The Greening of Nuclear Energy:
completing the fuel cycle

Sun City Summerlin Nuclear Science Club

Nevada

5 October 2008

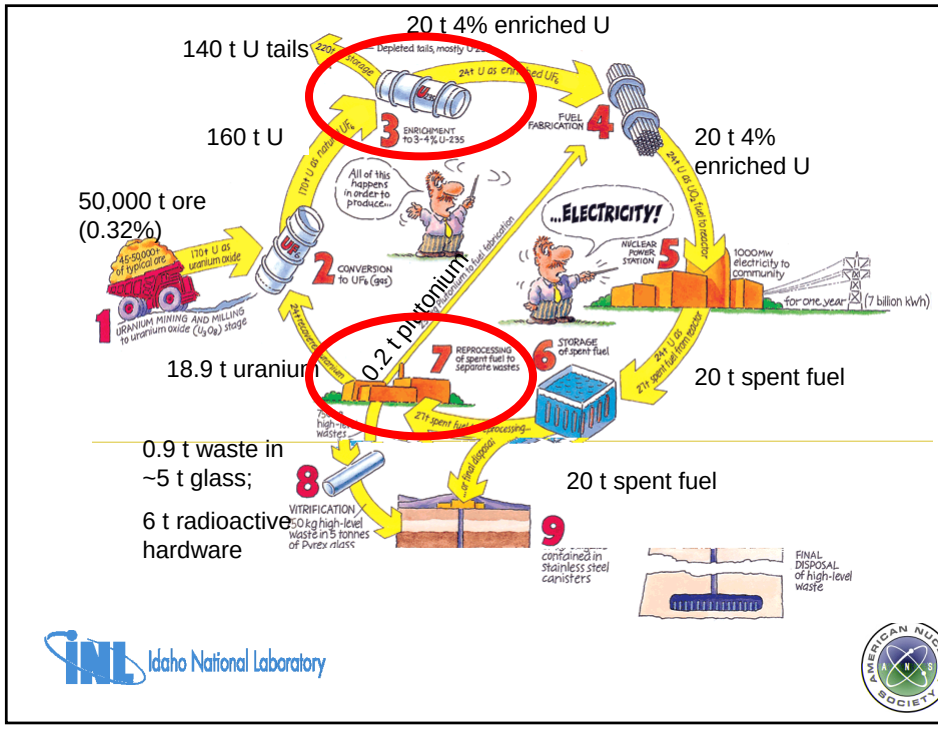
Harold McFarlane

Deputy Associate Laboratory Director for Nuclear Programs, INL

&

President, American Nuclear Society

Idaho National Laboratory



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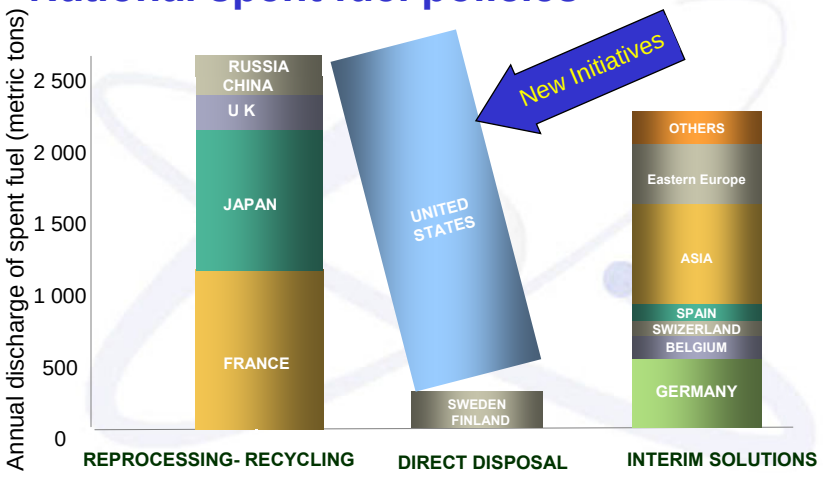
National spent fuel policies



Courtesy Areva

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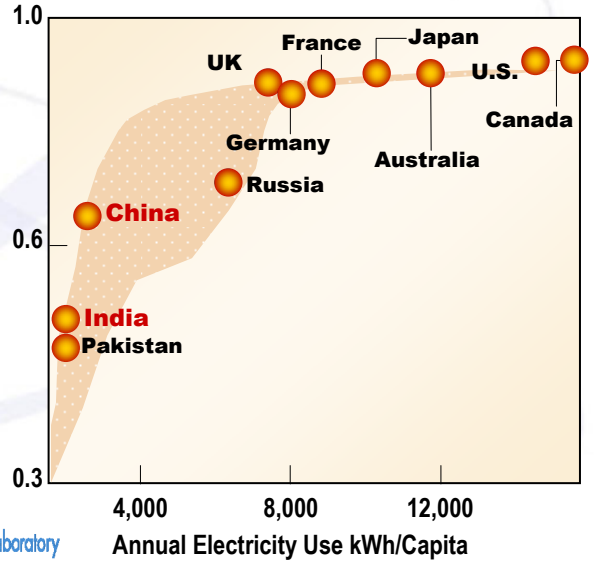
Access to energy essential to quality of life

80% of the world's population is below 0.8 on the UN's Human Development Index (HDI)

Prosperity

Education

Life span



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Energy is the fuel of national prosperity

Source: Royal Dutch Shell, “Exploring the Future - Energy Needs, Choices and Possibilities

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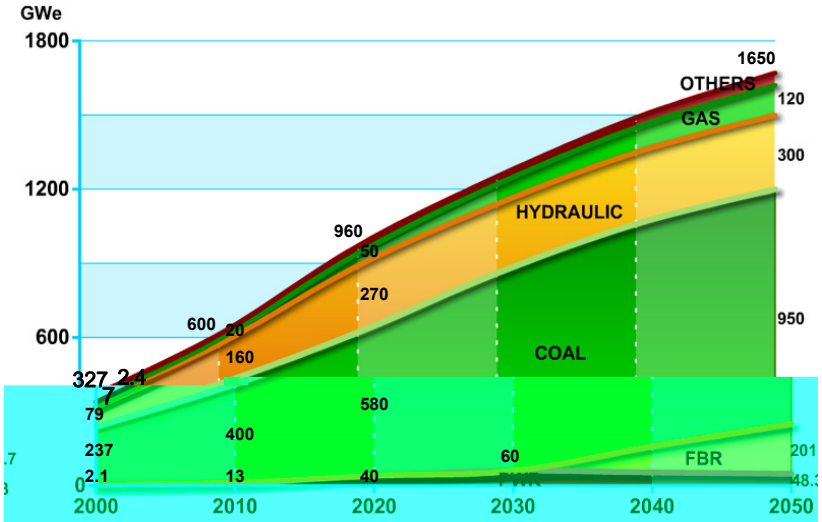
XU MI, Oct. 2005

CHINA INSTITUTE OF ATOMIC ENERGY



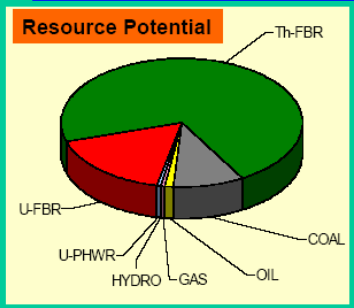
Electric Capacity Development Envisaged In China

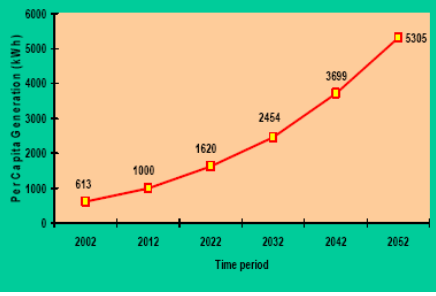
Indian Energy Growth Scenario

		2003-04	2052
➢ Electricity Generation	(GWe)	112.0	~ 1344
➢ Nuclear Energy Share	(GWe)	2.72	~ 275
➢ PHWR	(GWe)	2.10	~ 0

➢ Faster Growth is needed to reach the target

➢ FBR with Closed Fuel Cycle is inevitable





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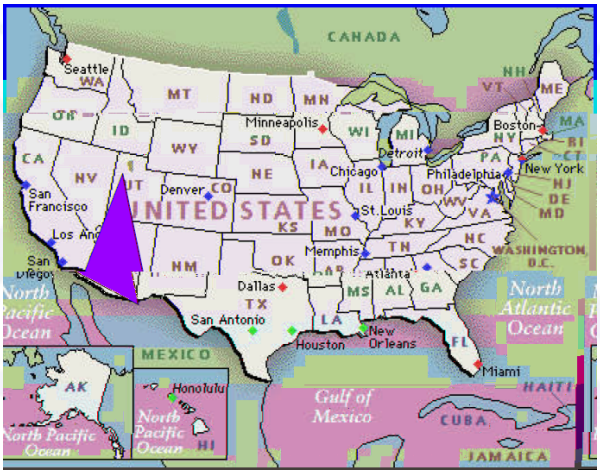
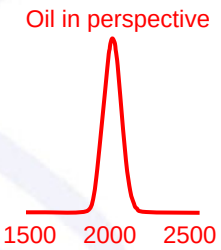
Baldev Raj, GLOBAL 2005, October 2005

Most oil production in the "Golden Triangle" in the Middle East



From Simmons & Company, International

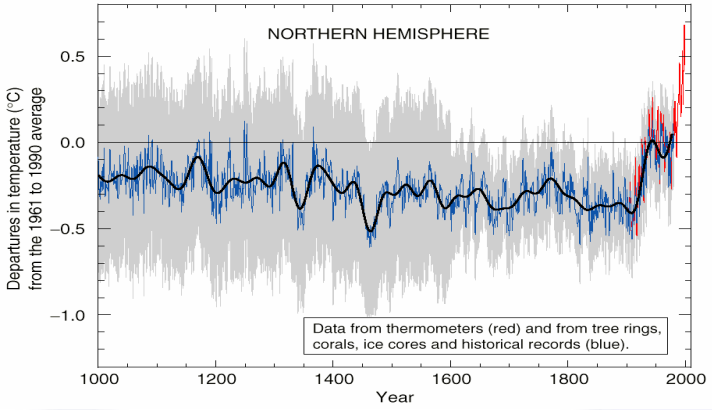
Ultimately the geologists have it right: traditional oil production will peak



Friday, April 21, 2006, spot oil prices hit $75/barrel—a new record

Also this week, President Bush complained to President Hu about ***China's*** increasing demand for oil

Climate change is taking place



Estimated Change in Northern Hemisphere Temperature Since 1000 AD

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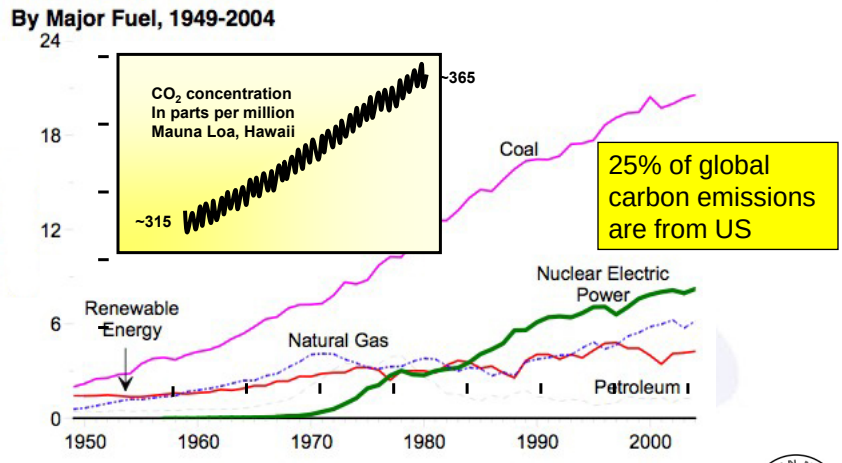
Carbon based fuel use is growing



25% of global carbon emissions are from US

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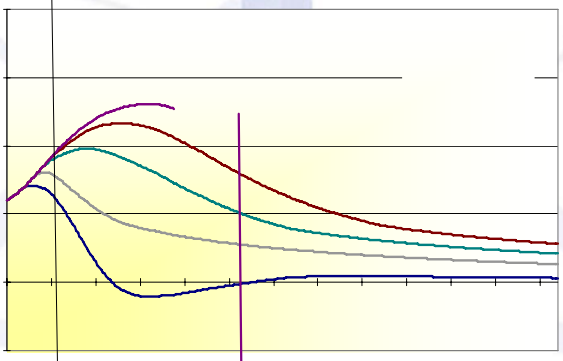

Why nuclear is green; why it's not green enough

- Safe
- Potentially sustainable
- Minimal air emissions
- Readily expandable
- Minimal solid waste
- It's now a "cool" conversation topic
- Strong environmental endorsements
- Economically competitive

- Extractive industry
- Much remains to be proven
- Much remains to be implemented
- Lingering nonproliferation issues

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US nuclear generation: 104 reactors; 100 GWe; 2000 t SNF/year

Today's operating plants are "Generation-II"

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Conditions for nuclear to be a significant part of the 21st century energy mix

- Low carbon emission technology
- Affordable
- Expandable
- Sustainable
- Safe
- Accepted
- Doesn't leave a mess
- Consistent with national and international policy

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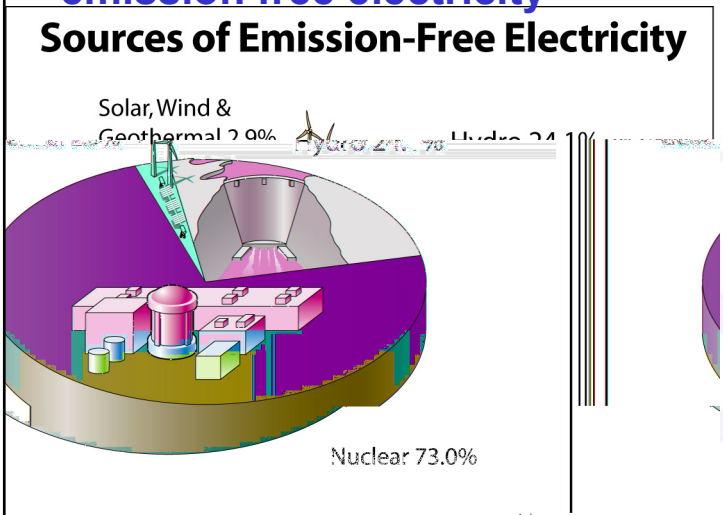
Nuclear generates most of America's emission free electricity



Worldwide nuclear plants save more than twice the Kyoto carbon target annually.

In the US, nuclear plants avoid tons of emissions:

- 3.4 million tons of sulfur dioxide
- 1.1 million tons of nitrous oxides
- 700 million tons of carbon dioxide

Courtesy NEI and ENTERGY

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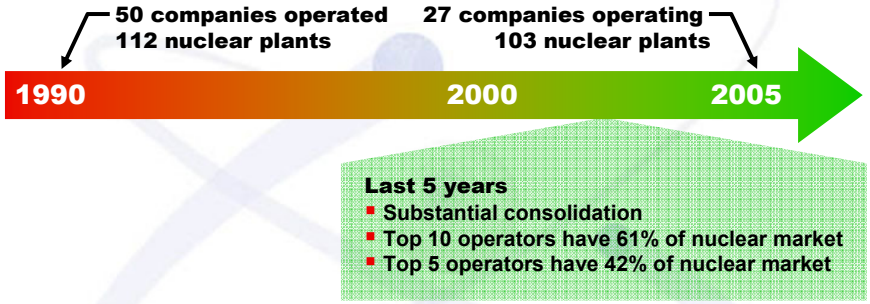
Consolidation of nuclear ownership



Last 5 years
- Substantial consolidation
- Top 10 operators have 61% of nuclear market
- Top 5 operators have 42% of nuclear market

Consolidation of Ownership *resulted*

- Corporate mergers and acquisitions
- Asset sales by companies desiring to exit nuclear ownership

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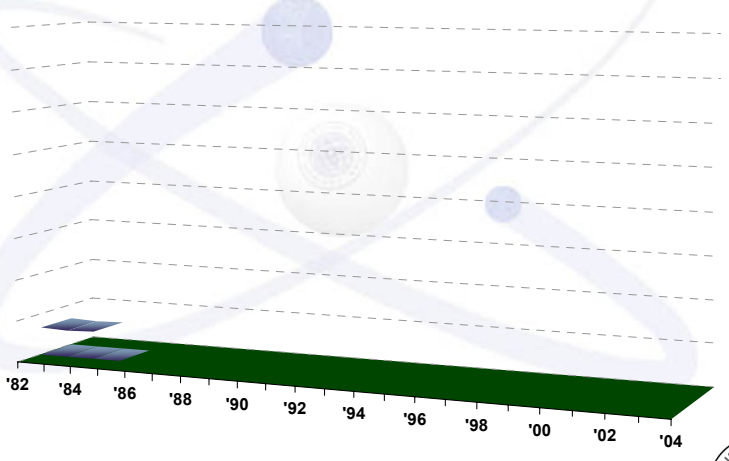

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Performance improvements since President Carter's administration

Performance indicator	1979	Today
No. of commercial reactors	69	103
Electricity produced (kilowatt-hours)	255 billion	789 billion
Fleet average capacity factor	56.3%	90.5%
Unplanned reactor shutdowns/7000 hr	7.3%	0
Industrial safety accident rate/200k-hr	2.1	0.25

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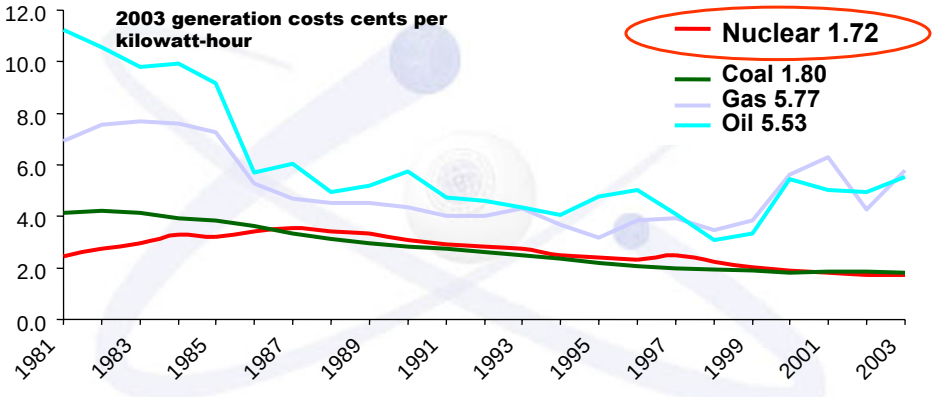
Nuclear energy is competitive



Nuclear is the lowest cost of all (except hydro)

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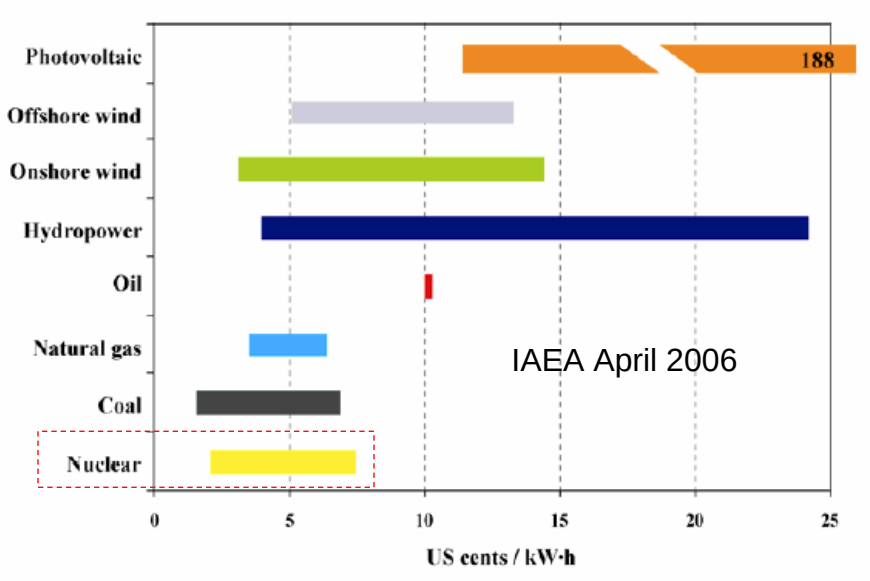
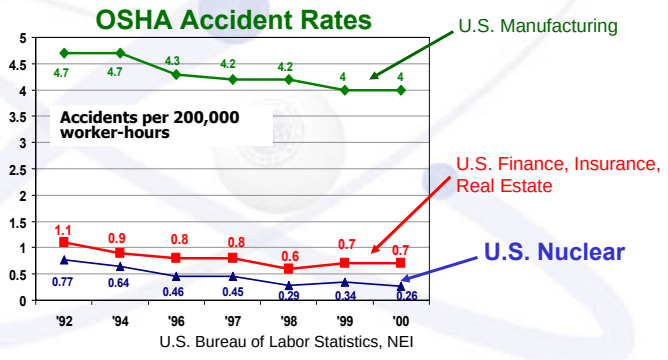
Nuclear Energy Institute

Results of 7 recent forward cost studies



Nuclear energy has a strong safety record



U.S. Bureau of Labor Statistics, NEI

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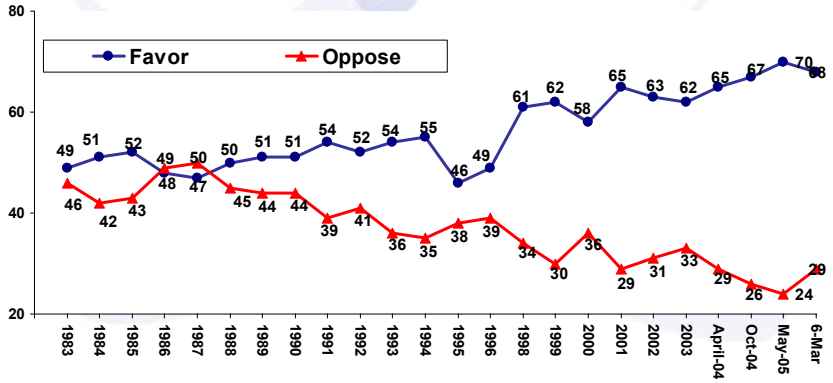
Nuclear Energy widely favored in USA



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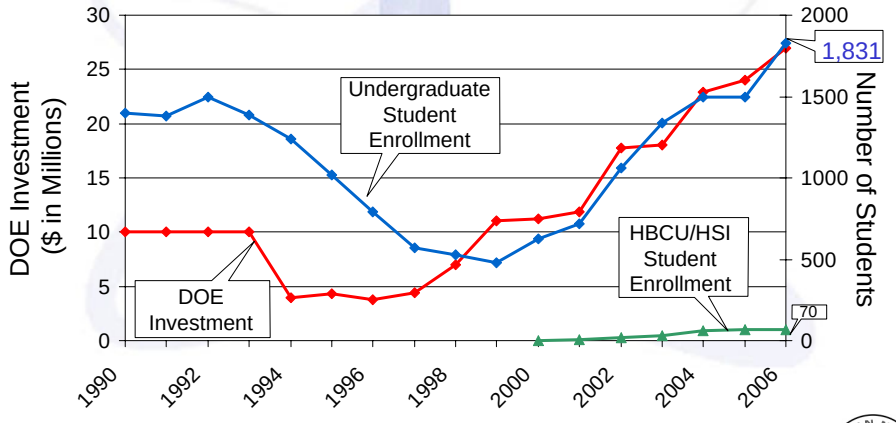
Trends in nuclear engineering enrollment



US DOE August 2006

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Better international alignment on nuclear nonproliferation goals

8% of American electricity is generated by uranium from former USSR nuclear warheads.

…atoms for peace.
2005 Nobel Peace Prize

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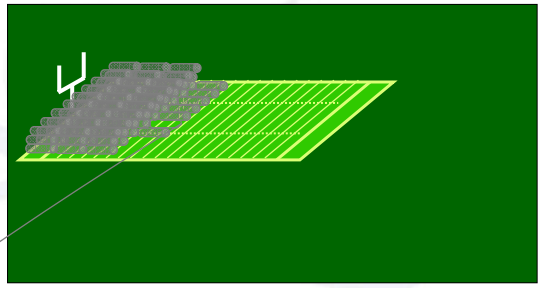
Total amount of used fuel generated is relatively small and readily manageable

Current high-level waste volume after 40 years of operations would fill an area about the size of a football field five yards deep



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Good news abounds

Feb. 8, 2006
U.S. Must Maintain Nuclear Power Plants to Address Climate Change, Says Pew Center

The New York Times
nytimes.com

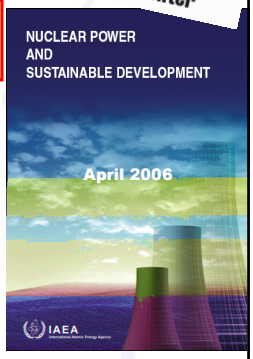
"The replacement of Britain's nuclear power stations is "back on the agenda with a vengeance," Tony Blair, May 17, 2006

May 13, 2006

EDITORIAL

The Greening of Nuclear Power

Not so many years ago, nuclear energy was a hobgoblin to environmentalists, who feared the potential for catastrophic accidents and long-term radiation contamination. But this is a new era, dominated by fears of tight energy supplies and global warming. Suddenly nuclear power is looking better.



How to Fix America's Energy Crisis
Reader's Digest
October 2006
Nuclear power. Clean and economically feasible, spent nuclear power even retains 95 percent of its energy, which means
that by recycling used fuel, we could cut waste while powering up.

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washingtonpost.com

Going Nuclear
A Green Makes the Case

By Patrick Moore
Sunday, April 16, 2006; B01

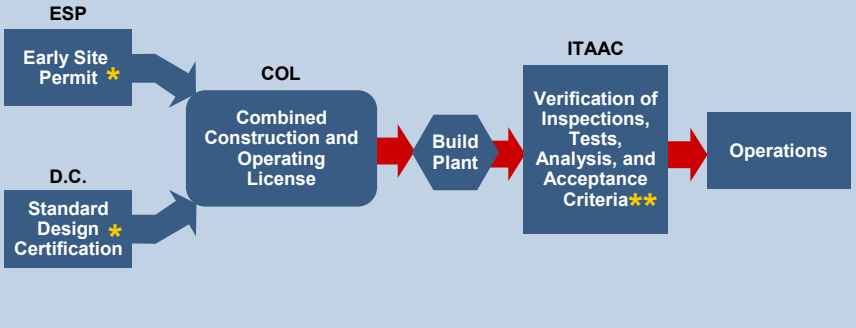
In the early 1970s when I helped found Greenpeace, I believed that nuclear energy was synonymous with nuclear holocaust, as did most of my compatriots. That's the conviction that inspired Greenpeace's first voyage up the spectacular rocky northwest coast to protest the testing of U.S. hydrogen bombs in Alaska's Aleutian Islands. Thirty years on, my views have changed, and the rest of the environmental movement needs to update its views, too, because nuclear energy may just be the energy source that can save our planet

EPACT 2005 provisions for new plant construction

Loan guarantees	80% of project cost	• Higher leverage • Lower debt cost
Production tax credit	$18/MW hr	• Through 2021 • $125M/1000 MW per year • 6,000 MW eligible • IRS rule making: February 2006
Risk assurance	Delay protection	• $500M for 1st 2 plants • $250M for next 4 plants
Price-Anderson	Liability insurance	• Reauthorization for 20 years
Decommissioning funds	Updates for treatment	• Allows companies to establish funds and make contributions • Allows transfer of nonqualified funds to qualified funds

New Process

Combined licensing process (10 CFR 52)



* Opportunity for public comment
** Opportunity for hearing

Necessary reform to attract financing

9 Years

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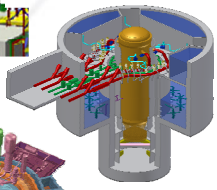
Designs competing for US market: *Generation III & III+*

- Standardized designs based on modularization producing shorter construction schedules
- Passive or redundant systems to enhance safety
- Easier to protect from terrorist attacks

AP-1000

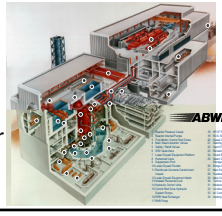
Gen-III+



ESBWR

EPR

Gen-III



ABWR
Advanced Boiling Water Reactor

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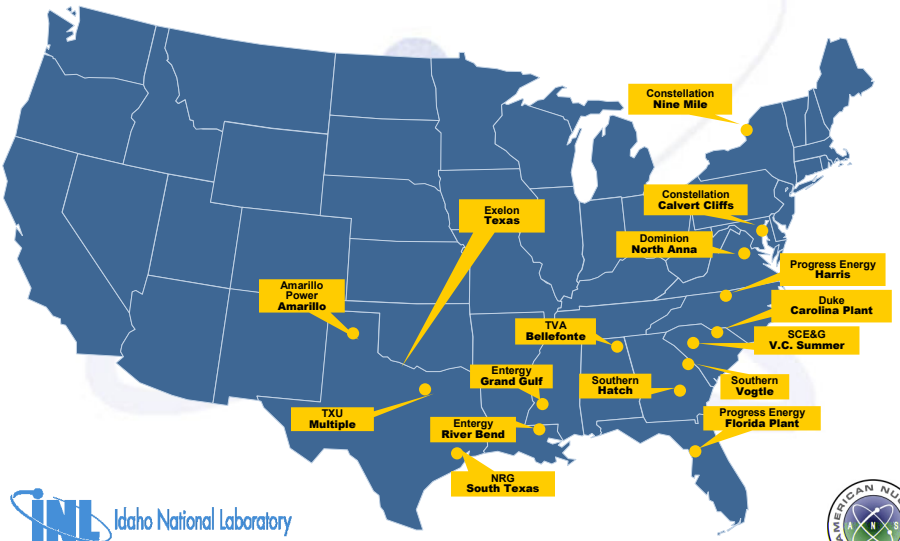
U.S. nuclear industry—first movers for new build



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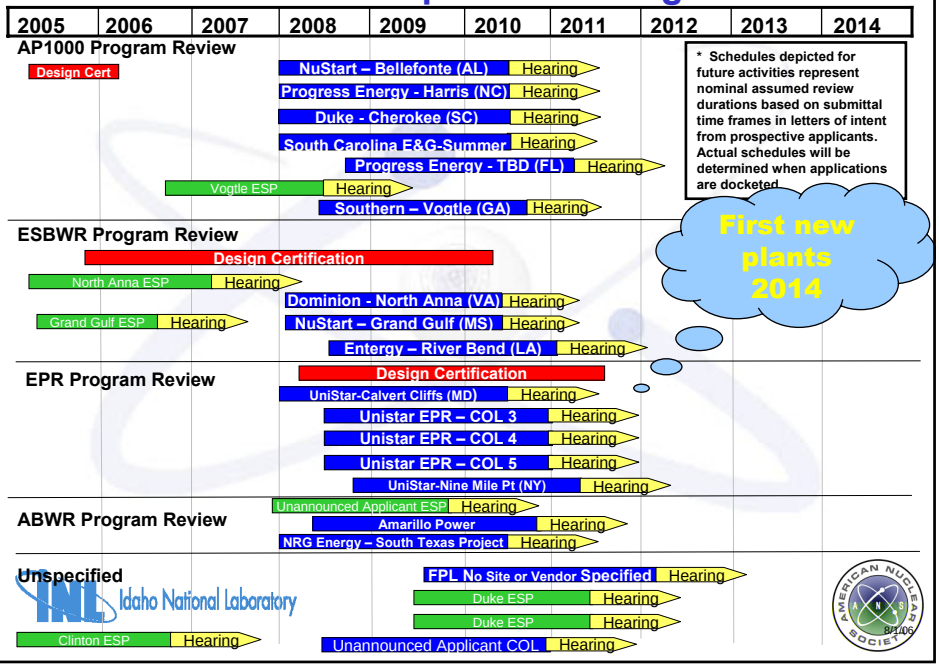
NRC's estimated new plant licensing schedule



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30 new nuclear plants in 2020?

New Eurostaf report says 78 additional GWe by 2030

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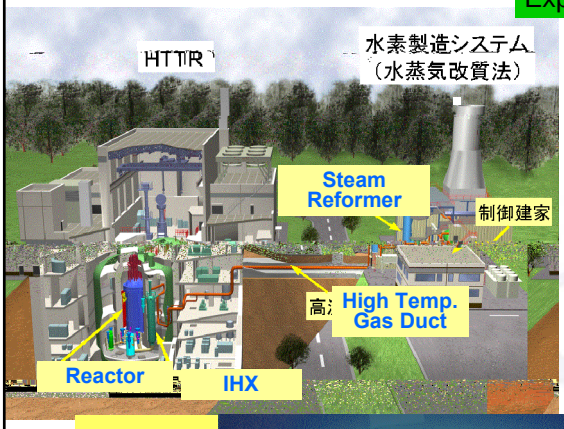
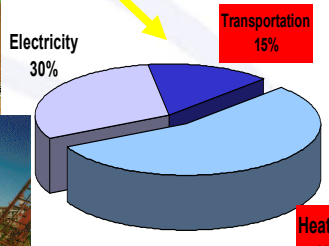
Non-electricity applications of nuclear energy

Expandable to other applications ✔



- Sea-water desalination
- Industrial and district heating
- Hydrogen production



Kazakhstan, 350

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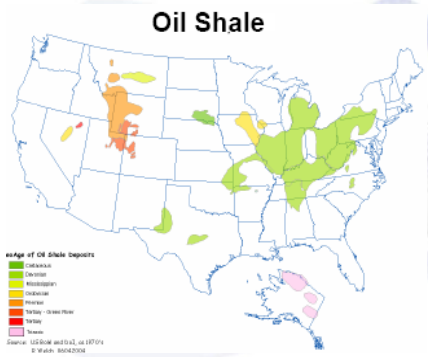
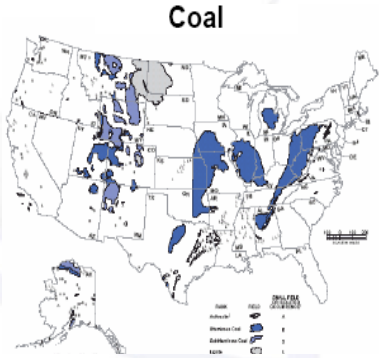
Sokolov IAEA

Resources in United States





~2 Trillion BOE

~800 Billion BOE

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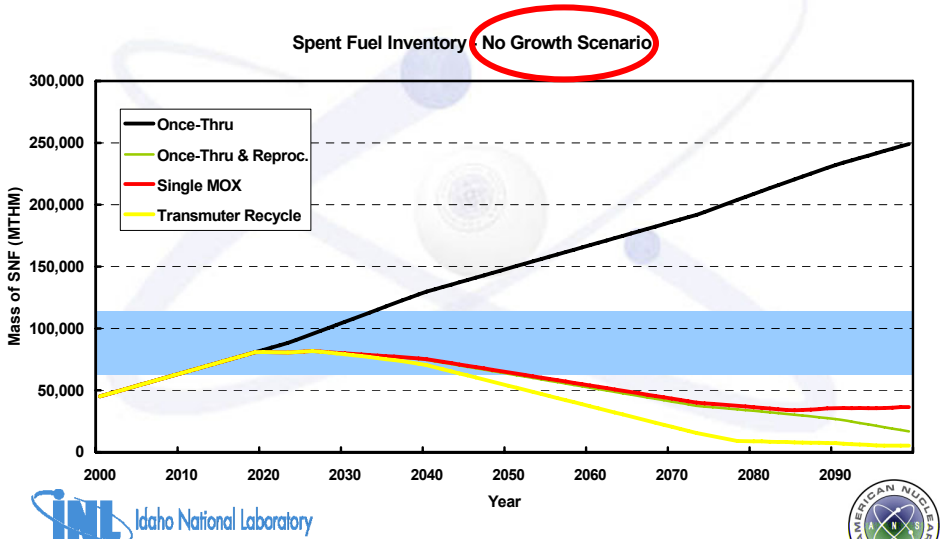
BOE – Barrels of Oil Equivalent

Source: EIA, 2005

Reprocessing a logical option for growth



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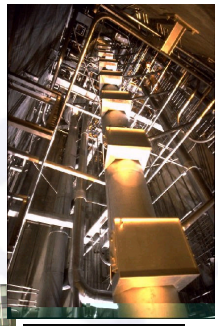
Requirements for sustainable fuel cycle



Recover uranium, plutonium and minor actinides

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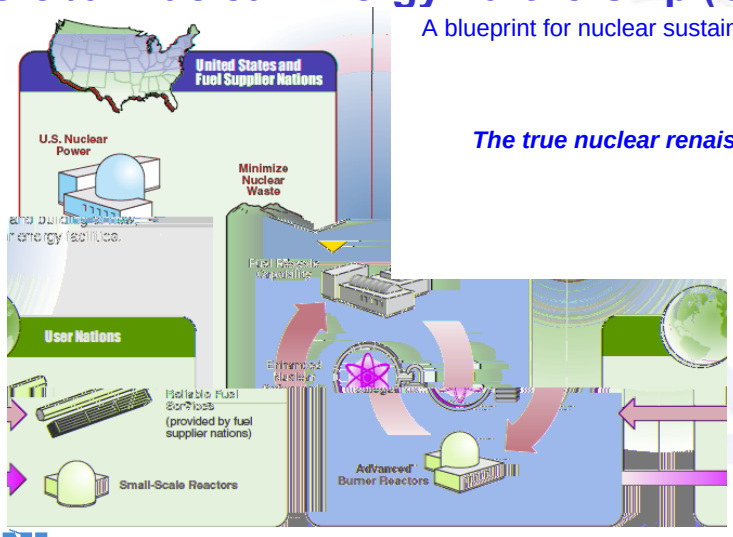
Global Nuclear Energy Partnership (GNEP)

A blueprint for nuclear sustainability

The true nuclear renaissance



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Source: www.gnep.energy.gov

Minimum conditions for a renaissance

- **Continued safe and efficient operation of existing nuclear power plants**
- Complete license extension and power uprate
- Construct, license and operate new units
- Reestablish industrial base
- Create a 21st century workforce
- Maintain public approval
- Complete the fuel cycle—get green
- Successful research, development and demonstration of advanced technologies to establish global leadership

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Many changes in nuclear energy since 1986

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Managing used fuel in the renaissance

- Fix nuclear policies
  - Remove the 70,000 ton cap
  - Adopt recycle
  - Lose the EPA million-year criterion
- Engineer and license the repository by stages
  - Expand to include larger area analyzed in 1999 EIS
  - Design system for actual loading
- Apply advanced technologies
  - Recycle uranium, immobilize waste, avoid proliferation

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Nevada has 40 open-pit gold mines

Barrick Goldstrike Mine, Nevada

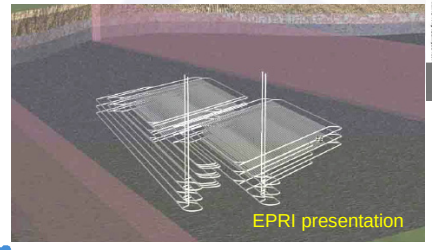
Where is the 1-million year safety standard?

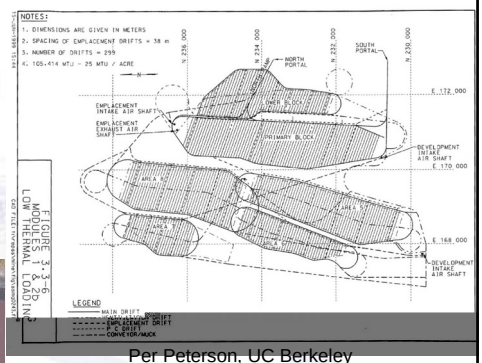
Abandoned Pit Mine refilling with water

- Up to 1600 feet below the water table
- After pumping stops, take decades to centuries to refill
- Groundwater evaporation rates ~300 million gallons per year
- Concentrate selenium, arsenic, heavy metals and acid
- Long-term impacts unknown: NY Times, 12/30/05, “They will be like huge desert sponges, sucking from the aquifer eternally”

Several options to increase capacity

- Use available land
- Multi-level
- Reprocess and transmute





Per Peterson, UC Berkeley

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Senator Domenici's Yucca Mountain Bill

- Authorizes DOE to withdraw 147,000 acres (BLM, USAF, NTS)
- Replaces arbitrary 70,000 ton capacity with scientifically based capacity
- Authorizes infrastructure construction after EIS
- Gives DOE authority to accept and store SNF
  - Starts with defense waste and fuel
  - After construction permit, legacy civilian fuel
- Withdraws land for rail line
- Changes "standard contract" to 25 after start of operation

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Domenici's bill, continued

- Takes Waste Fund off budget
- Requires NRC to accept legislation as satisfying waste confidence for new plant construction

- Basically the bill integrates YMP with GNEP and incorporates some recommendations of the National Academies' 2003 report on "staging"

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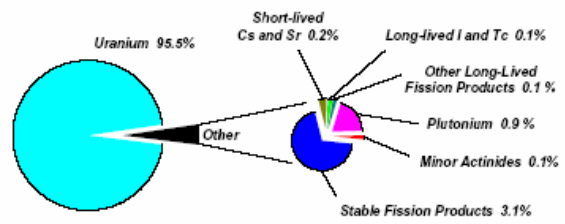
Composition of Spent Nuclear Fuel



(Standard PWR 33GW/t, 10 yr. cooling)

1 tonne of SNF contains:

955.4 kg U
8.5 kg Pu

Minor Actinides (MAs)
0.5 kg ^{237}Np
0.6 kg Am
0.02 kg Cm

Long-Lived fission Products (LLFPs)
0.2 kg ^{129}I
0.8 kg ^{99}Tc
0.7 kg ^{93}Zr
0.3 kg ^{135}Cs

Short-Lived fission products (SLFPs)
1 kg ^{137}Cs
0.7 kg ^{90}Sr

Stable Isotopes
10.1 kg Lantanides
21.8 kg other stable

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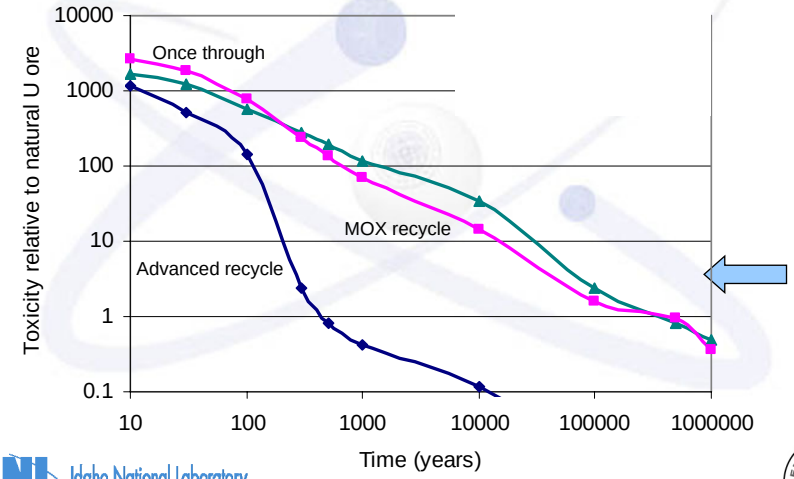
Courtesy of Max Salvatores

Radiotoxicity of nuclear waste



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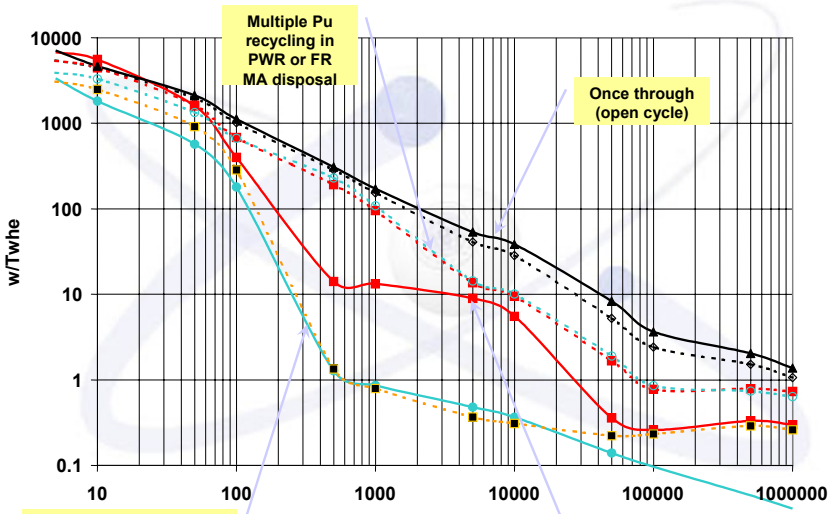
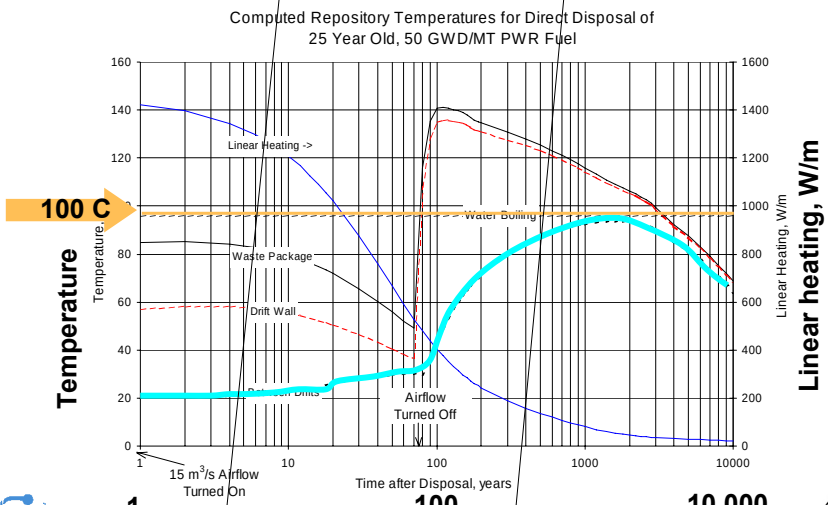
Heat load in a repository



Massimo Salvatores

WNU Summer Institute

Inter-drift temperature for direct disposal



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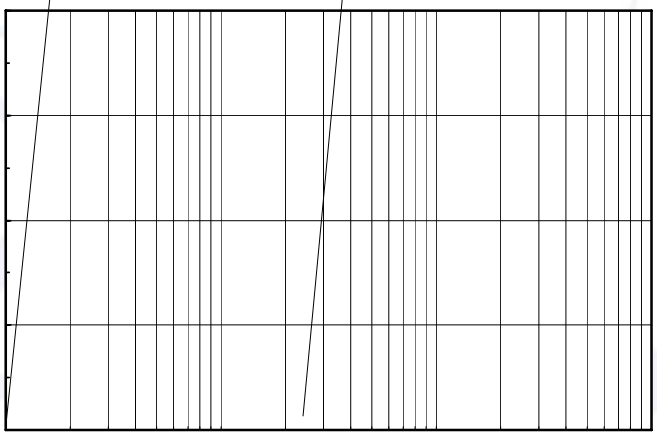
Yucca Mountain temperature between drifts



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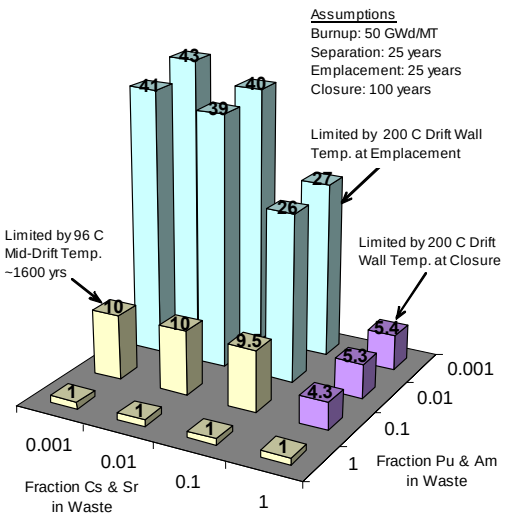
Potential Repository Drift Loading Increase

(Courtesy of R.Wiegland and T.Bauer, Argonne National Laboratory)



- **Separation of Pu & Am allow for denser loading of the repository**
  - up to a factor of 6 with 99.9% removal
- **Subsequent separation of Cs & Sr provides for much greater benefit**
  - up to a factor of 50 with 99.9% removal
- **Removal of Cm further increases the potential benefit (with Pu & Am)**
  - greater than a factor of 100 with 99.9% removal
- **Appropriate waste forms are needed to take advantage of this potential**

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Massimo Salvatores

WNU Summer Institute

Nuclear energy policy remains controversial

If we're to get in step with the world effort to reduce greenhouse gases, we are going to need to rely more, not less, on carbon-free nuclear energy."
New York Times editorial April 26, 2006.

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US Nuclear's 3 R's

Reawakening (2006)

- Outstanding performance
- License extensions
- Power uprates
- Climate change
- Energy security

Resurgence (~2020)

- New LWR plants
- Yucca mountain license
- Fuel cycle policy

Renaissance

- US technology leadership
- Gen-IV reactors
- Recycle

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Thank you!

The Greening of Nuclear Energy:
completing the fuel cycle

Harold McFarlane

Idaho National Laboratory