Future of Nuclear Energy

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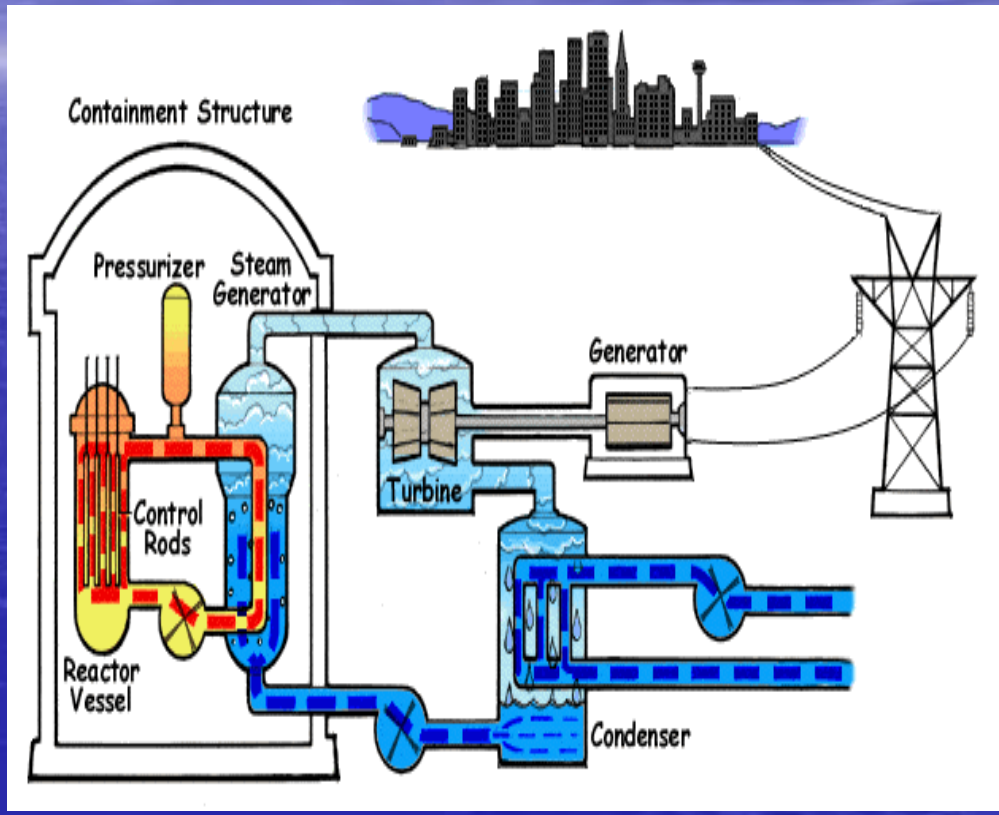
Quick Overview of Nuclear Energy Today

- 104 US reactors (20% of electricity), 440 World reactors 30 countries.
- 34 new reactors in various stages of construction World-wide.
- In 2007 highest ever nuclear energy production in the US.
- 51 reactor licenses extended, from 40 years to 60 years of operation, 17 more reactors in process.
- 2 orders (4 units total) for new reactor construction signed, 17 license applications (26 units total) filed with NRC, 10+ more units expected



A renaissance in Nuclear Power Worldwide Location of Nuclear Plants

- "We made the mistake of lumping nuclear energy in with nuclear weapons, as if all things nuclear were evil. I think that's as big a mistake as if you lumped nuclear medicine in with nuclear weapons" Patrick

Worldwide Nuclear Power Usage and Total Electric Usage Per Capita (kWh/day per person)

Nuclear Total

- Sweden 19.6 (40.63)
- France 19.0 (20.45)
- Belgium 12.2 (21.82)
- Finland 11.8 (46.07)
- Switzerland 9.7 (22.01)
- South Korea 7.7 (21.12)
- USA 7.5 (35.06)
- Canada 7.4 (45.86)
- Slovenia 7.4 (19.09)
- Japan 5.7 (20.84)

Norway 0 (67.54)
China: 0.12 (5.95)
India: 0.04 (1.21)

Reactor Generations

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

- ABWR
- System 80+

Generation III +

Evolutionary Designs Offering Improved Economics for Near-Term Deployment

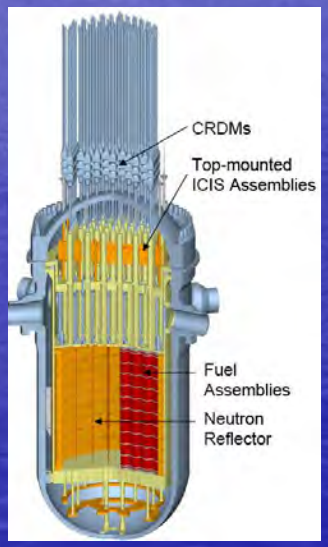
Generation IV

- Highly Economical
- Enhanced Safety
- Minimal Waste
- Proliferation Resistant

Five Advanced Reactor Designs Used in the US

ABWR (GE-Hitachi)

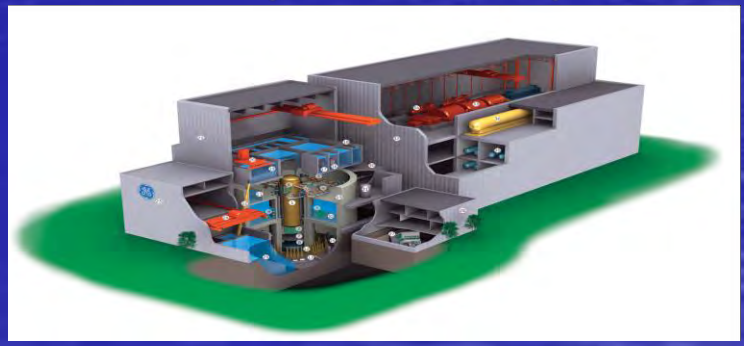
US-APWR (Mitsubishi)



AP1000 (Toshiba: Westinghouse)

US-EPR (AREVA)

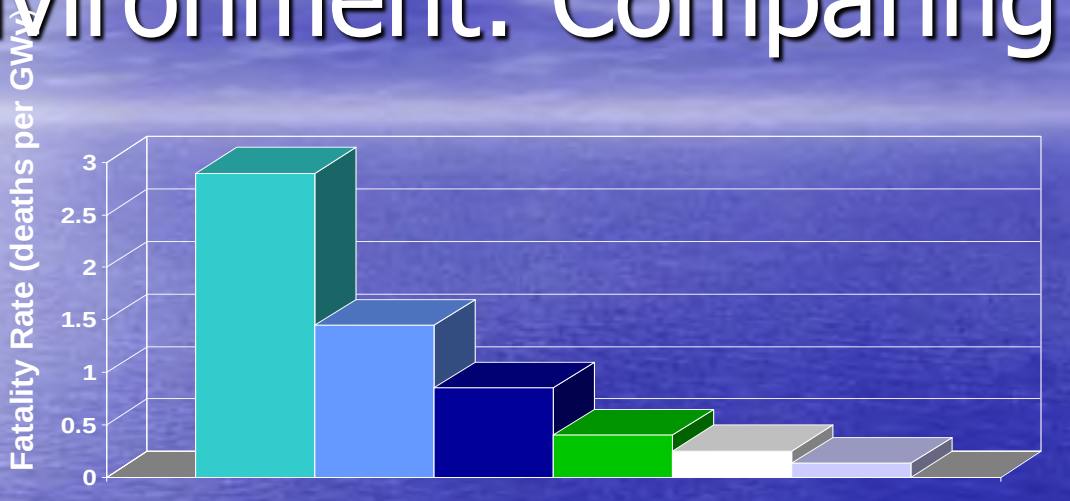
ESBWR (GE-Hitachi)

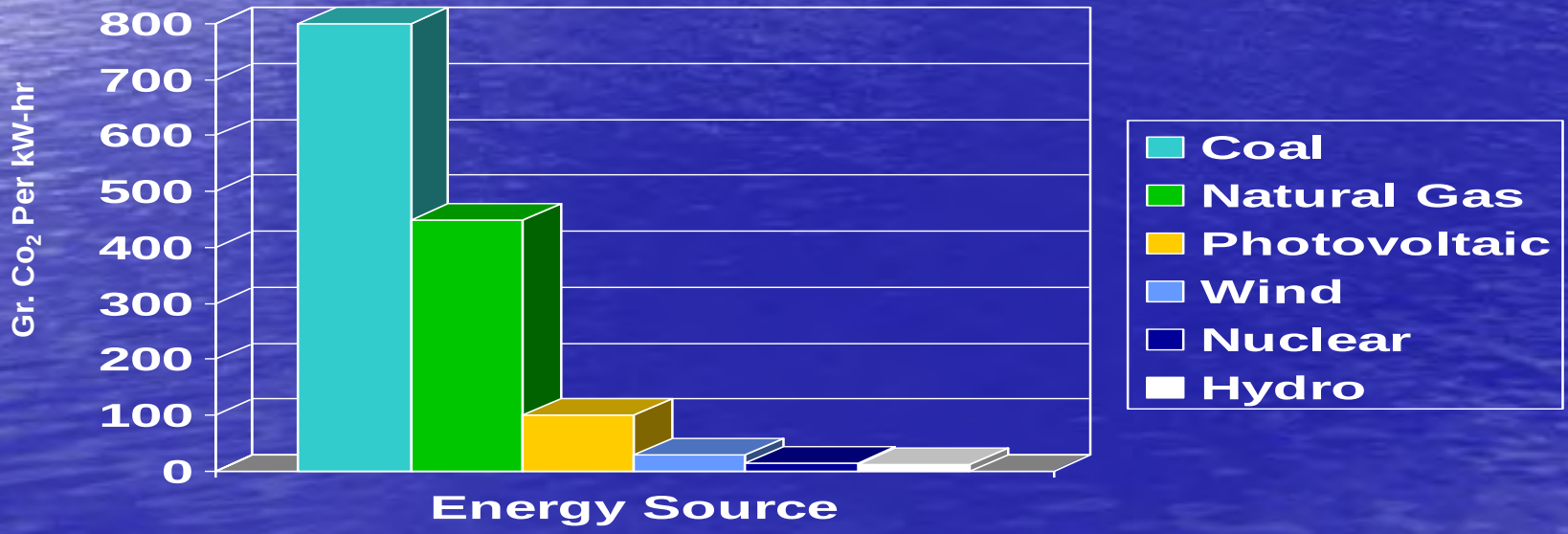


Key Features of New Designs

- Improved economics
  - Increased plant life (60-80 years)
  - Shorter construction time (24-48 months)
  - Low capital cost (~$1000-2000/kWe)
  - Low cost of electricity (~ 3-5¢/kWh)
  - High Burnup
- Improved safety and reliability
  - Reduced need for operator action
  - Passive Safety Features
  - Reduced core damage and release frequency

Public Health, Safety & Environment: Comparing Options





Source: Center for Innovation in Carbon Capture and Storage, University of Nottingham

The Concerns

- **Capital intensity**
  - New nuclear plants remain very expensive to build
  - Loan guarantees in 2005 energy bill help the financial risk (2008 applications totaled $122M vs. $18M allocation)
- **Nuclear Waste**
  - Geological repository is the current approach in the U.S.
  - Yucca Mountain site selected, license application submitted to the NRC, its future is uncertain
- **Proliferation**
  - Technical features of fuel cycle can hinder proliferation (e.g., high burnup, use of thorium, modular sealed reactors, etc.)
  - Ultimately it is a political issue; New IAEA treaty?

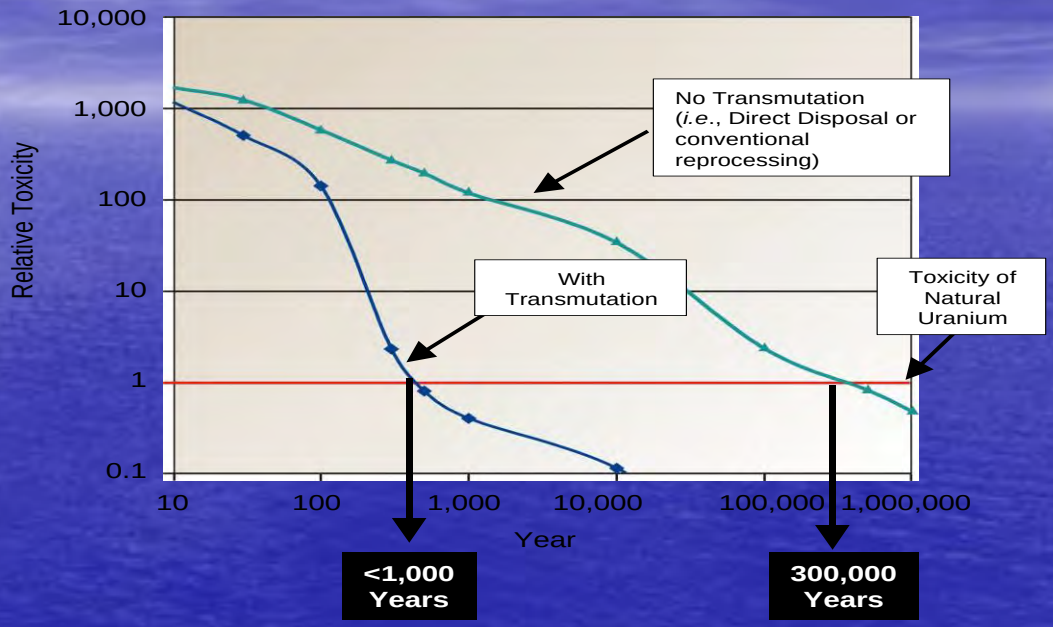
Capital Intensity/Needs

- Capital cost comes to $1000-$2500/ KWhr
- With "Cap and Trade" this would be competitive, otherwise subsidies would be needed

Nuclear Waste

- Interim storage at plants (storage pools and dry casks, successfully implemented for 22 years)

- Pu+U recycled in (sodium-cooled) fast reactors (being reconsidered in Russia, Japan, France and US under GNEP umbrella)



- Separated Pu is recycled in LWRs (MOX approach, done in France and Japan)

Fuel Cycle: Known recoverable Sources of Uranium

Million tons in Ground

- Australia 1.14
- Kazakhstan 0.82
- Canada 0.44
- USA 0.34
- South Africa 0.34
- Namibia 0.28
- Brazil 0.28
- Russian Federation 0.17
- Uzbekistan 0.12

World total 4.7

Million tons Elsewhere

- Phosphate deposits 22
- Seawater 4,500
- Uranium in wastes due to previous activities 1.3

Fuel Cycle: Sustainability of Once-Through Option

- At today's rate of consumption, once-through fuel cycle could keep going for a hundred year
- At 40-fold increase worldwide, in order to compensate for all fossil fuels, once-through nuclear is not a sustainable option unless seawater Uranium recovery is used.
- Japanese have a technique for extracting uranium from seawater at a cost of $200–500/Kg (current cost is ~$20/kg for ore).

Fuel Cycle: Sustainability, Fast Breeder & Reprocessing Option

- With Recycling (Reprocessing) and re-use in fast breeder reactors the fuel-cycle will be sustainable without reliance on seawater
- Reprocessing plus fast breeder increases the resources by 80 folds
- Beside Uranium, Thorium can be used with ground reserves 4 time larger than Uranium

Conclusions

- A renaissance in new nuclear plants underway in the US and the World for first time in 30 years
- New plants feature offer far higher levels of safety through increased redundancy and use of passive safety features
- Nuclear is available (today!) to reduce reliance on fossil fuel and slow carbon emissions
- The most challenging issue is the long-term disposal of spent fuel