The Climate Change Imperative
and
The Future of Nuclear Energy

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The Climate Change Imperative

"Stabilization of GHG concentrations at a level that would prevent dangerous anthropogenic interference with the climate system.

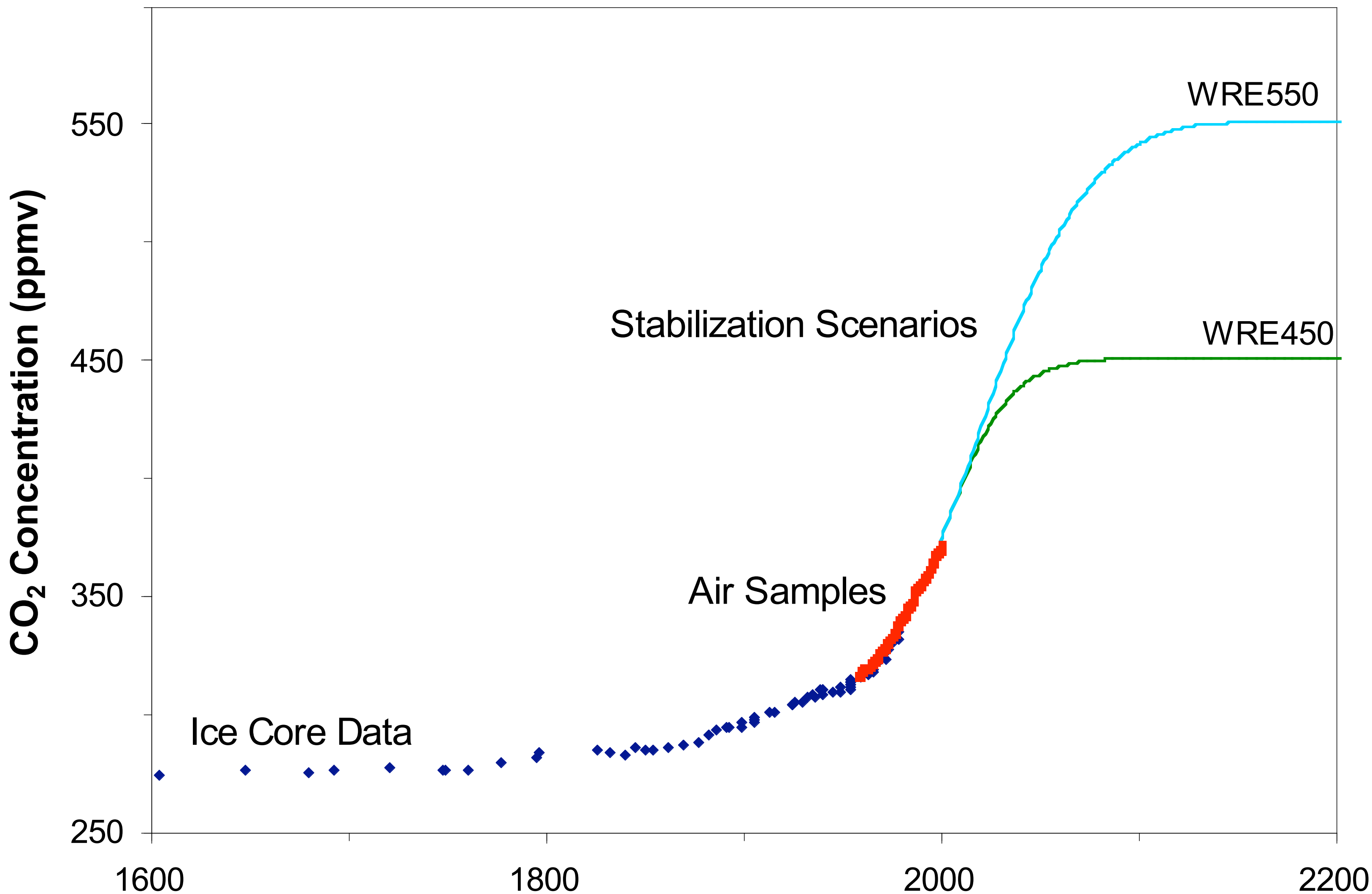
Such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally, ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner."

Article 2, UNFCCC

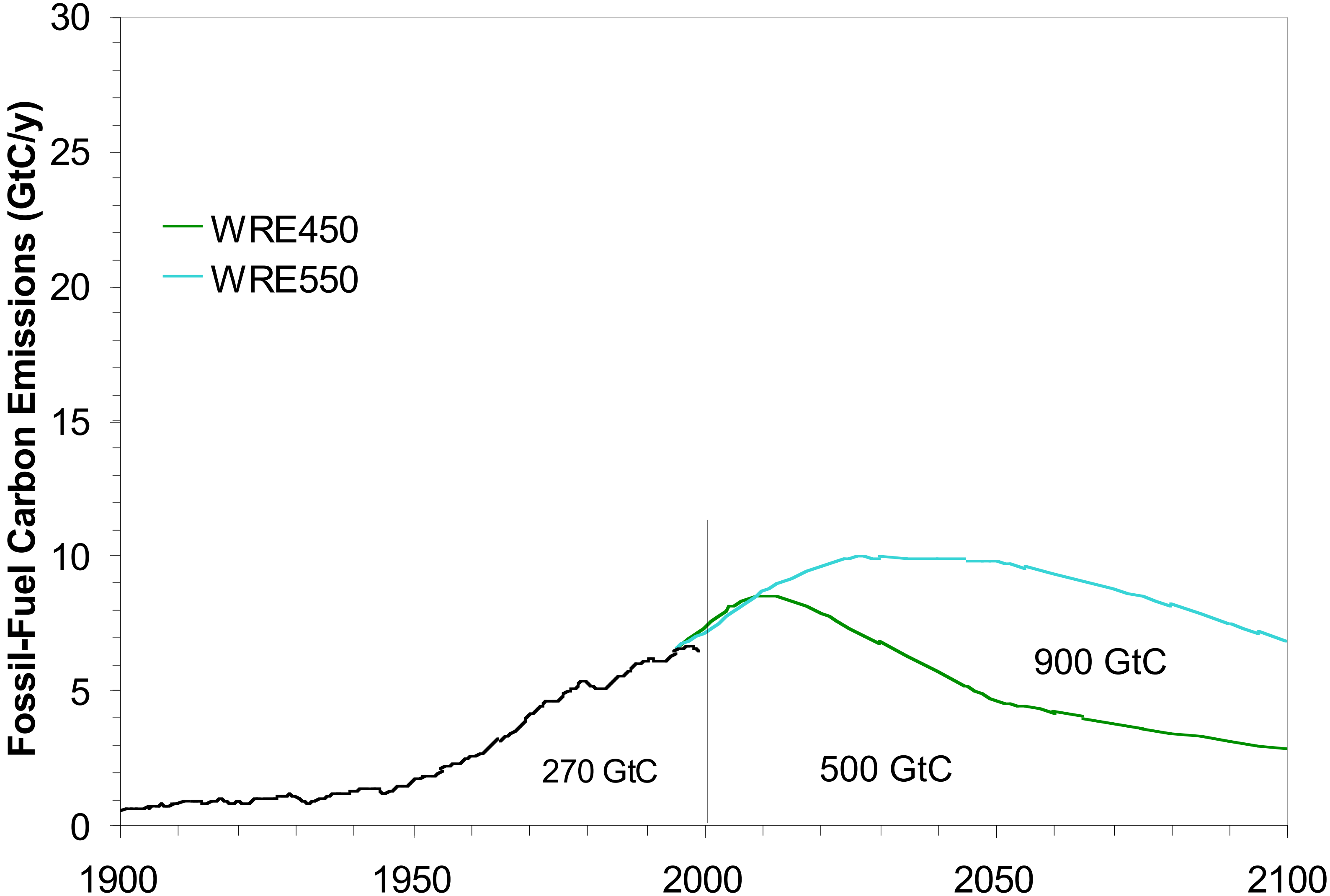
The Stabilization Goal

- "Dangerous change" seems inevitable; the challenge is to avoid "catastrophic" change
- Most impact studies focus on a "doubling" of CO2, from 275 to 550 ppmv
  - ΔT_{avg} = 1.5 to 4.5 C (compare to –5 C for ice age)
  - Severe impacts possible on precipitation patterns, ecosystems and biodiversity
  - True catastrophe—collapse of THC or WAIS, runaway feedbacks, state change—seems unlikely
- 450 ppmv CO_2 + other GHGs – SO_2 aerosols = "equivalent doubling"

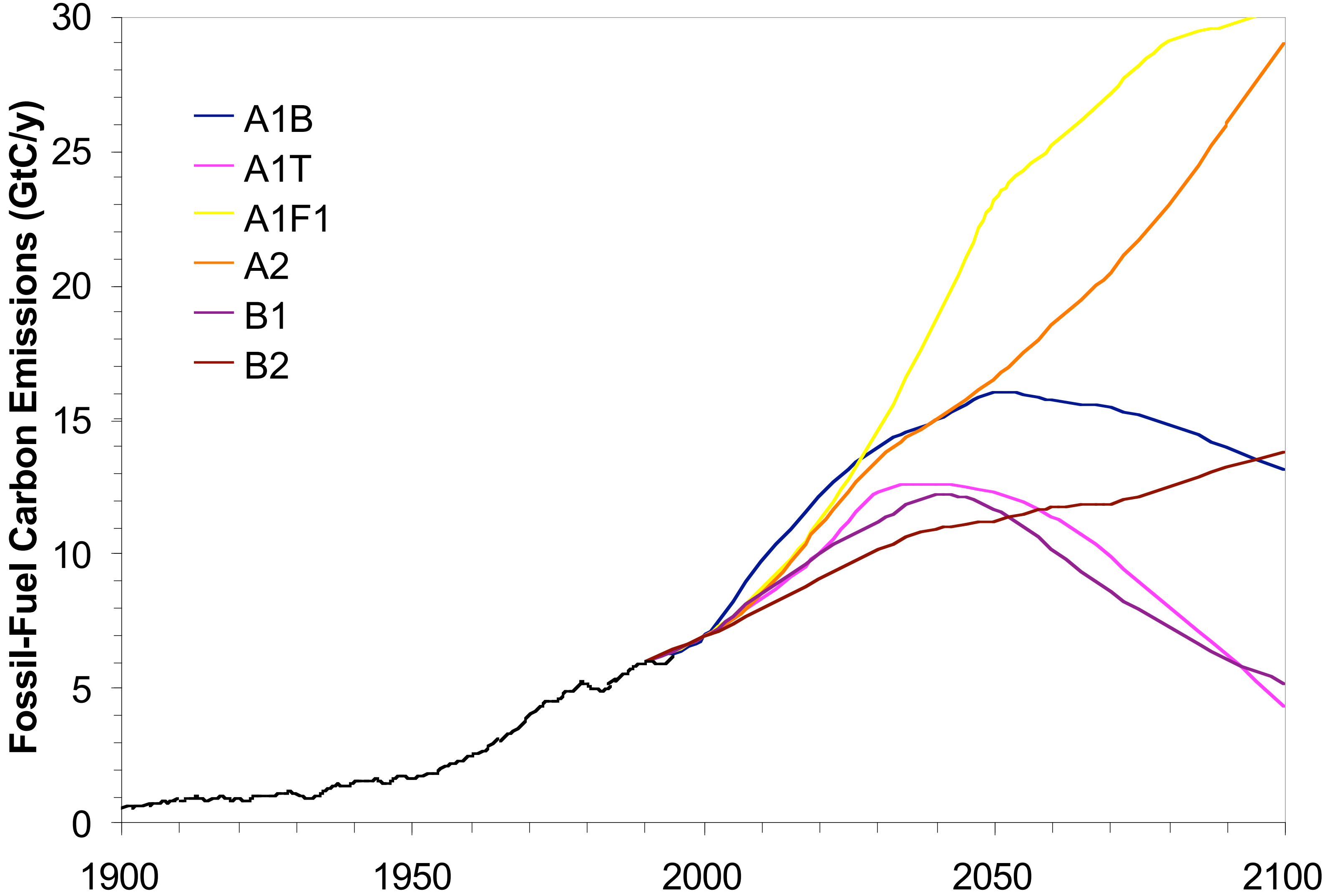
Stabilization Scenarios



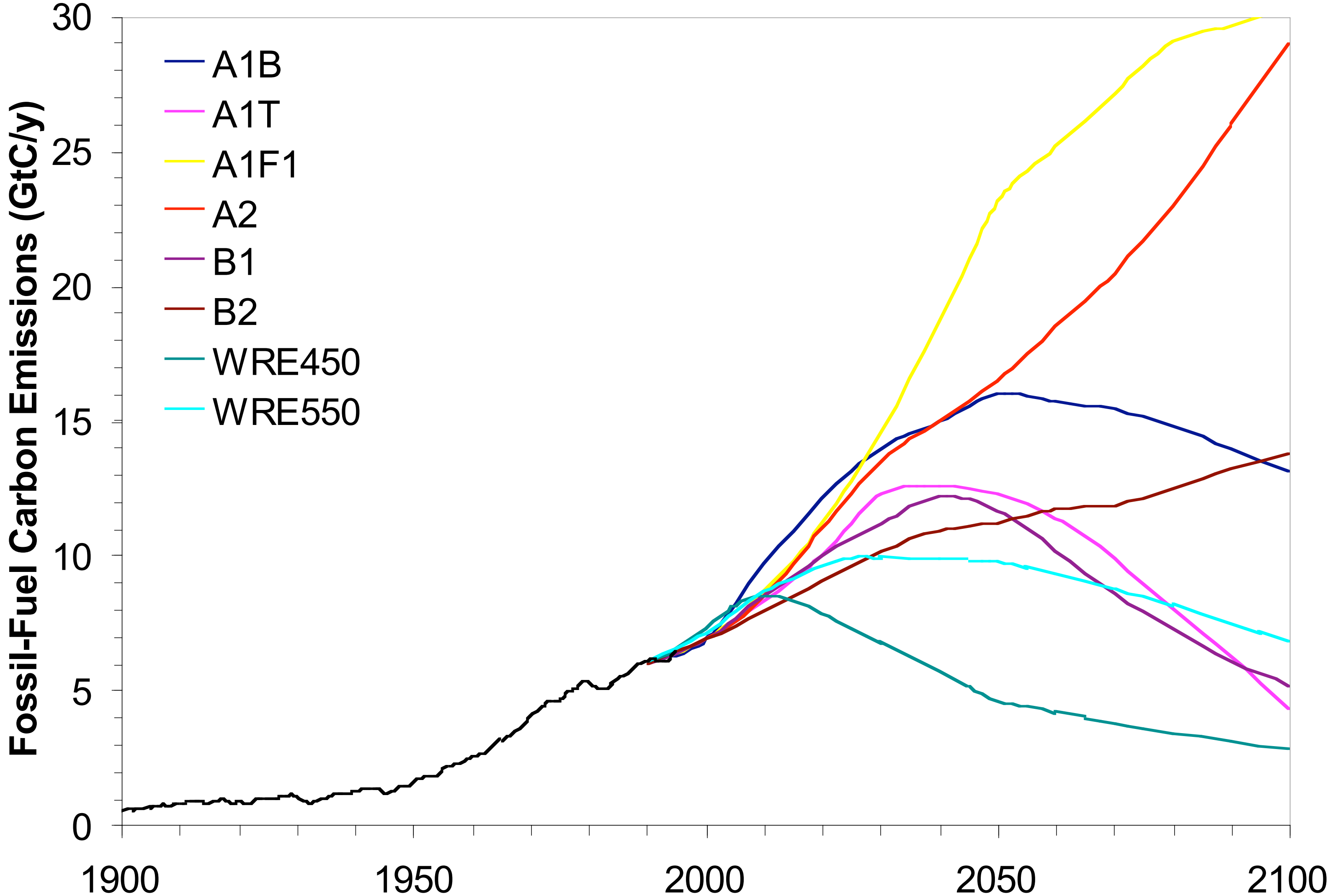
CO_2 Emissions to Stabilization



Reference Emission Scenarios



Reference v. Stabilization



Carbon Reductions for 450 ppm

	BAU	450 ppm	Reduction
GtC/y, 2050	14	5	9
GtC/y, 2100	20	3	17
GtC, 2000-2050	550	350	200
GtC, 2000-2100	1200	500	700

1 GtC/y ≈ 1000 GW_e of coal

Carbon Reductions for 550 ppm

	BAU	550 ppm	Reduction
GtC/y, 2050	14	10	4
GtC/y, 2100	20	7	13
GtC, 2000-2050	550	450	100
GtC, 2000-2100	1200	900	300

1 GtC/y ≈ 1000 GW_e of coal

Required Carbon Reductions

- To stabilize at 450 to 550 ppmv, we must reduce traditional coal-fired electricity by
  - 4,000 to 9,000 GW_e in 2050
  - 100,000 to 200,000 $GW_e y$ by 2050
- Options:
  - Increased efficiency, other demand reductions
  - Renewables: wind, solar, biomass
  - Carbon sequestration
  - Nuclear

Growth Scenario

- Carbon taxes sufficient to stabilize at 550 ppmv, carbon sequestration, unlimited uranium
- Build rate:

  35 GW/y by 2025, 70 GW/y by 2050
- Installed nuclear capacity:

  1500 GW_e in 2050, 4500 GW_e in 2100
- Total generation:

  30,000 $GW_e y$ by 2050, 170,000 $GW_e y$ by 2100
- MIT study uses similar scenario; 25-40% of C reduction for stabilization at 450-550 ppmv

Key Issues

- Cost (capital, fuel-cycle, O&M)
  - market penetration is highly sensitive to cost
- Safety
  - serious accident could halt nuclear expansion
- Waste
  - political resolution sufficient to allow expansion
- Proliferation
  - expansion must not make it significantly easier for countries or groups to acquire weapons

The Best Path: LWRs

- For the next 50 years, thermal reactors (“third-generation” LWRs) operated on a once-through fuel cycle offer the best hope for large-scale carbon mitigation using nuclear power

Cost

- The LWR is the most mature reactor technology, with relatively well-known construction and O&M costs and a high capacity factor
- The only technology that can be deployed on the required scale in the 2010-2030 time frame.
- The once-through fuel cycle, with long-term storage or geologic disposal of spent fuel, will remain the least expensive option for at least 50 years

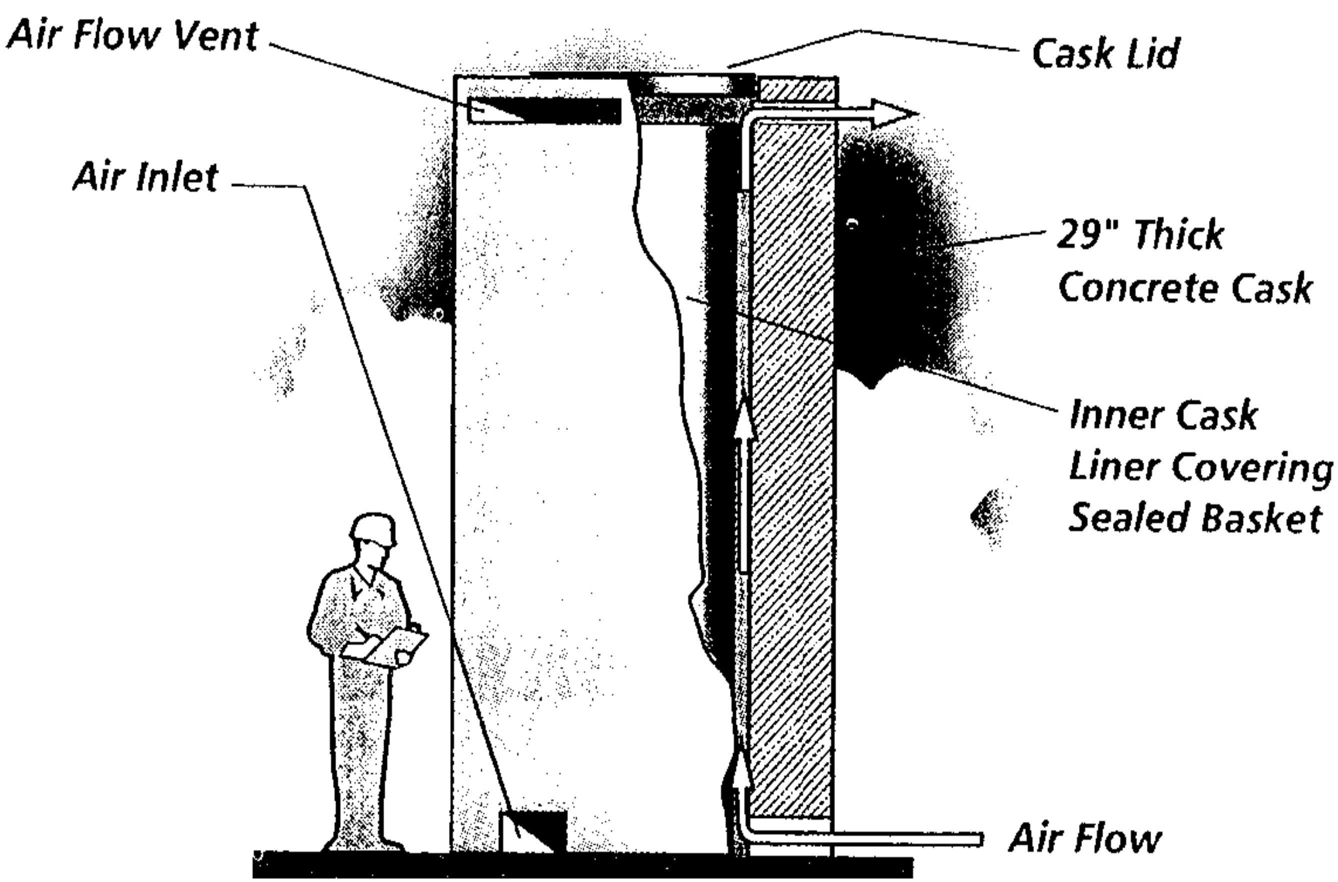
Safety

- Generation-III LWRs are calculated to have accident probabilities 10-100x smaller than current LWRs:
  - core damage < 10^{-6} per reactor-year
  - large release < 10^{-7} per reactor-year
- If these calculations are correct, <3% risk of core damage, <0.3% chance of large release in next 50 years in the baseline growth scenario

Waste

- Promote the long-term (50-100 y) dry storage of spent fuel in centralized national or international facilities pending resolution of longer-term issues
  - Storage safe, secure, inexpensive (~$200/kgHM, ~0.5 mill/kWh)
  - Long-term future will be much clearer in 50 y
    - If growth of nuclear continues, fuel value is preserved for later reprocessing and recycle; otherwise, direct geological disposal
- Promote international repositories for disposal of spent fuel and vitrified high-level waste

Two dry casks can store fuel from operation of large reactor for one year



Proliferation

- LWRs, spent-fuel storage are easy to safeguard, highly resistant to diversion and theft
- Main issue is enrichment; in growth scenario 16+ countries have >10 GW_e by 2050, each requiring >1.5 million SWU/y
  - enrichment safeguards can be improved, to detect LEU diversion or HEU production
  - but clandestine centrifuge enrichment very difficult to detect
- Can spread of centrifuge technology be limited through leasing/take-back? Internationalization?

Medium-term alternatives

- Alternative reactor/fuel-cycle concepts that might have substantial advantages over LWRs:
  - High-temperature gas-cooled reactors
    - Higher efficiency promises cost, makes H_2 production possible
    - Potential safety and nonproliferation advantages
  - Small, long-lifetime sealed-core reactors
    - Cost likely to be higher, but mass production of standard designs in factories could bring cost down
    - Potential safety and nonproliferation advantages

The Long Term

- If nuclear grows to 4500 GW_e, fast reactors operating on a closed fuel cycle will be required
  - Other long-term possibilities are molten-salt reactors operating with a Th fuel cycle, or thermal reactors using seawater U if cost of extraction < $300/kgU)
- No need to press for early commercialization of fast reactors and/or reprocessing and recycle
- Risks of diversion and theft relatively high unless reprocessing and use of plutonium fuels can be centralized to “safe” locations