Uranium Information Centre

Nuclear Power and Global Warming

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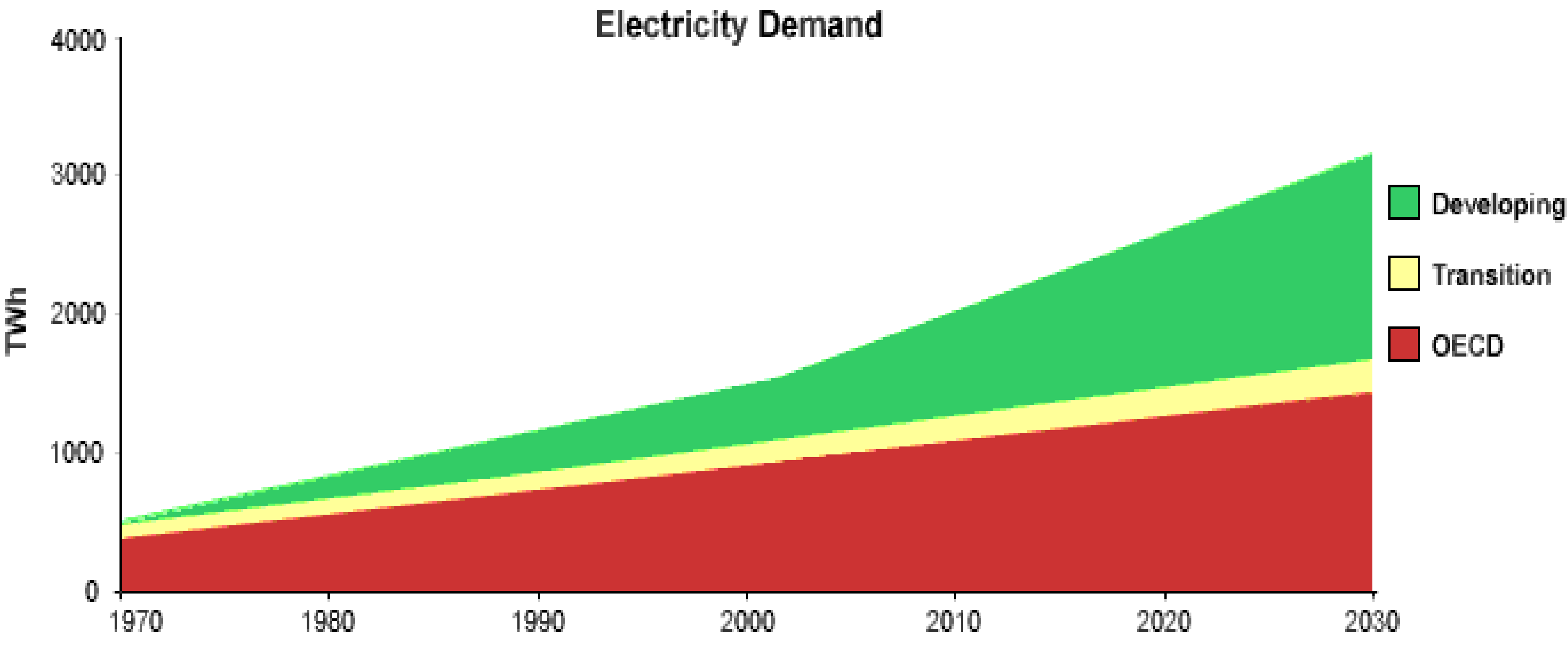
Australian Uranium Association &

Head of Communications,
World Nuclear Association

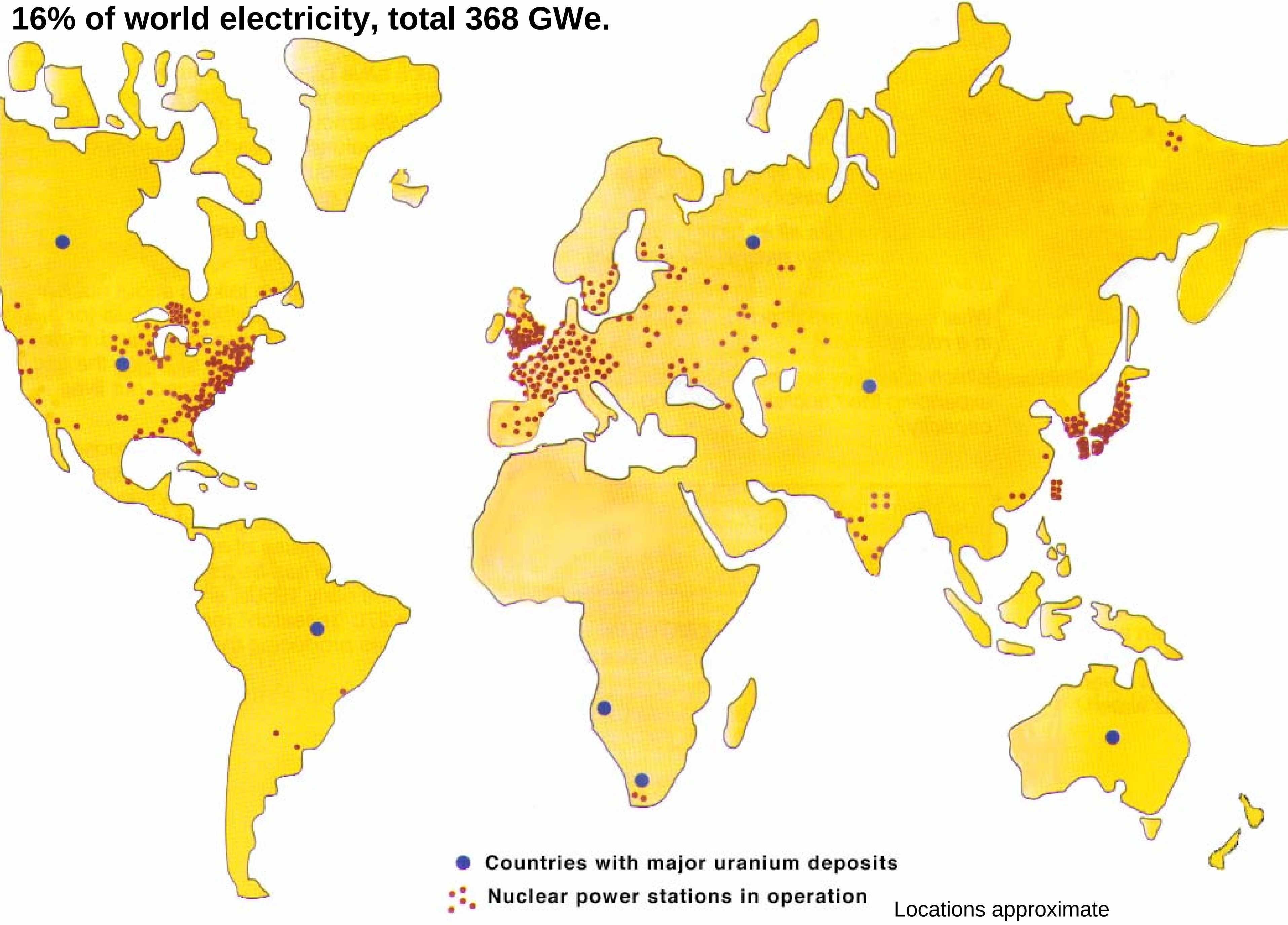
Hawke Centre & ANZSES, October 2006

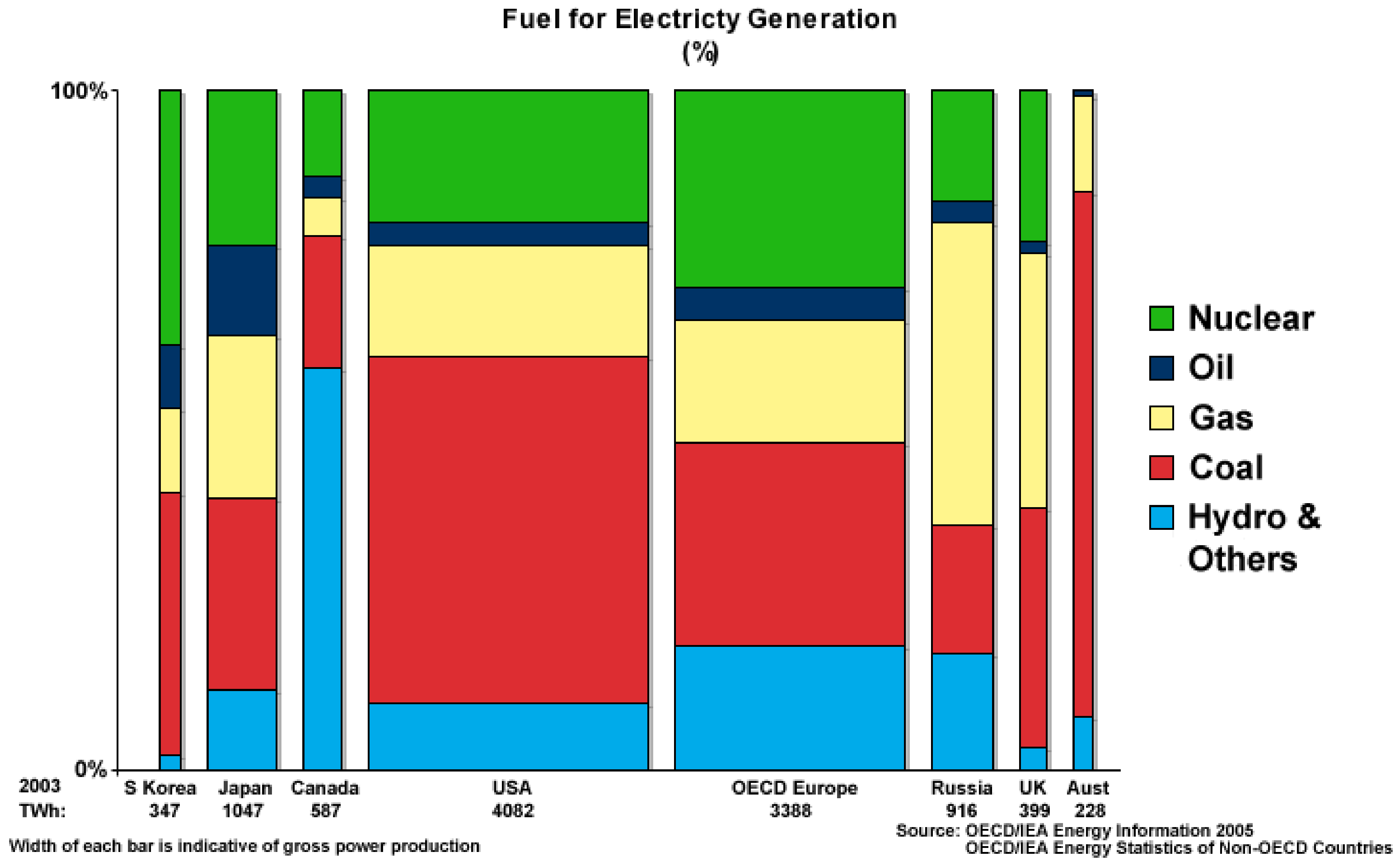
www.world-nuclear.org www.uic.com.au



OECD/IEA *World Energy Outlook* 2004

Total 441 operating nuclear power reactors, 25 under construction, late 2005
16% of world electricity, total 368 GWe.




Fuel for Electricty Generation
(%)
100%
0%
Nuclear
Oil
Gas
Coal
Hydro & Others
2003
TWh:
S Korea
347
Japan
1047
Canada
587
USA
4082
OECD Europe
3388
Russia
916
UK
399
Aust
228
Source: OECD/IEA Energy Information 2005
OECD/IEA Energy Statistics of Non-OECD Countries
Width of each bar is indicative of gross power production

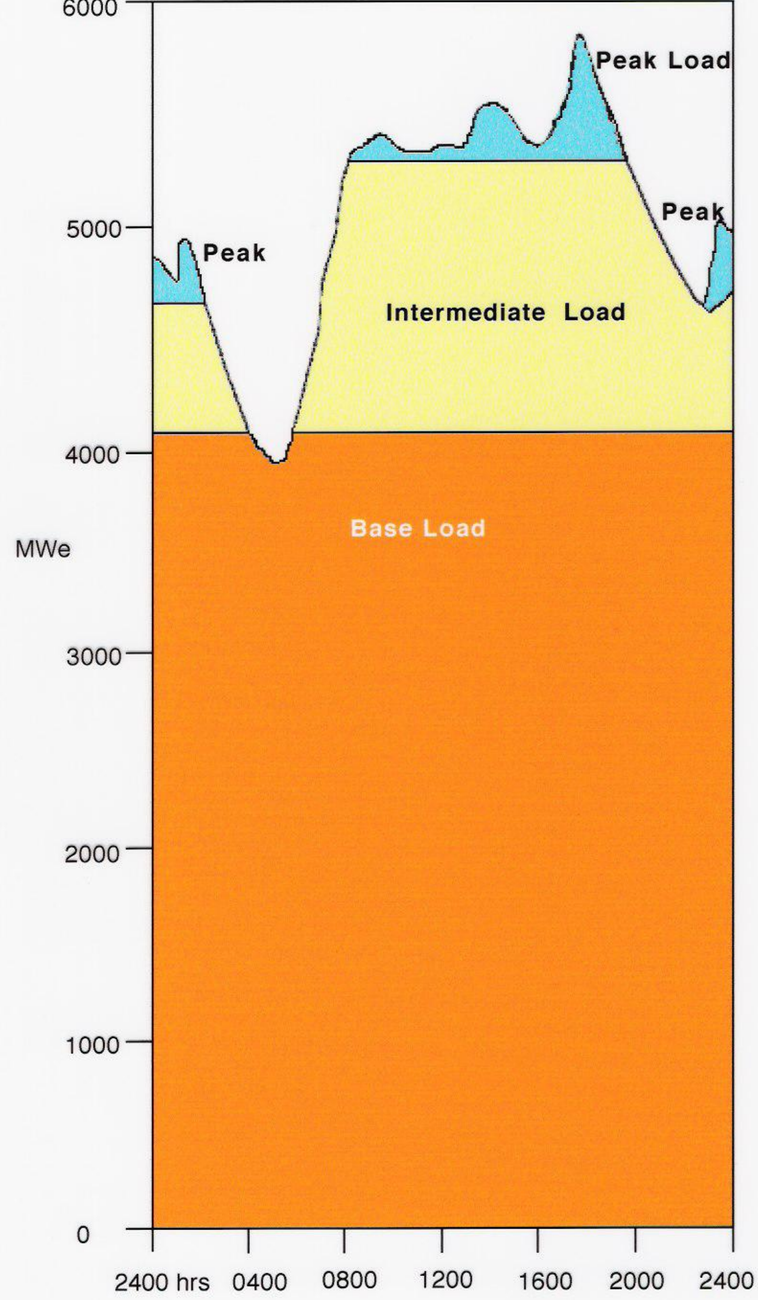
Drivers overseas:

- Basic economics,
including increased fossil fuel prices

- Prospect of carbon emission costs

- Insurance against future fuel price increases

- Energy security - geopolitical

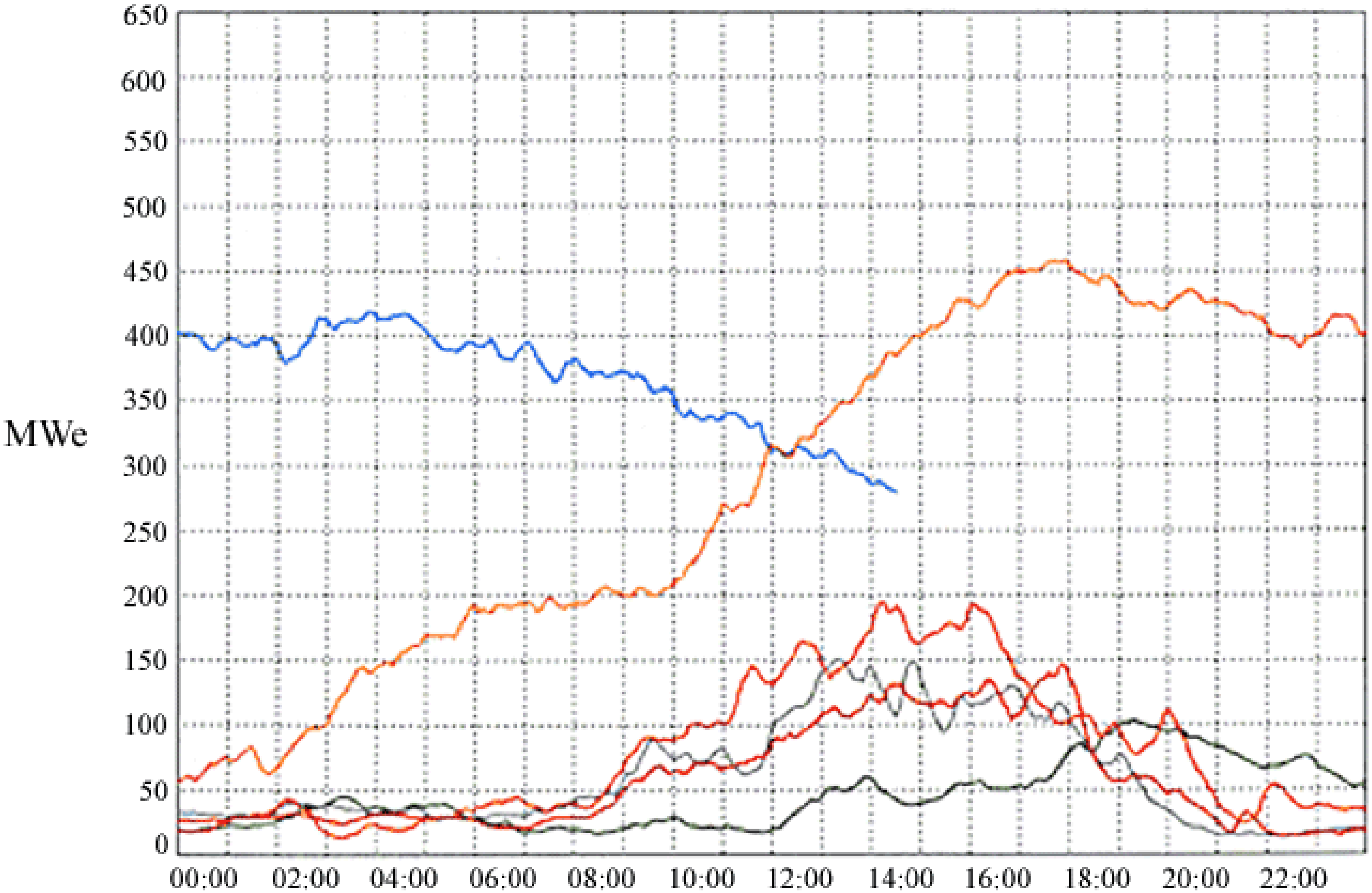


Load curve for Victorian electricity grid, June day in 1996

Most demand is for continuous, reliable supply on a large scale = base-load

Wind Energy production during One Week in Western Denmark

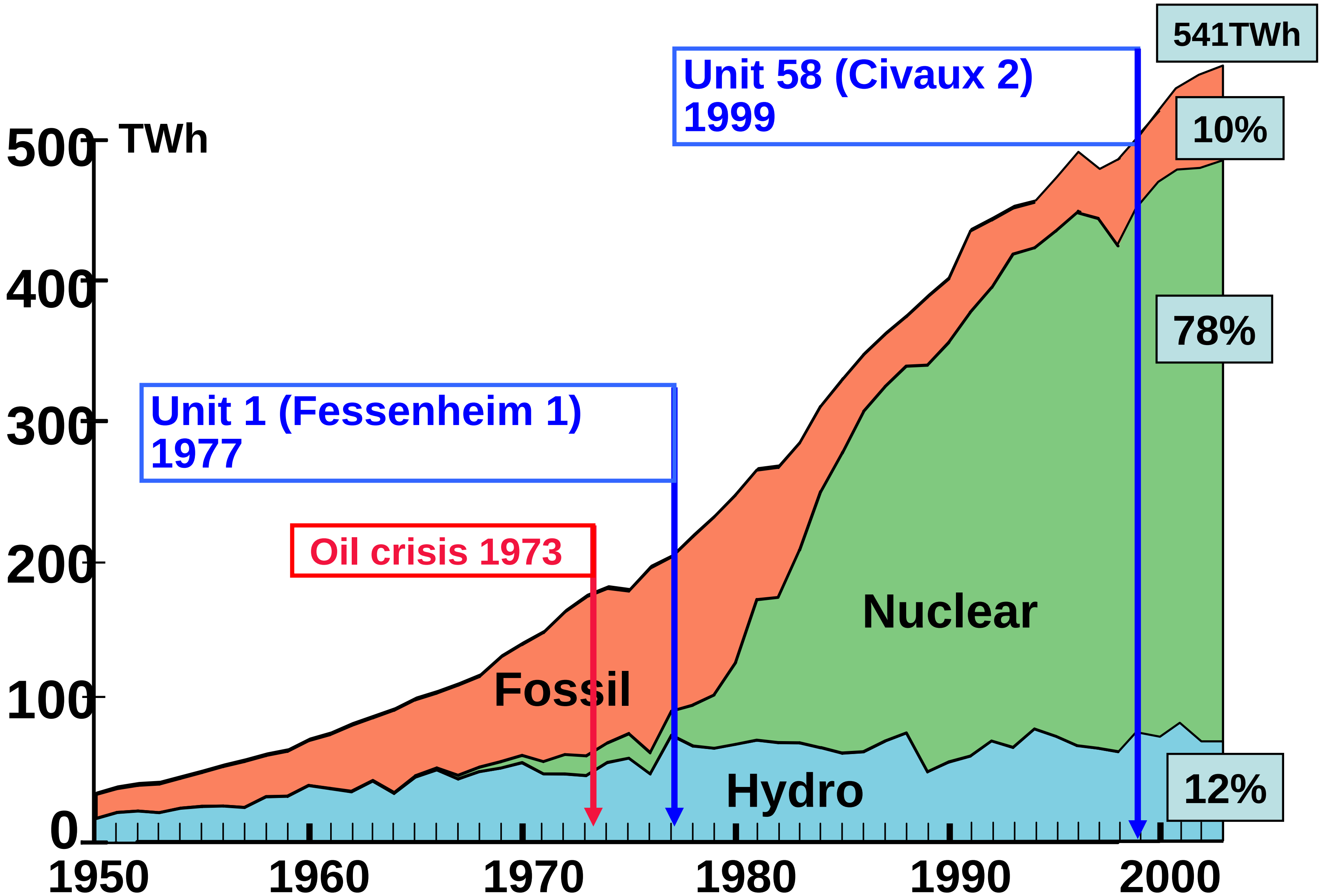
is one day, capacity 650 MWe.



Danish Wind Energy Association

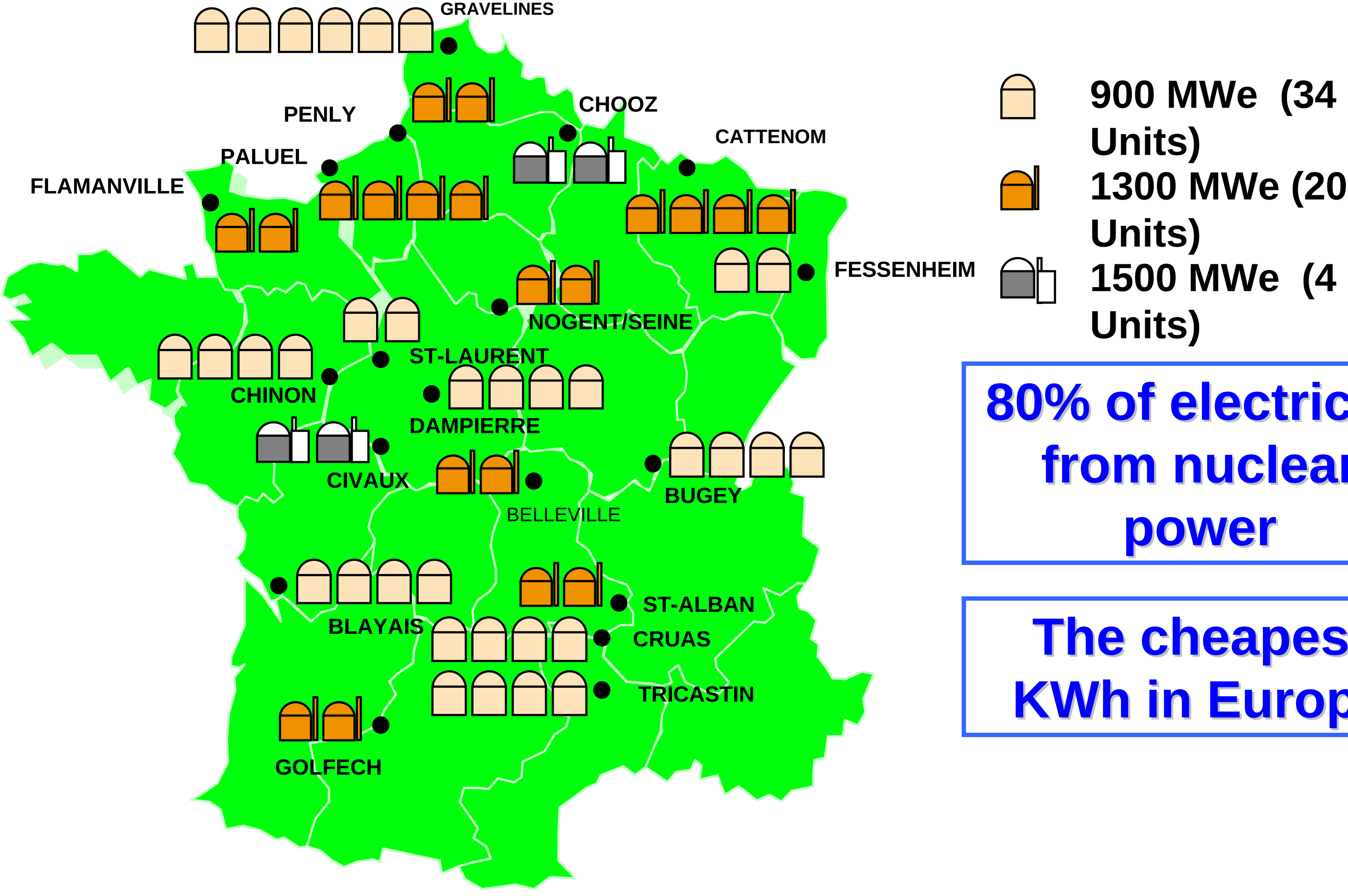
Diablo Canyon nuclear power plant, USA

French electrical mix evolution



The nuclear reactor fleet in France

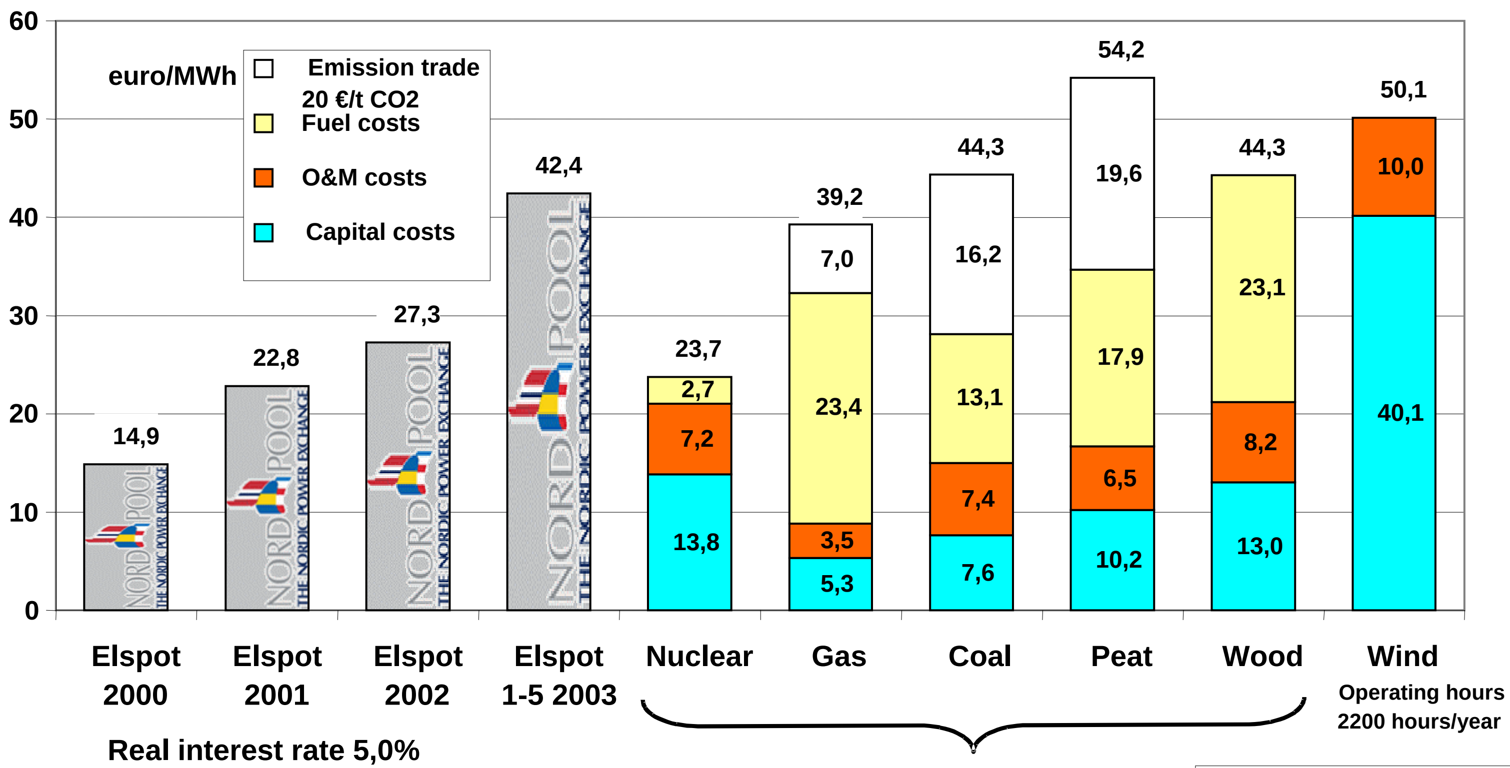
58 units in operation on 19 sites



80% of electricity from nuclear power

The cheapest KWh in Europe

Electricity generation costs, with emission trading case: Finland



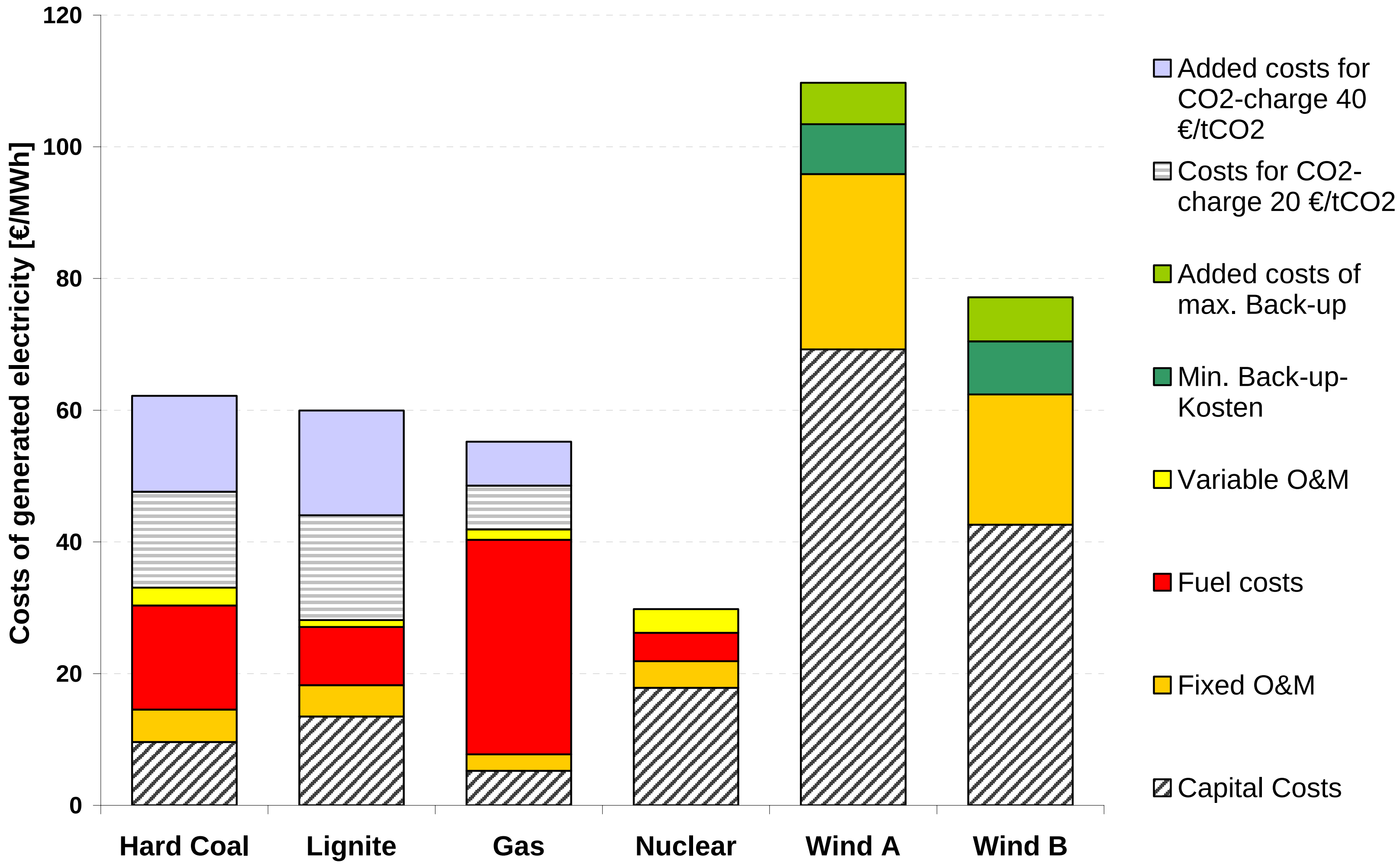
Real interest rate 5,0%

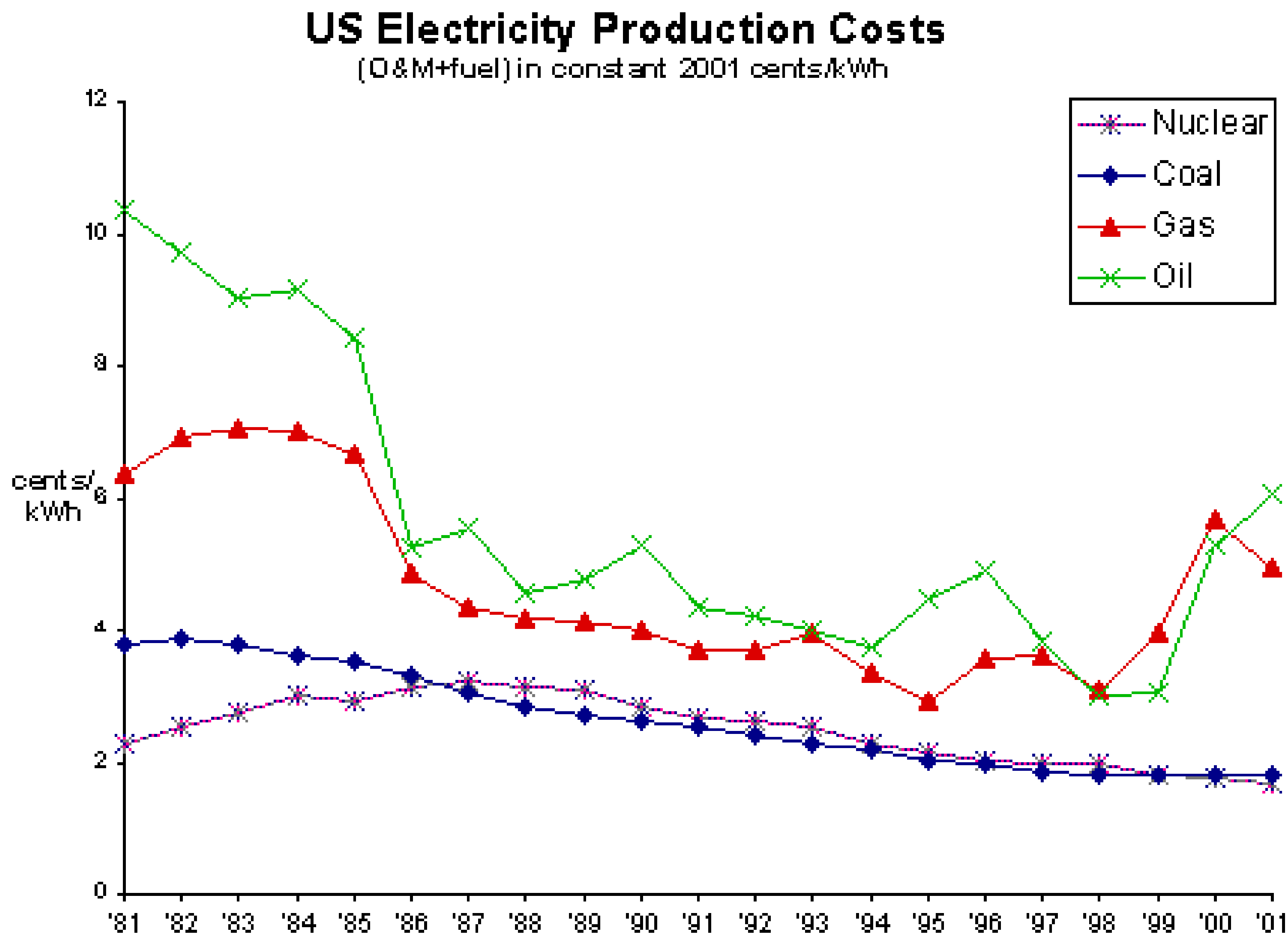
March 2003 prices

R.Tarjanne&K.Luostarinen 03.07.2003
Lappeenranta University of Technology

Generation costs without investment subsidy and the return of electricity tax (wood and wind)

Impact of a carbon value on levelised generation costs at 7,5% discount rate




US Electricity Production Costs
(O&M+fuel) in constant 2001 cents/kWh
12
10
8
6
4
2
0
cents/
kWh
'81
'82
'83
'84
'85
'86
'87
'88
'89
'90
'91
'92
'93
'94
'95
'96
'97
'98
'99
'00
'01
Nuclear
Coal
Gas
Oil

Fuel cost

In mid October 2006, to get 1 kg of uranium as reactor fuel:

U_3O_8 8 kg x \$145 = 1160 - 55%
conversion 7 kg U x \$12 = 85
enrichment 4.8 SWU x \$131 = 629 - 30%
fuel fabrication, per kg UO_2 = <u>240</u>

total, approx: US\$ 2114

This yields 3400 GJ thermal which gives 315,000 kWh, hence fuel cost: **0.67 c/kWh**.

Construction costs

From 2005 OECD NEA + IEA report, for overnight capital cost:

Nuclear: $1000/kW (Czech) - $2500/kW (Japan)

Coal: $1000 - $1500/kW

Gas: $500 - $1000/kW

Wind: $1000 - $1500/kW

So: *interest rates are a critical factor for nuclear*

Electricity costs, 2010 on

	Nuclear	Coal	Gas
Finland	**2.76**	3.64	-
France	**2.54**	3.33	3.92
Germany	**2.86**	3.52	4.90
Czech Rp	**2.30**	2.94	4.97
Japan	**4.80**	4.95	5.21
USA	3.01	**2.71**	4.67
Canada	**2.60**	3.11	4.00

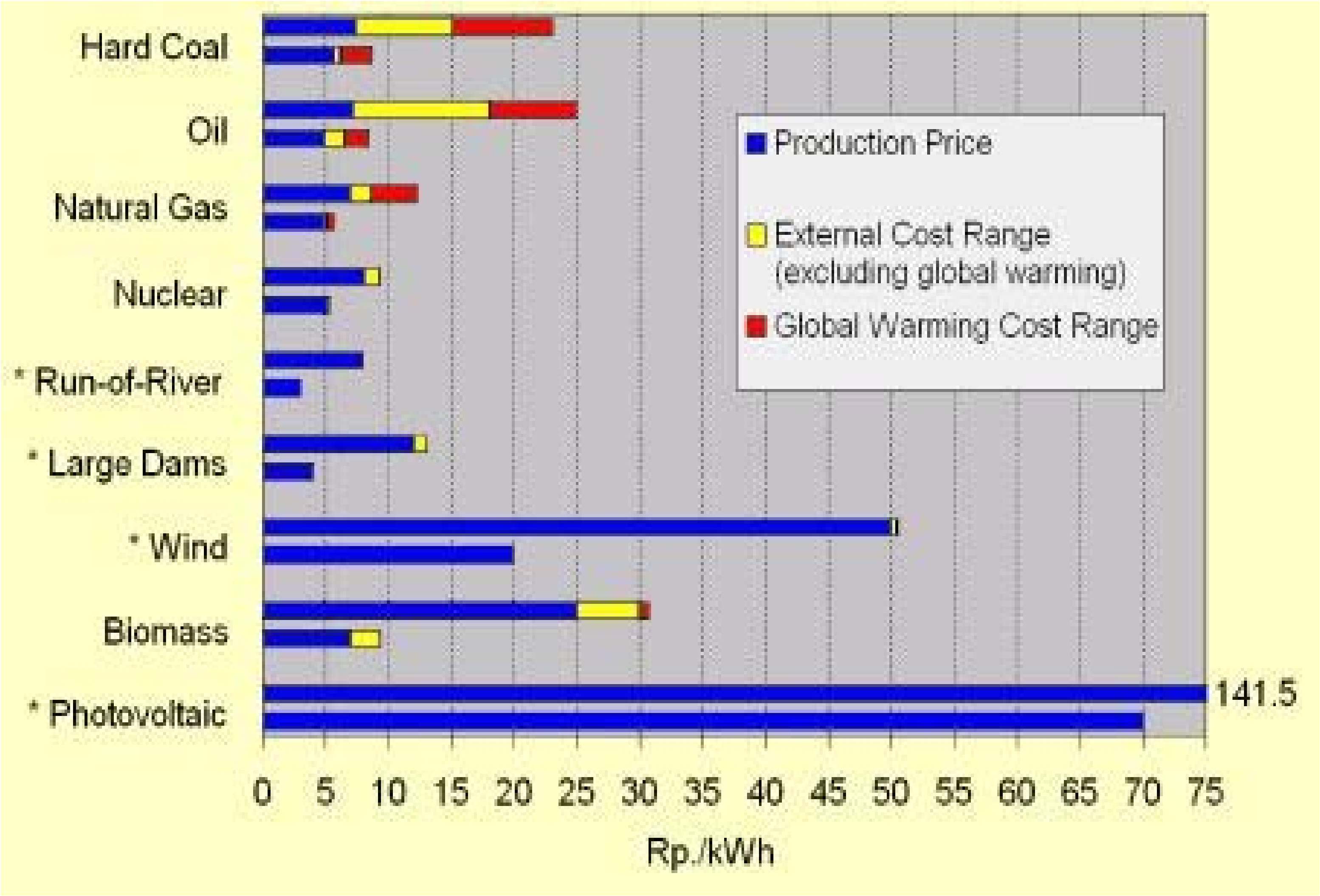
US 2003 cents/kWh, 5% discount rate, 40 year lifetime, 85% load factor. OECD 2005

UK electricity costs - p/kWh

	Basic cost	With back-up	With CO2 cost @ £30/t, $45/t
Nuclear	**2.3**	N/a	N/a
Gas CCGT	2.2	N/a	**3.4**
Coal	2.5	N/a	**5.0**
Wind onshore	3.7	**5.4**	N/a
Wind offshore	5.5	**7.2**	N/a

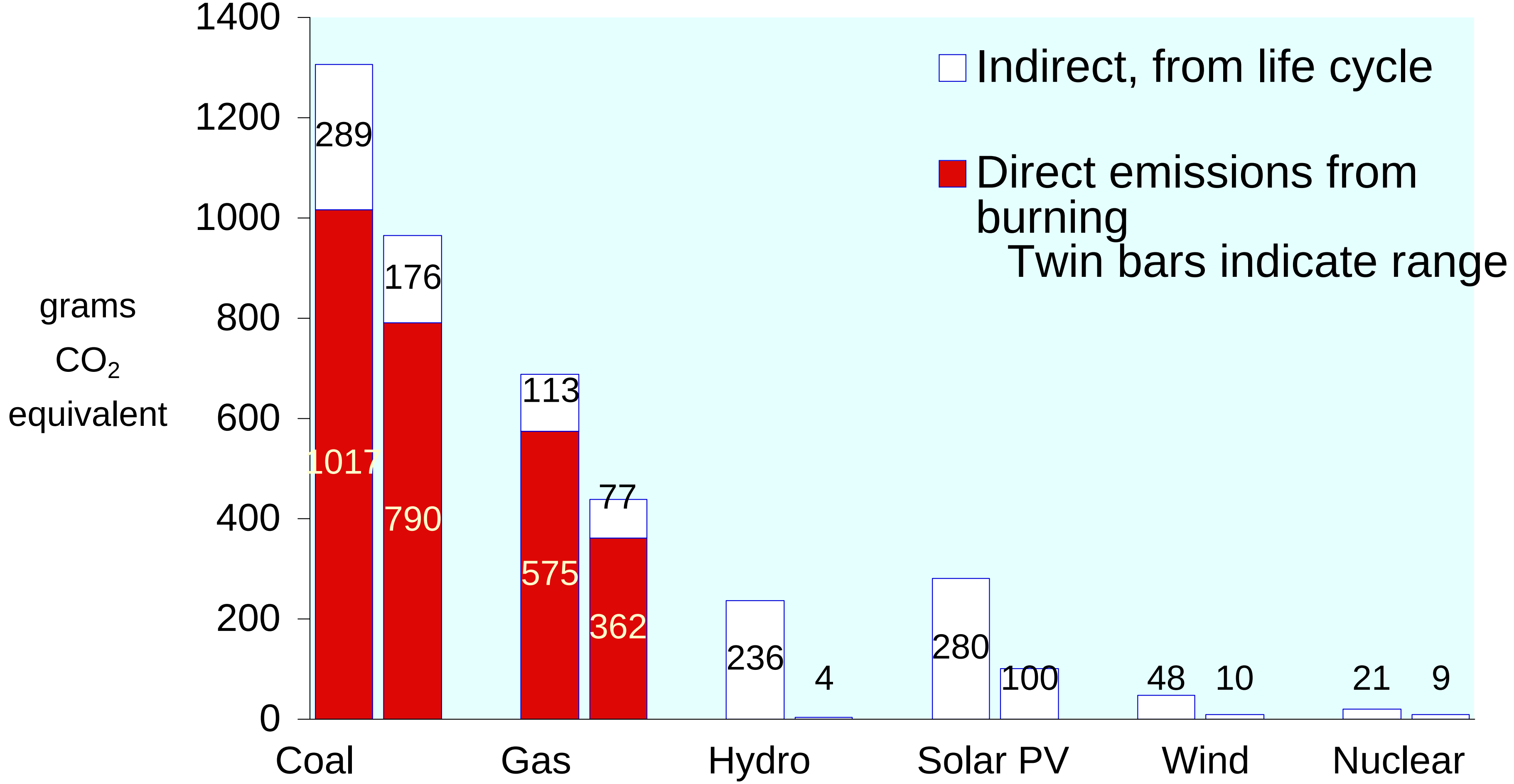
Royal Academy of Engineering 2004,
nuclear plant cost US$ 2100/kW

Total costs of electricity generation in Switzerland



Paul Scherrer Inst. Twin bars indicate range

Greenhouse Gas Emissions from Electricity Production



Source: IAEA 2000

EVERY 26 TONNES U_3O_8

USED SAVES

1 MILLION TONNES CO_2

RELATIVE TO COAL!

Typical Energy Accounting

For 1000 MWe:	**PJ - 40 yr**
Mining & milling	1.56
Conversion	9.24
Enrichment - initial	0.14
Enrichment - reloads (centrifuge)	3.12
Fuel fabrication	5.76
Construction & operation	24.69
Wastes	1.5
Decommissioning	6.0
TOTAL INPUT ENERGY	52 - **1.7% of output**

Output over 40 years: 3020 PJ

Audited LCA for Forsmark NPP

Per 1000 MWe:	**PJ - 40 yr**
Mining & milling	5.5
Conversion	4.1
Enrichment (80% centrifuge)	23.1
Fuel fabrication	1.2
Plant operation	1.1
Plant build & decommission	4.1
Waste management	4.3
TOTAL ENERGY INPUT	43.4 - **1.35% of output**

Total output over 40 years: 3226 PJ

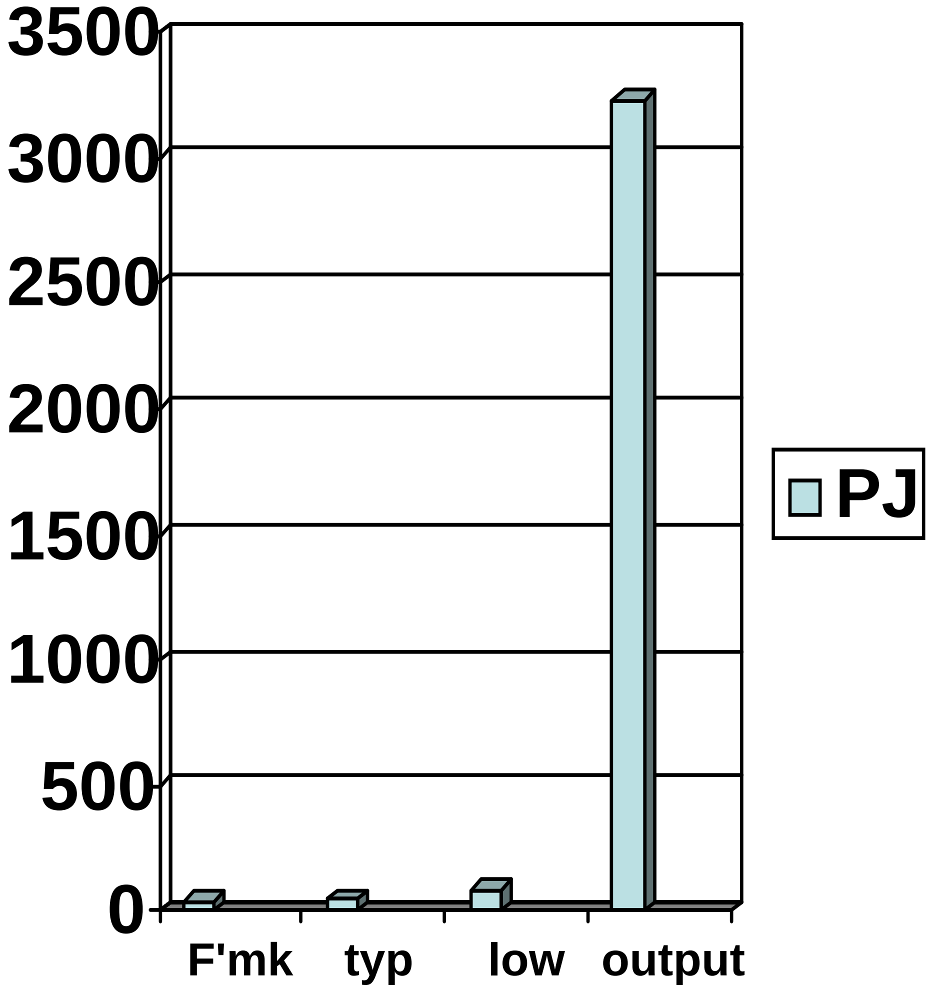
Energy Accounting - low grade ore

For 1000 MWe:	**PJ - 40 yr**
Mining & milling 0.01% ore	37
Conversion	9.24
Enrichment - initial	0.14
Enrichment - reloads (centrifuge)	3.12
Fuel fabrication	5.76
Construction & operation	24.69
Wastes	1.5
Decommissioning	6.0
TOTAL INPUT ENERGY	89 - **2.9% of output**

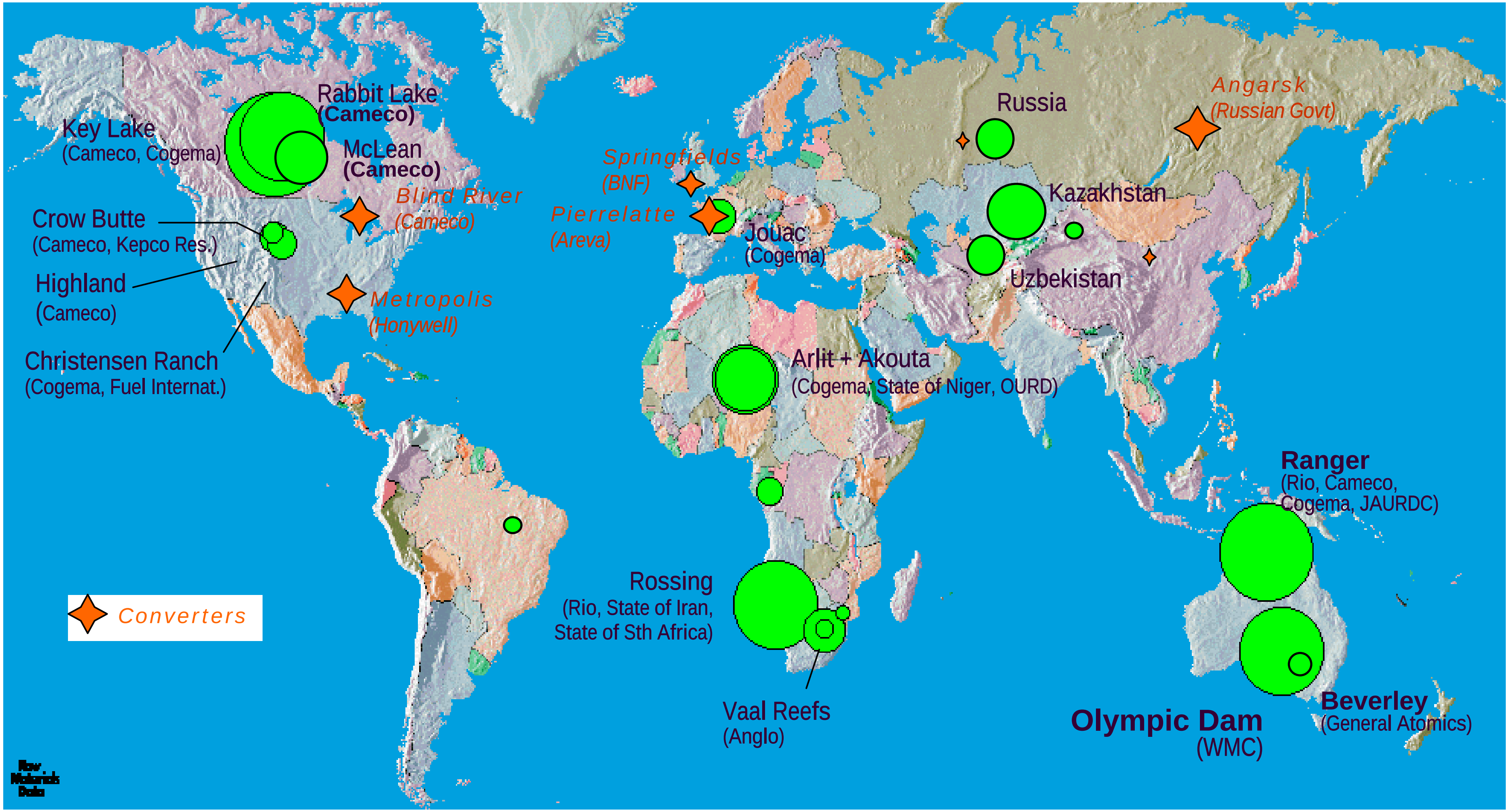
Output over 40 years: 3020 PJ

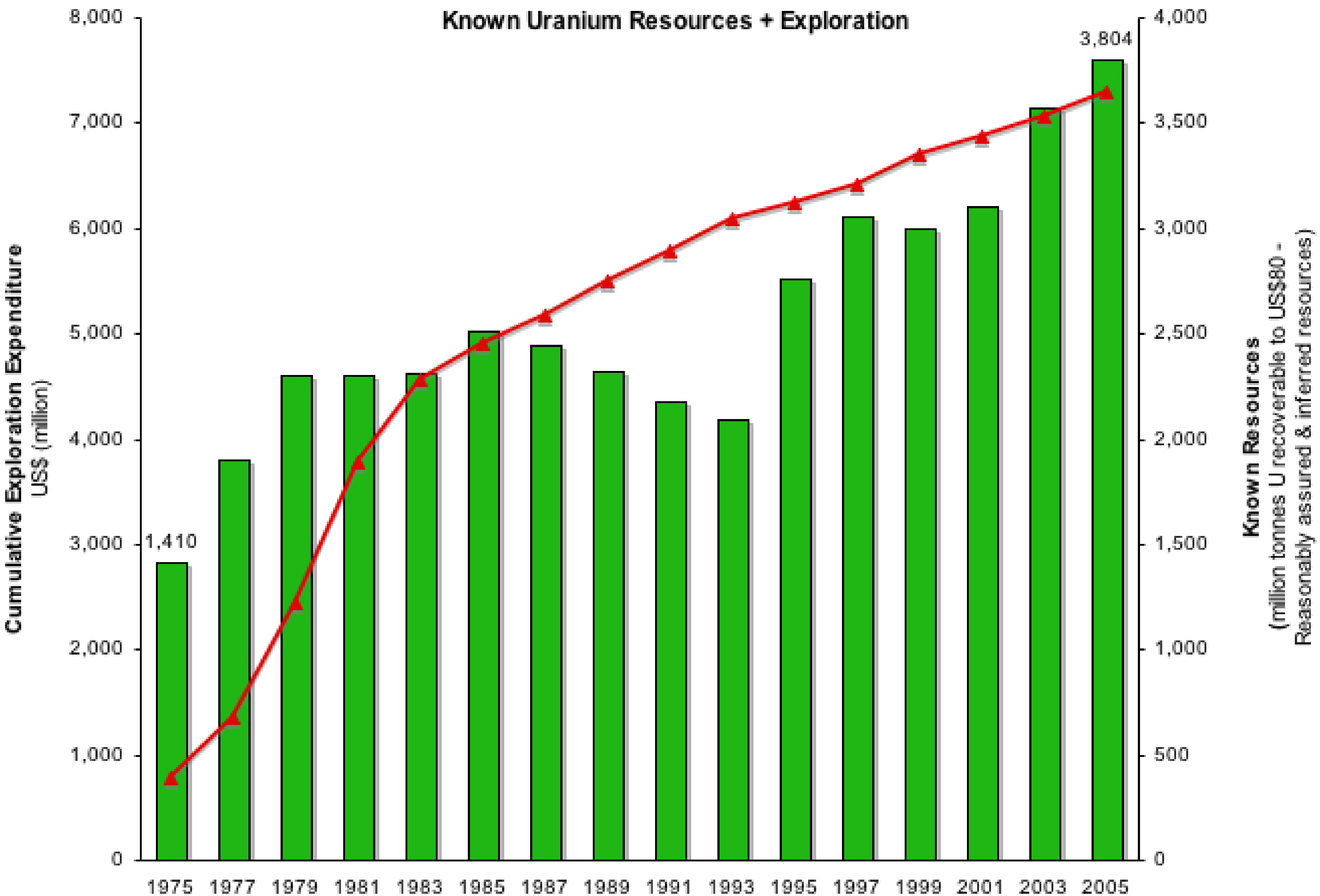
Energy accounting

- Vattenfall Forsmark audited LCA: input is 1.35% of output.
- Typical: 1.7% of output.
- Very low grade ore: 2.9% of output.
- 40 year output for 1 GWe.



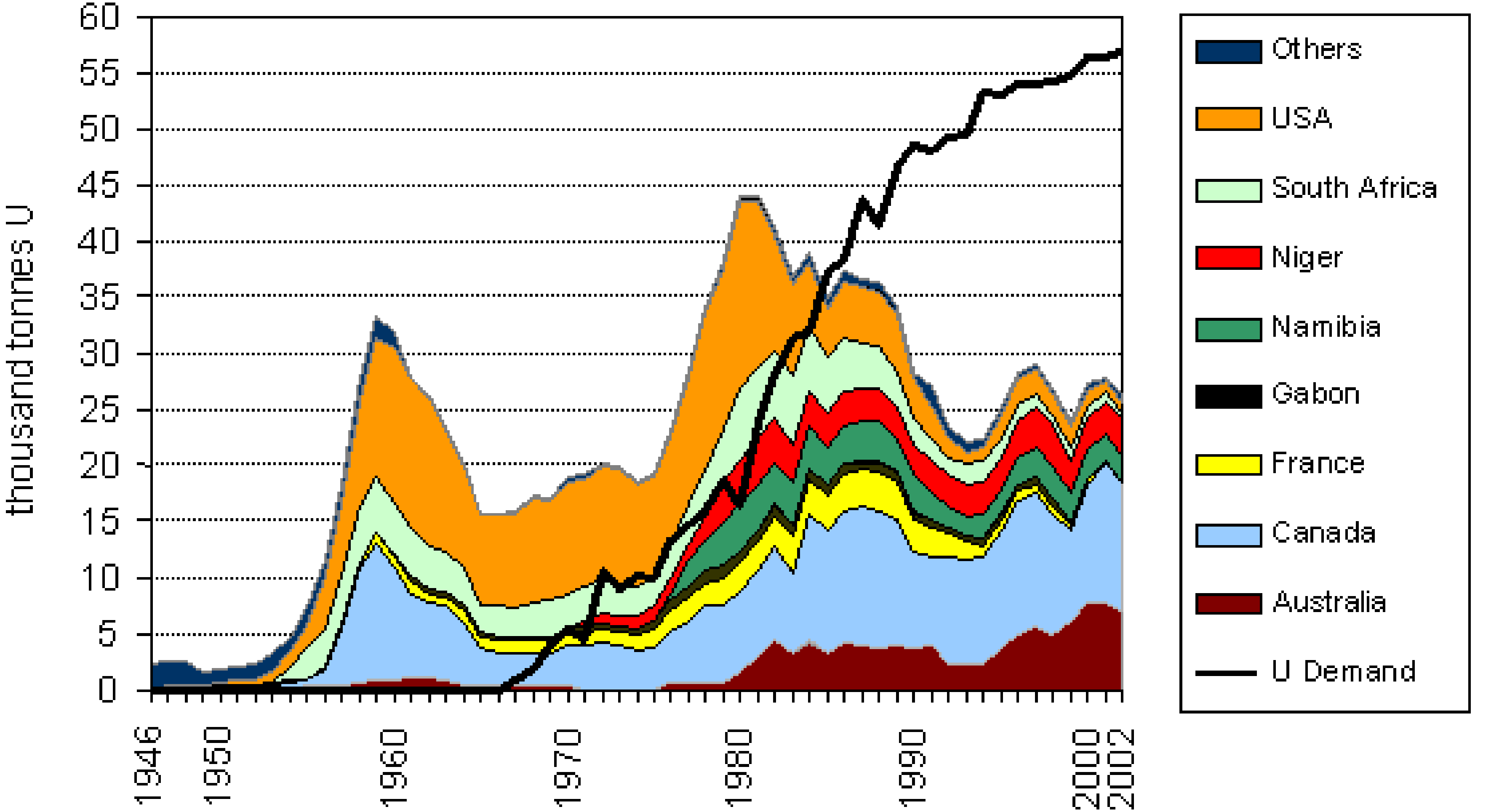
Major Uranium Operations



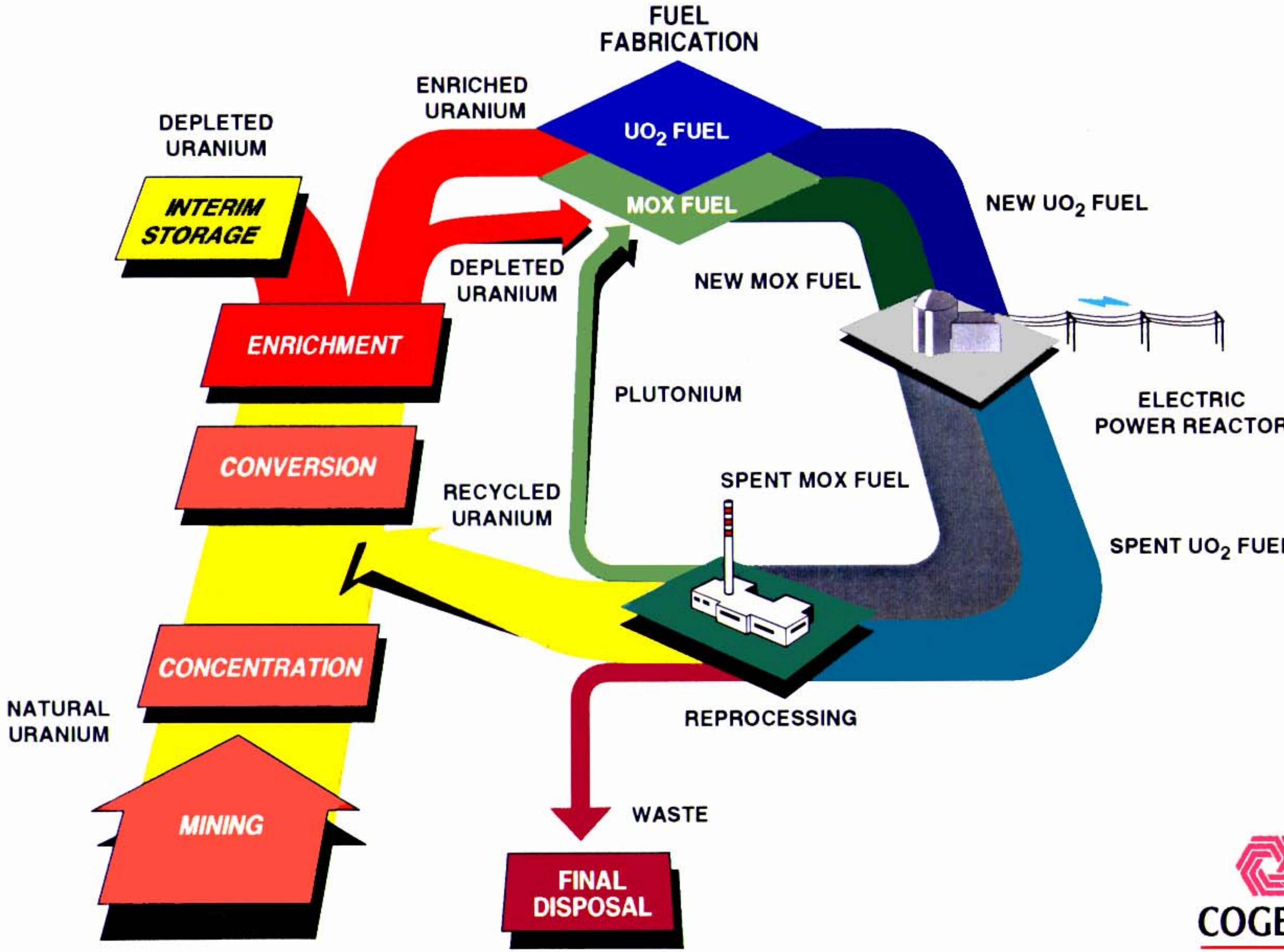

Known Uranium Resources + Exploration
Cumulative Exploration Expenditure
US$ (million)
Known Resources
(million tonnes U recoverable to US$80 -
Reasonably assured & inferred resources)
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
1,410
3,804
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005

Uranium production and demand for power generation

- western world



THE NUCLEAR FUEL CYCLE



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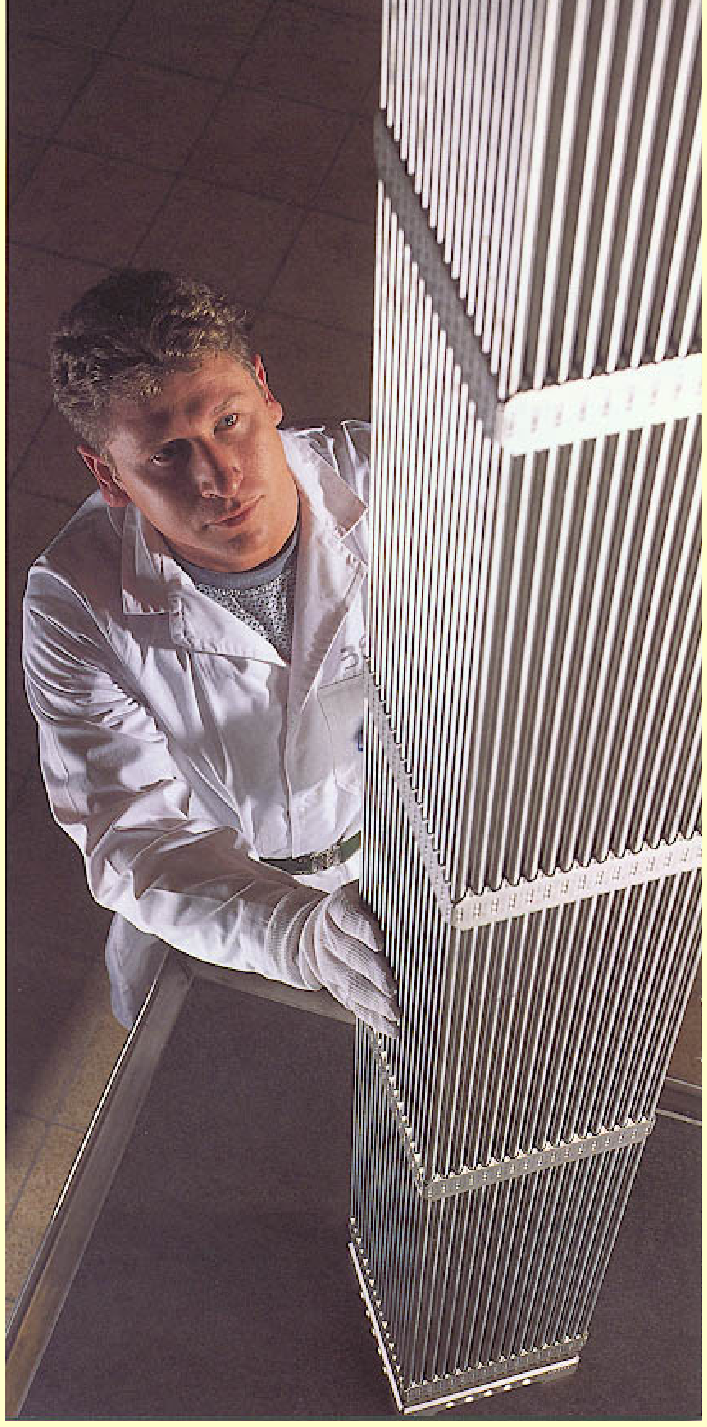
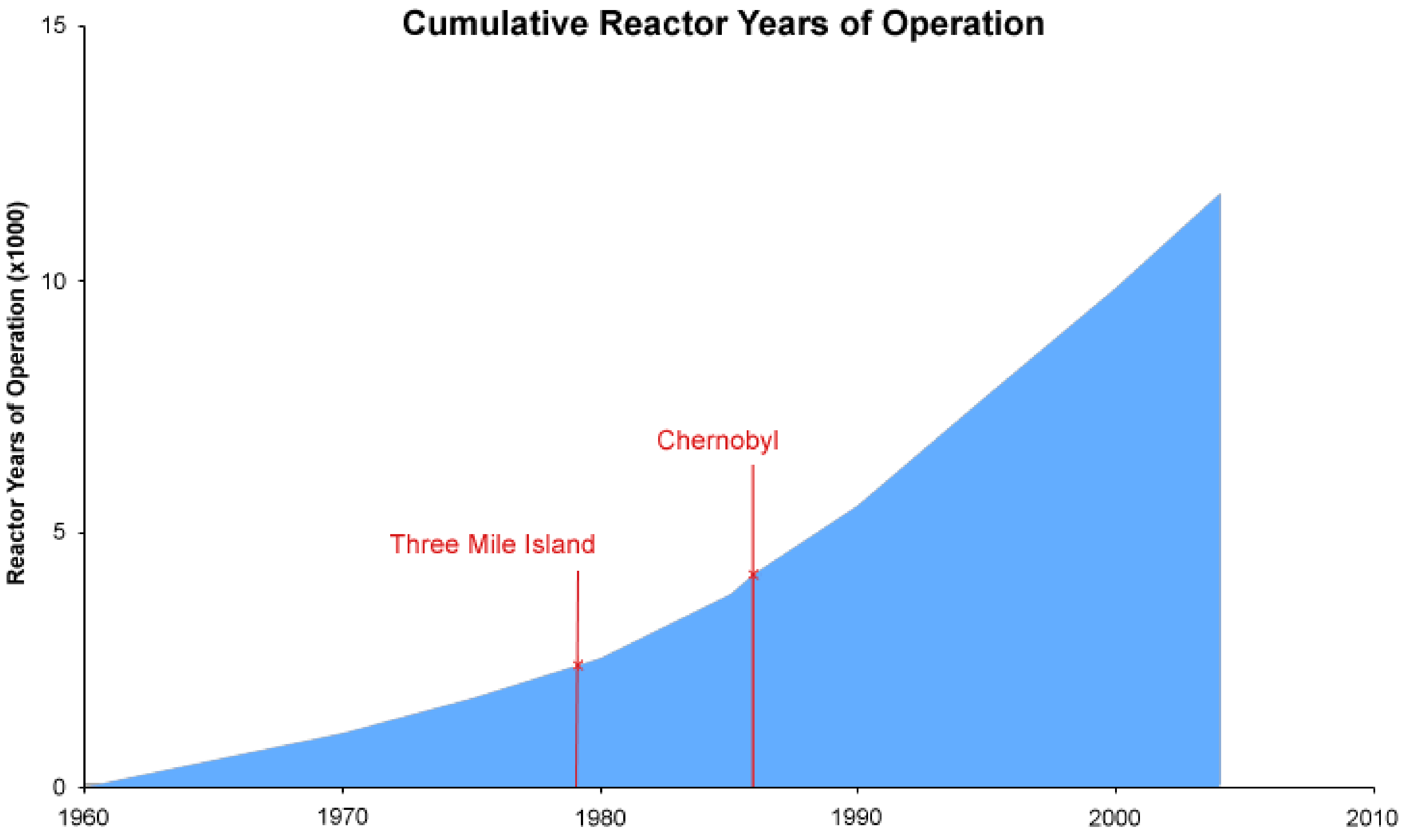
COGEMA

Fuel Assembly
 for Nuclear
Reactor



Sizewell B
UK



A safety record unmatched by any major technology!
12,000+ reactor-years civil, similar for naval

Kashiwazaki Kariwa 6 & 7, Japan

Main late 3rd generation nuclear reactors:

- Areva NP **EPR** - 1600 MWe
- Westinghouse **AP1000** - 1100 MWe
- General Electric **ESBWR** - 1400 MWe
- Korea HNP **APR** - 1400 MWe
- Mitsubishi et al **APWR** - 1500 MWe
- AECL **ACR-1000** - 1000 MWe
- Gidropress **VVER-V448** - 1500 MWe
- Eskom/INET **PBMR** - 165/195 MWe

Generation IV Reactors

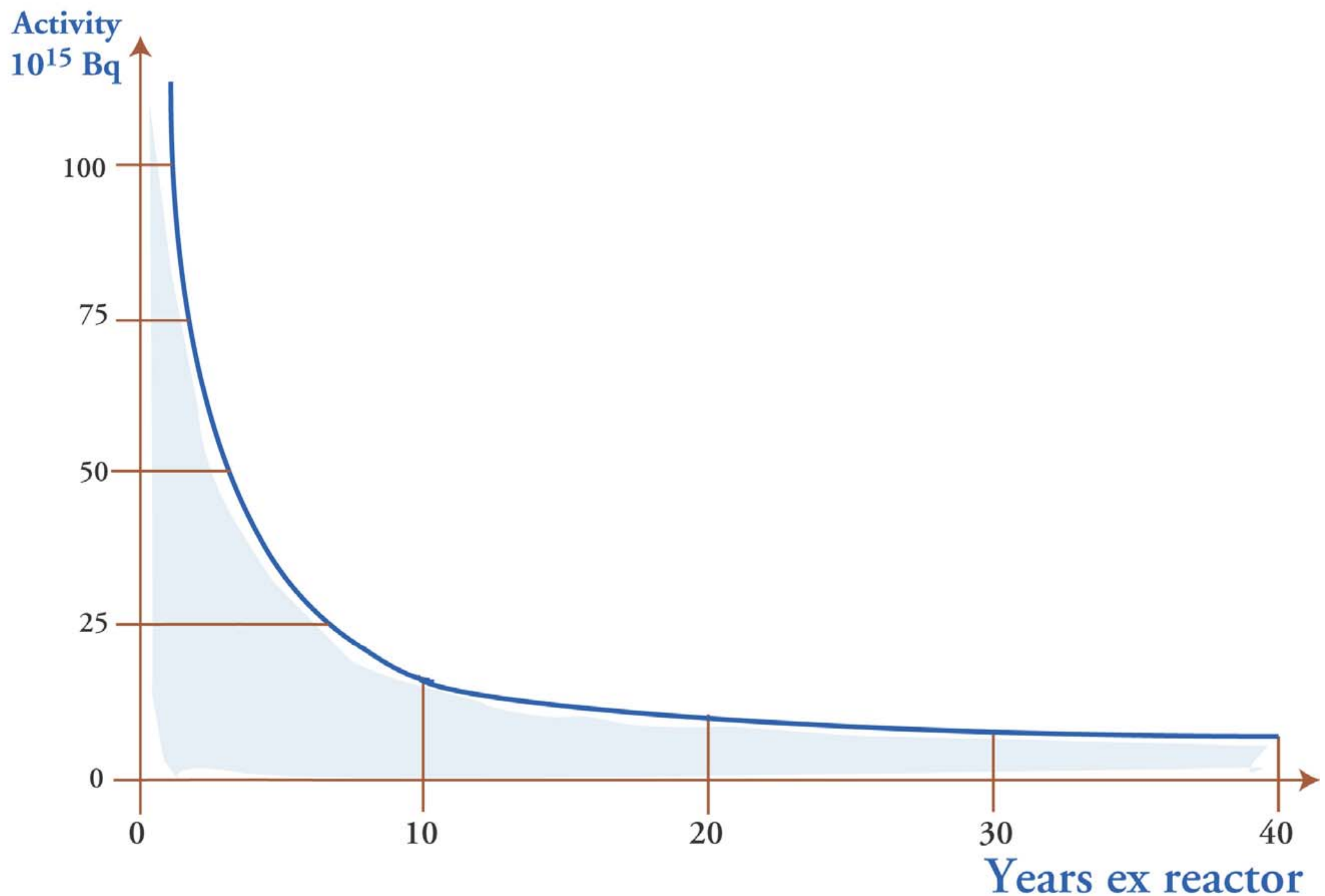
	Neutron spectrum	Coolant, Temp	pressure	Fuel	Uses
Gas-cooled	Fast	Helium 850 C	High	U-238+	Electricity & hydrogen
Lead-cooled	Fast	Lead 550-800 C	Low	U-238+	Electricity & hydrogen
Molten salt	Medium	Fluoride, 700-800 C	Low	Thorium, U-238+	Electricity & hydrogen
Sodium-cooled	Fast	Sodium 550 C	Low	U-238 & MOX	electricity
Super-critical	Fast or slow	Water 550 C	Very High	U-235	electricity
High-temp gas-cooled	Slow	Helium 1000 C	High	U-235	Hydrogen & electricity

Nuclear power costs

Waste management and disposal costs: internalised

Decommissioning costs: internalised

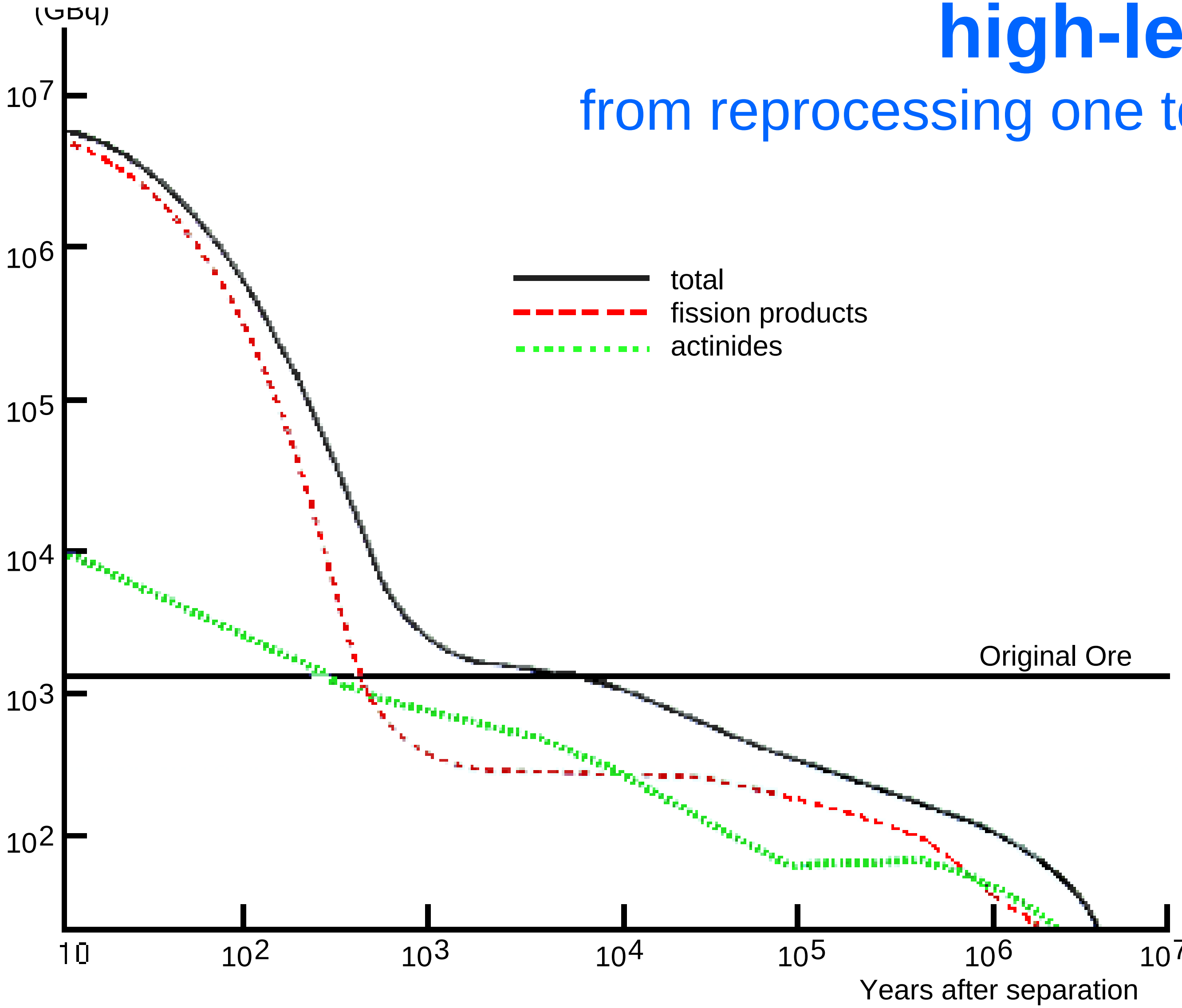
Decay in radioactivity of fission products in one tonne of spent PWR fuel



Cogema

Decay in radioactivity of high-level waste

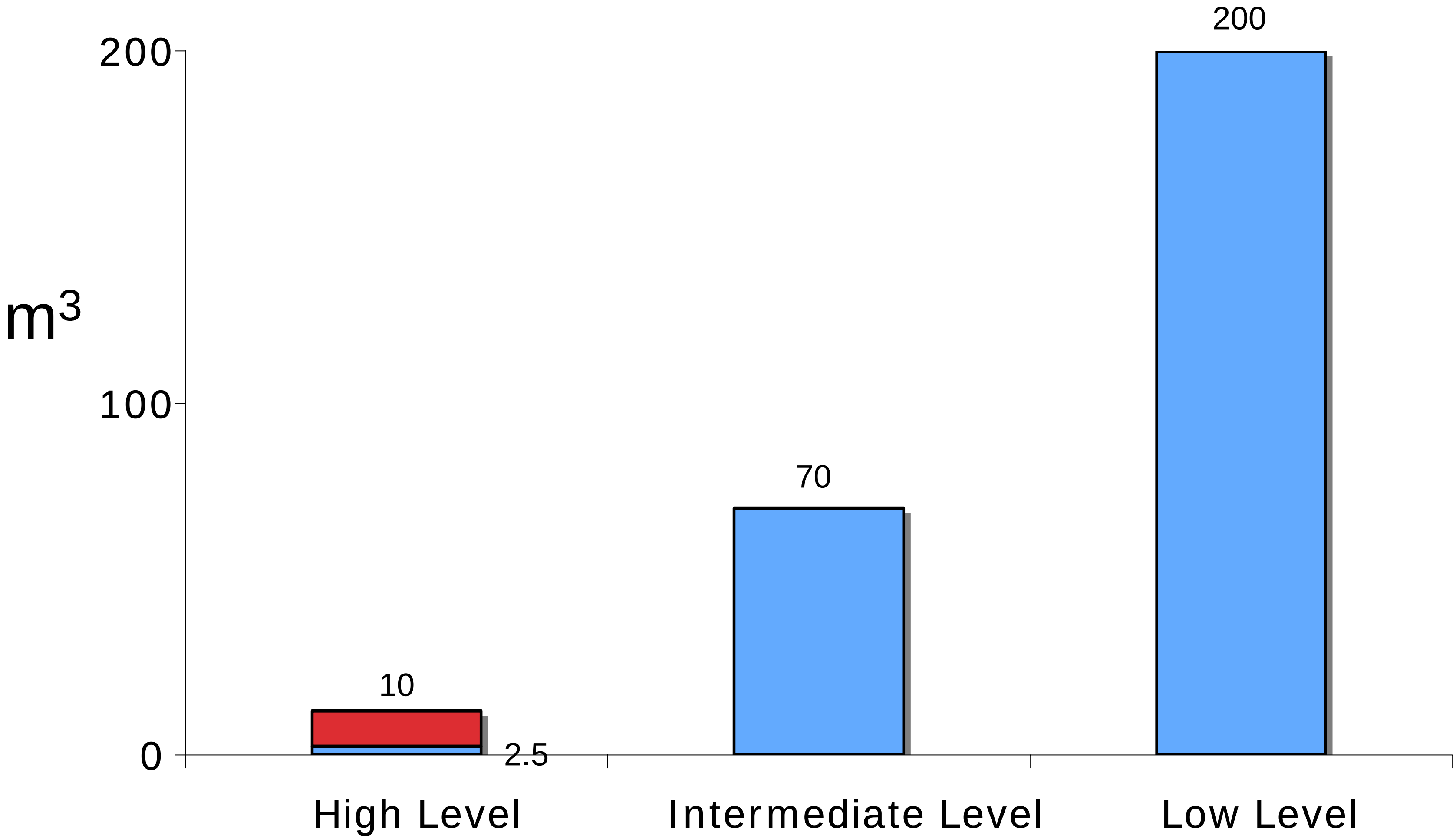
from reprocessing one tonne of spent PWR fuel



Gbq = 109 becquerel
The straight line shows the radioactivity of the corresponding amount of uranium ore.NB both scales are logarithmic.
Source: OECD NEA 1996, *Radioactive Waste Management in Perspective.*

Amount of Radioactive Wastes

(from 1000 MWe for 1 year)



- very small amount of waste for much energy!

Source: OECD NEA 1996

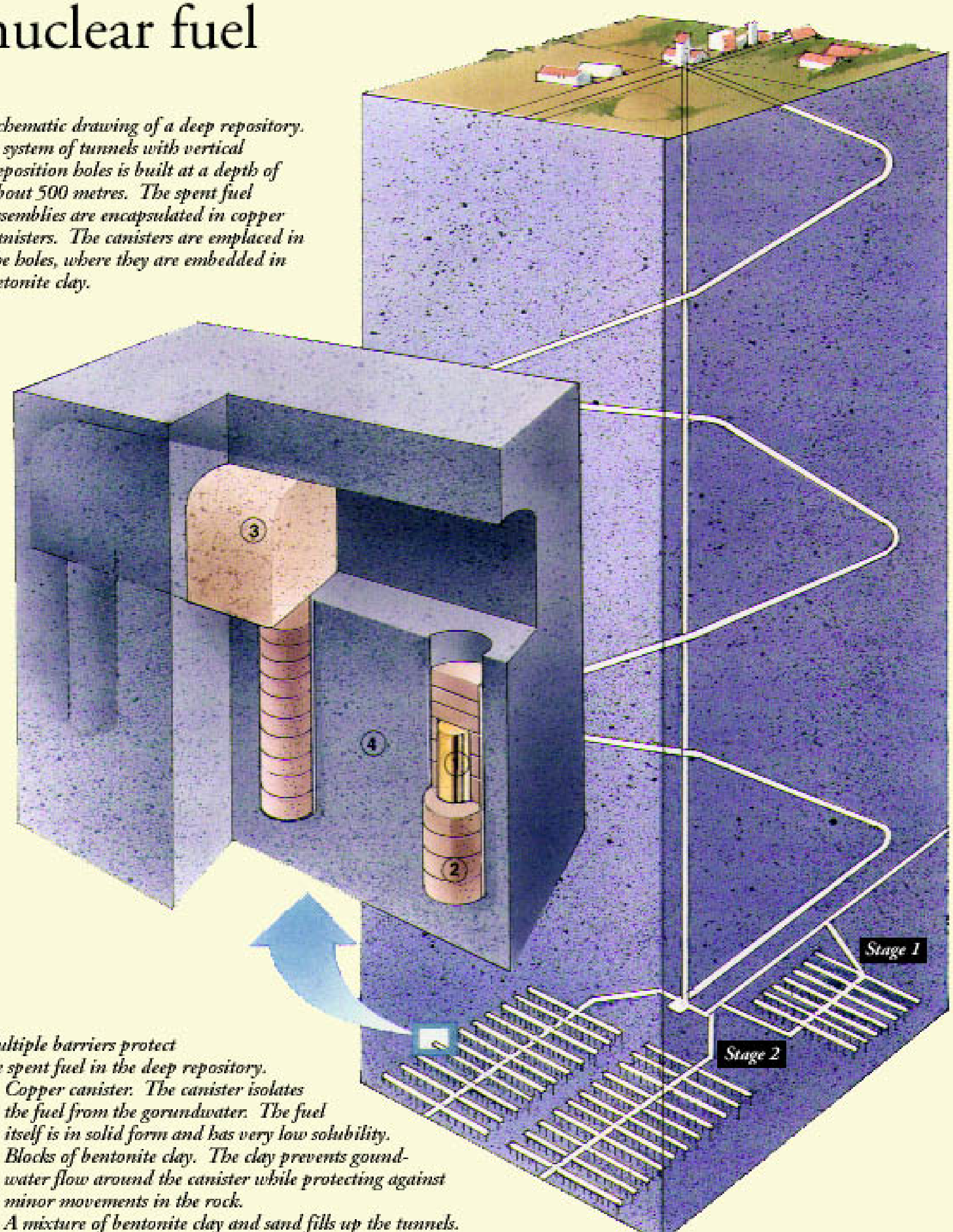
Spent Fuel Storage, Sellafield

Transport Cask,
for spent fuel

Sweden:

Deep repository for spent nuclear fuel

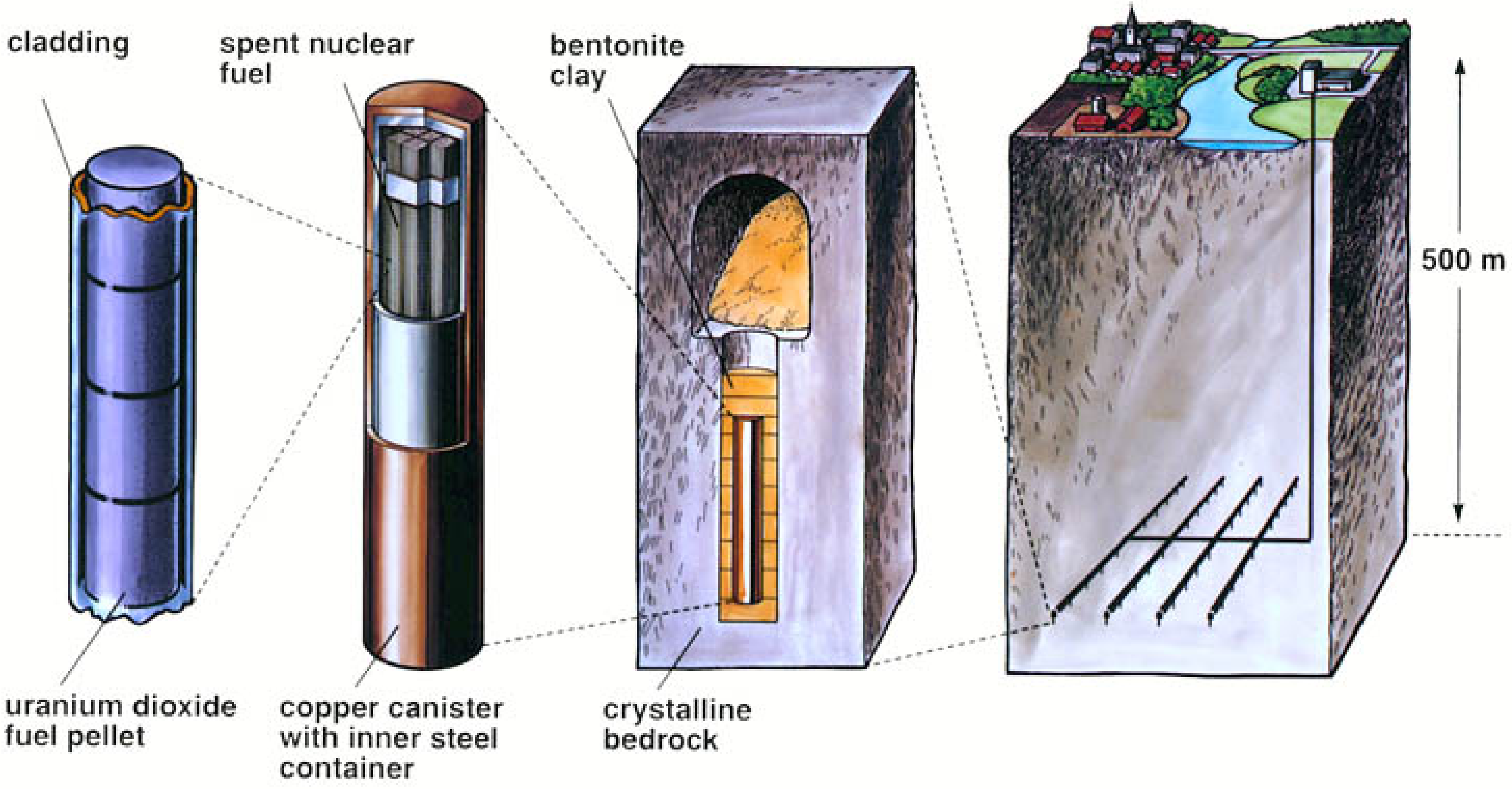
Schematic drawing of a deep repository. A system of tunnels with vertical deposition holes is built at a depth of about 500 metres. The spent fuel assemblies are encapsulated in copper canisters. The canisters are emplaced in the holes, where they are embedded in betonite clay.



Multiple barriers protect the spent fuel in the deep repository.

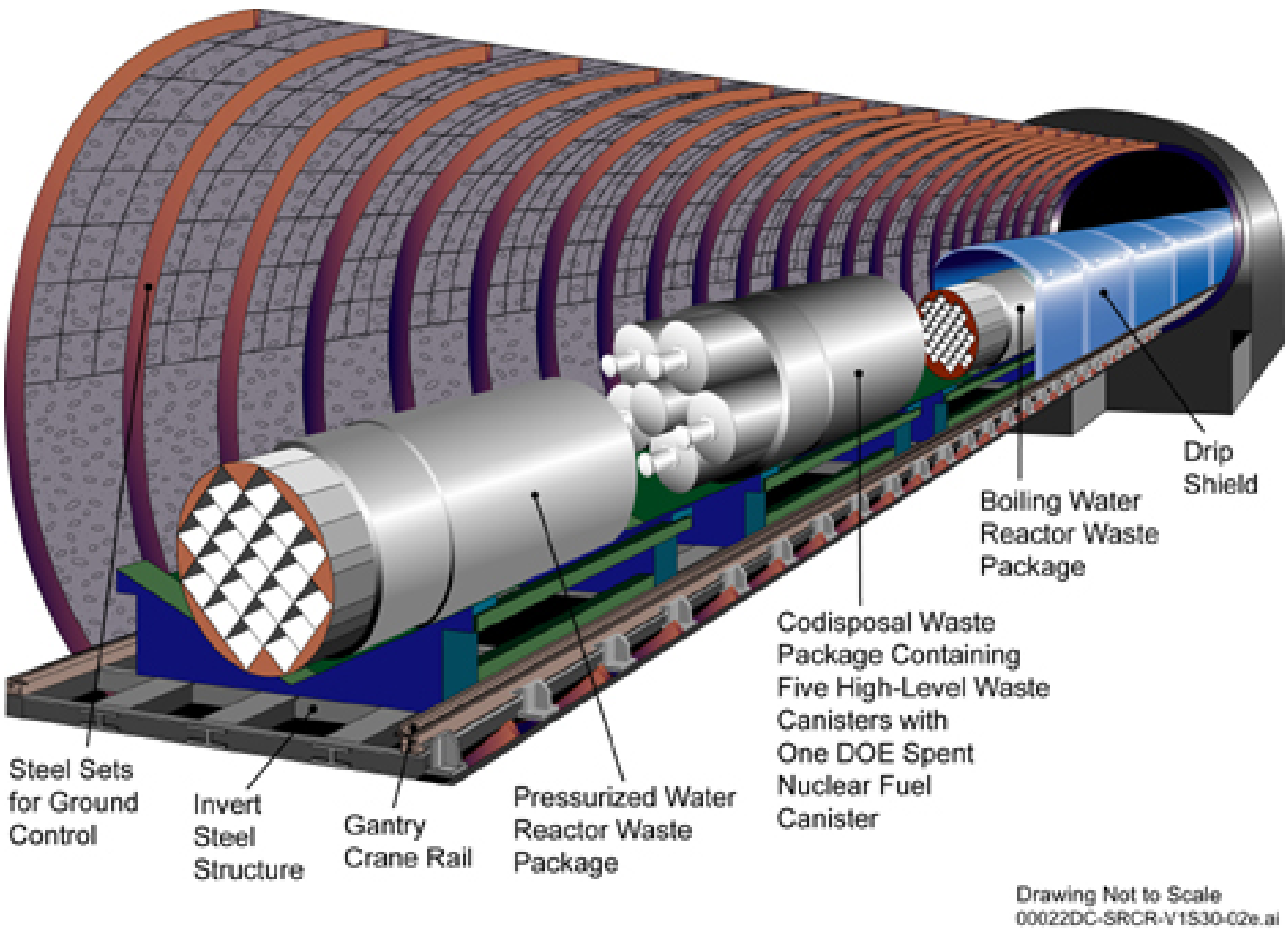
1. *Copper canister. The canister isolates the fuel from the gorundwater. The fuel itself is in solid form and has very low solubility.*
2. *Blocks of bentonite clay. The clay prevents gound-water flow around the canister while protecting against minor movements in the rock.*
3. *A mixture of bentonite clay and sand fills up the tunnels.*
4. *The rock offers a durable environment, both mechanically and chemically. It also acts as a filter for the groundwater.*

Safety barriers



Yucca Mountain, Nevada, USA

Storage of High-Level Wastes under Yucca Mountain



Waste Isolation Plant for ILW, New Mexico

ILW disposal: WIPP, New Mexico

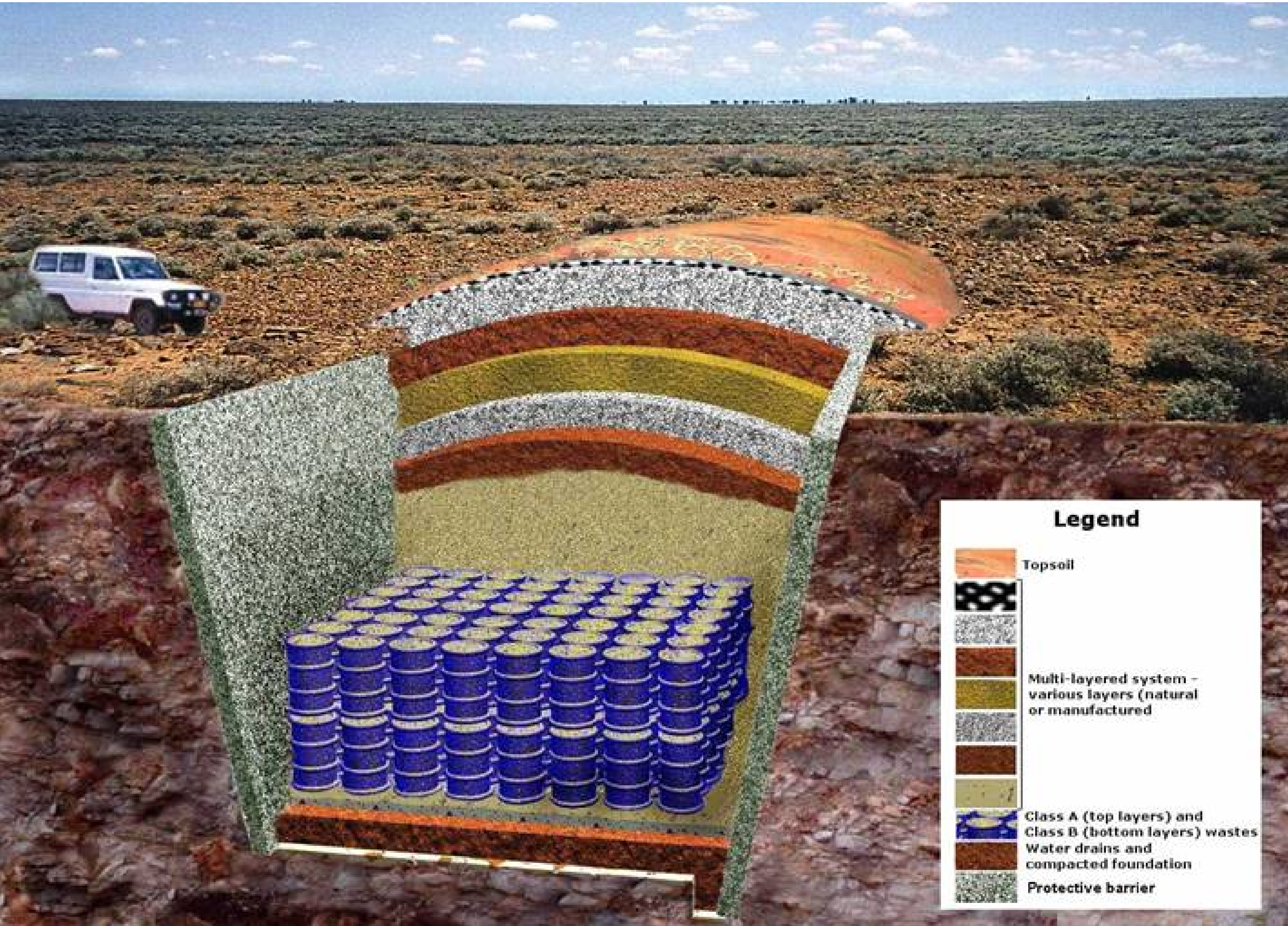
Intermediate-level waste store, Sweden

Low-level waste store

French Low-level waste repository in Normandy

- half million cubic metres

Australian LLW Repository



DEST

Nuclear weapons vs civil programs

- **With nuclear weapons**
- USA, Russia, UK, France, China, India, Pakistan, Israel
- None from civil program
- 1960s expectation of over 30 countries

- **Proliferation concerns**
- Iran - via enrichment, North Korea - via plutonium,
- (formerly: Iraq, Libya, S.Africa)

Nuclear weapons vs civil programs

- **Controlled civil use**
- 28 countries plus Taiwan - under NPT
- + India, Pakistan - partly under NPT

- **Proliferation concerns**
- Not related to civil program
- Iran, North Korea

Clearly need to focus on problems. But how?

Nuclear Desalination

Reverse osmosis - electric pumps off-peak

Distillation - scope for cogeneration

Transport & Hydrogen Economy

- Plug-in Hybrid Electric Vehicles
- Then hydrogen in fuel cells
- Now: 50 million tonnes per year hydrogen, future: 1000 Mt/yr +
- Now: steam reforming of natural gas
- High temperature electrolysis of water
- Thermochemical production from water using nuclear heat - needs 950ºC

The Nuclear Future

- Mature technology
- Increasingly competitive
- Environmental drivers
- Energy security drivers - EU & USA
- Part of future supply more widely

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