

Nuclear Energy: The Future.

An Overview of World Activities

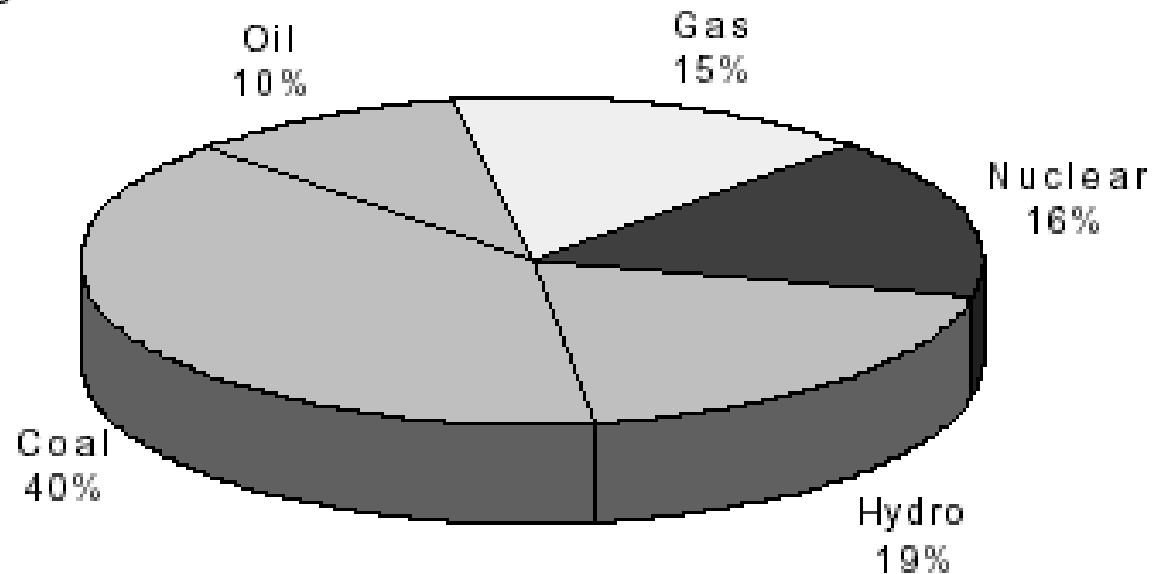
Professor John H Gittus.

F R Eng. D Sc. D Tech.

Nuclear Resources: Reactors and Fuel.

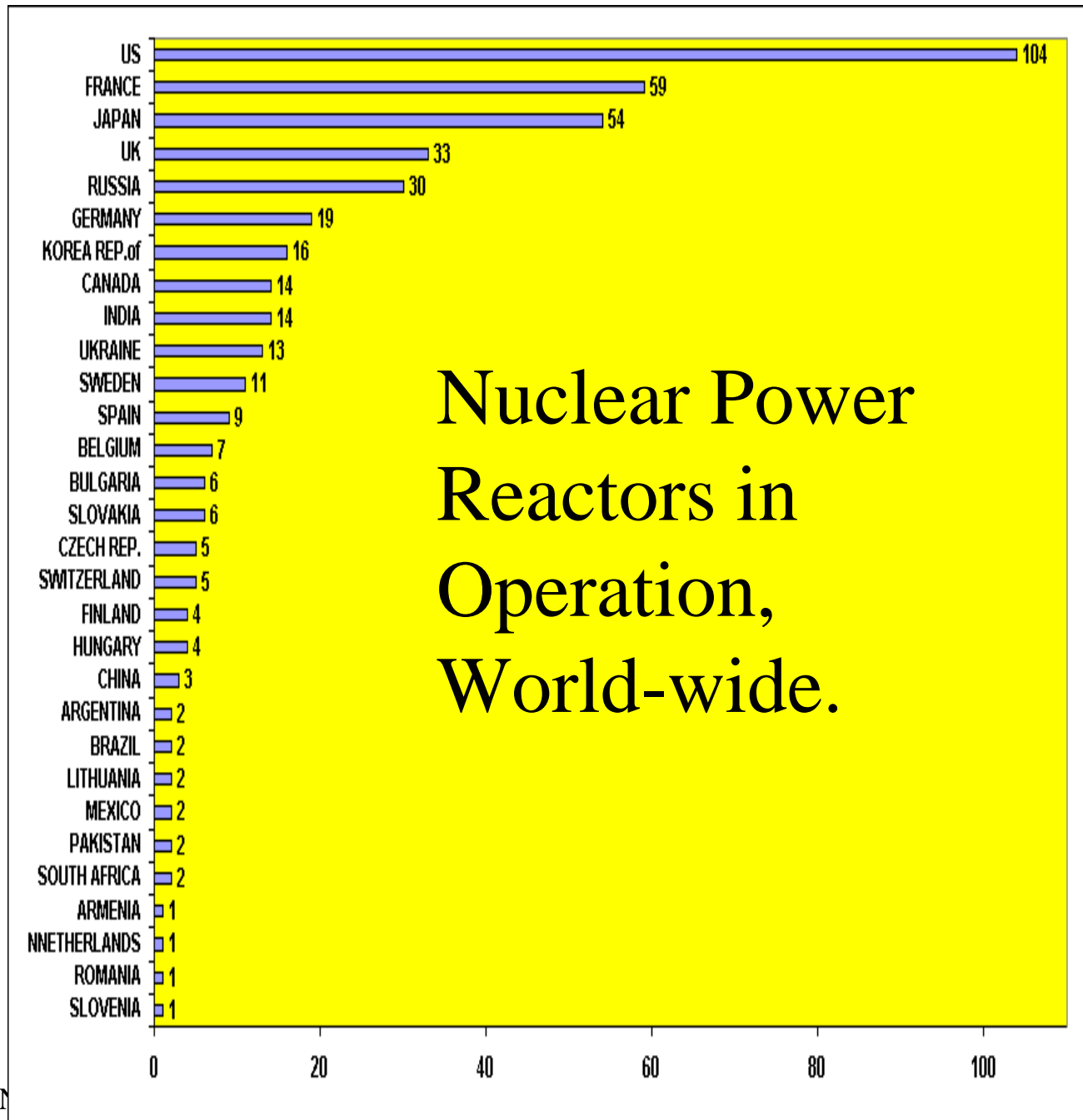
Nuclear Power Provides about 16% of the World's Electricity.

World Electricity



Nuclear Power Reactors in the World.

- 31 countries have a total of 437 commercial nuclear power reactors.
- They produce over 16% of the world's electricity.
- A further 31 commercial power reactors are under construction and
- 25 more commercial power reactors are planned
- In addition, 56 countries have 284 civil research reactors operating.



Power Reactors Under Construction

| YEAR † | COUNTRY | REACTOR | TYPE | MWe |
|--------|----------------|-------------|------|-----|
| 2001 | Czech Republic | Temelin 2 | PWR | 912 |
| 2002 | Japan | Onagawa 3 | BWR | 796 |
| 2002 | Korea RO | Yonggwang 5 | PWR | 950 |
| 2002 | Korea RO | Yonggwang 6 | PWR | 950 |
| 2002 | China | Qinshan 2 | PWR | 610 |
| 2002 | China | Lingao 1 | PWR | 935 |
| 2002 | Argentina | Atucha 2 | PHWR | 692 |
| 2003 | Romania | Cernavoda 2 | PHWR | 650 |
| 2003 | Iran | Bushehr 1 | PWR | 950 |
| 2003 | China | Lingao 2 | PWR | 935 |
| 2003 | China | Qinshan 3 | PWR | 610 |
| 2003 | China | Qinshan 4 | PHWR | 665 |

| | | | | |
|------|----------|---------------|------|------|
| 2004 | China | Qinshan 5 | PHWR | 665 |
| 2004 | Russia | Kalinin 3 | PWR | 950 |
| 2004 | Russia | Kursk 5 | RBMK | 925 |
| 2004 | Ukraine | Khmelnitski 2 | PWR | 950 |
| 2004 | Taiwan | Lungmen 1 | ABWR | 1350 |
| 2004 | Korea RO | Ulchin 5 | PWR | 950 |
| 2004 | China | Tianwan 1 | PWR | 950 |
| 2005 | Korea RO | Ulchin 6 | PWR | 950 |
| 2005 | Japan | Higashidori 1 | BWR | 1067 |
| 2005 | Japan | Hamaoka 5 | ABWR | 1325 |
| 2005 | Taiwan | Lungmen 2 | ABWR | 1350 |
| 2005 | Russia | Rostov-2 | PWR | 950 |
| 2005 | China | Tianwan 2 | PWR | 950 |
| 2005 | India | Tarapur 3 | PHWR | 450 |
| 2006 | Ukraine | Rovno 4 | PWR | 950 |
| 2006 | Japan | Shika-2 | ABWR | 1315 |
| 2006 | India | Tarapur 4 | PHWR | 450 |
| 2006 | Russia | Balakovo 5 | PWR | 950 |

† Latest announced year of proposed commercial operation. Onagawa-3 started up recently.

Initiatives to Build New Nuclear Power Stations

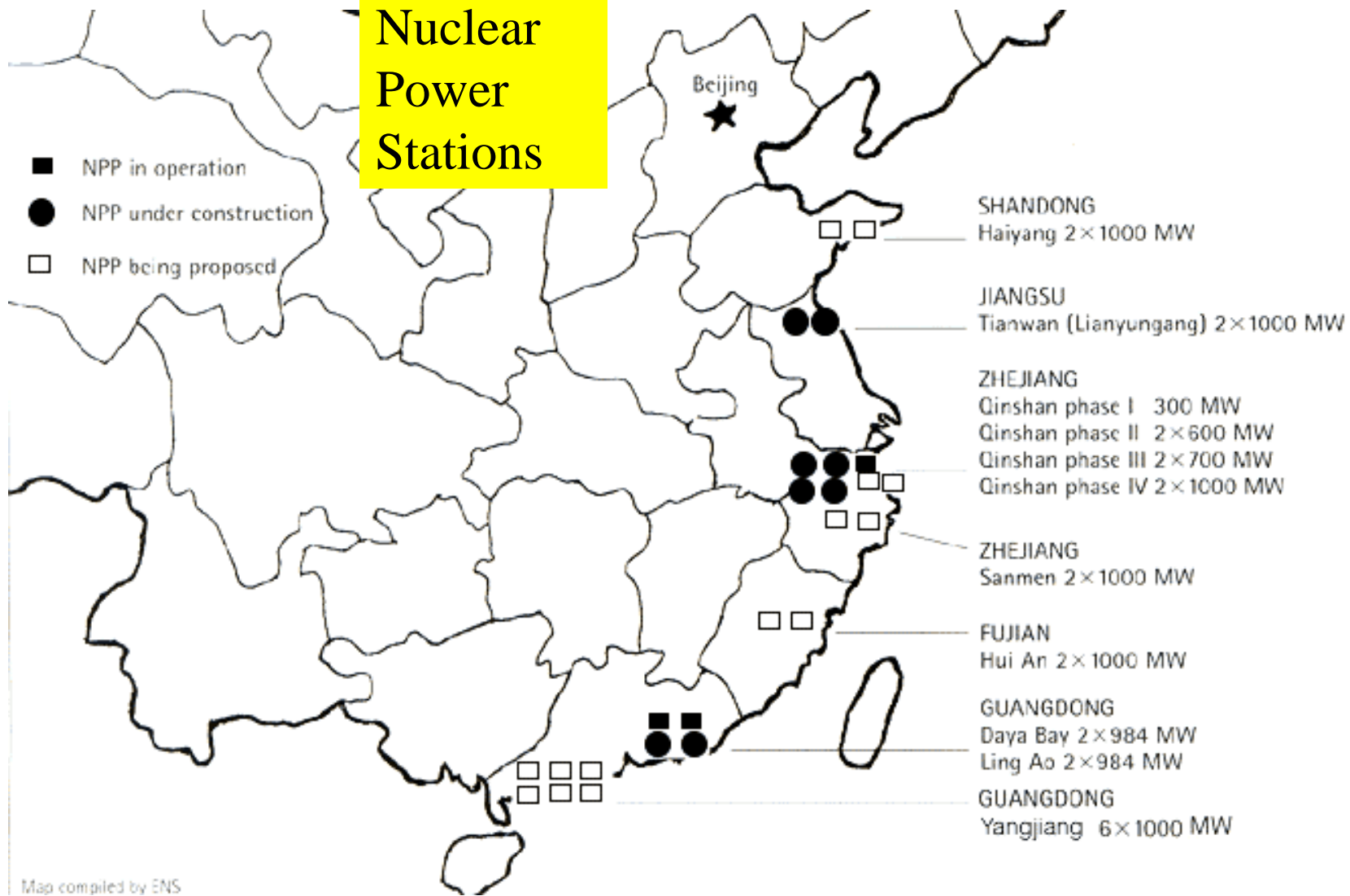
- U.S. Energy Secretary Spencer Abraham's recent "Nuclear Power 2010" initiative
- British Nuclear Fuels plc (BNFL)/British Energy (BE) collaborative venture to look into the feasibility of building the AP 1000 reactor in the U.K. and
- A similar effort in the U.S. involving BNFL, Bechtel and a seven-utility consortium.
- Finland's decision to build a new Nuclear Power Station.

Some Power Reactors planned or on order

| start operation | start construction | COUNTRY | REACTOR | TYPE | MWe (each) |
|-----------------|--------------------|-------------|--------------------|---------------|------------|
| 2006 | 2002 | India | Kudankulam | PWR (VV-1000) | 950 |
| 2006-7 | 2002 | Japan | Fukushima 7 & 8 | ABWR | 1325 |
| 2007-8 | | North Korea | Sinpo 1 & 2 | PWR (KNSP) | 950 |
| 2008 | 2003 | Japan | Ohma | ABWR | 1350 |
| 2007-8 | | Russia | Sosnovy Bor 1 | PWR (VV-640) | 600 |
| 2010 | | Russia | Balakovo 6 | PWR | 950 |
| 2010-11 | 2003? | RO Korea | Kori 1 & 2 | PWR (KNSP) | 950 |
| 2009-10 | 2003? | RO Korea | Wolsong 5 & 6 | PWR (KNSP) | 950 |
| 2008 | 2003 | Japan | Tomari 3 | PWR | 912 |
| 2010 | 2003 | Japan | Tsuruga 3 & 4 | APWR | 1500 |
| 2010 | 2003 | Japan | Shimane 3 | ABWR | 1375 |
| | | India | Rajasthan 5 - 8 | PHWR | 450 |
| | | India | Kaiga 3 - 6 | PHWR | 450 |
| | | RO Korea | Kori 3 & 4 | APR (KNGR) | 1350 |
| | | RO Korea | | APR (KNGR) | 1350 |
| 2010-11 | 2003-5 | Japan | Higashidori 1-2, 2 | ABWR | 1320 |
| 2012-15 | 2007-10 | Japan | Kaminoseki 1-2 | ABWR | 1320 |

according to announcements 1998-2001

China's Nuclear Power Stations



New Reactors for the USA.

- Exelon has announced that it is considering applying for permission to build a new reactor on its Clinton site.
- Entergy has announced that it intends to apply for funding under Bush's Nuclear 2010 scheme, with which to develop an application to build a new reactor on its Grand Gulf site.

New Designs of Reactors Under Development.

- General Atomics' (GA) HTR
- ESKOM PBMR.
- CNNC HTR 10,
- JAERI HTTR.
- BNFL AP 1000
- ABWR
- APWR.

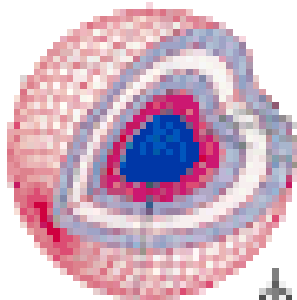
Fuel for PBMR.



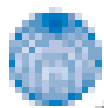
Coated Particle for HTR.

TRISO COATING

Outer Isotropic Pyrolytic Carbon
Silicon Carbide Barrier Coating
Inner Isotropic Pyrolytic Carbon
Porous Pyrolytic Carbon Buffer



ϕ 1mm

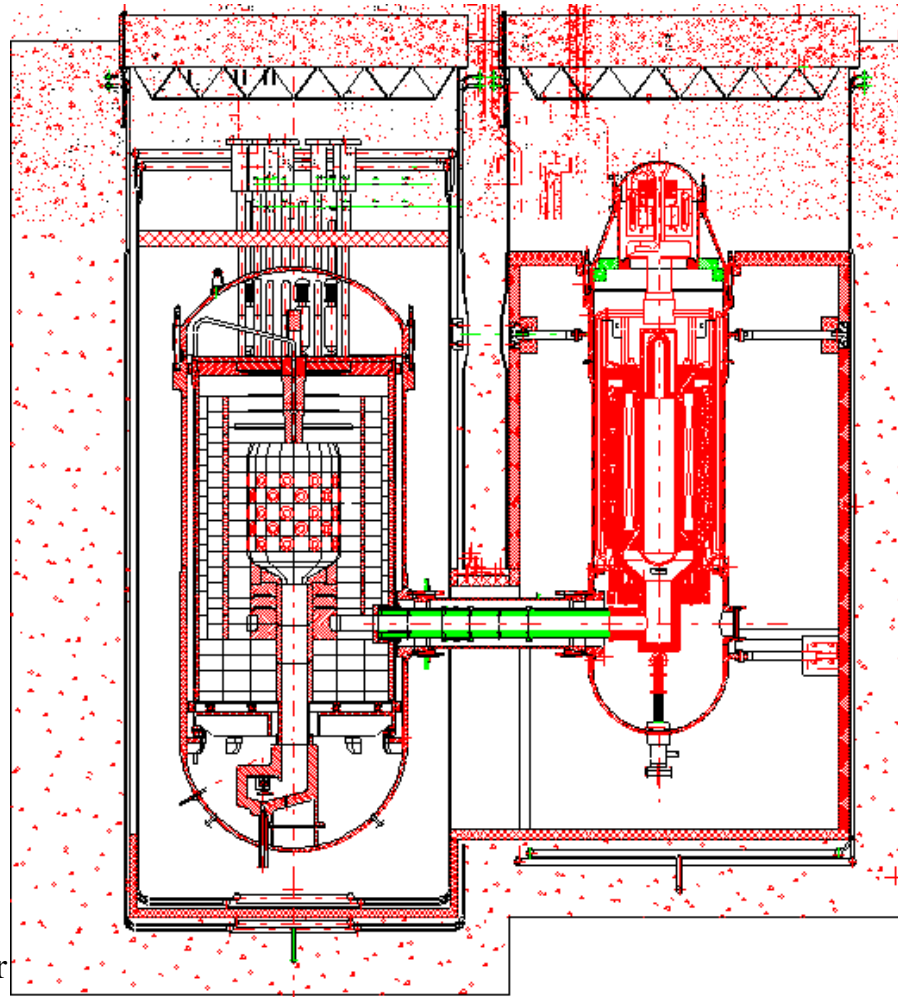


Uranium Dioxide
 ϕ 0.5mm

China's HTR 10 Reactor, for Process Heat and Electricity.

- This reactor will come into operation in September 2002.
- It is a Pebble Bed Reactor, moderated by graphite and cooled by Helium.
- It will produce electricity from steam and (later) a gas turbine.
- It will produce hot helium for use as a primary source of energy: process heat.

The HTR 10, 10MW High Temperature Reactor.

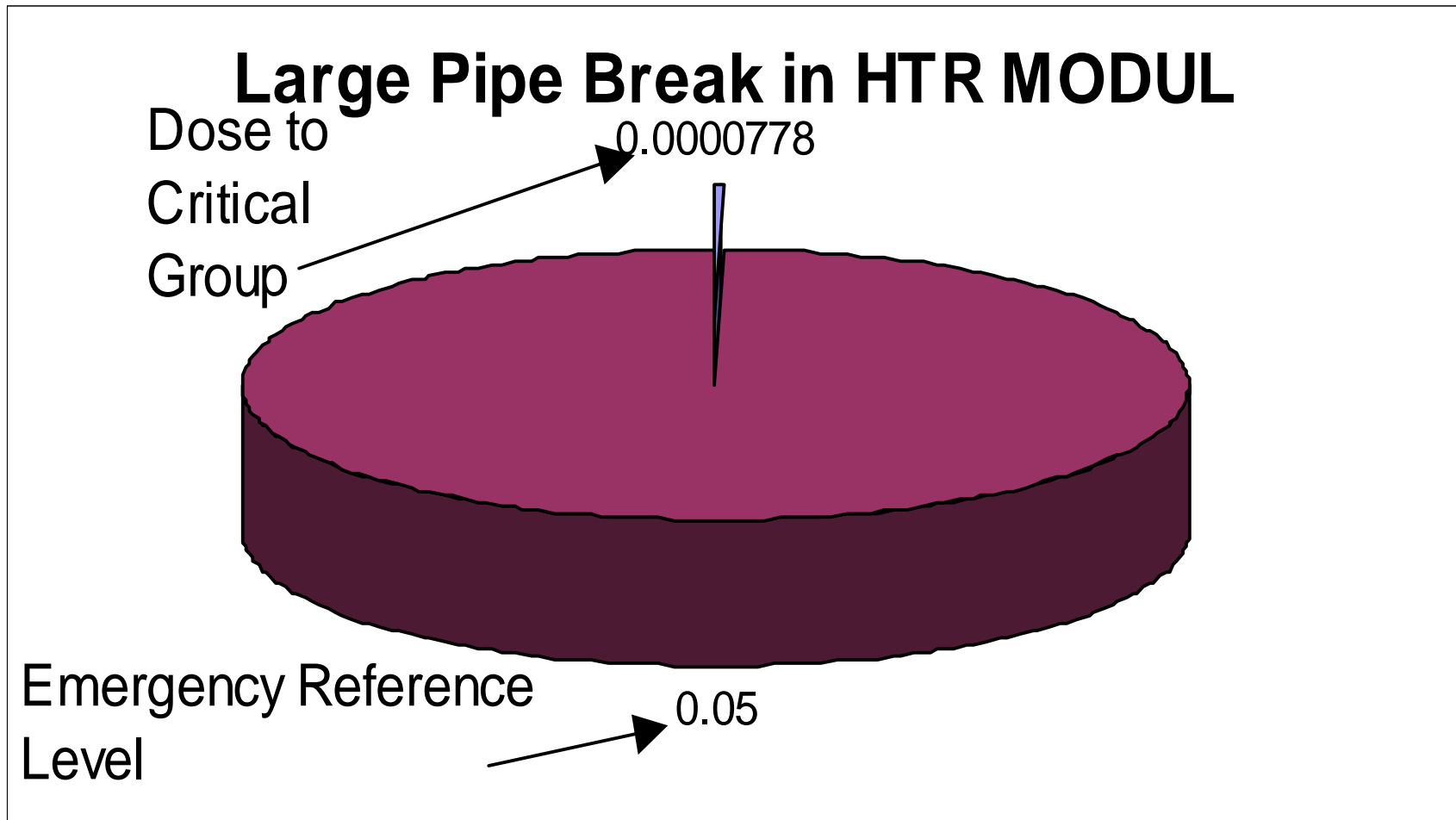


Future of Nuclear
Energy

Japan's 30 MW HTTR.

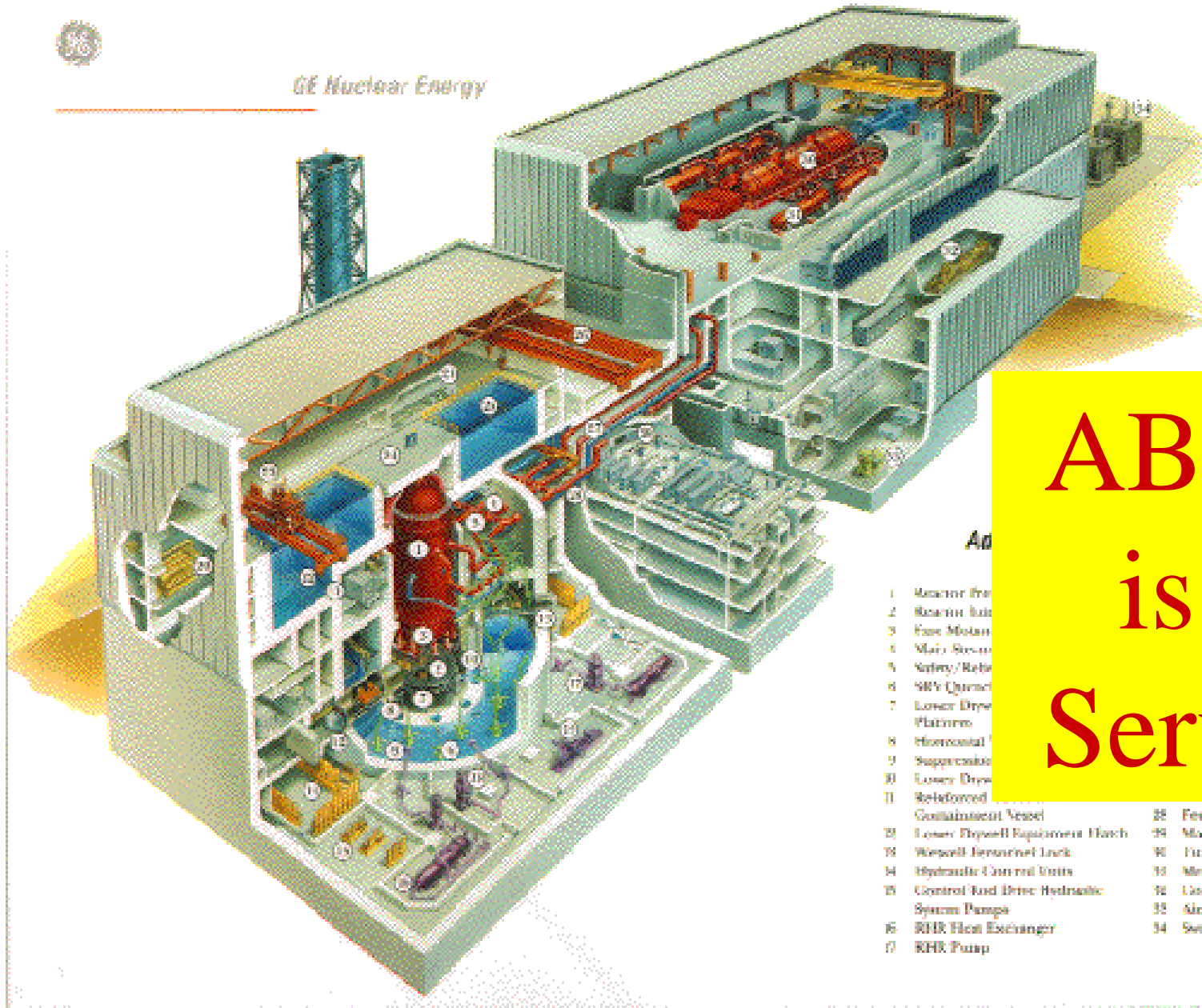
- On November 10th 1998 the JAERI HTTR went critical.
- It heats Helium to 900 deg C.
- Its main purpose is the development of a method of producing Hydrogen from water.
- This Hydrogen is a Primary Fuel, which can substitute for oil, coal and gas in Transport and Industry.

New Reactors are Very Safe:





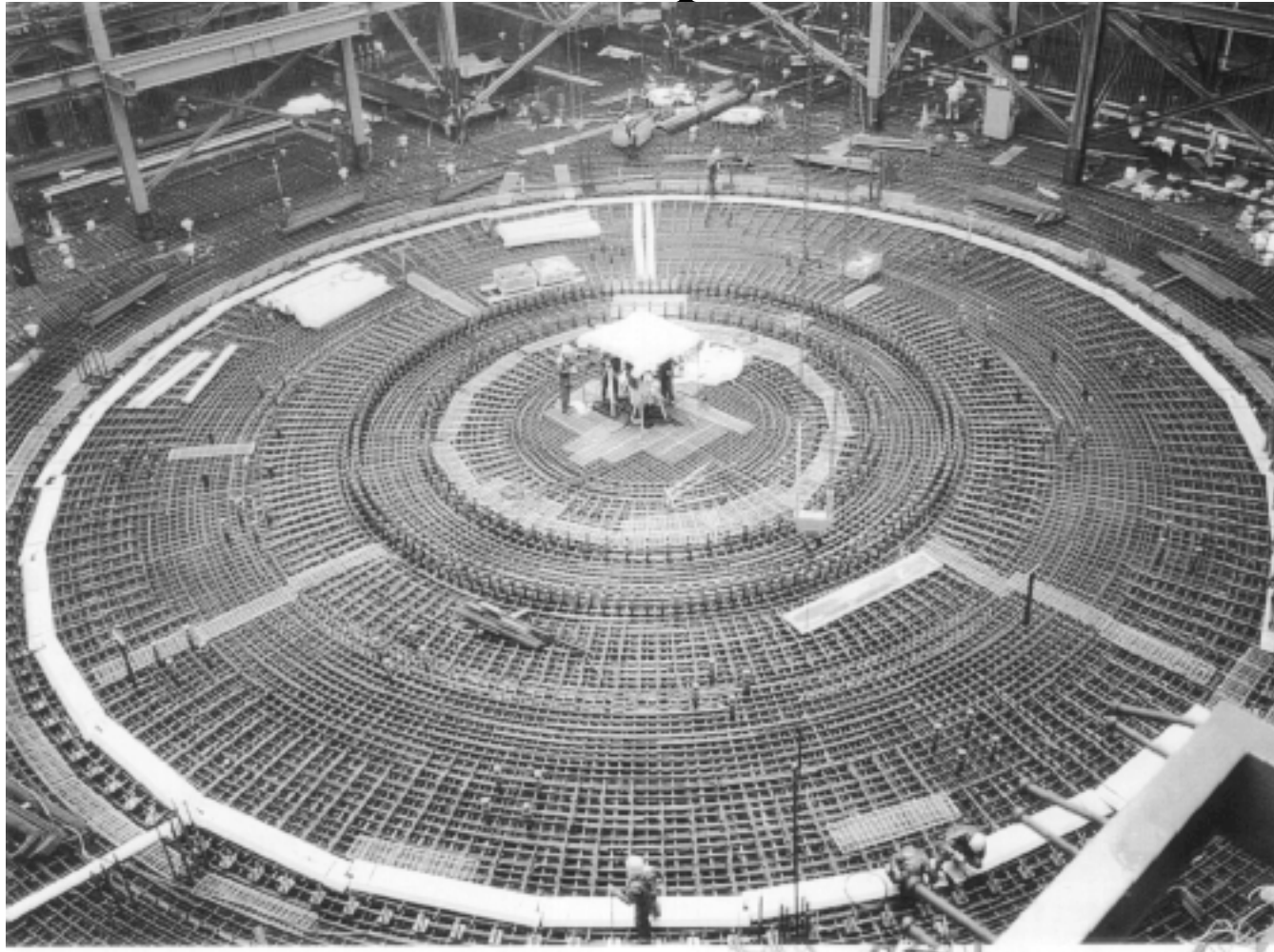
GE Nuclear Energy



ABWR
is in
Service

- Ad
- | | | | |
|----|-----------------------------|----|--------------------------------|
| 1 | Reactor Vessel | 28 | Feedwater Lines |
| 2 | Reactor Inlet | 29 | Main Control Room |
| 3 | Core | 30 | Turbine-Generator |
| 4 | Main Steam | 31 | Mixing Separator-Relocater |
| 5 | Safety/Relief | 32 | Condensation Turbine-Generator |
| 6 | SRV Quench | 33 | Air Compressor and Dryers |
| 7 | Lower Dryer | 34 | Switchyard |
| 8 | Platform | | |
| 9 | Horizontal | | |
| 10 | Supercritical | | |
| 11 | Reinforced | | |
| 12 | Containment Vessel | | |
| 13 | Lower Dryer/Relocater Hatch | | |
| 14 | Weghoff Reinforced Leak | | |
| 15 | Hydraulic Control Units | | |
| 16 | Control Rod Drive Hydraulic | | |
| 17 | System Pumps | | |
| 18 | RHR Heat Exchanger | | |
| 19 | RHR Pump | | |

ABWR Under Construction in Japan



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Overview of World Activities: Gittus

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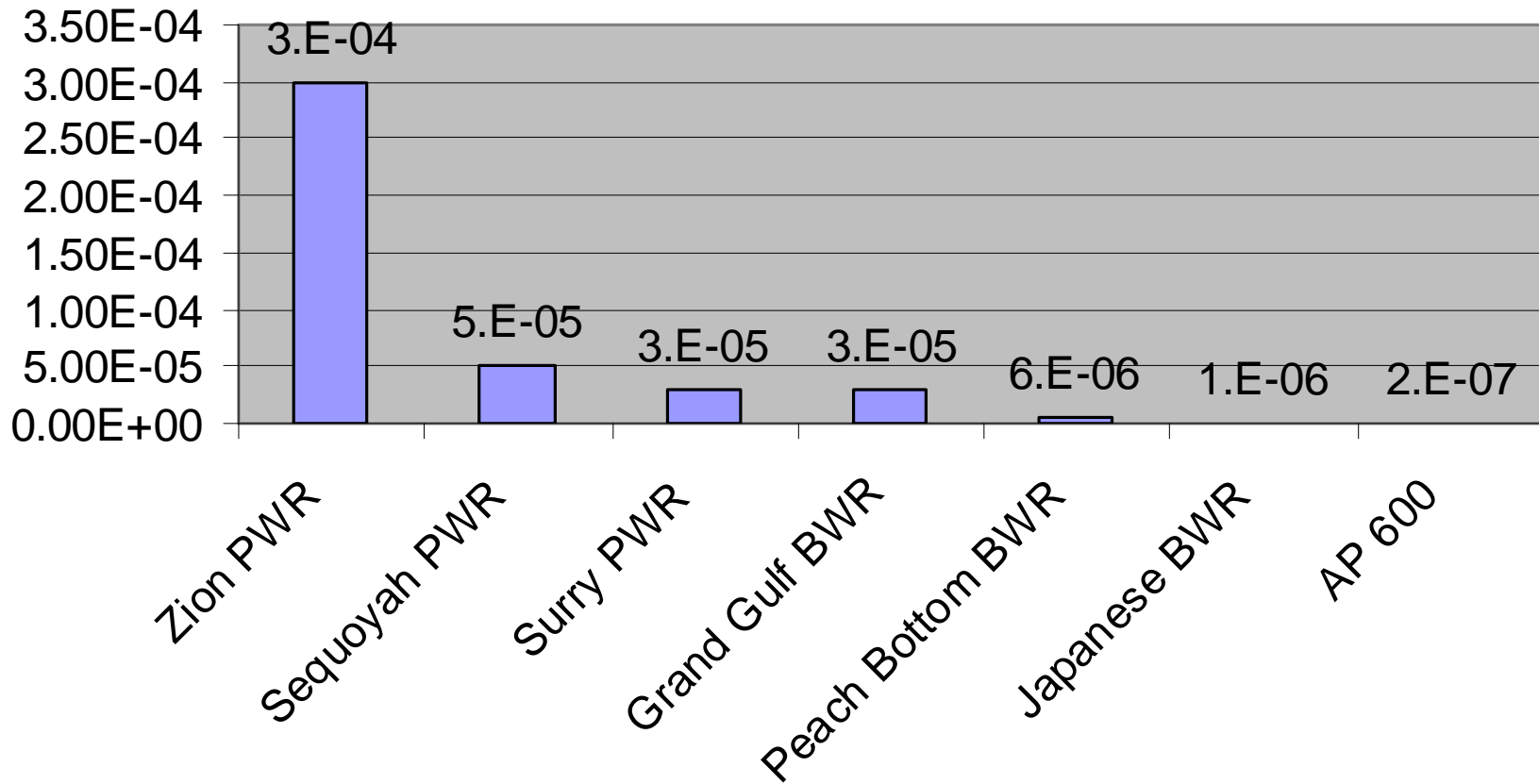
PSA Results for ABWR

- ABWR Core Damage Frequency, per Reactor.Year $< 3 \times 10^{-7}$
- ABWR Containment Failure Frequency, per Reactor.Year $< 6 \times 10^{-8}$

NG Candu

- The NG CANDU concept will combine the heavy water moderator of the CANDU with the compact pressurised light water cooling of the PWR.
- The aim is to achieve an overnight capital cost target of USD \$1000/kWe, and
- Be ready for market by the end of 2005.
- Levelised unit energy costs are projected to be around 30 US\$/MWh, while
- Availability is put at 90 per cent .

Core Damage Frequencies, Per Reactor Year



Reserves of Uranium

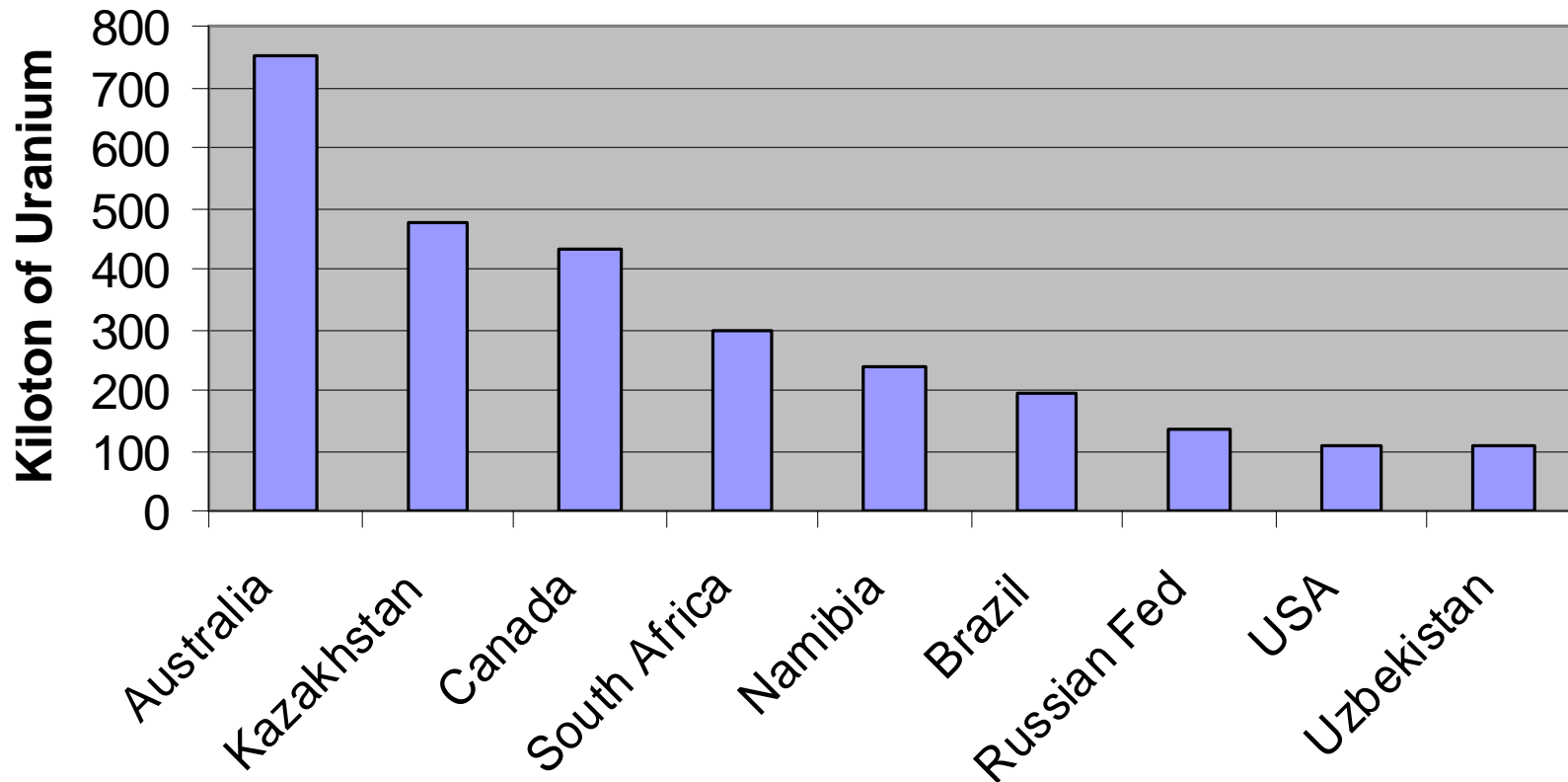
- Known Reserves of Uranium are adequate for more than 65 years for a world program of the present size.
- Potential Reserves, the use of MOX and ex-military U_{235} and Pu_{239} raise this to over 300 years.
- The Fast Breeder Reactor would raise this to over a thousand years.
- Uranium prices are low and non-volatile.

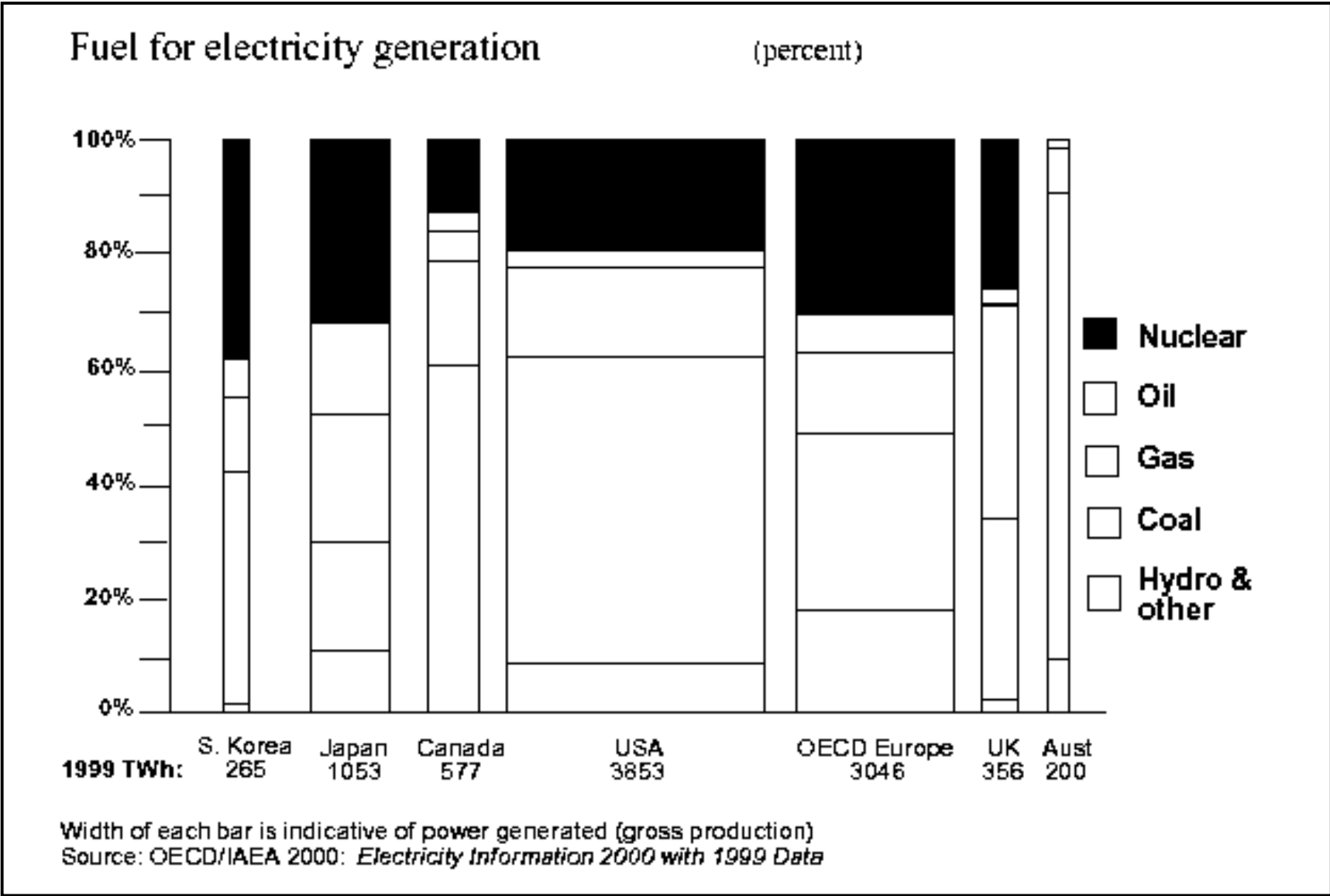
Burning The UK Plutonium Stockpile as MOX.

- The U.K. stockpile of plutonium could be burned in new AP1000s rather than immobilizing it as a waste.
- This would result in a discounted "resource cost saving" to the U.K. of between 700-million and 1.2-billion pounds.

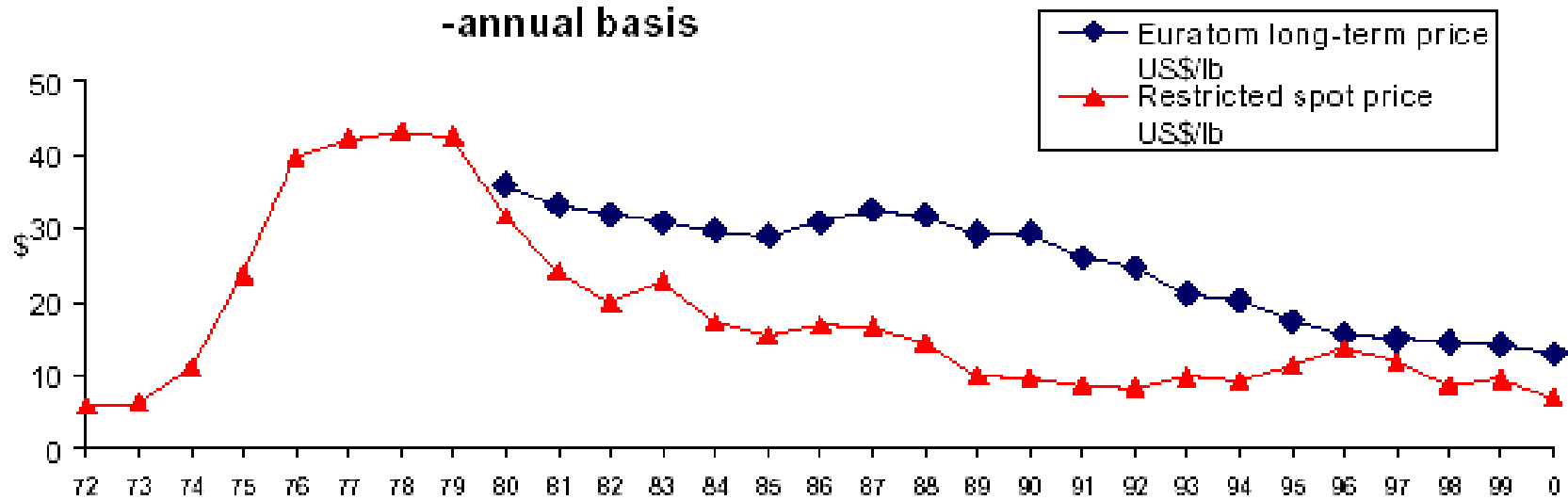
[Conclusion of an evaluation of the two options by former British Nuclear Fuels plc (BNFL) board member Bill Wilkinson, February 2002].

Reserves of Uranium, kton U

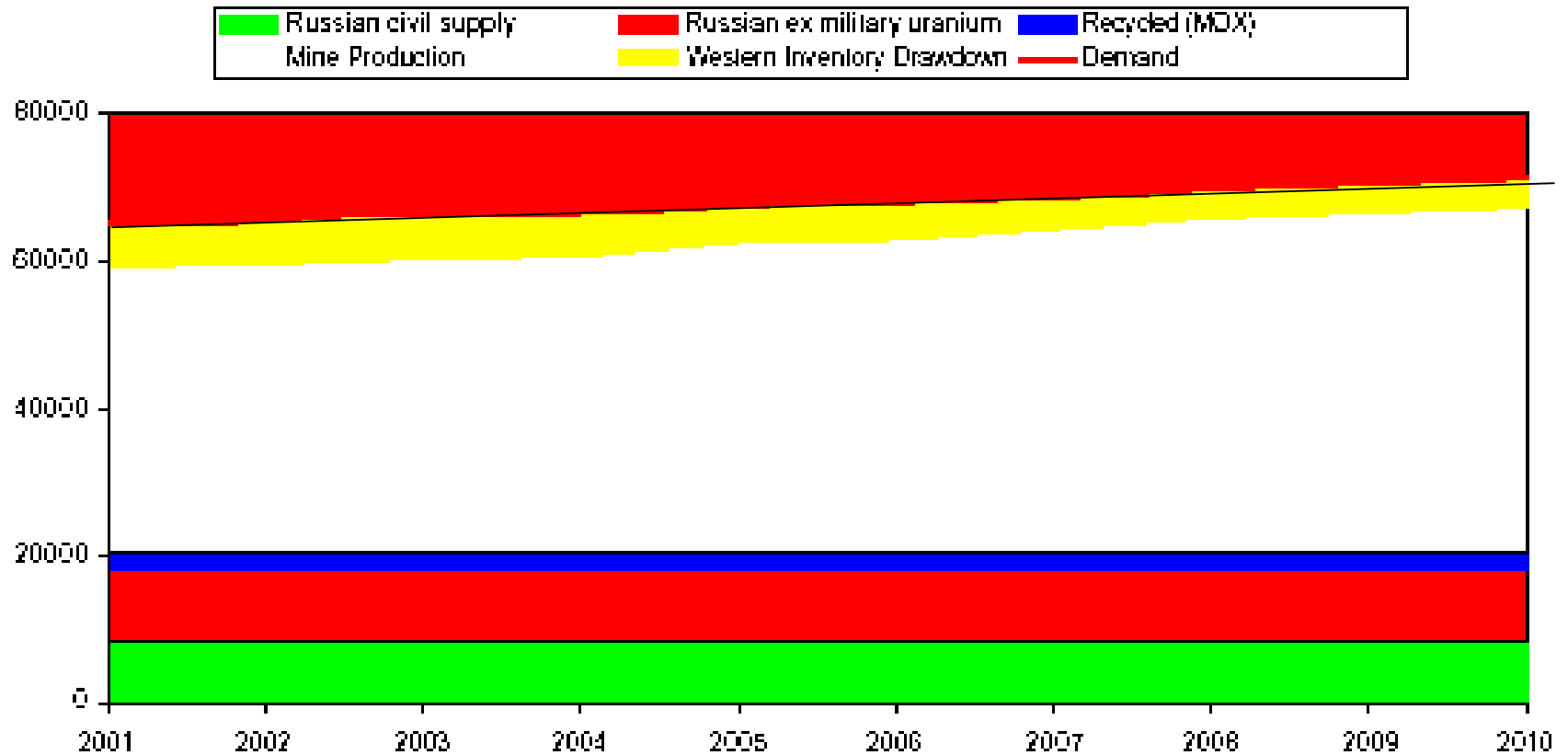




Uranium (U_3O_8) Prices 1972-2000
-annual basis



World Supply and Demand Scenario (tonnes U)



Sources: Demand for reactors: World Nuclear Association 2001 (reference scenario for demand)
Other data: Industry estimates

Conclusions On Nuclear Resources: Reactors and Fuel.

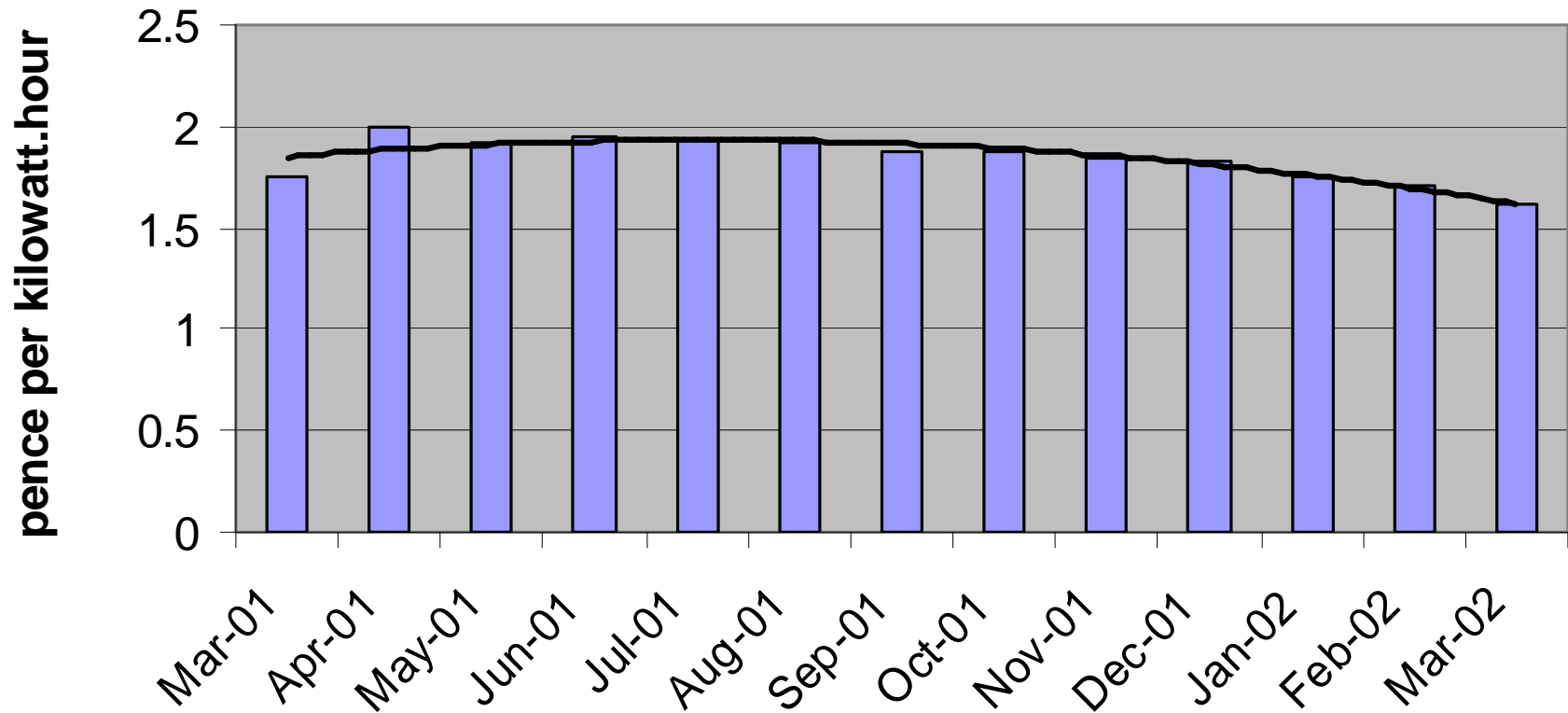
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2. U.S. Energy Secretary Spencer Abraham's recent "Nuclear Power 2010" initiative aims to help build more, in USA.
3. Cheaper, safer reactors are in late stages of development.
4. Known and potential Uranium reserves, the use of MOX and ex-military U235 and Pu239 will extend the world's nuclear fuel reserves to over 300 years.

Economics: Production Costs and the Cost to the Environment.

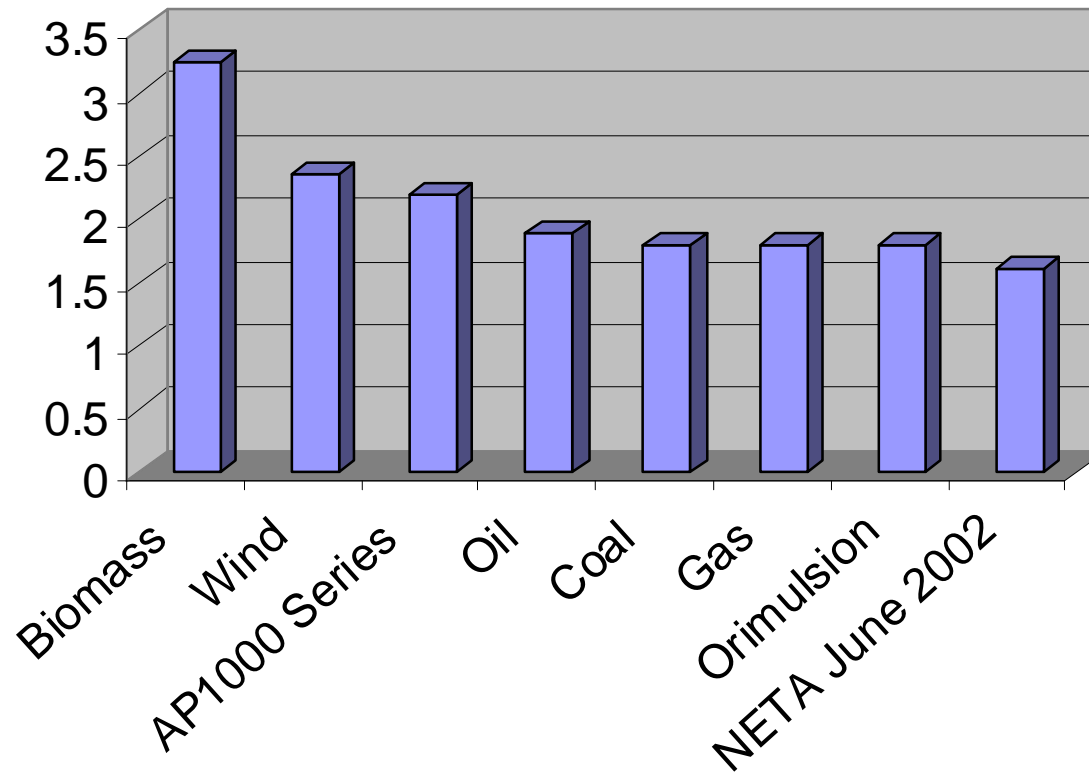
Economics: NETA

- The New Electricity Trading Arrangements (NETA) were introduced in England and Wales on Tuesday 27 March 2001.
- More than 98 per cent of electricity is now sold like any other commodity.
- Under NETA, the price paid to UK Utilities has fallen to levels at which it is un-economic to build new power stations *of any type* without subsidy.

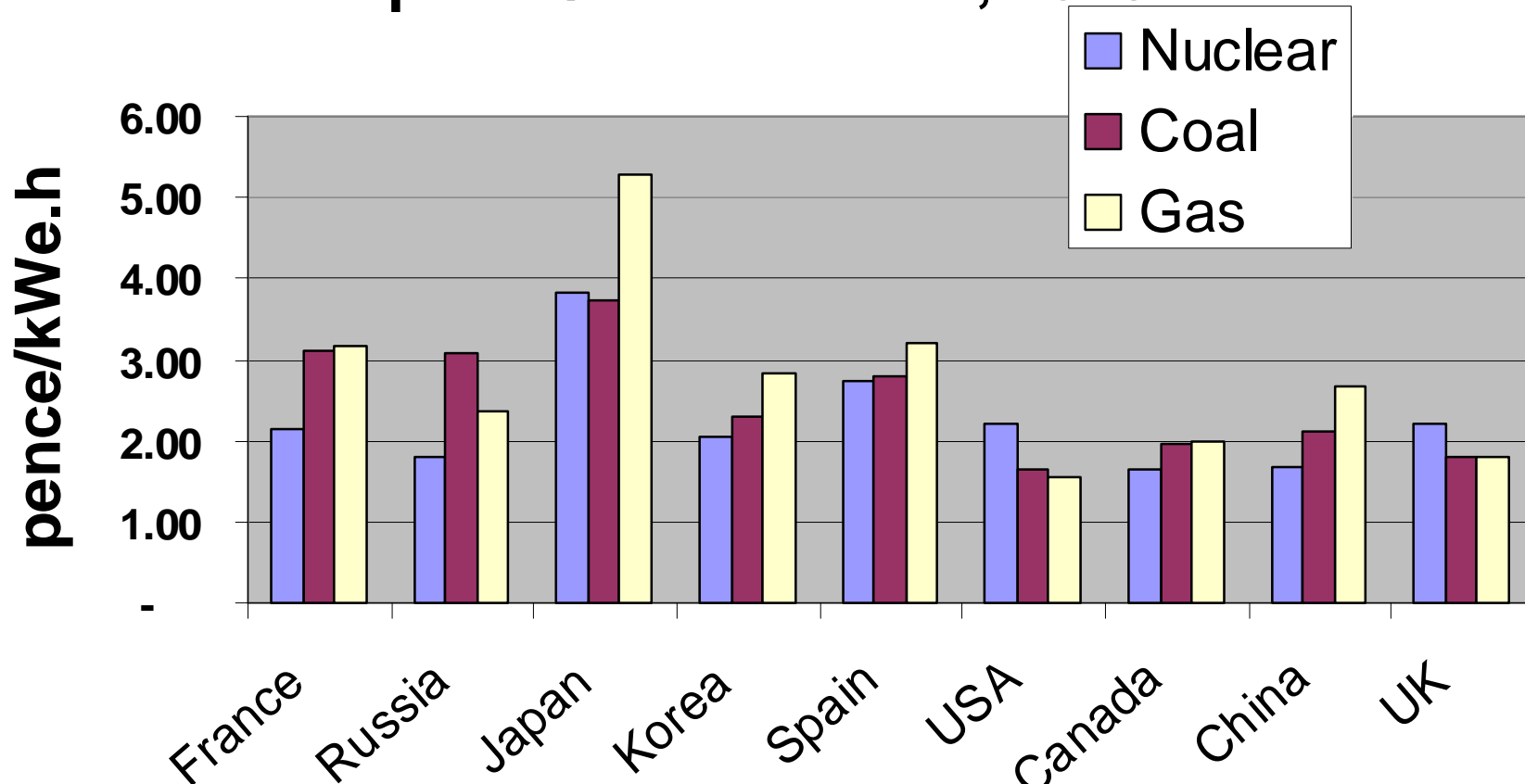
NETA Price of Electricity, p/kwh



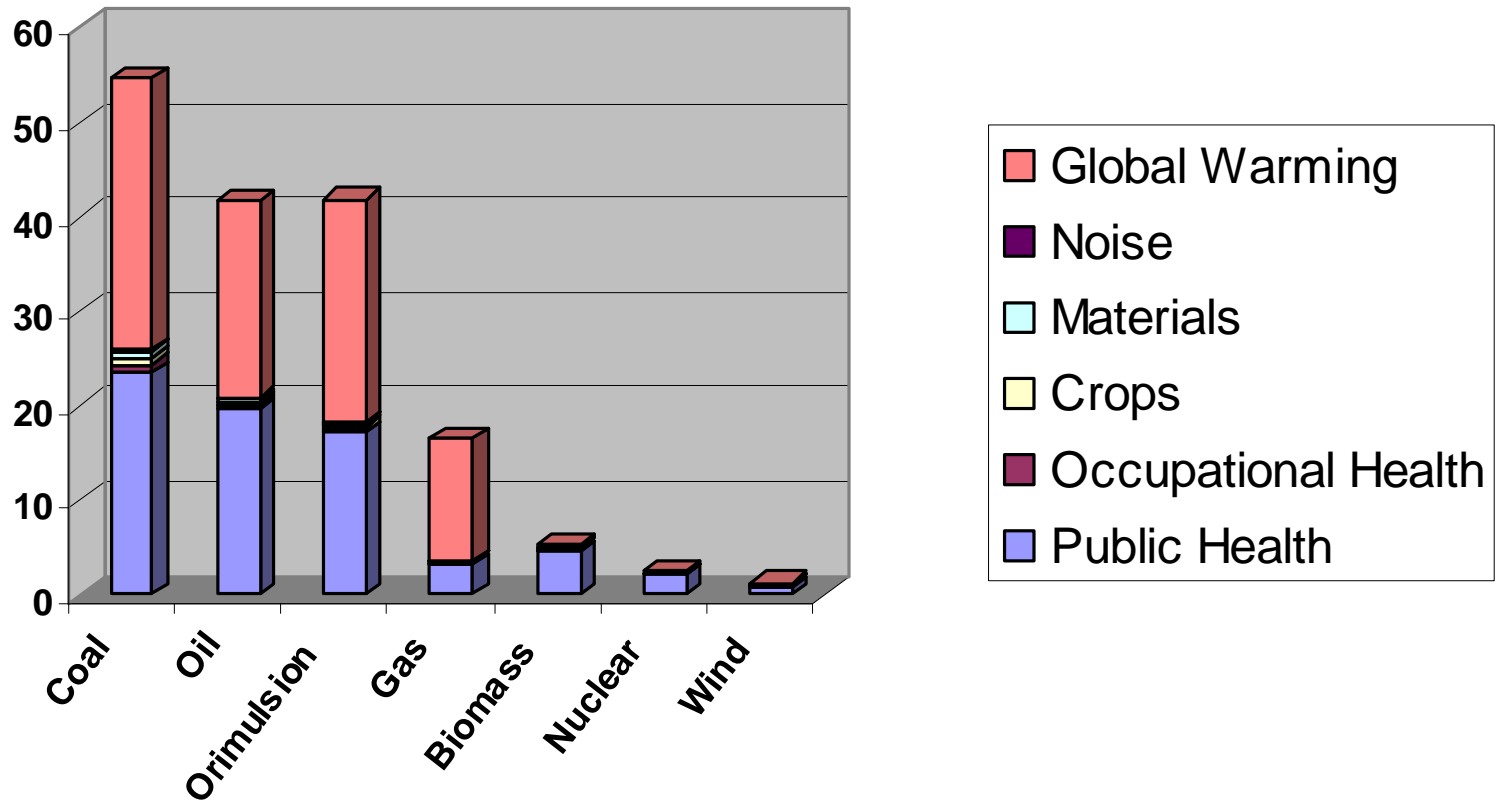
UK Electricity, Some Costs of Production, pence per kilowatt.hour



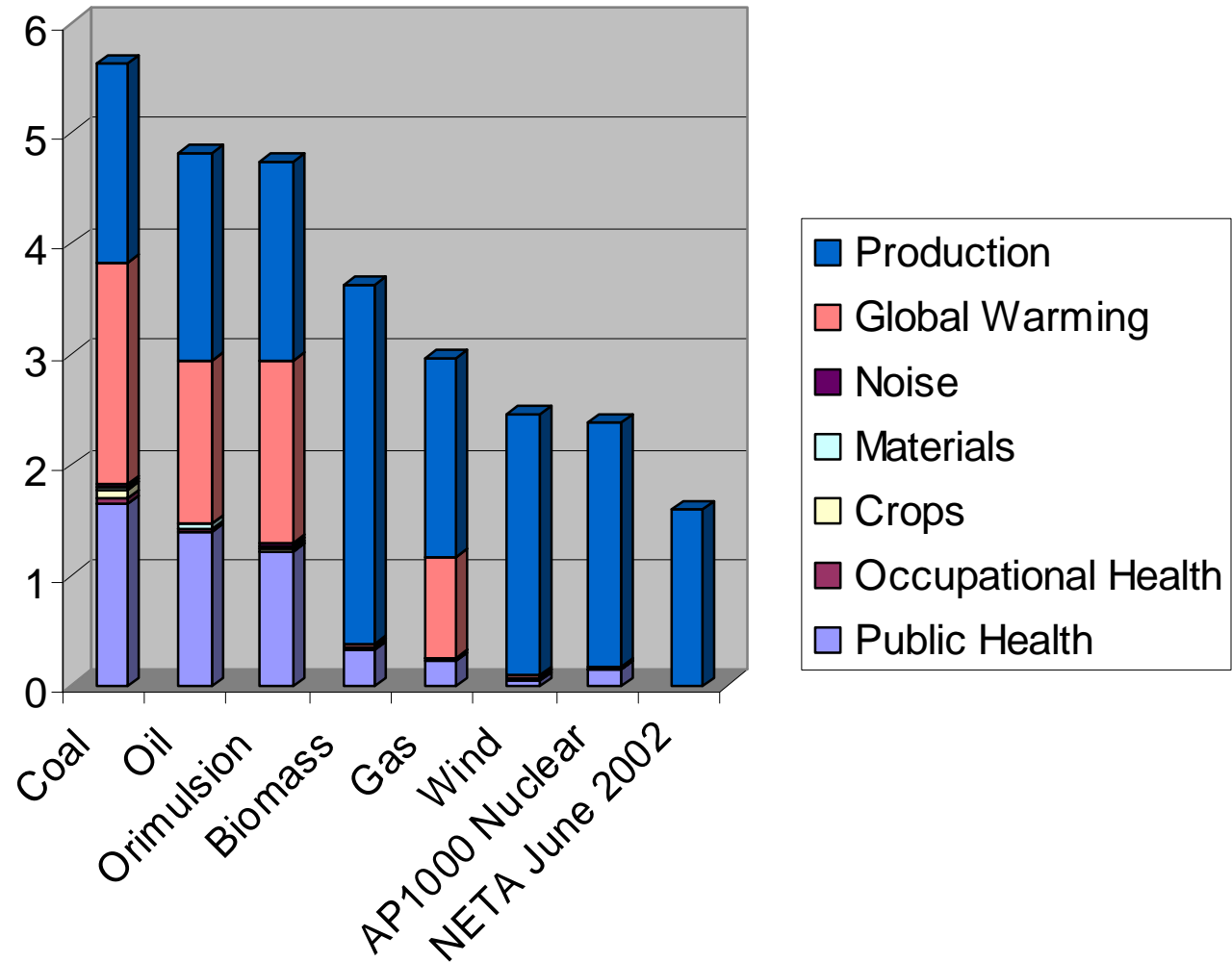
World Costs of Electricity, pence/kilowatt.hour, 2010.



External Costs of Electricity, mECU/kWe.h [EU "EXTERNE" Study]



UK: Cost of Electricity, pence per kilowatt.hour



Conclusions on Production Costs and Costs to the Environment.

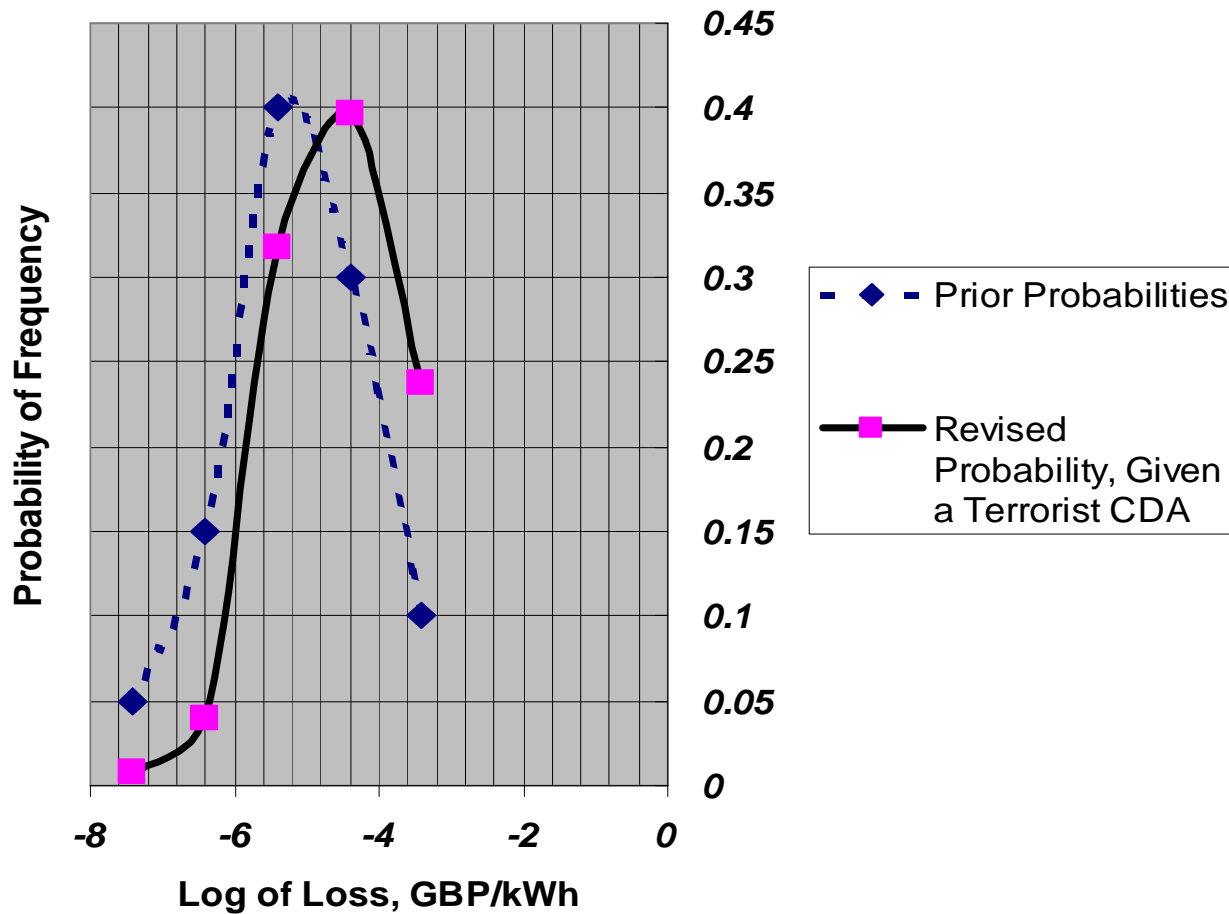
5. Under NETA, the price paid to UK Utilities has fallen to levels at which it is un-economic to build new power stations *of any type* without subsidy.
6. Nevertheless, when the cost of environmental impacts is added to the cost of generation, *nuclear is half the cost of coal and oil.*

Political Risks: Security of Supply.

Political Risks in the Aftermath of September 9th 2001

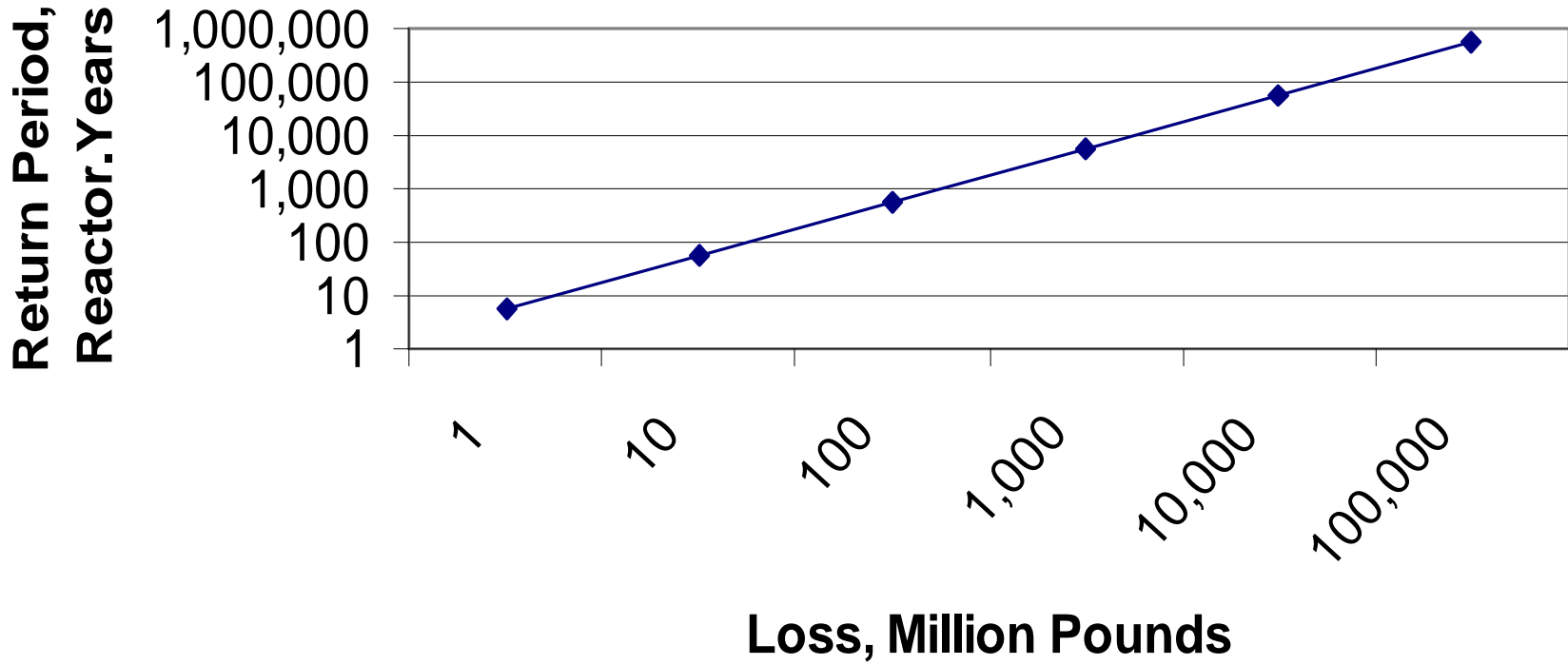
- In the aftermath of the terrorist attacks on the World Trade Centre and the Pentagon on September 9th 2001, Political risks, including terrorism, are being re-evaluated for nuclear, oil, gas etc.
- Information from the actuarial data-bases of the Lloyds of London insurance market has been used to form a view on these risks.
- The nuclear risk has been affected less than the risk to oil and gas supplies from Russia.

Probability of A Given Loss Due to Terrorist Activities, Bayes Analysis



Future of Energy

Post 9-11-01. Return period, Reactor.years For Nuclear Loss, Millions of Pounds Sterling

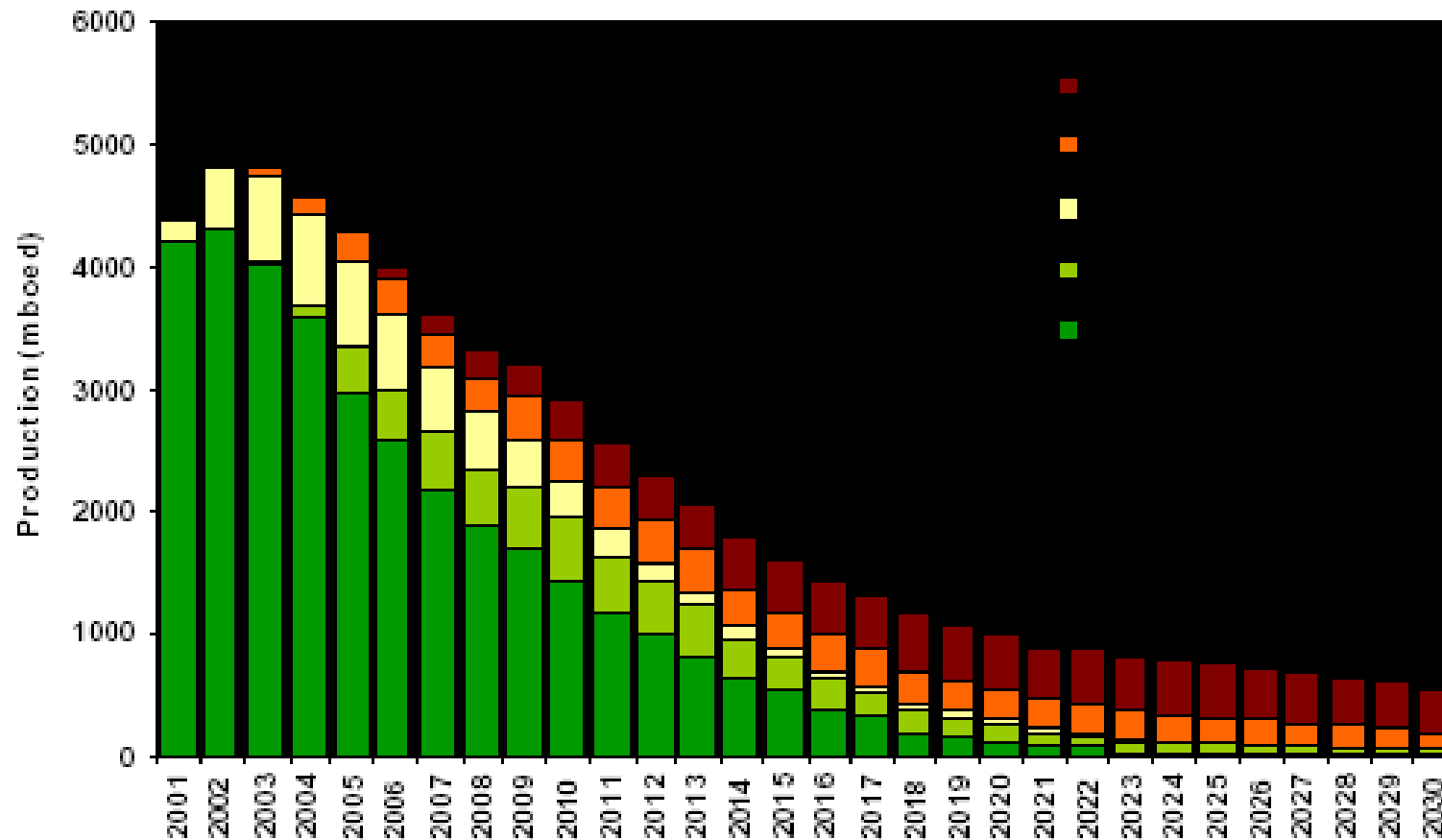


Political Risks: Oil and Gas.

- World-wide, 90 terrorist incidents concerning pipelines, oil and gas facilities, and personnel involved in the discovery, construction and exploitation of these resources are recorded for the period 1980 to 2000.
- These are part of the data-base used by insurers to estimate the premium to charge for insuring such “political risks”.

UK Gas Production.

Most of UK Electricity will be
Generated from Russian Gas.

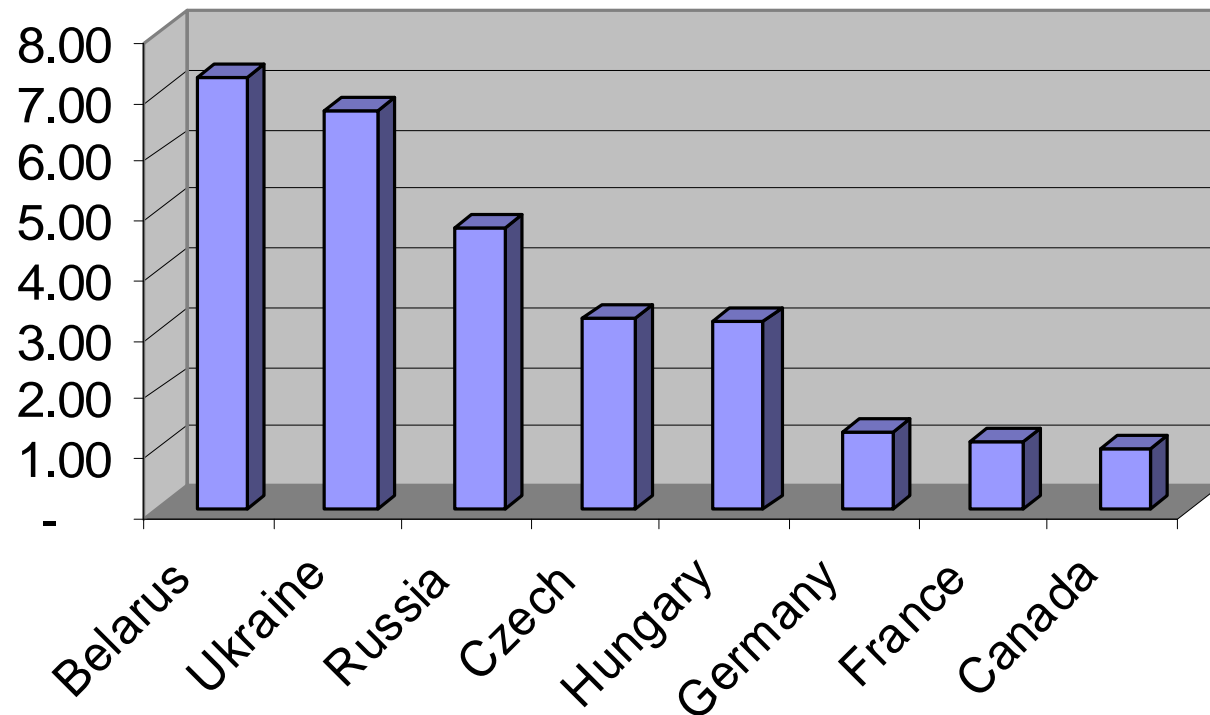


Future of Nuclear
Energy

Overview of World Activities: Gittus

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Insurance Against Political Risks: (Net Premium)/(Net Premium for UK)





Gas Pipe Lines In Europe

Political Risk, as Assessed by Insurers, in countries through which Russian Gas Pipelines will pass...

10 = Highest, Sweden (=1) and Switzerland (=1) for comparison.

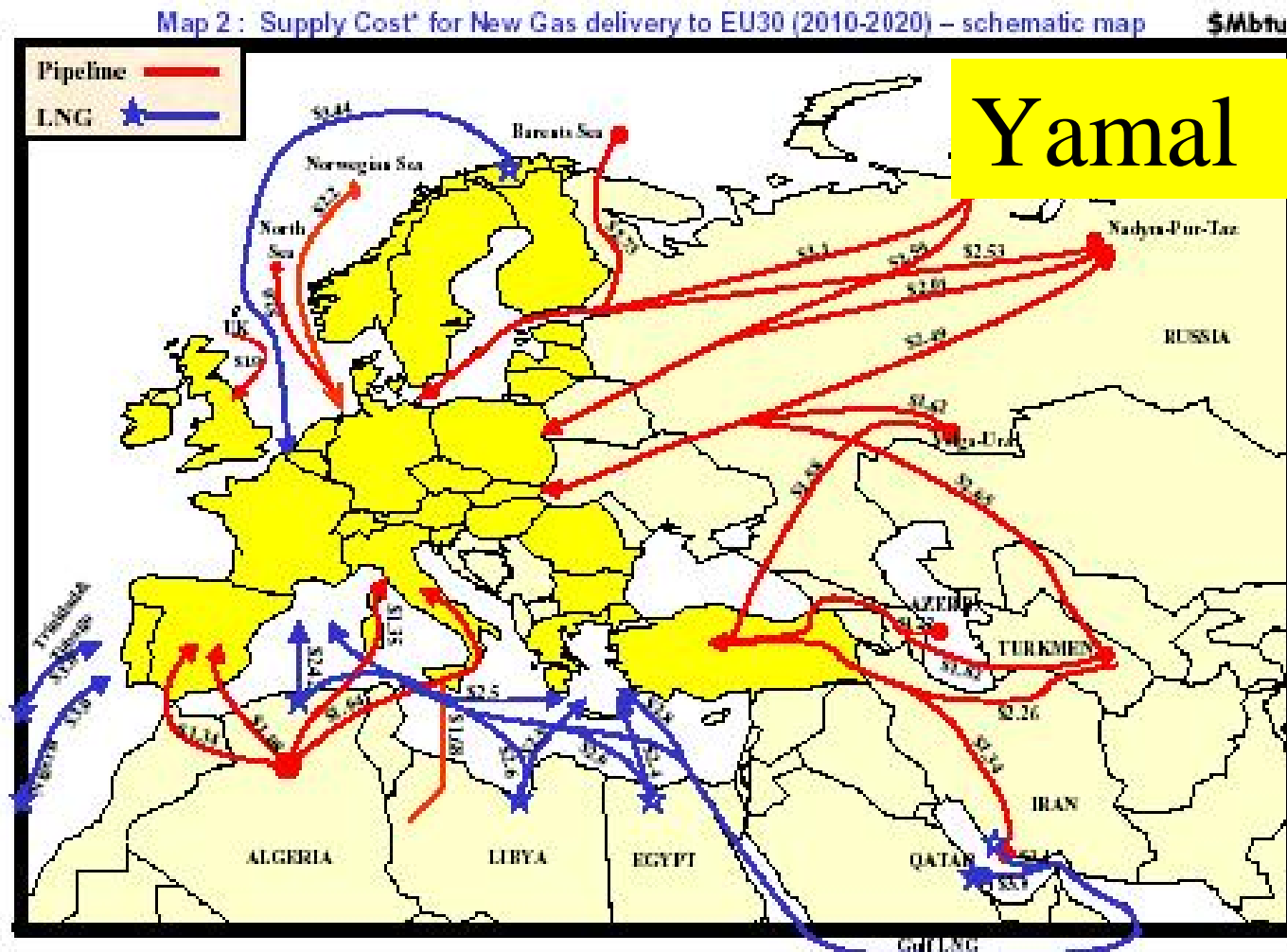


Future of Nuclear Energy

Most of the UK's Energy will Arrive by the Two Yamal Pipelines in 2020

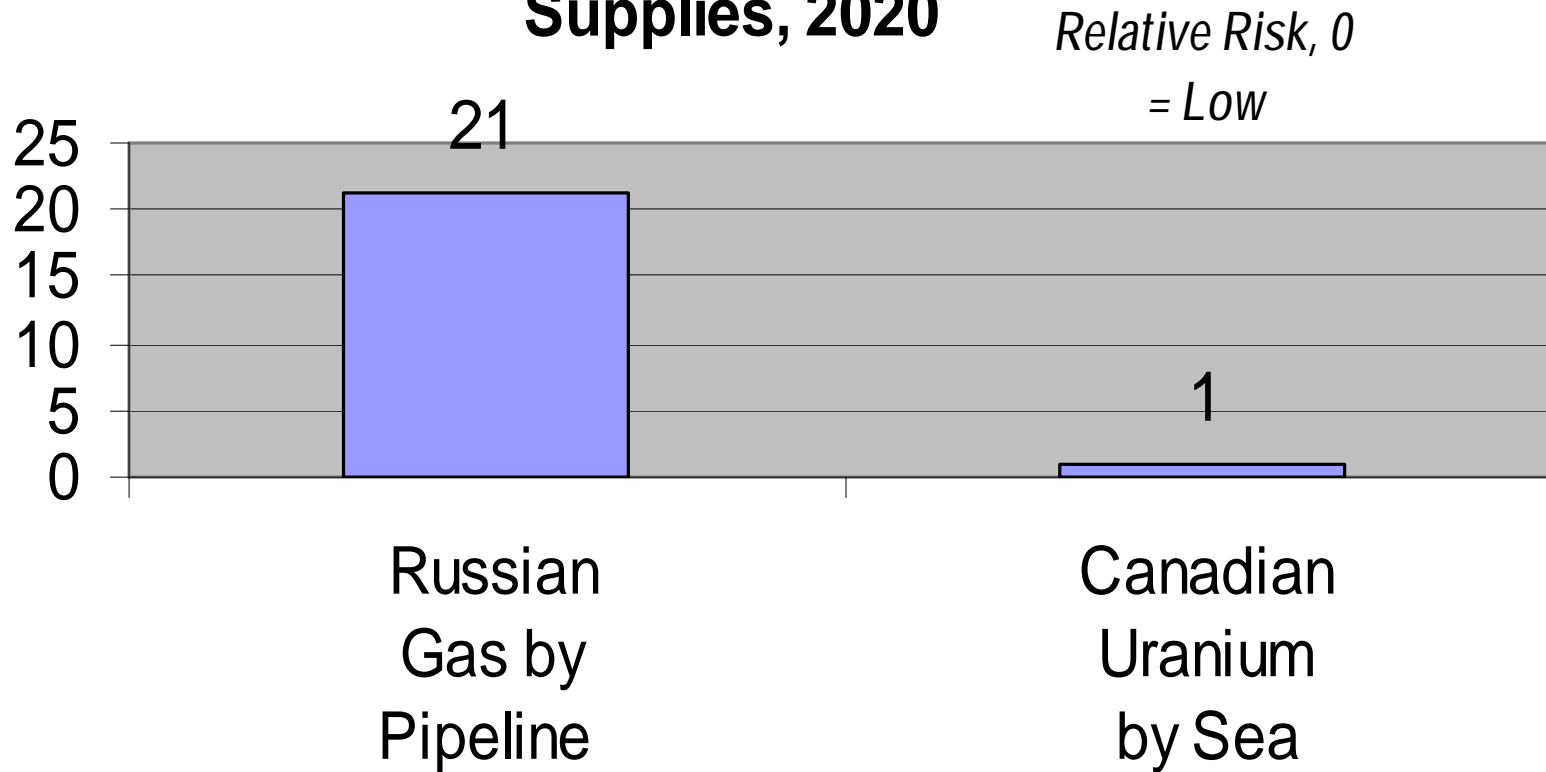
- The Route of Yamal Pipeline number 1 passes through Russia, Belarus, Poland, Germany.
- The Route of Yamal Pipeline number 2 will pass through Russia, Belarus, Poland and Slovakia.
- Political disruptions of Gas flow in Russia, Belarus or Poland are expected every 10 years.

Yamal and Other New Gas Pipelines.



Source: OMD: 2007 * excluding producer country's royalty

Relative Risk of Interruption of UK Energy Supplies, 2020



Conclusions on Political Risks: Security of Supply.

7. When the implication of the WTA terrorist strike is factored in, it transpires that the nuclear risk has been affected less than the risk to oil and gas supplies from Russia.
8. Nevertheless, currently the UK expects to generate most of its power from gas and import 90% of that gas from Russia, in 2020.

Radioactive Waste Management.

Radioactive Waste Management

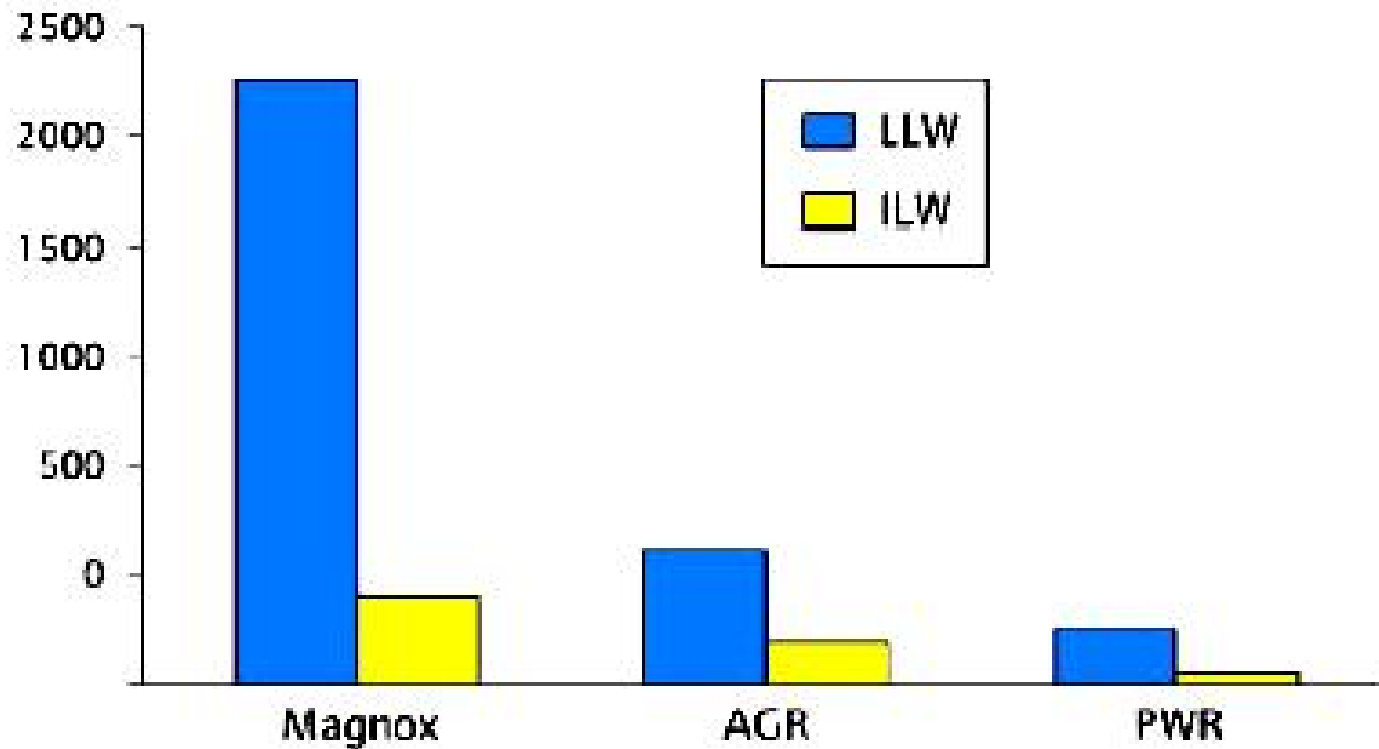
- If all the electricity you consume in your entire life was from nuclear plant, “your” HLW would be the size of a glass ashtray.
- 140 years after your death your descendants could handle it briefly, with safety.
- 2,300 years after your death it would be no more radioactive than the ore from which it was originally produced.

The Problem of Radioactive Waste Management.

- The technology for safe, economic management of radioactive wastes has existed for decades.
- It involves putting the waste and (if it is not reprocessed) the spent fuel in surface storage until decay heat evolution has fallen.
- Then it is put underground.
- Public and political objections have prevented these processes from being adopted.

Volume of waste produced by generating 1GW(e)year

m³ of Waste



Costs of Waste Management.

- Best estimates of waste storage and disposal costs are included in the levelised electricity cost.
- Even if pessimistic assumptions were to be made then these costs would only increase to be in the range of 7% to 10% of the total unit generating cost.
- In the USA the corresponding figure is 2%.

Yucca Mountain May Become the First US Waste Repository.

- Nevada Gov. Kenny Guinn April 8 vetoed the nuclear waste repository planned for Yucca Mountain, submitting his formal declaration of disapproval to the White House and congressional leaders.
- However, the House of Representatives, on May 9th 2002, voted 306-117 in favour of the plan.
- A Senate Panel Approved it on June 7th 2002.
- The full Senate has until July 25th to confirm that approval.

Russia Legislates to Take Some Foreign Wastes.

- Regulations implementing Russia's spent fuel import legislation should be promulgated by late June 2002,
- This would make it possible to negotiate contracts with foreign reactor operators for long-term spent fuel storage and reprocessing.
- Under certain conditions, the rules are expected to allow Minatom to *waive a general requirement to return foreign-origin reprocessing waste to its owners*

[Information from Alexei Lebedev, director of project management for Techsnabexport (Tenex), the Ministry of Atomic Energy (Minatom) subsidiary that is marketing the spent fuel services]

Conclusions.

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Conclusions, continued

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Conclusions, concluded.

9. The technology for safe, economic management of radioactive wastes has existed for decades.
10. Public and political objections have prevented these processes from being adopted.
11. Progress is now being made and Yucca Mountain may be the first repository in the USA.
12. Other countries are following suit.