next 10 years is limited, and will likely determine the rate of growth in deployed nuclear energy.

Stored spent fuel does not occupy a large volume, but the storage burden has to shift to government before the end of life of a plant.

Multi-recycling of burned fuel in reactors reduces the inventory of higher actinides in the system and the need for geologic disposal.

Introduction of fast spectrum reactors for fuel breeding is not likely to be economic for at least 40 years. This depends on the demand for nuclear energy for electricity and other purposes.