



A Human Turning Point – Nuclear Energy

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AECL
Atomic Energy
of Canada Limited

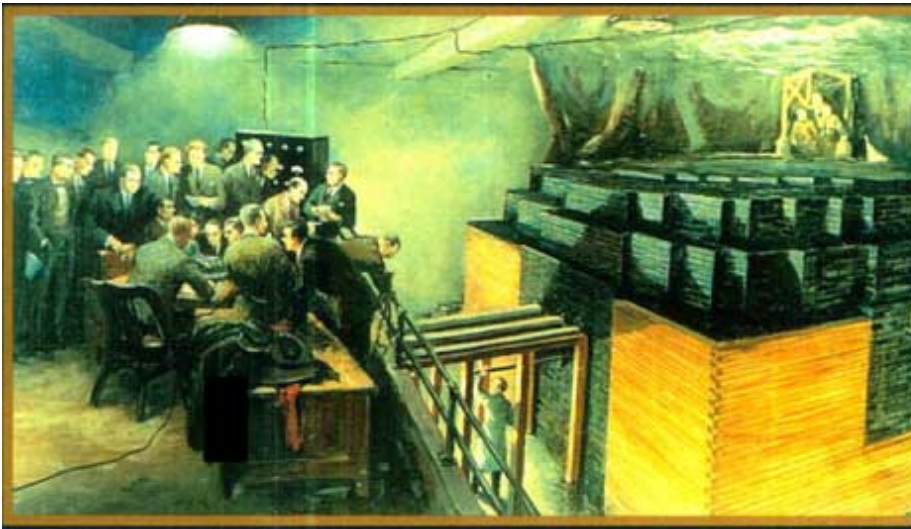
EACL
Énergie atomique
du Canada limitée

Canada 

Man-Made Reactors

First in World and First in Canada

CP1 – University of Chicago
December 2, 1942

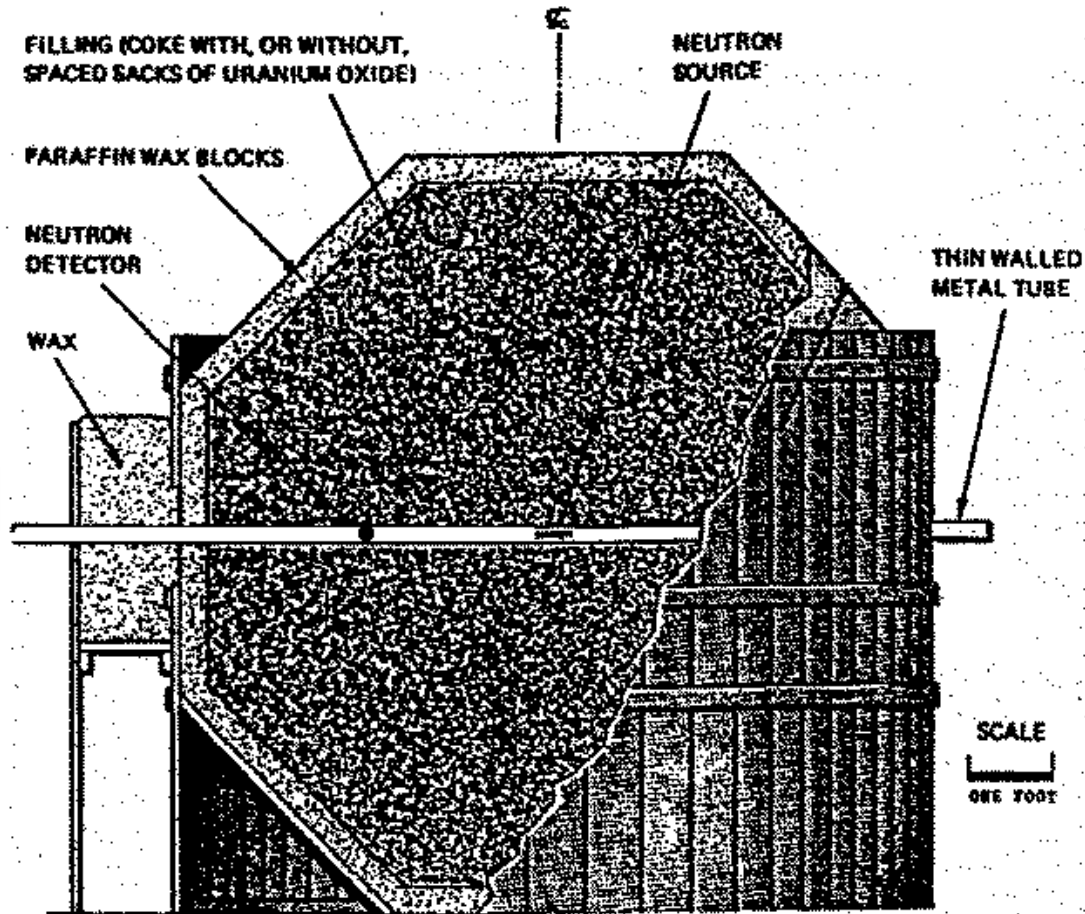


ZEEP – Chalk River Laboratory
September 5, 1945



First Try – NRC Ottawa, 1941-42

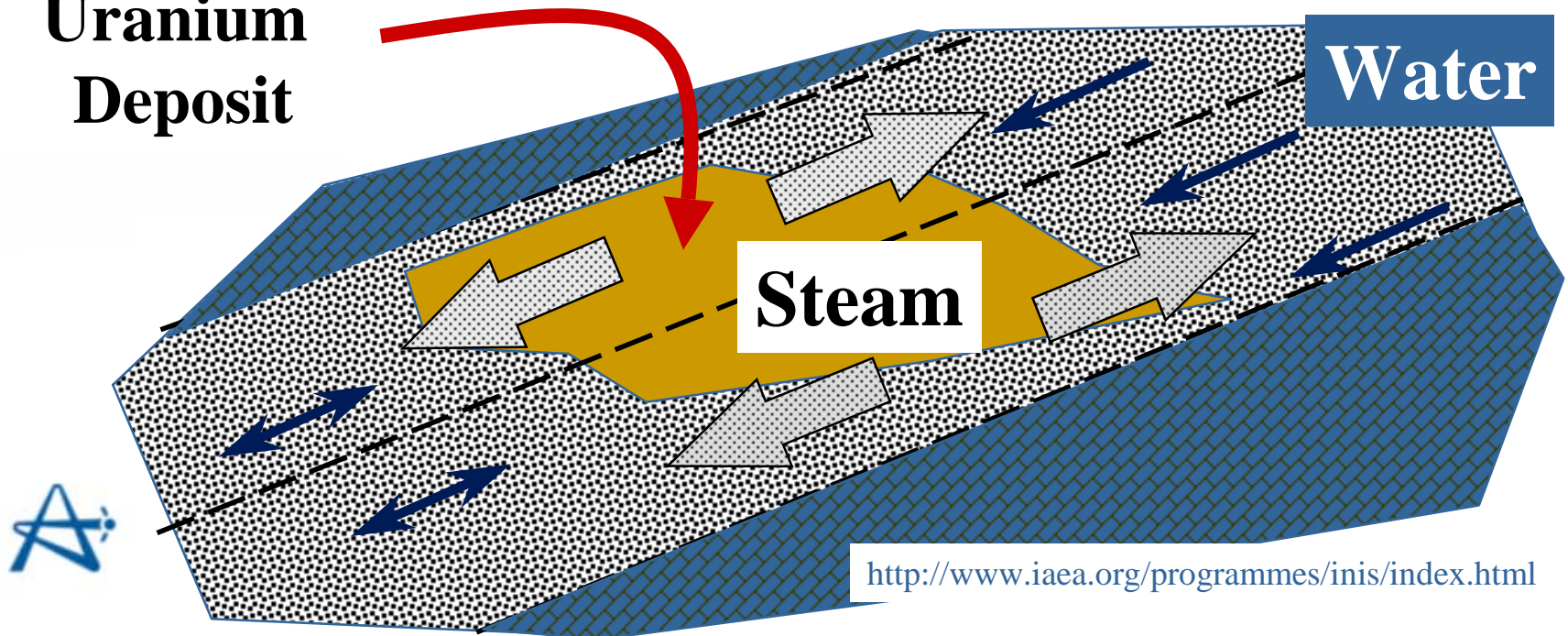
Dr. G.C. Laurence was the first to assemble a reactor using uranium and carbon



Nature's Reactors

- Remains of at least six natural reactors were found in Oklo, Gabon, West Africa on June 2, 1972
- As oxygen built up in earth's atmosphere, uranium from a river in East Africa was dissolved and carried to the river delta
- Uranium precipitated at high concentration in the river silt and sand
- Some time later, the uranium-sand-silt mixture was soaked with water. Natural reactors were created. They worked for thousands of years.

**Uranium
Deposit**



Uranium Through History

Heavy elements probably were produced in supernova explosions

Decay constants: $U235 = 9.8 \times 10^{-10}$ per year, $U238 = 1.5 \times 10^{-10}$ per year

<u>TIME</u>	<u>-4 b.yr.</u>	<u>-2 b.yr.</u>	<u>0 (now)</u>	<u>+2 b.yr.</u>
n_5	35.3	5.0	0.72	0.10
n_8	183.8	135.1	99.28	73.0
$n_5/(n_5+n_8)$	0.162	0.036	0.0072	0.0014
(uranium enrichment)	Fast Reactor Possible	Thermal Reactor (LWR)	Thermal (Graphite or D2O)	Enrichment of Fuel Required





Bombs and Reactors

- The idea of fission energy production emerged just before World War II.
- US made their decision to develop nuclear weapons in ~1941.
- US, Soviet Union, UK, France, China developed weapon arsenals.
- Intense hostility (Cold War) maintained military emphasis until ~ 1990.

- The “Atoms for Peace” idea offered peaceful nuclear technology in return for a promise not to make weapons.
- The future is, as always, uncertain. Many nuclear weapons now are obsolete – replaced by even more effective, non-nuclear offensive weapons.

- In early 1944, Canada was assigned task of building a high-power heavy water reactor (NRX) for production of Pu239 and U233 for weapons.

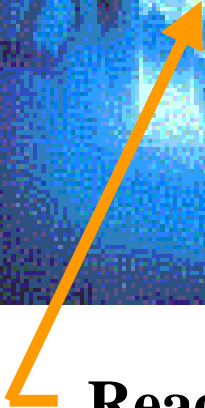
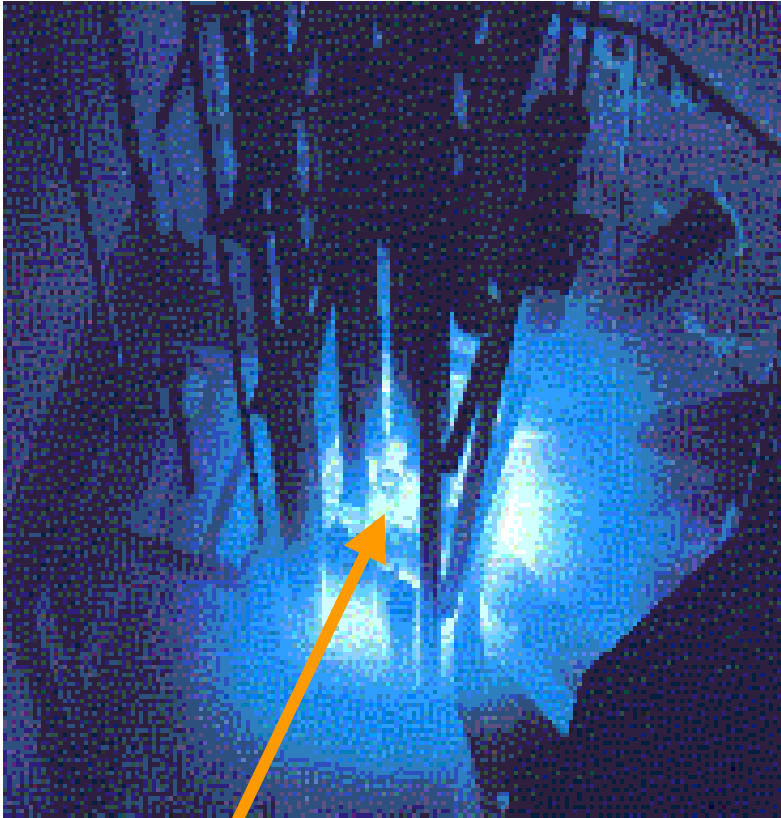
- Canada retired the Bomarc and Genie nuclear-tipped missile systems in ~1972





The McMaster Nuclear Reactor

A Quick Peek



Reactor Core



A Modern Nuclear Power Plant

- Darlington NGS, East of Oshawa. Four units, total power output of 3524 megawatts



Reactor Types: Prototypes and Successes

THERMAL											FAST	CLASS
GRAPHITE				WATER		HEAVY WATER				NONE	MODERATOR	
Molten Salt	Na	CO ₂	H ₂ O	He	H ₂ O	H ₂ O	H ₂ O	D ₂ O	Organic	CO ₂	Na/NaK	COOLANT
		MAG-NOX					BLW	CANDU	OCR			Natural U
	Hallam	AGR	RBMK	HTGR PBMR	PWR	BWR	SGHW	Atucha CVTR		KKN, EL4		Enriched U
MSBR				THTR	LWBR							Thorium - U
							ATR				FBR	Plutonium-U

FUEL

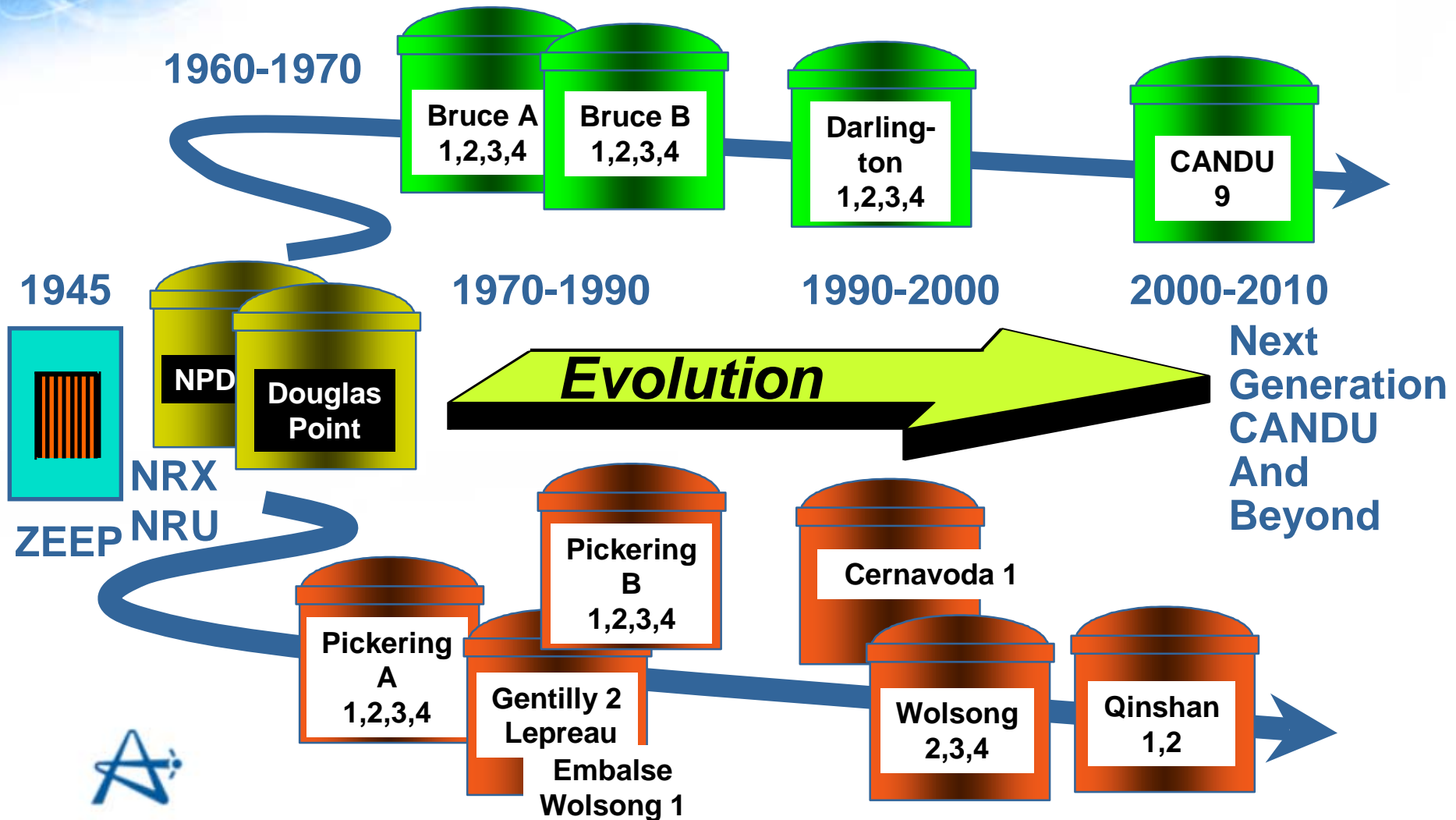


Success is Not Permanent

- Three Mile Island Unit 2 (a modern US pressurized water reactor)
 - Errors committed by operators, designers, and regulators
 - Zero environmental or health effects, but large losses (>5 b\$)
 - “Unjustified self-confidence” can be seen as the root cause
- Darlington station (designed, built by experienced companies)
 - Delays during construction – OH senior management and government
 - Errors in generator design – Swiss design organization
 - Error in heat transport system design - designers
- Chernobyl (USSR built several plants, and some of them operated well for years)
 - Errors were committed by government, designers, regulators, managers, operators
 - About 40 people were killed (operators, firemen, rescue workers)
 - Huge cost (>10 b\$)
- Ontario Hydro Operational Breakdown
 - Errors committed by management, directors, government, unions
 - Staff reduced drastically by management, without proper care
 - Maintenance neglected, units understaffed, so 7 units were forced to shut down
 - Pickering A (then Bruce) units will be extensively refurbished

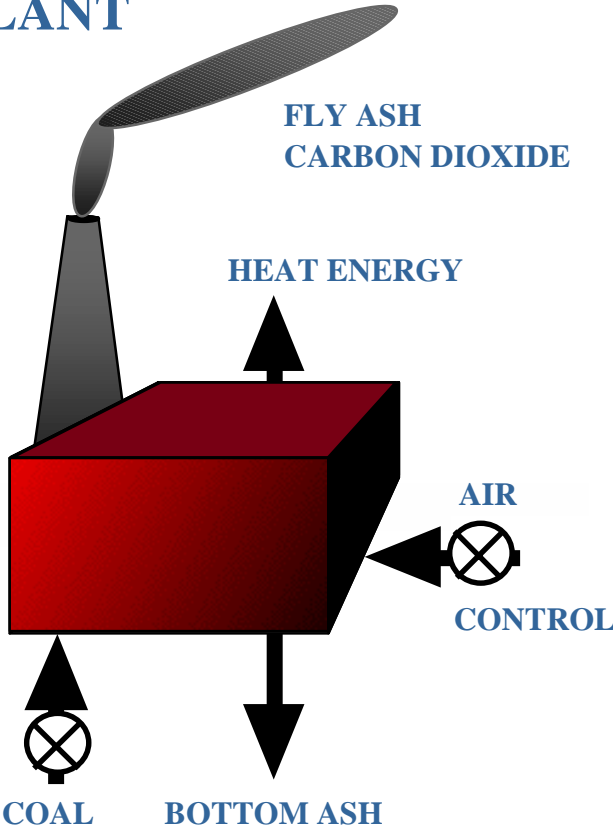


Genealogy of CANDU Power Plants

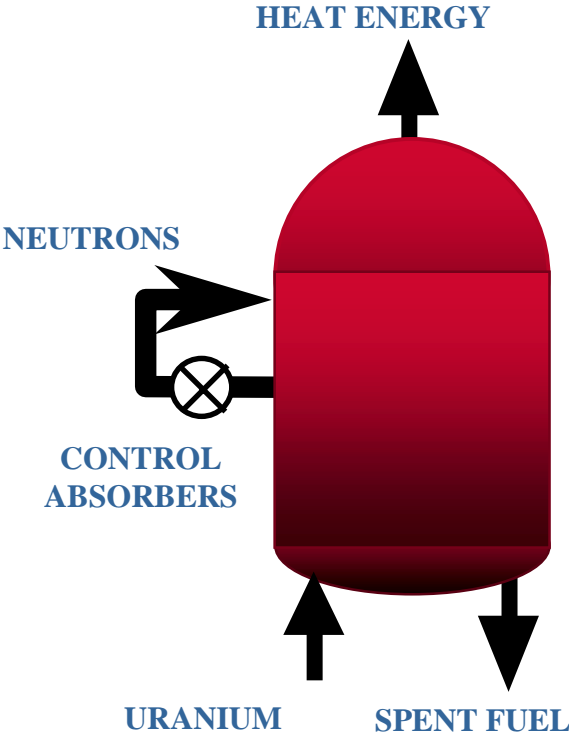


Fundamentals of Power Generation

COAL-FIRED POWER PLANT



URANIUM-FIRED POWER



Offshore Adventures

- India
 - AECL exported two units in early 1970's; Indian nuclear explosion led to isolation
 - Indian industry is now operating 10-12 small units, two larger units under construction
 - Fully mature industry, good performance
- Pakistan
 - One small unit operating (KANUPP, designed by Canadian General Electric)
- Korea
 - First CANDU6 unit started in 1983. Four units now operating. Two being considered
 - Fully mature industry. Both PWR and CANDU types
 - CANDU performance is excellent – several times at the top of world charts
- Argentina
 - Mature industry
 - One CANDU 6 unit started in 1983. An above-average performer
- Romania
 - One CANDU 6 unit started in 1986 – excellent performance. Second unit to be completed
- China
 - Growing industry – 2 operating, 8 under construction
 - Two CANDU 6 units under construction, for startup in 2002
- Turkey
 - Project cancelled by Turkish national government in 2000



Today's Viewpoint

- World Market Status
 - Continued fierce opposition from much of the green movement
 - Some interesting recent exceptions – e.g. Sweden, Switzerland
 - Low rate of ordering for new nuclear plants
 - Difficult to sustain experienced design and research staff
 - Low intake of new, young staff
 - Improving performance of, and reliance on, existing plants
 - Especially US and India
 - Service business is good – older plants are being refurbished
 - Extreme competition from remaining international competitors
 - UK, US, Russia, France, Germany
- Main Short-term Issues
 - Public acceptance
 - Governments follow; people lead
 - Recovery from a bad reputation takes time
 - Economics
 - High capital cost – a barrier
 - The “eternal supply of fossil fuel at low price” myth
 - Confusion in the electricity supply industry
 - Deregulation, privatization, mismanagement – most rates are rising
 - Instability of fossil fuel prices





Questions For Our Grandchildren

- Big Systems
 - How many people?
 - How much wealth do you need?
 - How much wealth do you want?
 - What wealth can be sustained?
 - Do you care about the welfare of foreign people?





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