Status of Nuclear Power: A Global View

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GLOBAL 2005

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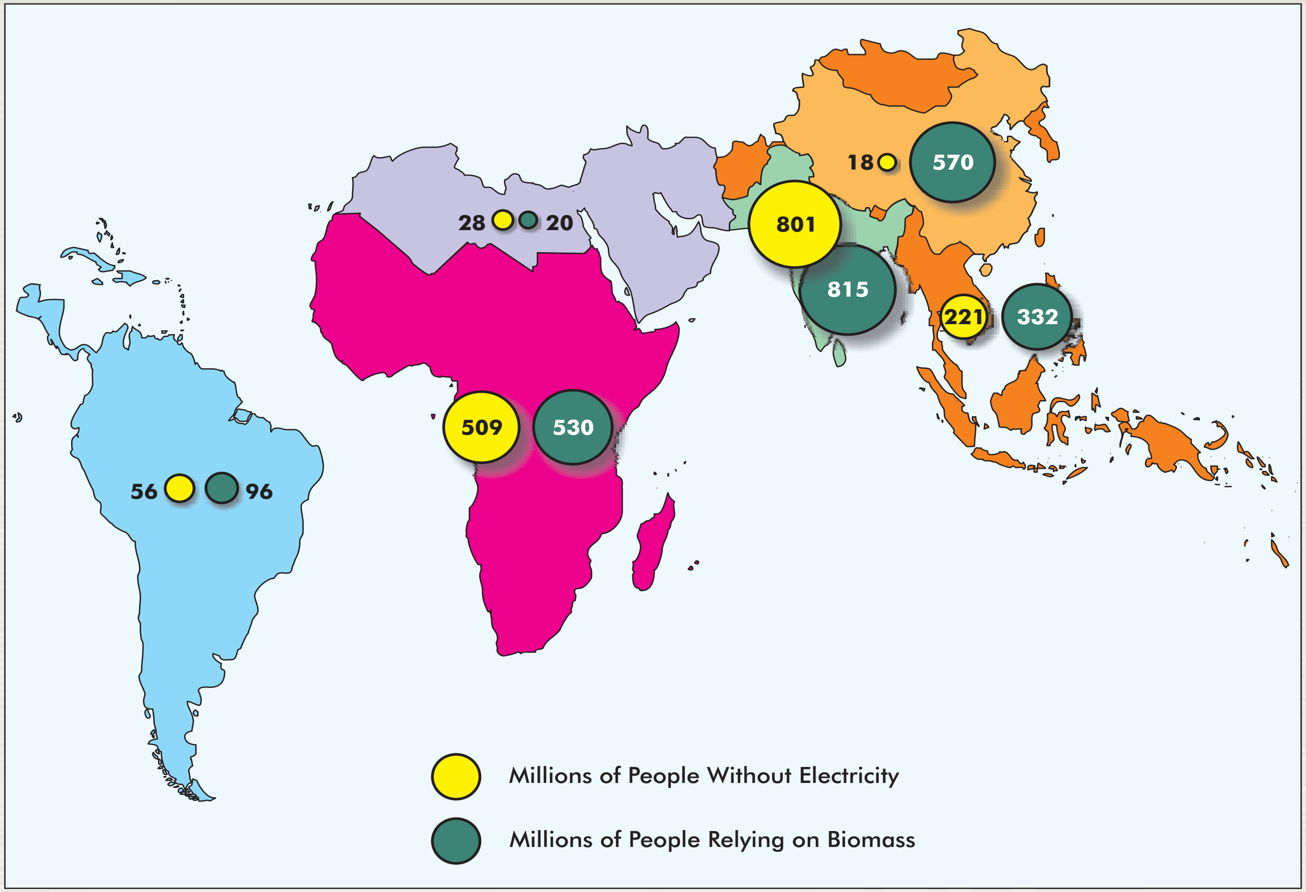
International Atomic Energy Agency

Map of Global Energy Poverty



By 2030 (IAE):

GDP annual growth 3.2 %,

Electricity use 2,5 %,

New 4800 GW(e),

Investment 10 T$,

1.6 billion people have no access to electricity, 80% of them in South Asia and sub-Saharan Africa

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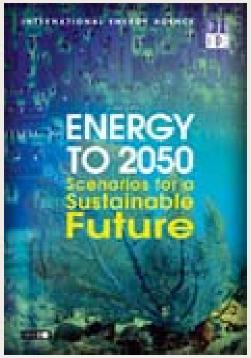
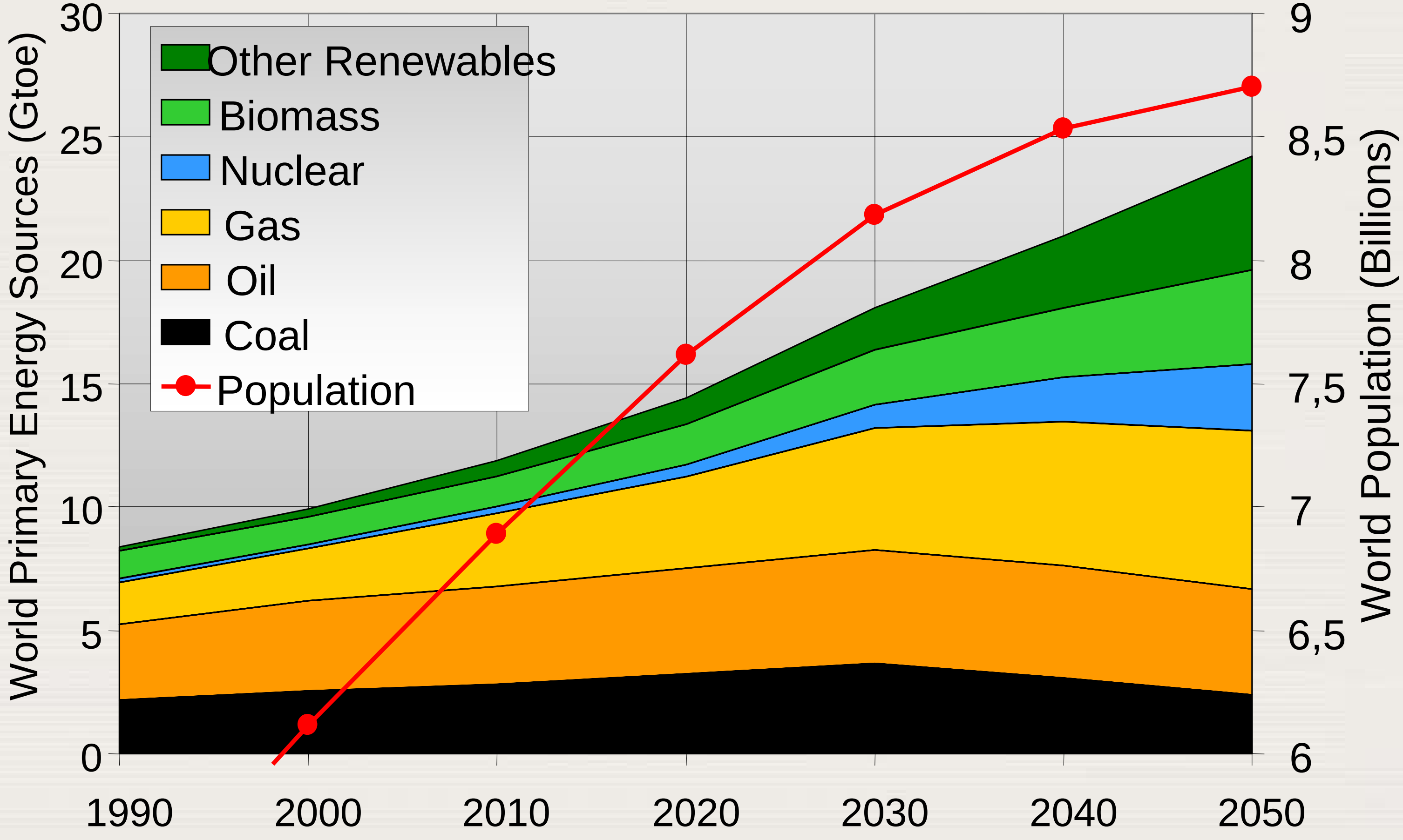
Sustainable Development Vision Scenario (*IEA 2003*)





Source IEA : Energy to 2050 -
Scenarios for a Sustainable Future

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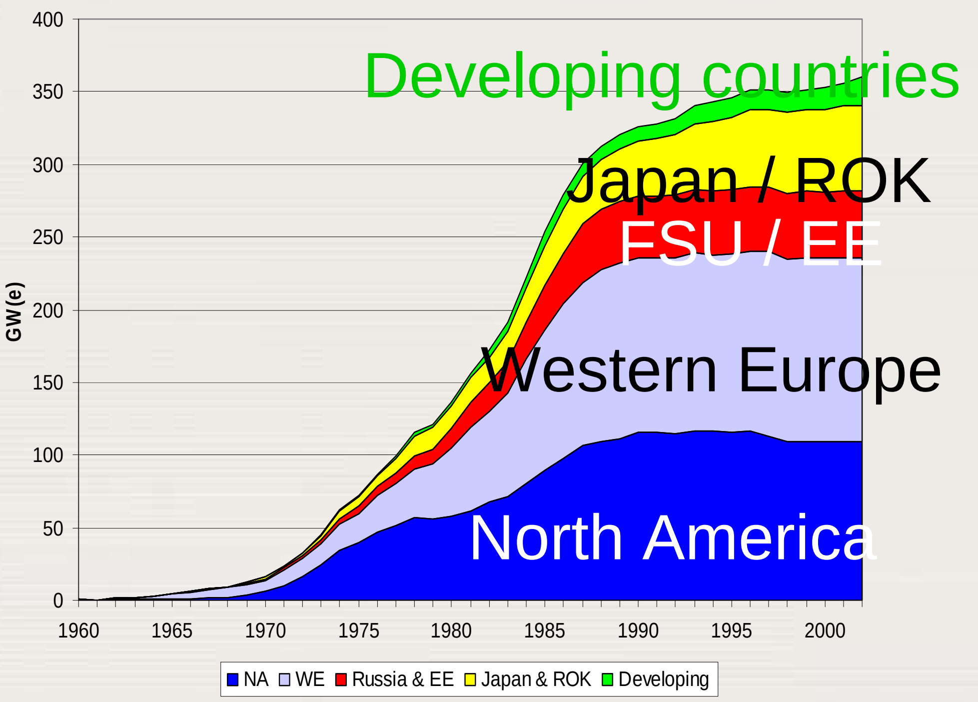
Break in Nuclear Power

1. Reasons for the break:
- Market deregulation,
- Slowing energy demand
- Investment risk,
- Management failure,
- Unstable regulation,
- Public perception,
- Safety concerns (Chernobyl)

2. Current trends & environment
- Best management and safety,
- Economic viability,
- Energy demand and security,
- Climate change concerns,
- Needs of developing countries

Installed Nuclear Power



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Energy Sustainable Development
(based on UN concept of SD)

Economic Dimension | **Environmental Dimension** | **Social Dimension** | **Institutional Dimension**

Sustainable development of Nuclear Energy

Economics | **Environment** | **Waste Management** | **Safety** | **Proliferation Resistance** | **Infrastructure**

Compatibility assessment, modelling of energy systems, holistic approach.

Decision on Nuclear Energy System implementation

Brundtland definition: “Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs.” *1987*

Status of Nuclear Power

- More than 11 000 reactor years of experience
- More than 440 power reactors in operation (installed capacity > 370 GWe)
- Average plant load factor: >80%
- Contributions to global electricity: ~16% in 2004
- Low electricity cost, good safety records
- In 2004, new capacity 7529 MWe connected to the grid.

  - South Korea: Ulchin 5 & 6 (2x960 MWe)
  - China: Qinshan 3 (610 MWe)
  - Japan: Hamaoka 5 (1380 MWe)
  - Ukraine: Khmelnitsky 2 & Rovno (2x950 MW
  - Russian Federation: Kalinin 3 (950 MWe)
  - Canada: Bruce 3 (769 MWe) restarted
- Shift in national energy strategies

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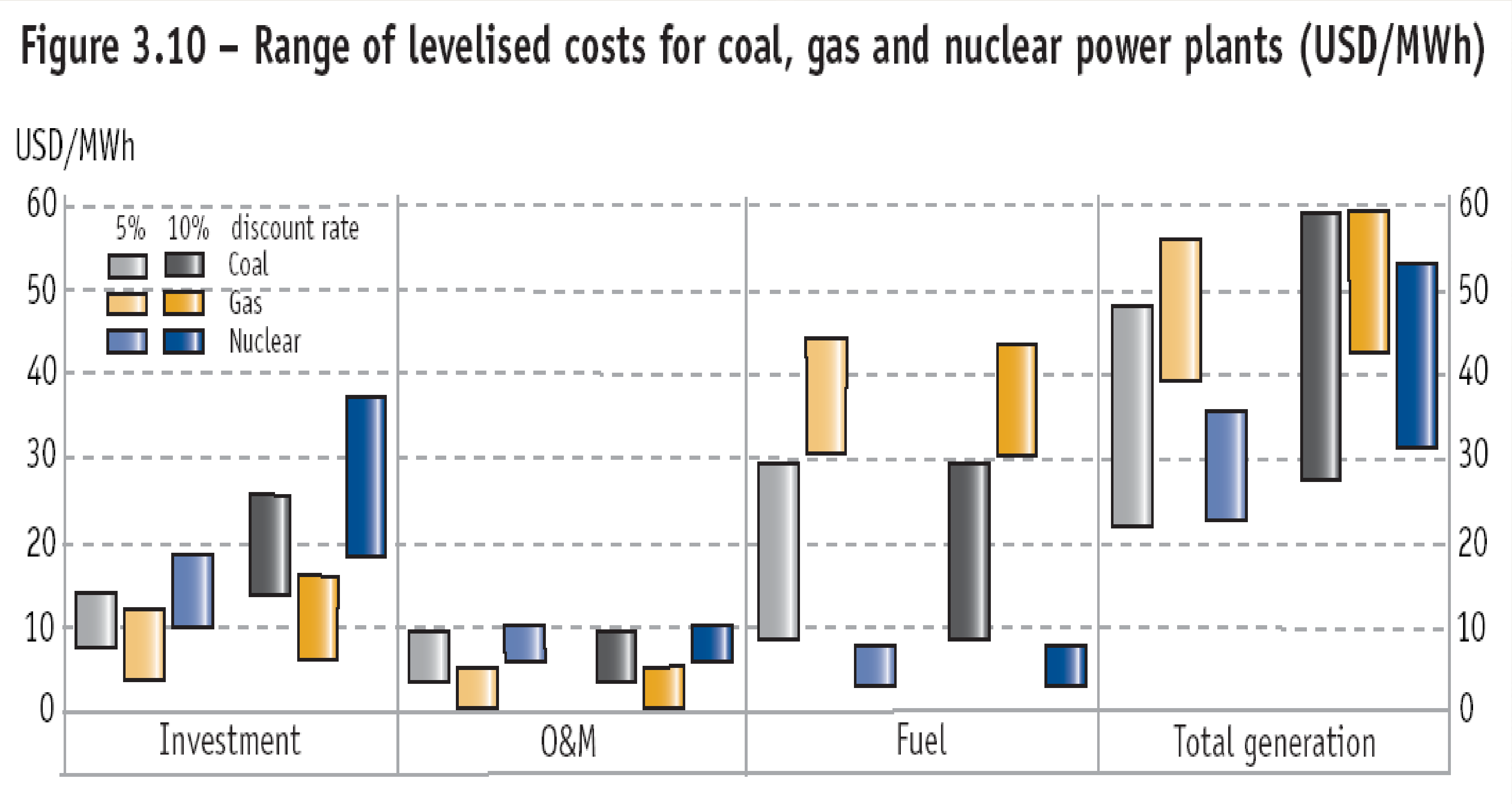
Nuclear Power Growth

Country	Years	Annual electricity consumption, per cap, kWh	Installed capacity of NP, GW(e)	NP growth, times
China	2002	1380	6,6	5-6
	2020		32-40	
India	2002	420	2,7	10
	2022		29	
Pakistan	2002	480	0,42	10
	2030		4,2	
Russia	2002	5370	22	2
	2020		40-45	
ROK	2005	6190	16,8	1,57
	2015		26,4	
USA	2002	12320	~ 100	~1,1 ?
	2020		~ 110	

Source: NEA and IEA: Projected costs of Generating Electricity: 2005 Update (OECD)



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Climate Change and Sustainable Development

G8 Action Plan

- We should mobilize all available opportunities to increase power efficiency for the space of an entire technological chain, starting from fuel production and finishing by power transmission, as well as to provide for maximum usage of considerable and unrealized potential alternative energy sources of low emission levels.
- We appreciate efforts of those G8 member-states which, though having an intention to use nuclear power as before, are eager to develop more advanced technology that is safer, more reliable and more protected from the attempts to use it for other purposes and proliferation.

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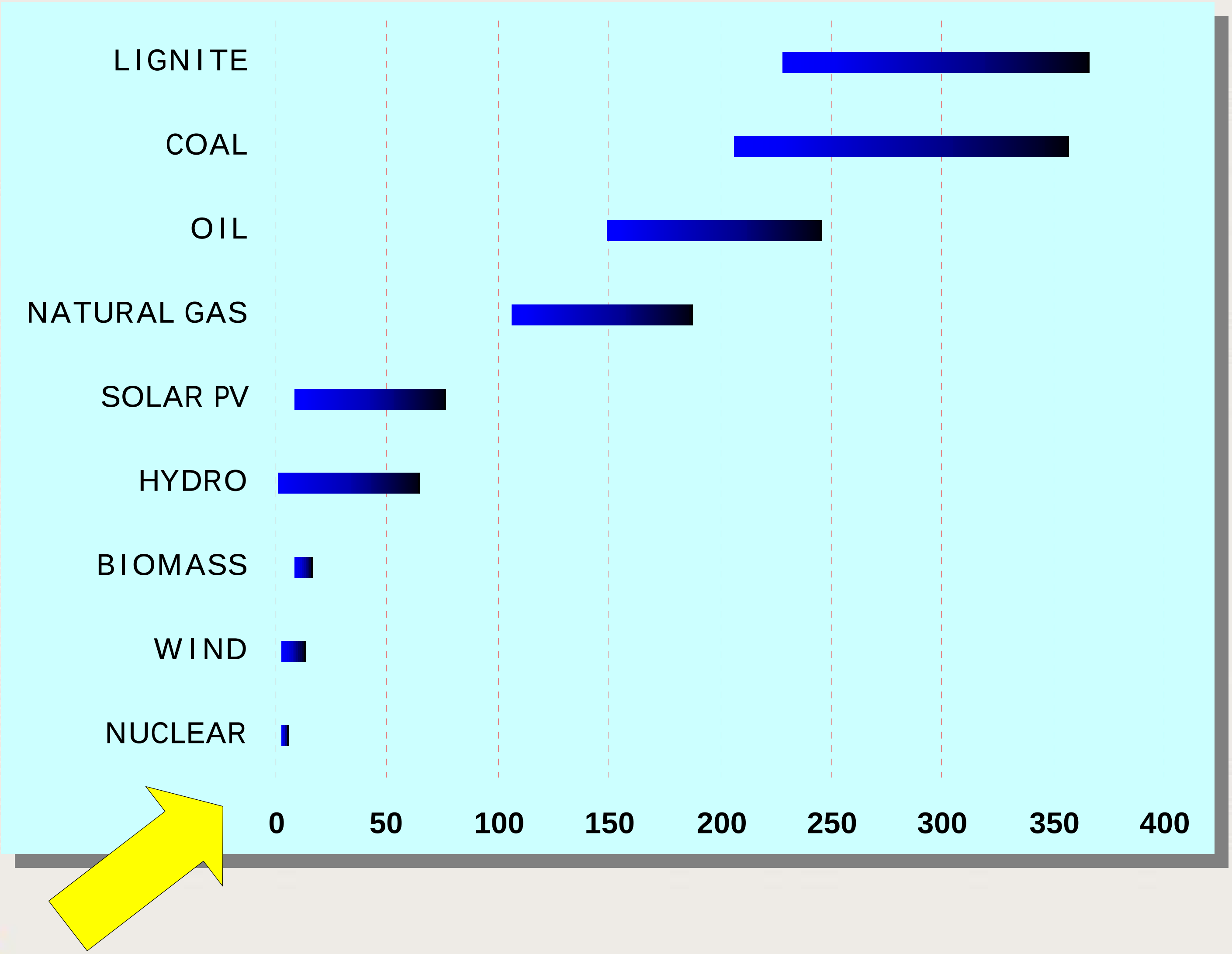
Greenhouse gas (GHG) emissions

GHG
gC_{eq}/kWh



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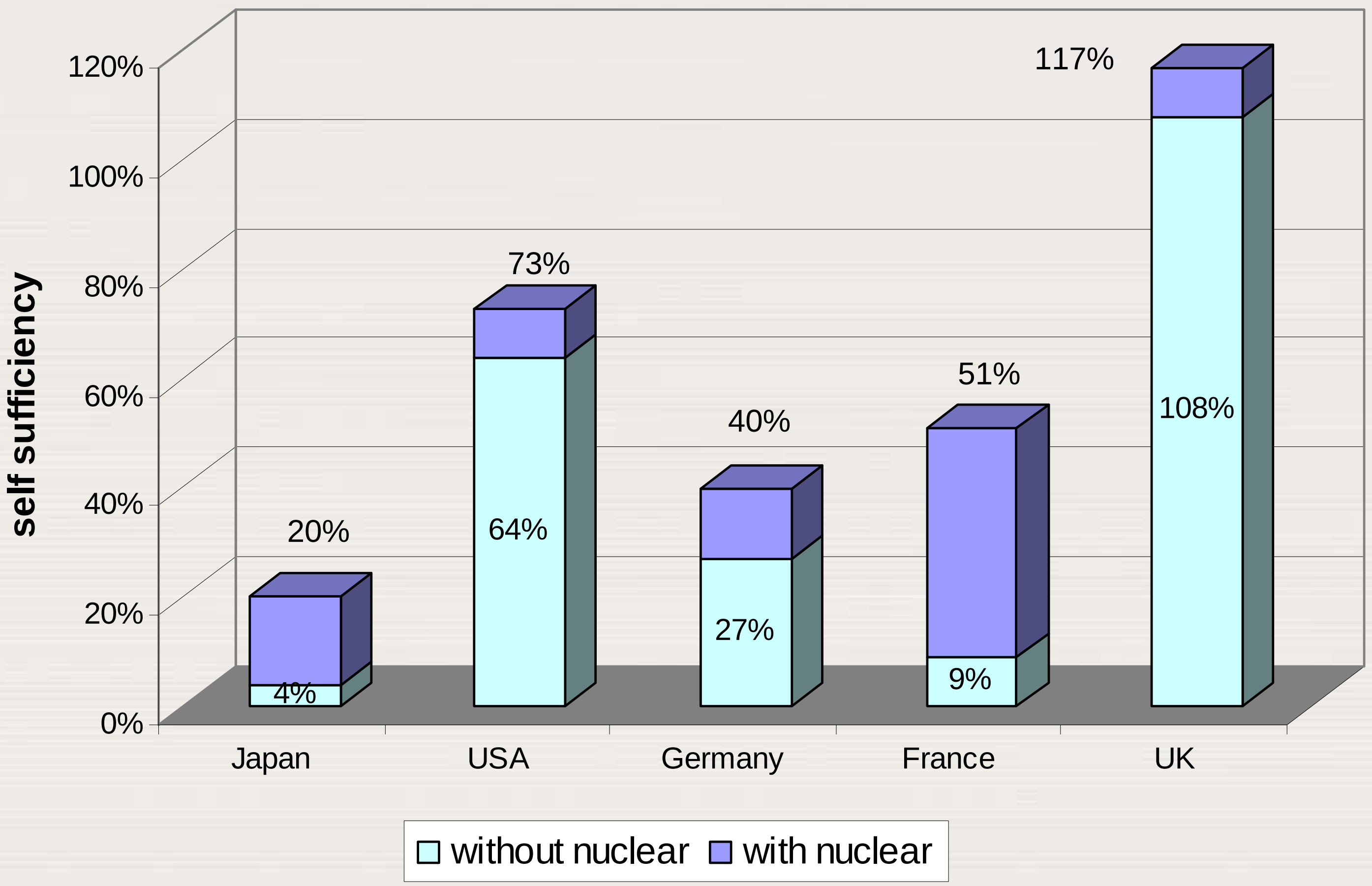
Self Sufficiency



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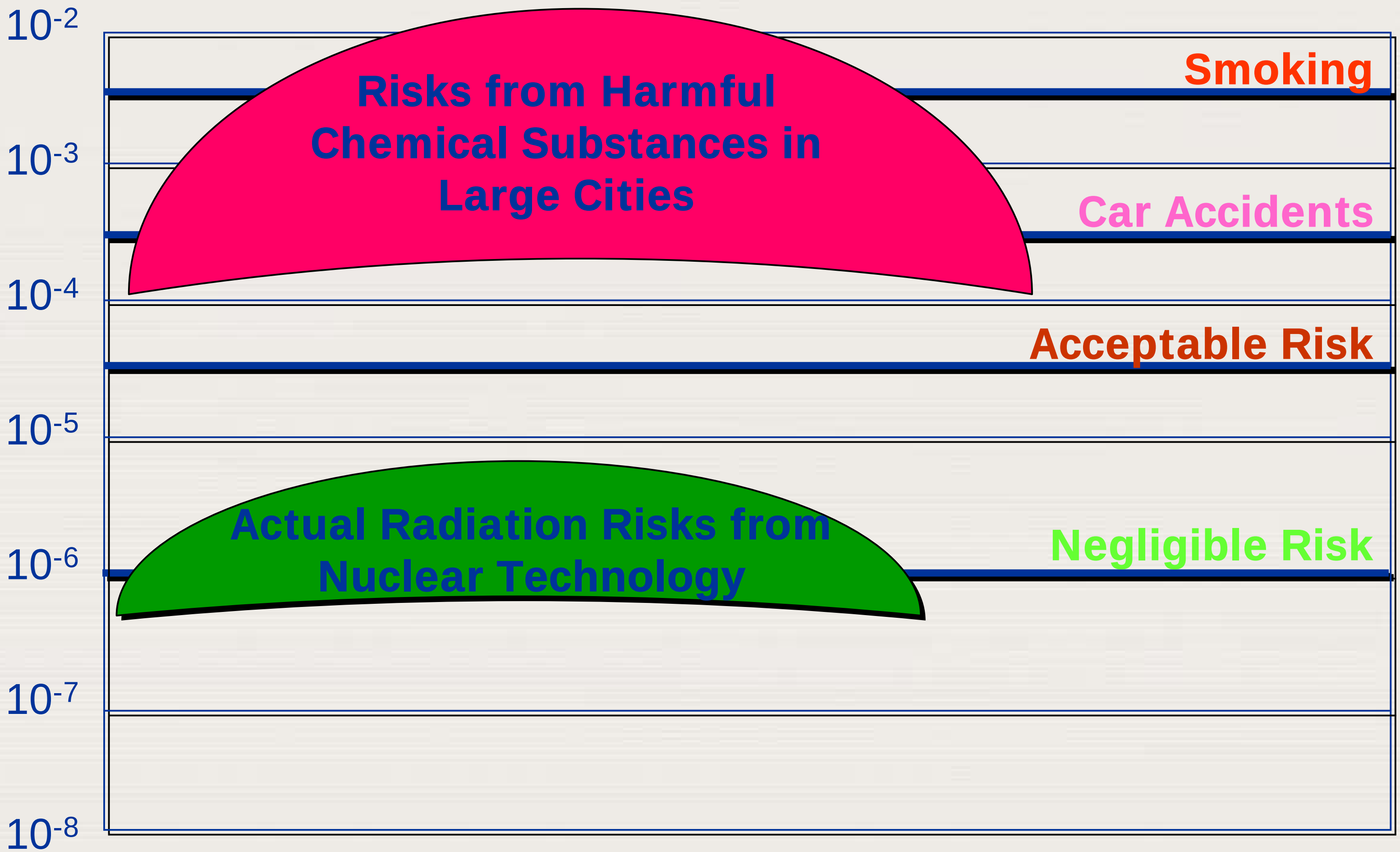
Risk Comparison



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Safety First

- Three Mile Island, Chernobyl: radical changes, strengthen IAEA's role.
- International Cooperation: **INSAG** – BSP for NPP(1988), INES, cooperation with OECD/NEA, WANO, national Regulators,
- Safety Standards, Activities: IAEA's Safety Series, Codes and Safety Guides (safe design, sitting, operation; regulator's purposes, functions, etc).
- Missions: **OSART, ASSET, ESRS**, **IPERS-PSA**, **ASCOT**, **IRRT**

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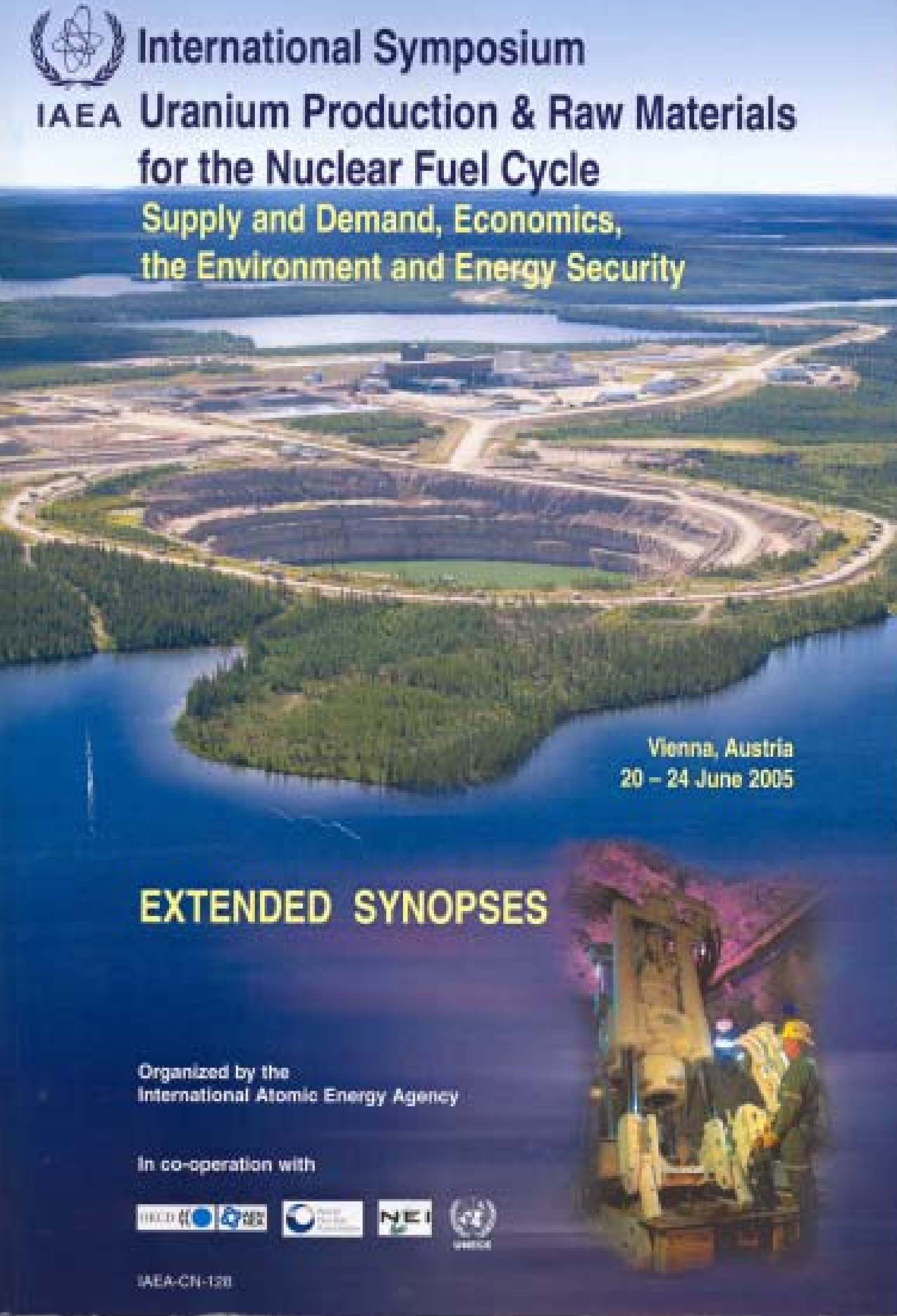


CONCLUSIONS

The uranium industry is looking up.

❖ The price of U nearly tripled, in the last three years;

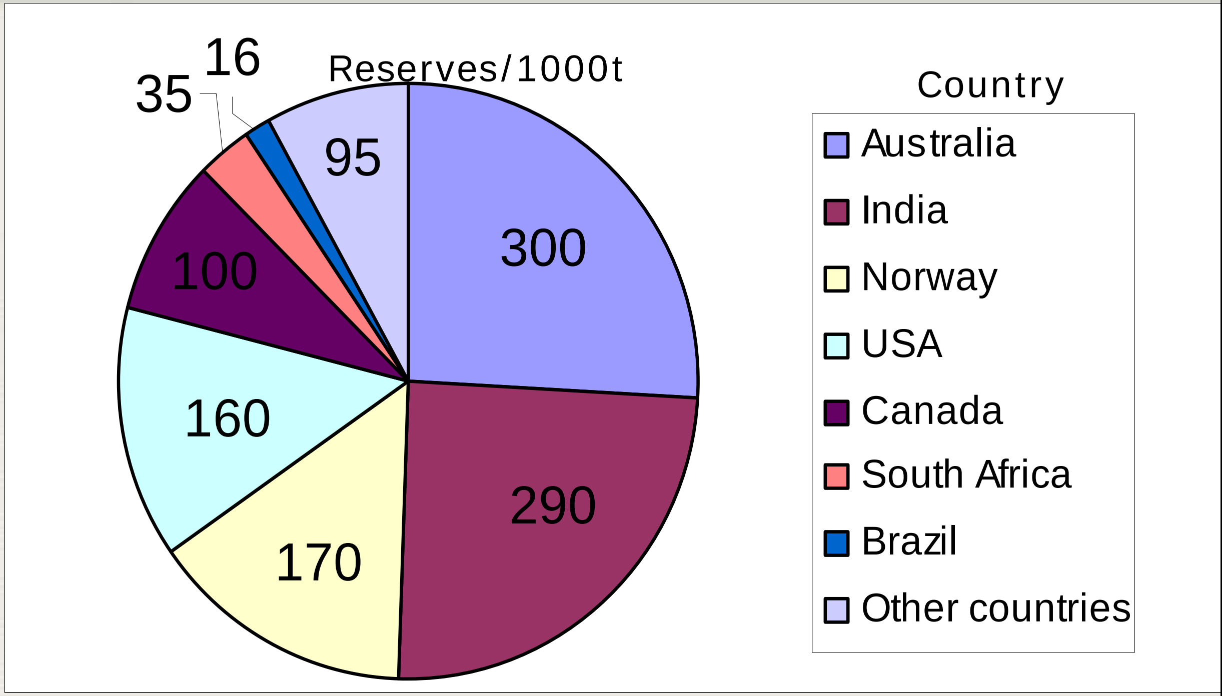
new exploration and mining initiated,and uranium producers increased production.

❖ Uranium resources are adequate up to 2030, if not 2050.

❖ Advanced exploration techniques could discover more U deposits.

❖ New mines and mills are required to be opened. Expansion of In-Situ Leaching (ISL) and other technologies may ensure timely delivery of U.

World Thorium Resources - economically extractable



Country	Reserves/t
Australia	300000
India	290000
Norway	170000
USA	160000
Canada	100000
South Africa	35000
Brazil	16000
Other countries	95000
World total	1200000

Source: USA Geological Survey, Mineral Commodity Summaries, January 1999 referred by World Nuclear Association in 2003 (http://www.world-nuclear.org/info/inf62.htm)

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Closing the fuel cycle

a) Waste minimization [in terms of Pu & MA]
b) Resource (natural uranium) utilization

Fresh unranium fuel (as oxide)

Reactor

SPENT FUEL

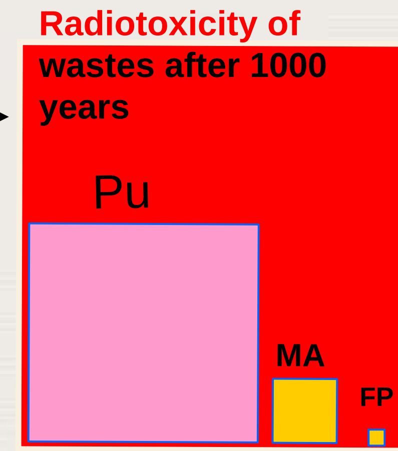
valuable materials 96%

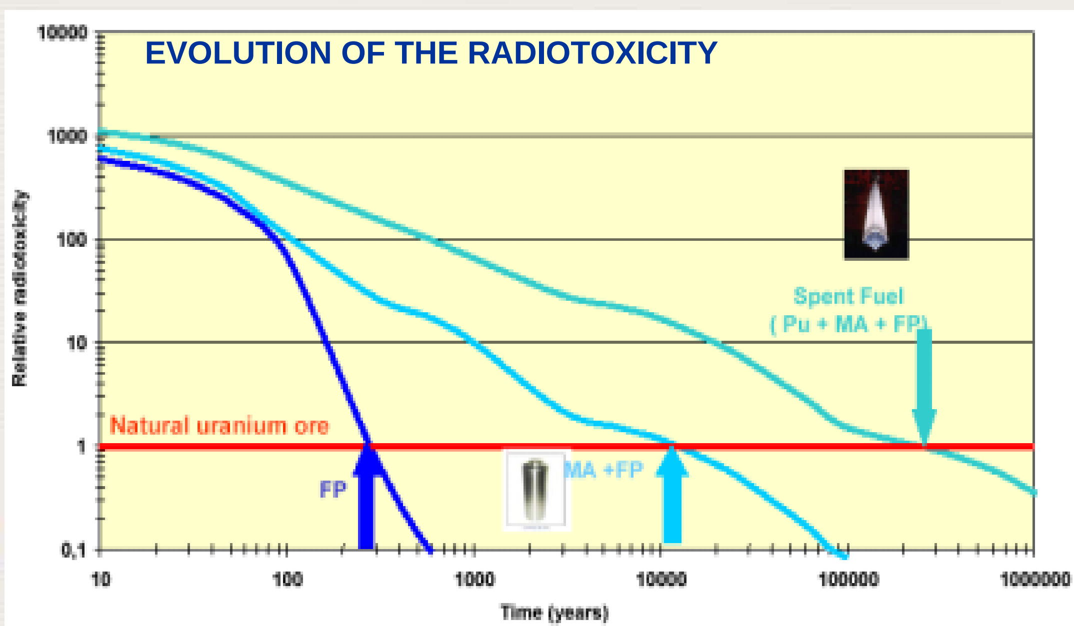
- U: 94-96%
- Pu: ~1%

+

Wastes 4%

- FP: 3-4%
- MA: ~0.1%





Accumulated experience in fast reactors

- Demonstration and prototype reactors
  - Phénix (France, 250 MWe)
  - BN-350 (Kazakhstan, 650+150 MWth, for electr. +desalination)
  - PFR (UK, 250 MWe)
  - MONJU (Japan, 280 MWe)
  - PFBR (India, 500 MWe, under construction)
  - CEFR (China, 25 MWe under construction)
- Full scale industrial reactor
  - BN-600 (Russia, 600 MWe)
  - Superphénix (France, 1200 MWe, shut down in 1998)
  - BN-800 (Russia, 800 MWe, under construction)
- In focus of GIF and INPRO

Construction of India's 500 MWe Prototype FBR (PFBR)

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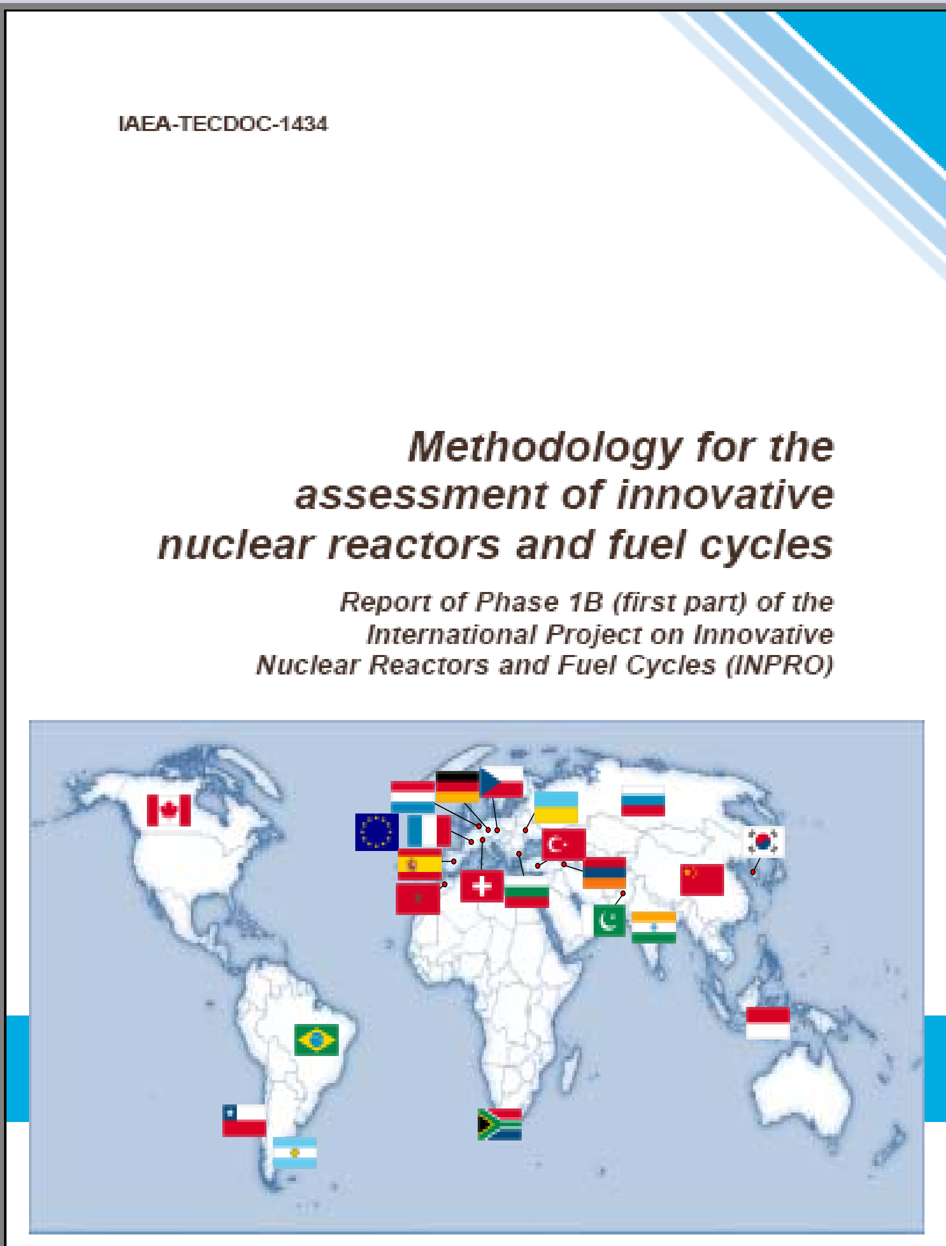
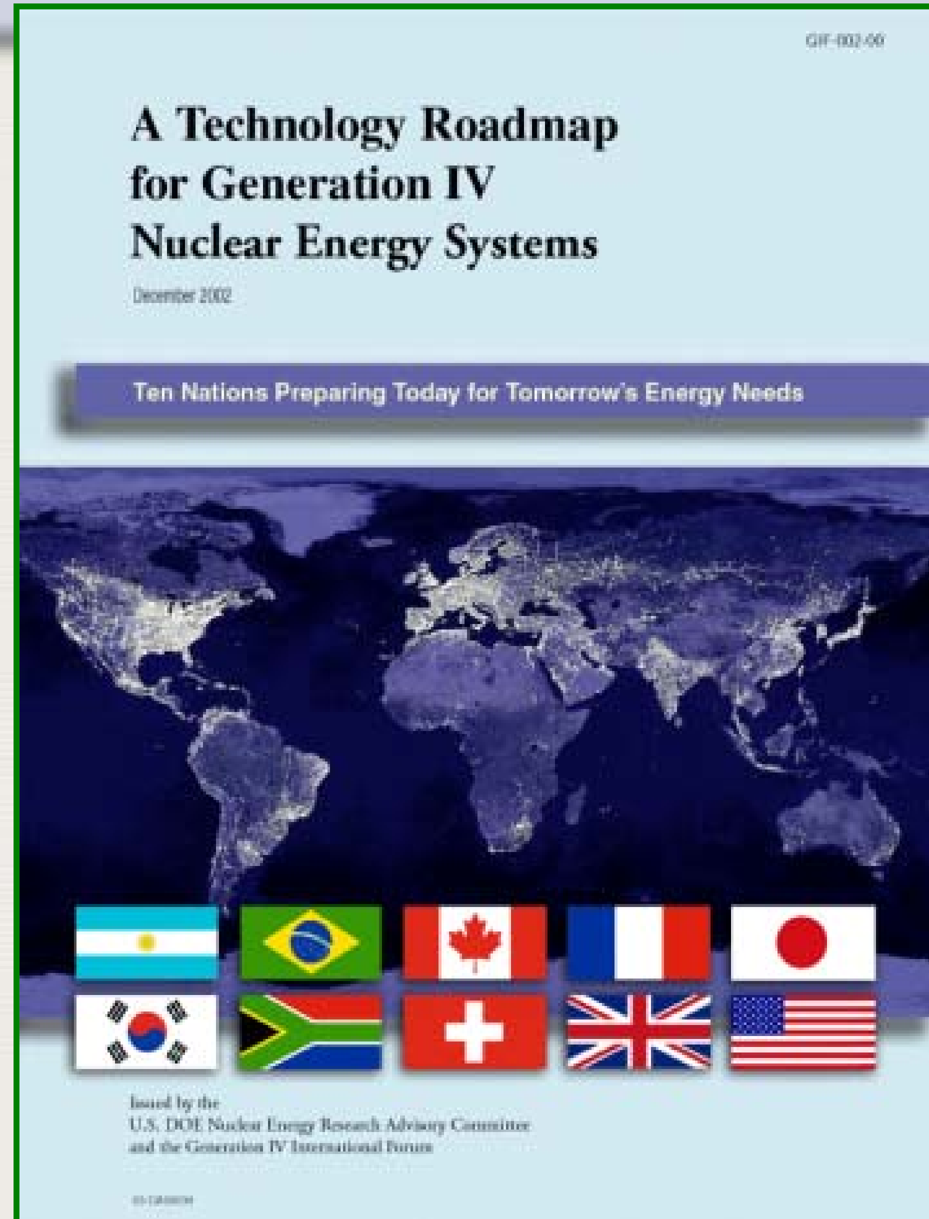
Two major international initiatives



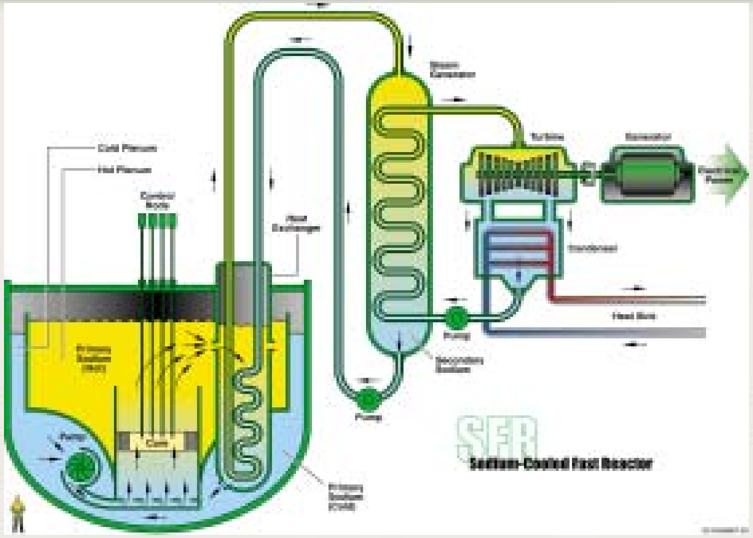


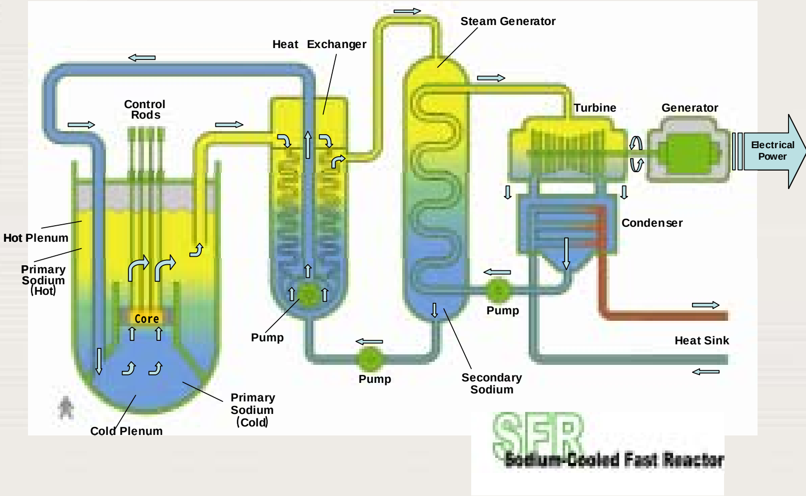
Sodium Fast Reactor SFR

SFR Objectives

- A new generation of sodium fast reactors
- High level of safety (passive safety)
- Cost reduction (Pool/Loop system, innovative technologies, ISI&R, PCS)
- High burn-up TRU fuel
- Deployment: 2015 - 2020

  (Demo Monju 2015)





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How to step into nuclear power future

- Energy Planning **(Energy options, national resources…)**

- Infrastructure Development **(E&T, Regulator,…)**

- Development and Deployment **(Assist , best practice …)**

- Assessment of future INS **(INPRO, G-IV…)**

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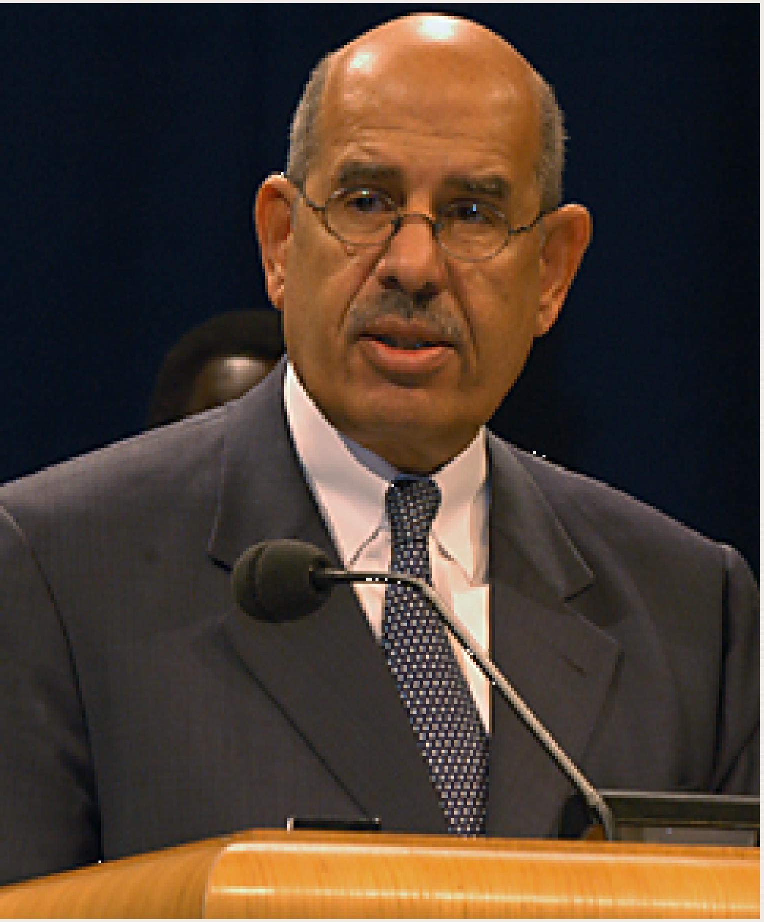
Infrastructure development (1/2)

"One size does not fit all"

- **Guidance on minimum infrastructure to adopt nuclear power**
  - Education and training, Human resources
  - Financial / economical / industrial
  - Legal, Regulatory, International agreements
- **Guidance on regional sharing of nuclear power infrastructure**
  - Exploring co-operation (interconnected grids; shared: facilities,education and training program, skilled labour pools…)
  - Developing of regional agreements (Africa: ECOWAS, WARTS,…)
  - Different scenarios for going nuclear (buy N electricity and/or services, lease reactor or fuel, share investment/construction of NPP,…)

Strengthening the Nuclear Non-Proliferation Regime



"the wide dissemination of the most proliferation-sensitive parts of the nuclear fuel cycle…could be the 'Achilles' heel' of the nuclear non-proliferation regime. It is important to tighten control over these operations, which could be done by bringing them under some form of multilateral control, in a limited number of regional centers….."

-*Introductory Statement* to the IAEA Board of Governors by the Director General, March 2004

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Findings of the Group: five suggested approaches

1. Reinforcement of existing commercial market mechanisms: long-term contracts with government backing, fuel leasing and fuel take-back offers, commercial offers to store and dispose of spent fuel, commercial fuel banks,
2. Development of international supply with the IAEA as guarantor of service supplies,
3. Voluntary conversion of existing facilities to MNAs as confidence-building measures,
4. Creation multinational, and in particular regional, MNAs for new facilities based on joint ownership,
5. In further expansion of nuclear energy the development of a nuclear fuel cycle with stronger multilateral arrangements and broader cooperation, involving the IAEA and the international community.

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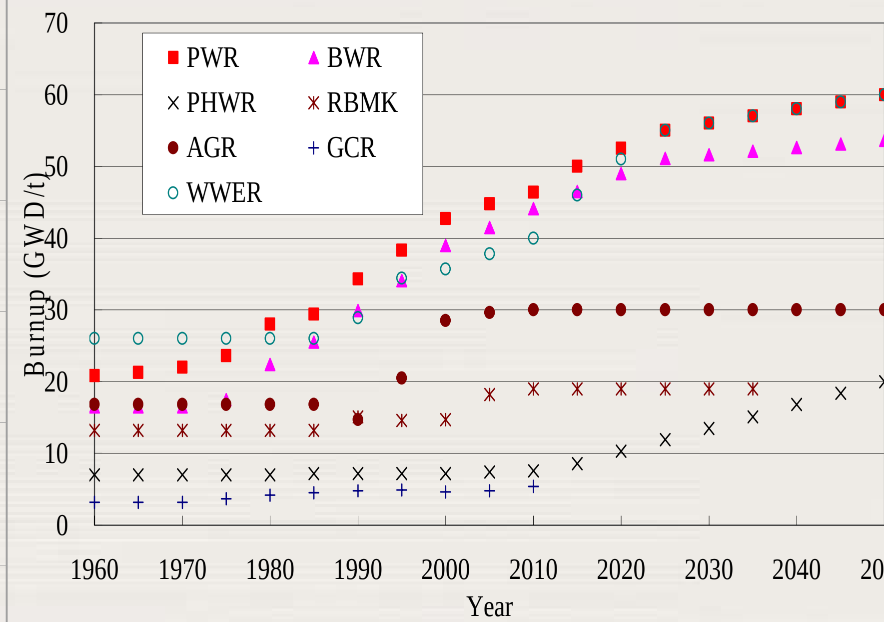
Status of nuclear fuel development

EXPERIENCE OF LMFBR FUEL

Property	(U-20%Pu)O2	(UPu) C	(UPu) N	U-Pu-Zr
Meeting Point(ºC)	2750	2480	2650	1057 + 25
Boiling Point (ºC)	3150	4280	NA	3700
Density (g/cm³)	9.7	12.9	13.5	14.3
Thermal Conductivity (W/m/K)	4.1	18.1	17.0	20.4
Fabrication & Irradiation Experience	For Phenix, Super Phenix, BN 350 & 600, PFR, FFTF, Joyo, Monju, SNR 300	〈 500 kg For FBTR	〈 100 kg	〈250 kg For EBR II
Maximum Burn up	20 a/o	20 a/o ~12 a/o	12 a/o	18 a/o

TRs FUEL BURNUP



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Major issues in the back-end of the nuclear fuel cycle

- **Storage of spent fuel** - short and long term (burnup credit, corrosion resistance and safety)
- **Transportation** of spent fuel (burnup credit, safety and security)
- **Reprocessing** of spent fuel [dry and wet routes, minor actinide (MA) issues, intrinsic proliferation resistance]
- **Refabrication** of Pu and ^{233}U bearing highly radiotoxic ceramic & metallic fuels by advanced manufacturing routes amenable to automation and remotization
- **Waste management** including treatment and storage. Developing multinational radioactive waste repositories

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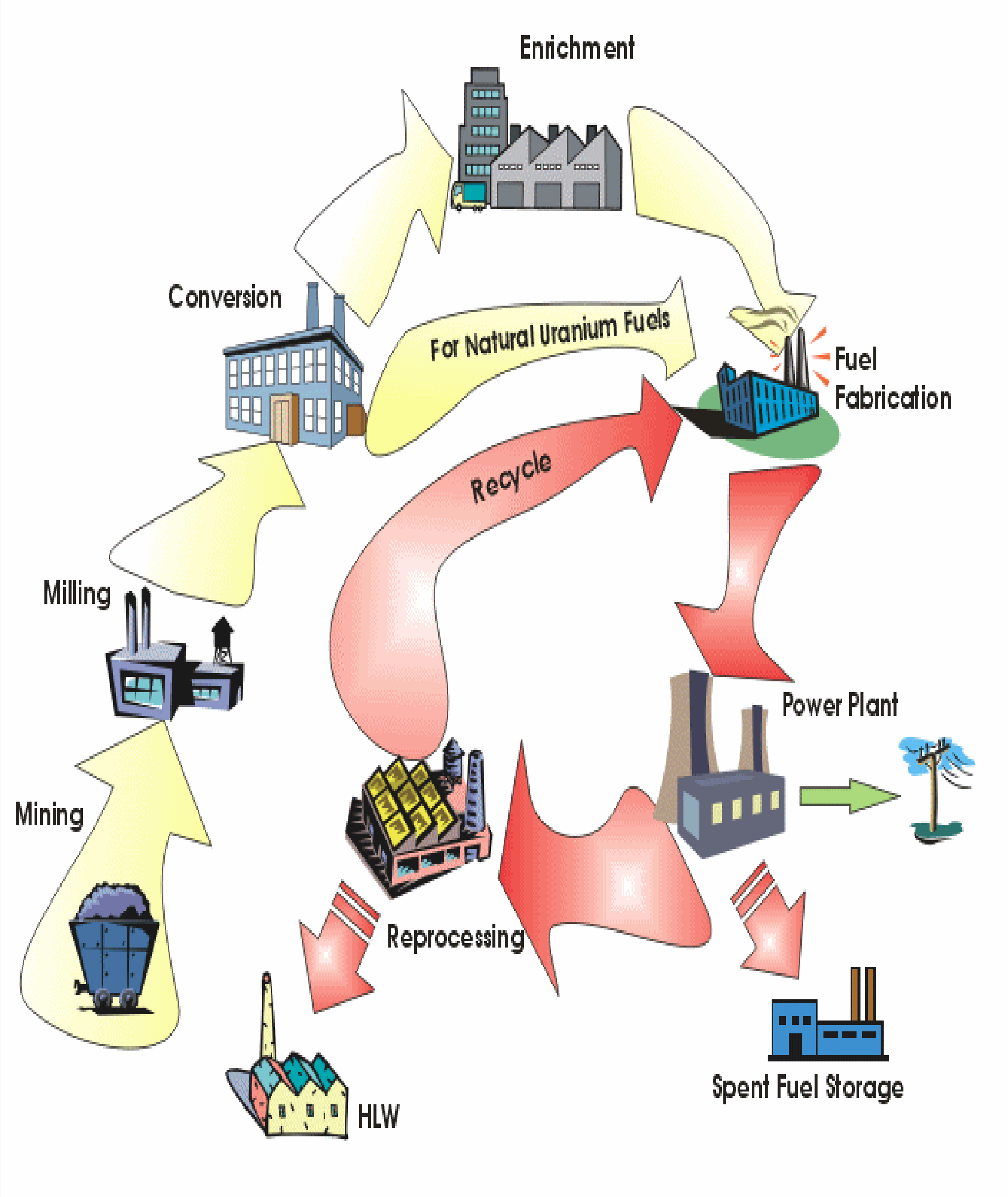
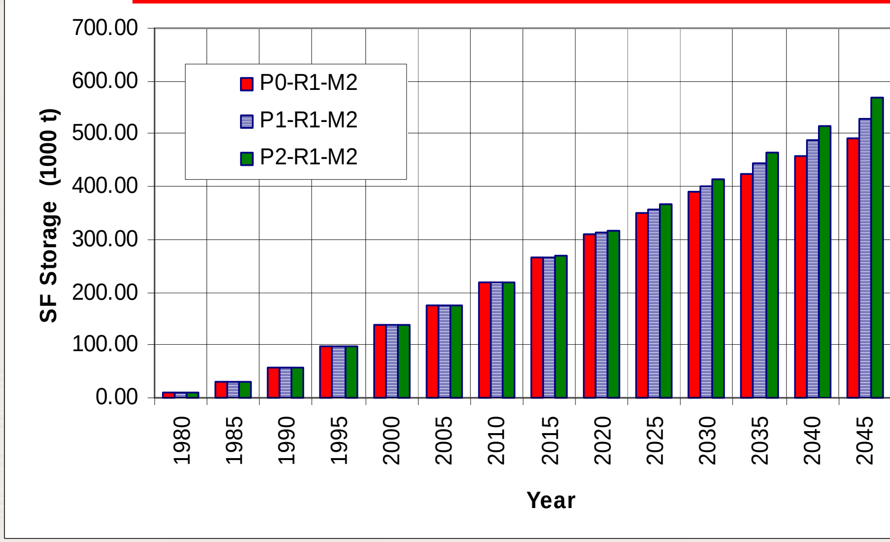
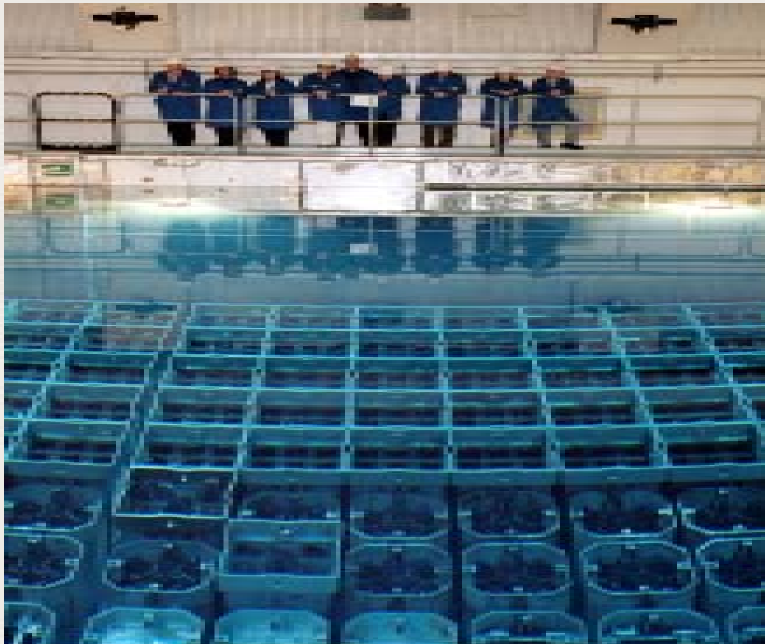


Spent fuel management

- Worldwide ~10 000t (HM)/y of SF and 460,000 t HM (total) by 2020
- ~1 500t HM/y are reprocessed
- Most SF in wet storage, use of dry storage is increasing
- Storage capacity is sufficient till 2015
- National situations differ and may require urgent attention
- A reality of long term storage (100 years)
- Social stability to maintain institutional control.
- Regional approaches

Accumulation of spent fuel





Decommissioning is as a major enterprise

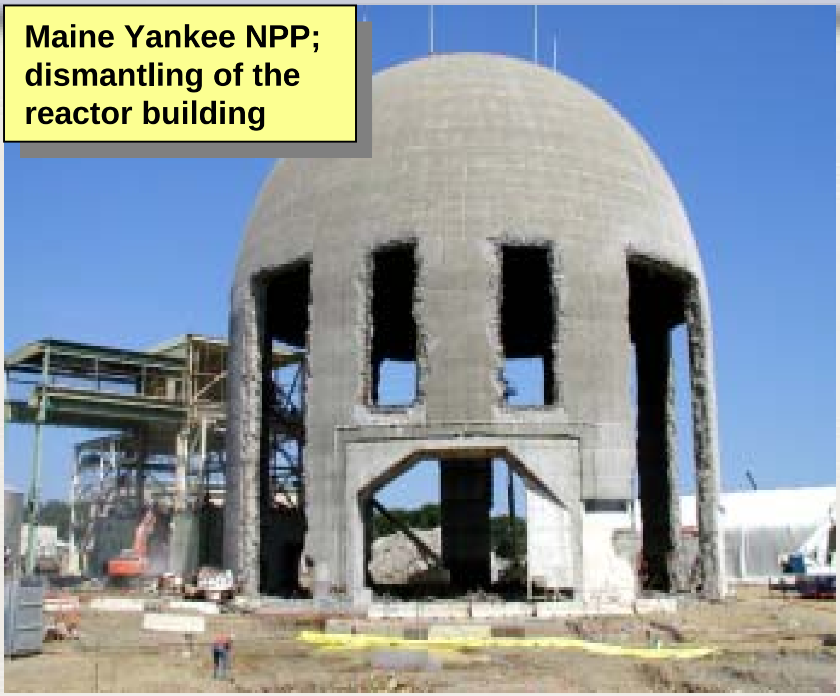
	NPPs	RRs	FCFs	RSs
1.	**107/ 14**	**214/ 173**	**297/ 192**	**10E5**
2.	**446/ 45**	**287/ 8**	**427/ 19**	**10E5**

1. Shutdown/decommissioned
2. In operation/under construction

Global liability 1000 B$.

Proven technology exists.

Funds for NNPs are in place.



Maine Yankee NPP; dismantling of the reactor building

Dismantling of a radio-biological lab, Dominican Republic

Waste disposal

- **Short Lived Low Level and Intermediate Level Waste**
  - **Near surface non-engineered disposal**
  - **Near surface engineered disposal**
  - **Subsurface disposal facilities**

El Cabril Facility, Spain

- **High Level Waste, Spent Fuel and other Long Lived Waste**
  - **Geological repositories**

WIPP, USA

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Conventional & advanced/innovative fuel reprocessing

AQUEOUS PROCESS:

** PUREX process is on an industrial scale:

* For UO2 and MOX fuels,
* Suitable for mixed nitride and metallic fuels.
* Modifications:
  - for proliferation resistance – U-Pu coextraction,
  - for economic - gelation process, dust-free and free-flowing U-Pub microspheres adjusted to vibro packed or pelletized fabrication process,
  - others: GANEX, PARC, UREX, REPA…

PYROPROCESSING:

** Pyroprocessing is yet to be adapted on an industrial scale.

* On laboratory scale demonstrated for carbide and nitride fuels.
* On a pilot plant scale for:
  - reprocessing of metallic fuels (U-Zr & U-Pu-Zr) in USA,
  - reprocessing of UO2 and vibro packing adjusted to waste management in Russia.

OTHERS:

** Have so far been demonstrated on a laboratory scale only:

- for example: fluoride volatilization.

Russian Federation

Development level for Oxide Fuel Pyro-process recycling technologies

Method	Fundamen-tal data	Laboratory testing	Pre-industrial testing	Industrial testing
Pyro-process	available	For fresh and spent fuel	Only with pure MOX	Started for BN-600
Vibro	available	For fresh and spent fuel	Only with pure MOX	Started for BN-600
Waste	Studies is continued	Studies is continued		
Remote equipment	Tested at ORYOL Facility for BOR-60 and BN-600			

Innovative Back-end Technology of Fuel Cycle Japan

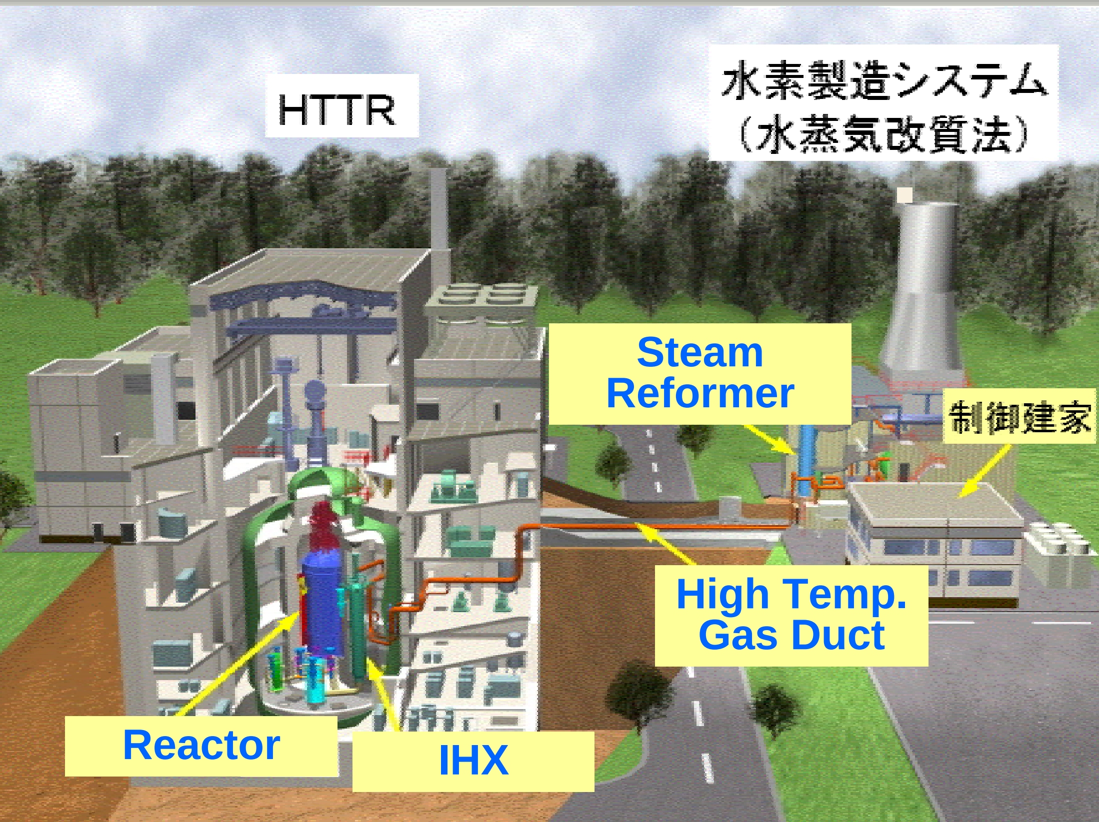
Reprocessing	Simplified PUREX Process	Alternative Aqueous Process	Oxide - Electrowinning Process	Metal - Electrorefining Process
	Dissolution	Direct Extraction Supercritical Fluid Extraction TBP-CO_2-HNO_3	Uranium Electrowinning	Oxide Reduction
U Recovery	Crystallization			U Electrorefining (solid cathode)
U, Pu,MA Recovery	Single Cycle Extraction		MOX Electro-codeposition	U, Pu, MA Electrorefining (Liq . Cd cathode)
MA Recovery	SETFICS Process /TRUEX Process	Ion Exchange / Amine Extraction	MA Electrowinning	Cd Extraction (pyro contactor)

Oxidation

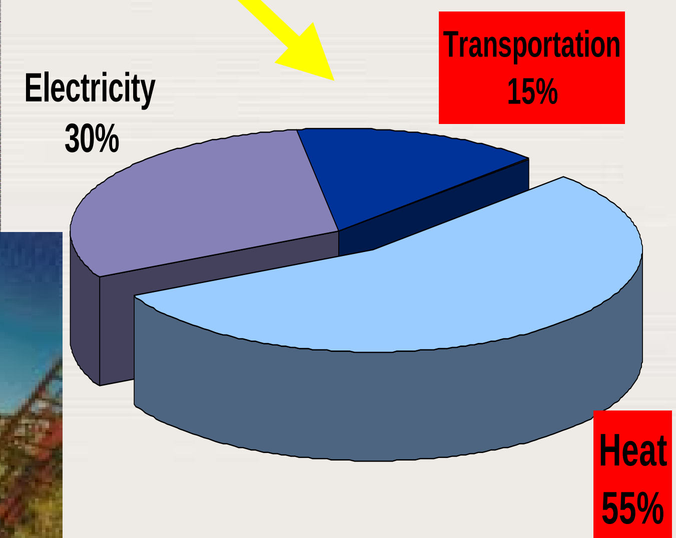
Fuel Refabrication				
	Pellet short Process	Sphere Packing Process	Vibro -Packing Process	Casting Process
	Simplified Pelletizing	Gelation (MOX– MA)	Granulation (MOX,MN-MA)	Casting (U,Pu -Zr -MA)
	Stacking	Vibration Packing	Vibration Packing	Stacking
	MOX Fuel		MOX Fuel	Metal Fuel

:MOX Aqueous Recycle :MO -Aqueous Recycle :Metal Non Aqueous Recycle

Non-electricity applications of nuclear energy



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



Kazakhstan BN-350

Evidence from opinion surveys

- UK
  - 2001: 19% approve, 60% disapprove
  - 2005: 35% approve, 30% disapprove
- Finland
  - 1994: 34% approve, 35% disapprove
  - 2004: 46% approve, 25% disapprove
- USA
  - 1983: 49% approve, 46% disapprove
  - 2005: 70% approve, 24% disapprove
- Sweden, 2005
  - 83% – keep existing reactors operating or expand
  - 13% – early closure

Conclusions

- Current centre of growth is Asia
- Policy shifts in China, India, USA, Japan, EU, Finland, Russia and EU recognize that nuclear has a part to play and suggest a broader revival
  - better reputation of nuclear among investors
  - more economical operations and better designs
  - contribution to energy security and environmental protection

Conclusions

- Importance of innovation
  - account for regional and national variation
  - new look at multilateral and regional approaches to the fuel cycle
  - international cooperation
  - link with non-proliferation, complementary institutional and technical measures are essential
- Importance of applications beyond electricity: heat, desalination, hydrogen
- Growing expectations are well established

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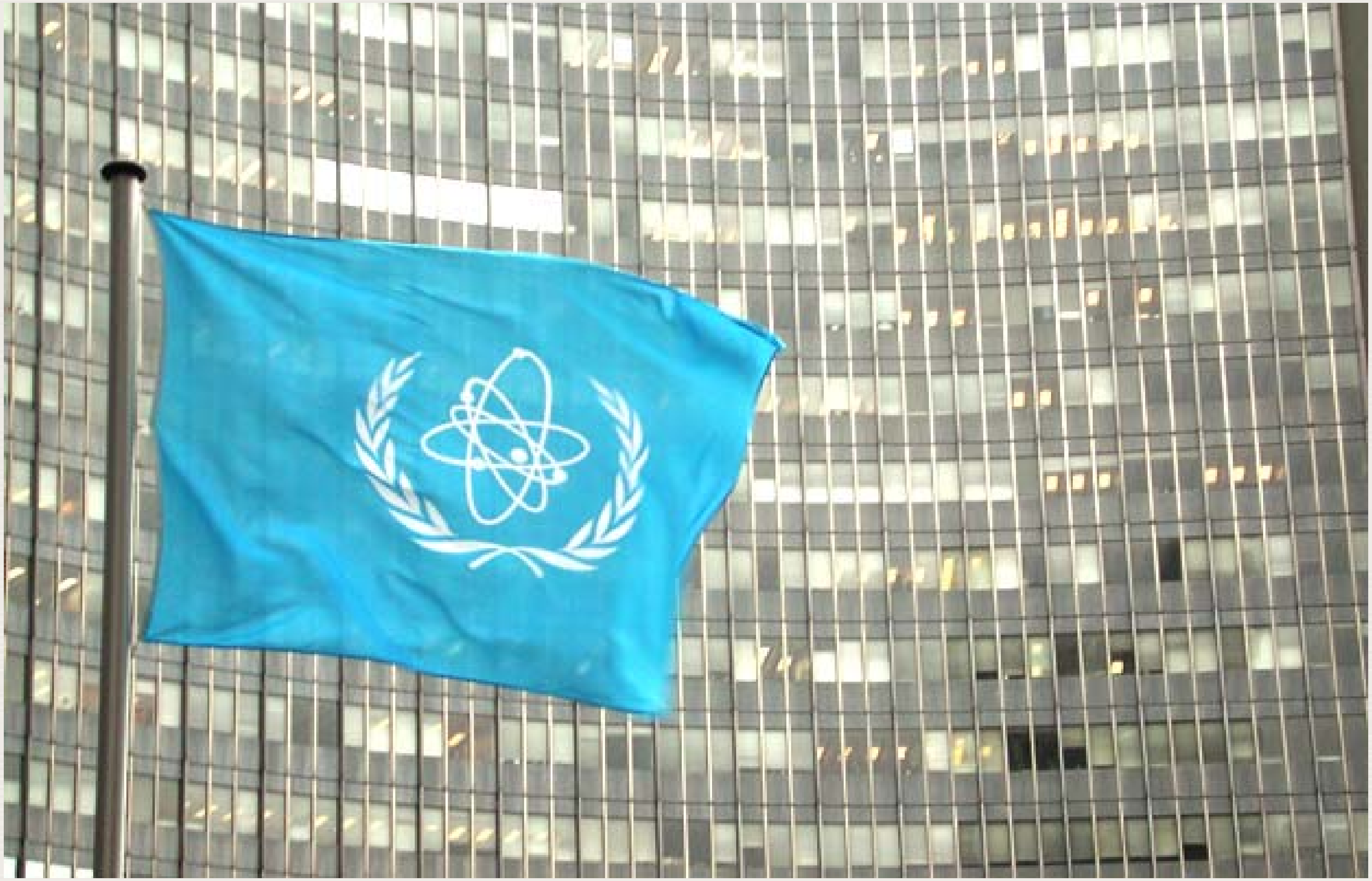

…atoms for peace.

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