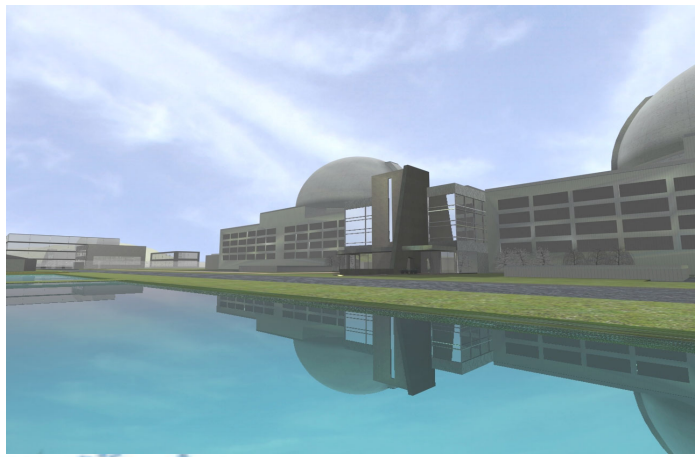
Powering the Future with Advanced CANDU Reactors - ACR



Stefan Doerffer

Ala Alizadeh

Jerry Hopwood

Nuclear Power Plants for Poland

Warsaw

2006 June 01 - 02

AECL EACL

Outline

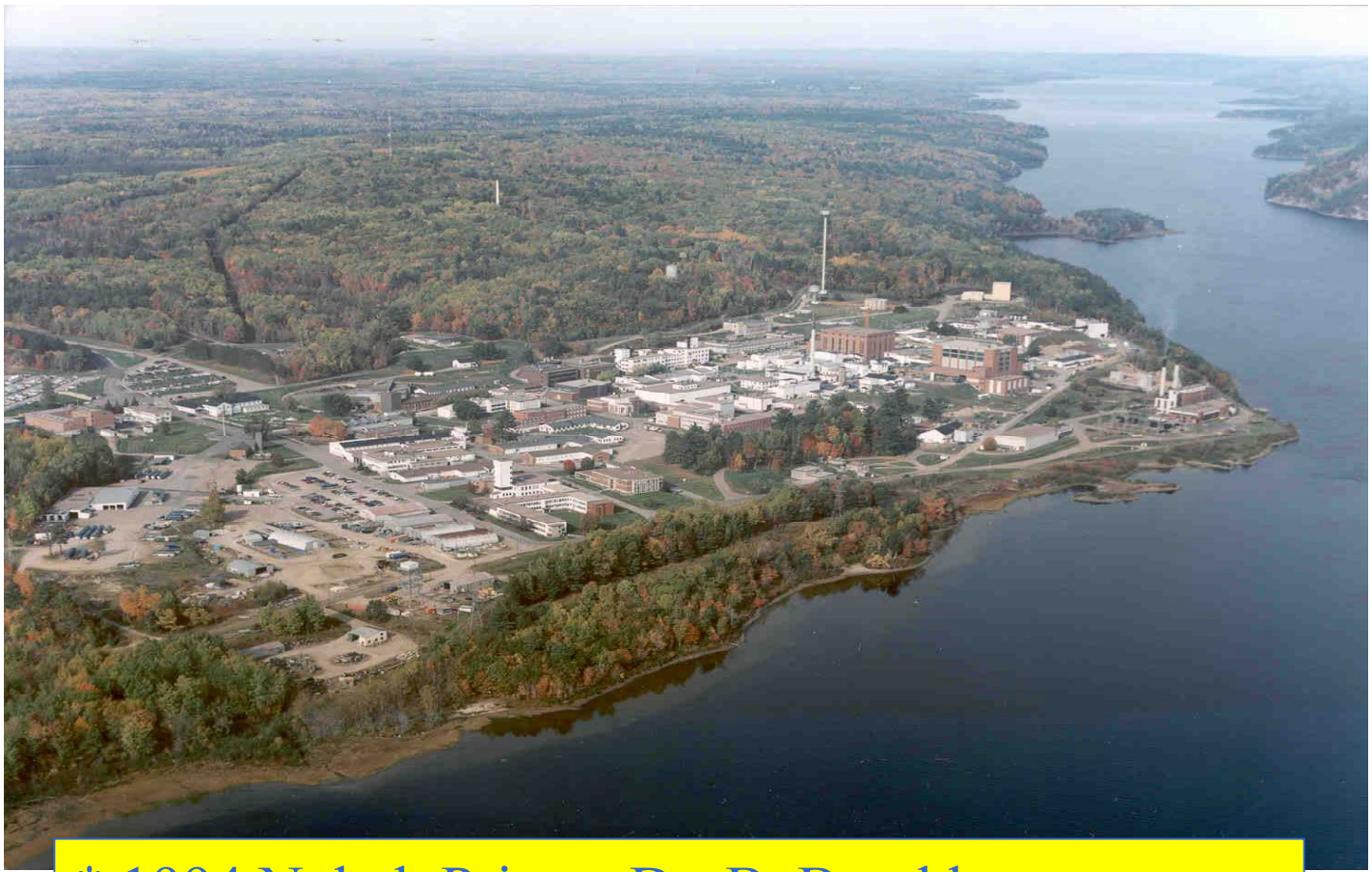
- Introduction
- AECL
- CANDU Reactor Development History & Current Projects
- Overview of Major Features of CANDU Reactors:
  - Enhanced CANDU 6, and
  - ACR-1000
- Summary & Final Remarks

Atomic Energy of Canada Limited

- Commercial Crown corporation, established 1952 to lead Canadian nuclear industry
- 4 000 staff
- AECL is unique: reactor designer, vendor, project management, R&D, reactor services, refurbishment, waste management
- $600-800M annual commercial revenues
- AECL designs, builds and services reactors around the world - more than $30B in profitable business

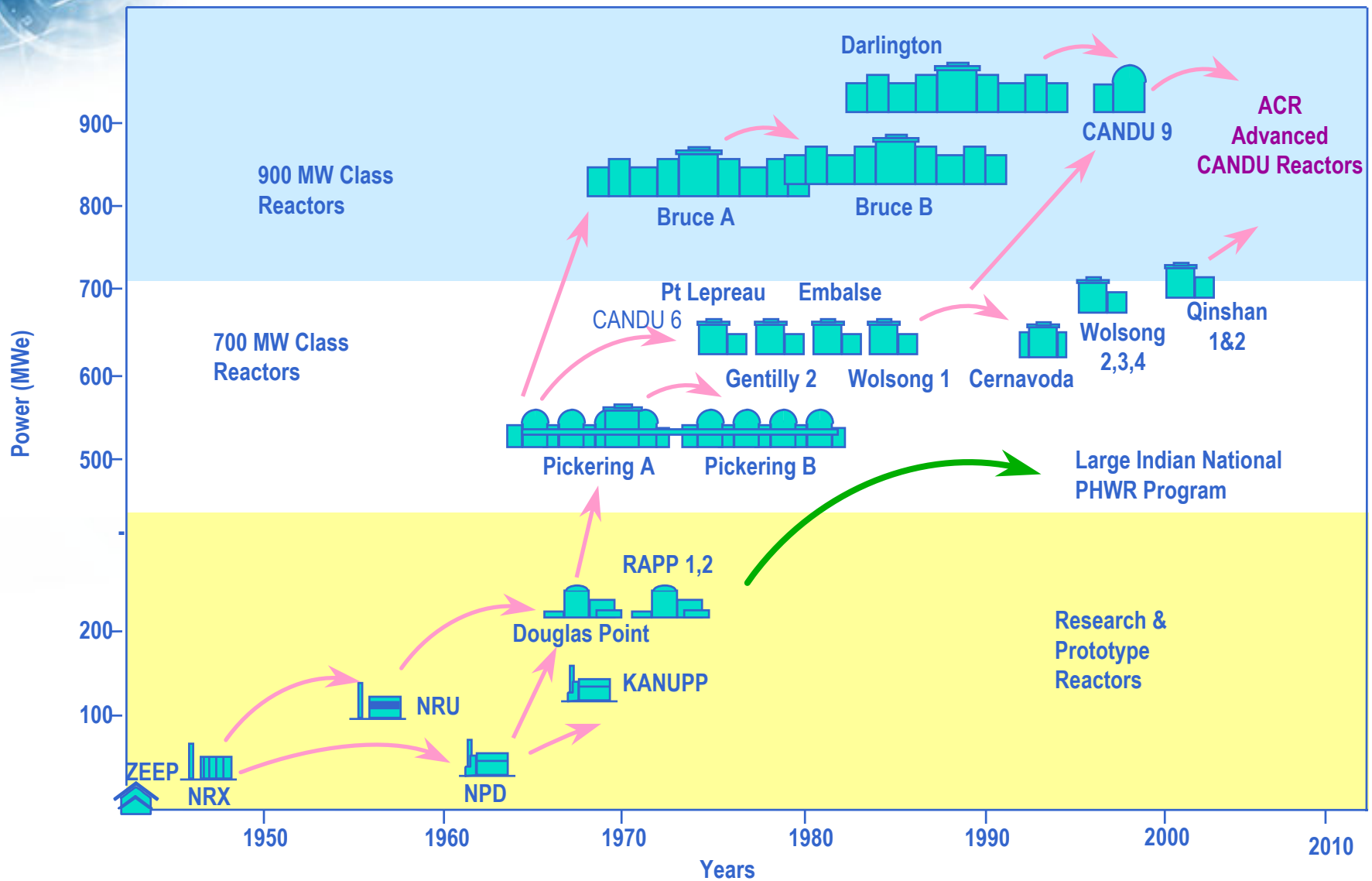
Origin of Canadian Nuclear Achievements

Chalk River Laboratories



* 1994 Nobel Prize – Dr. B. Brockhouse

CANDU: Built on a Strong History



42 CANDU Reactors Worldwide, plus 6 Under Construction, plus 3 in Pre-project Phase = 51 reactors

Quebec, Canada
Gentilly 2 1 unit

Ontario, Canada
Darlington 4 units
Pickering 6 units
Bruce 8 units

New Brunswick, Canada
Point Lepreau 1 unit

Argentina
Embalse 1 unit

Romania
Cernavoda 1 unit,
1 unit under construction

Republic of Korea
Wolsong 4 units

China
Qinshan 2 units

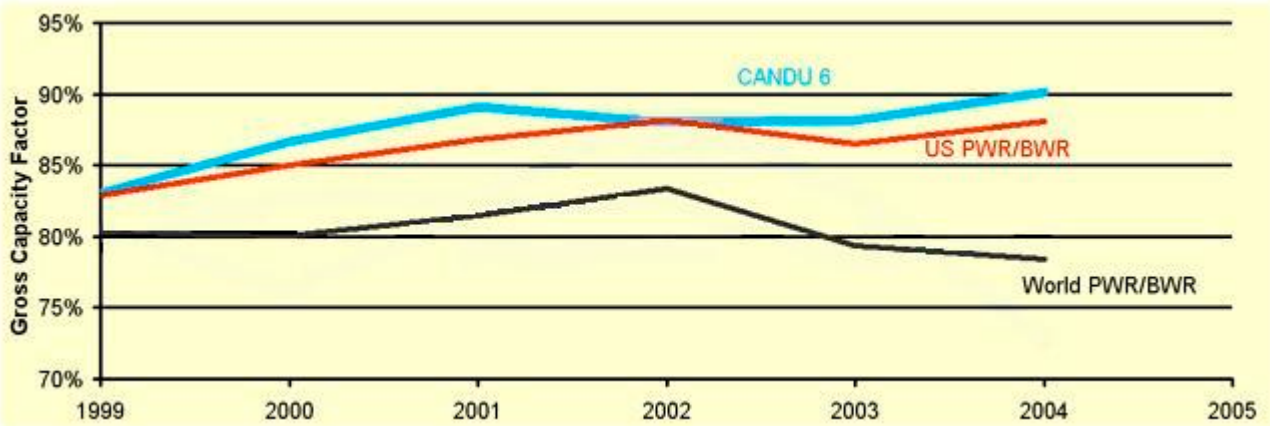
India (CANDU type)
13 units, 5 under construction

Pakistan
KANUPP 1 unit

7 Countries – 7 Jurisdictions

CANDU 6 Performance

- Lifetime average Capacity Factor of operating CANDU 6s to December 2004 is 87.7%
- Lifetime average of CANDU 6s entering service in the last decade to December 2004 is 90.2%
- Performance of the entire CANDU 6 fleet is superior to that of any other reactor design

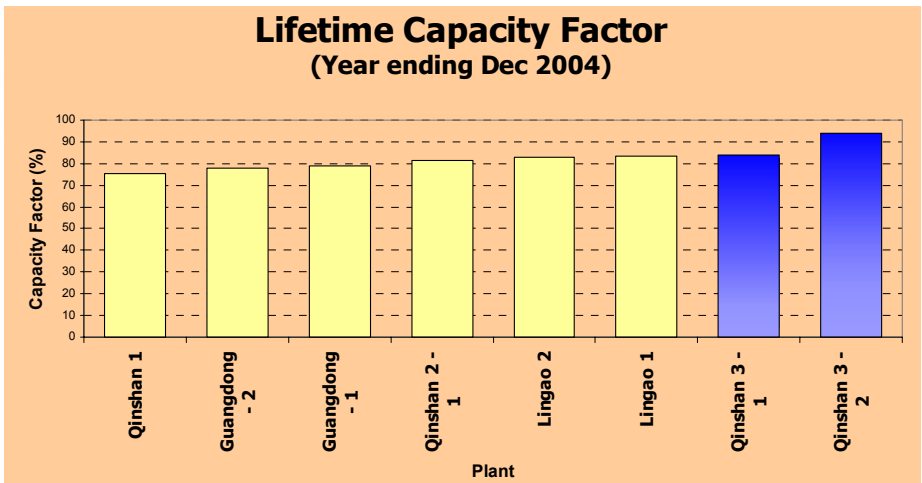


AECL Track Record on Major Projects

In-Service Date	Plant	Status
1996	Cernavoda Unit 1, Romania	On budget, on schedule (to new negotiated contract)
1997	Wolsong Unit 2, S. Korea	On budget, on schedule
1998	Wolsong Unit 3, S. Korea	On budget, on schedule
1999	Wolsong Unit 4, S. Korea	On budget, on schedule
2002	Qinshan Phase III, Unit 1, China	On budget, 6 weeks ahead of schedule
2003	Qinshan Phase III, Unit 2, China	Under budget, 4 months ahead of schedule
2007	Cernavoda, Unit 2, Romania	Under construction

Qinshan Phase III Project

- China's most successful nuclear project
  - 10% under project budget, 4 months ahead of schedule
  - Advanced construction and commissioning methods
  - Strongest Partnership Model
  - Top performer



AECL's Advanced Reactor Products

Enhanced CANDU 6

- Improvements based on Qinshan feedback and Ontario requirements
- Key areas: containment, licensability

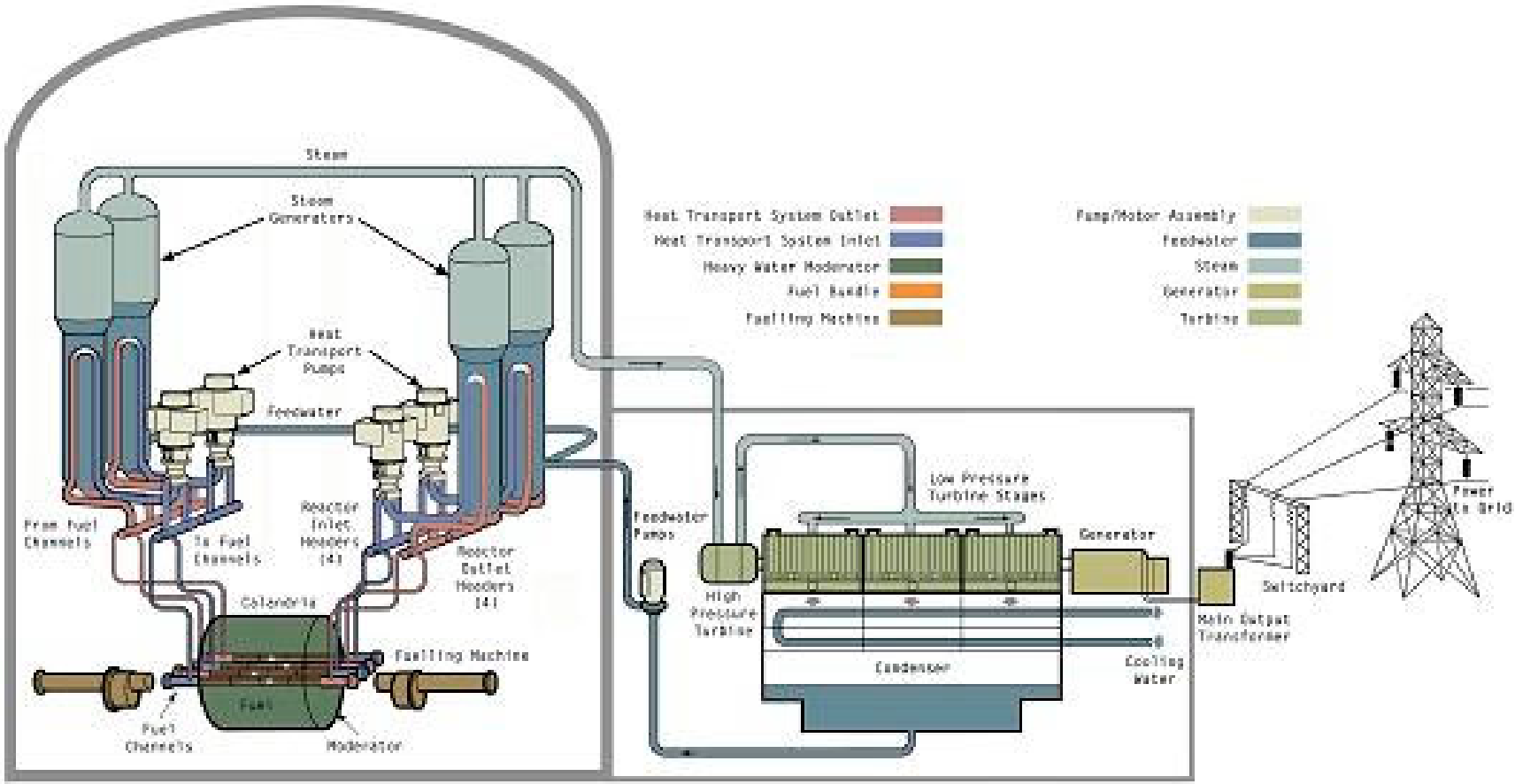
ACR-1000

- Generation III+ technology
- Current evolution of CANDU
- Combines experience of CANDU 6, domestic and offshore programs

Enhanced CANDU 6 Reactor

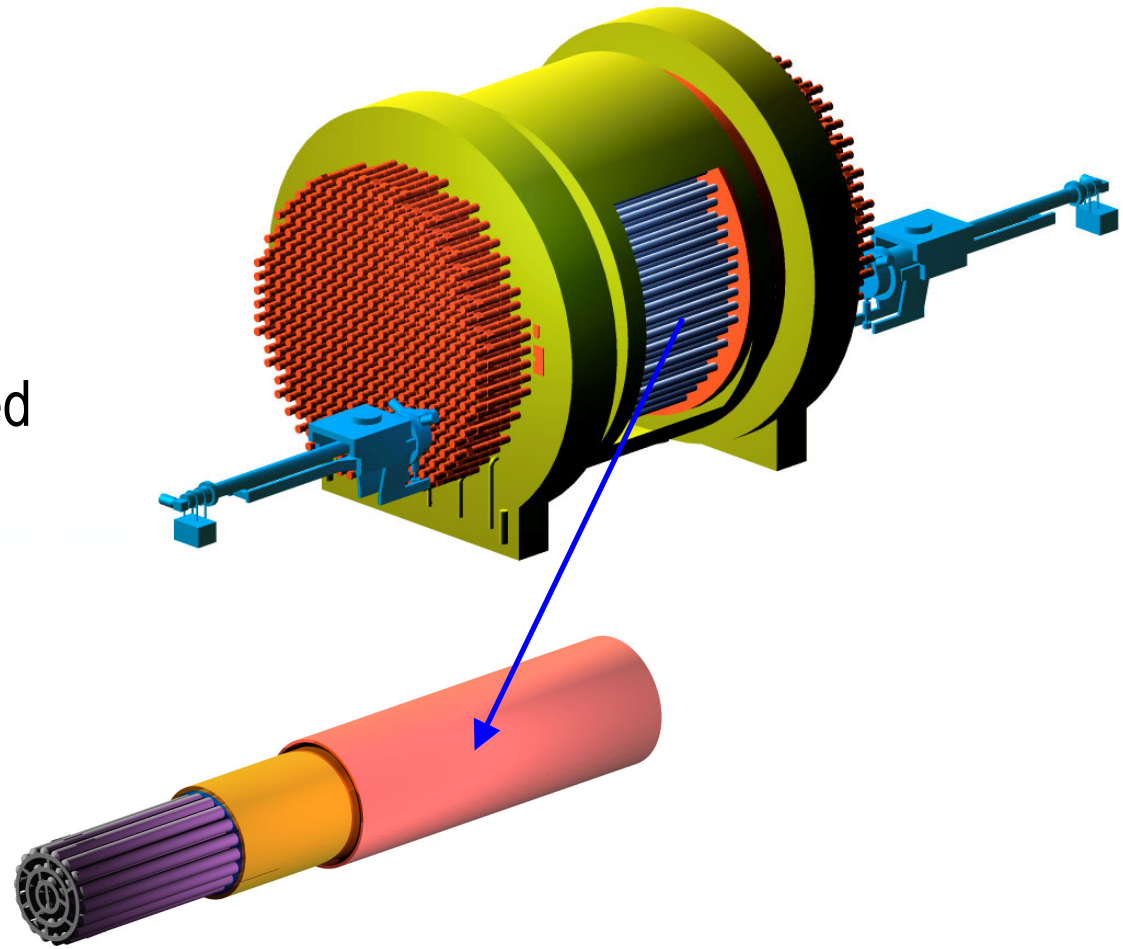
- Reference Design: Qinshan Phase III Units ½
- Ready for near-term deployment
- Meets Gen III criteria

General View of a CANDU Plant

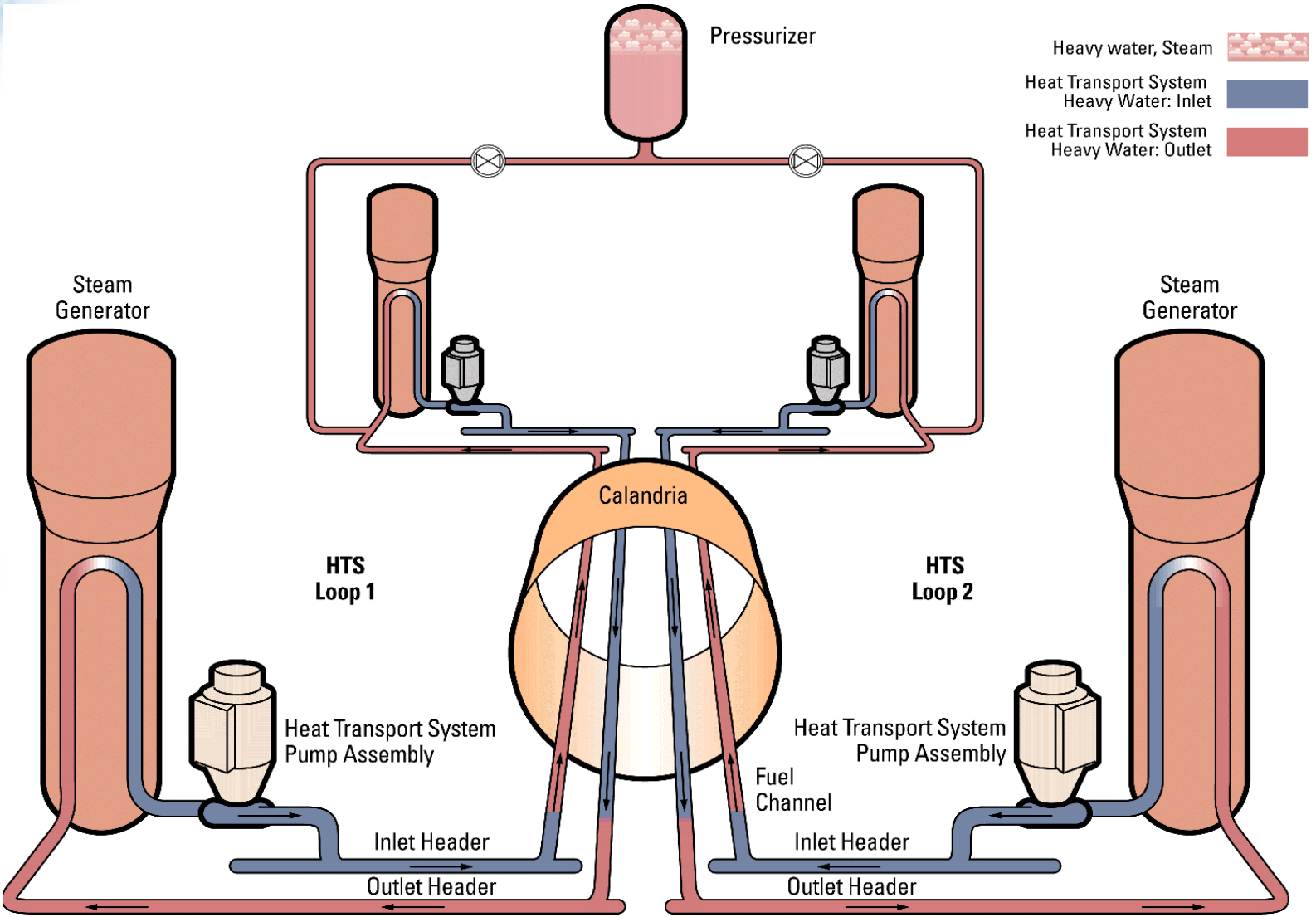


CANDU Reactor Fundamental Features

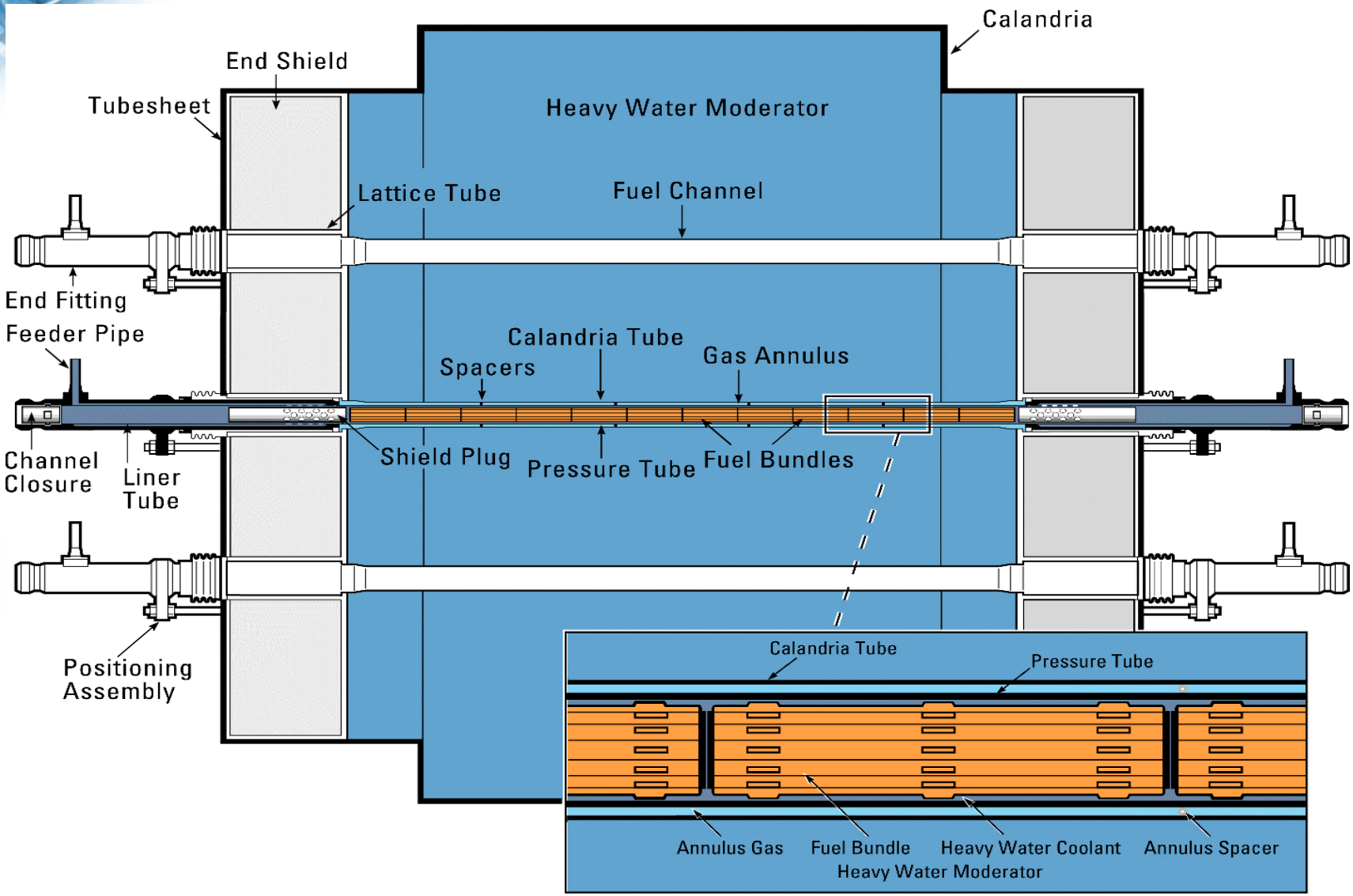
- Channel reactor
  - Horizontal channels
  - Pressure tube as core pressure boundary
  - Heavy-water cooled
  - Heavy-water moderated
- Separate coolant and moderator
- Short fuel bundles replaceable on-line



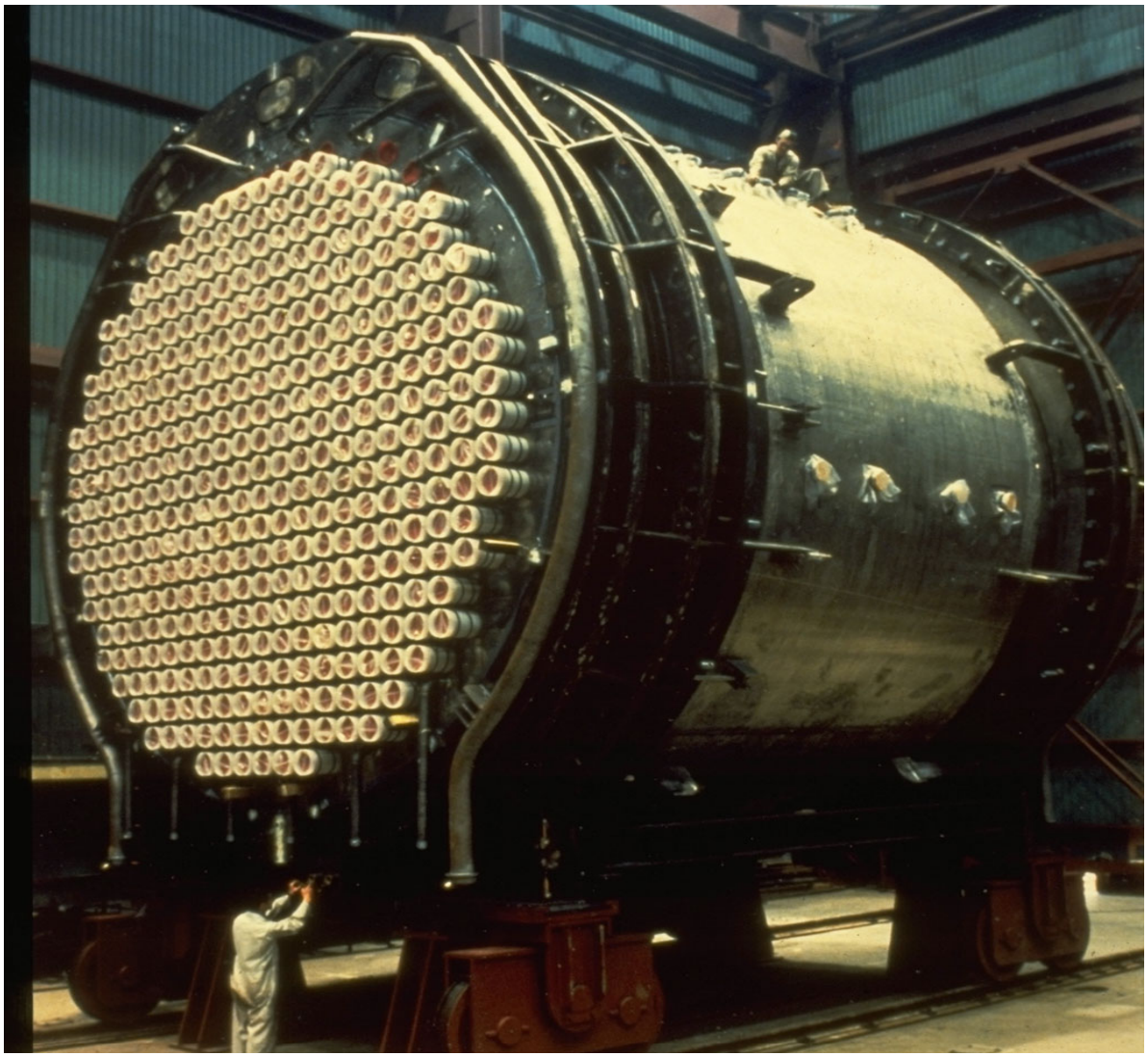
CANDU HEAT TRANSPORT SYSTEM



CANDU Fuel Channel Concept



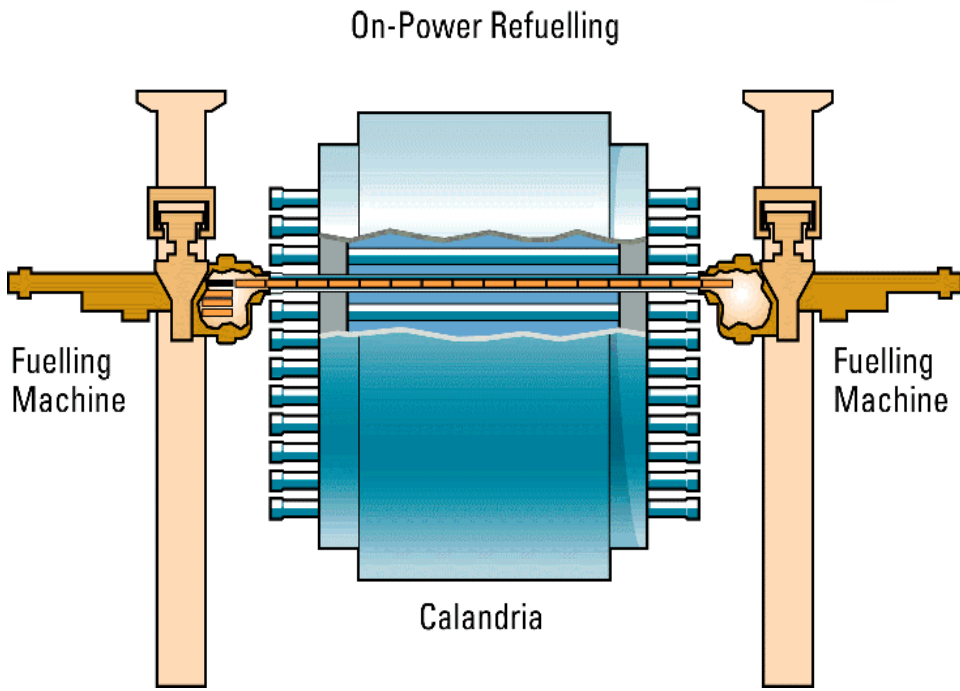
CANDU 6 Reactor



CANDU Refuelling System

On full-power refuelling leads to:

- a high performance,
- low operating costs,
- greater flexibility in scheduling outages, and
- enables long periods between maintenance outages



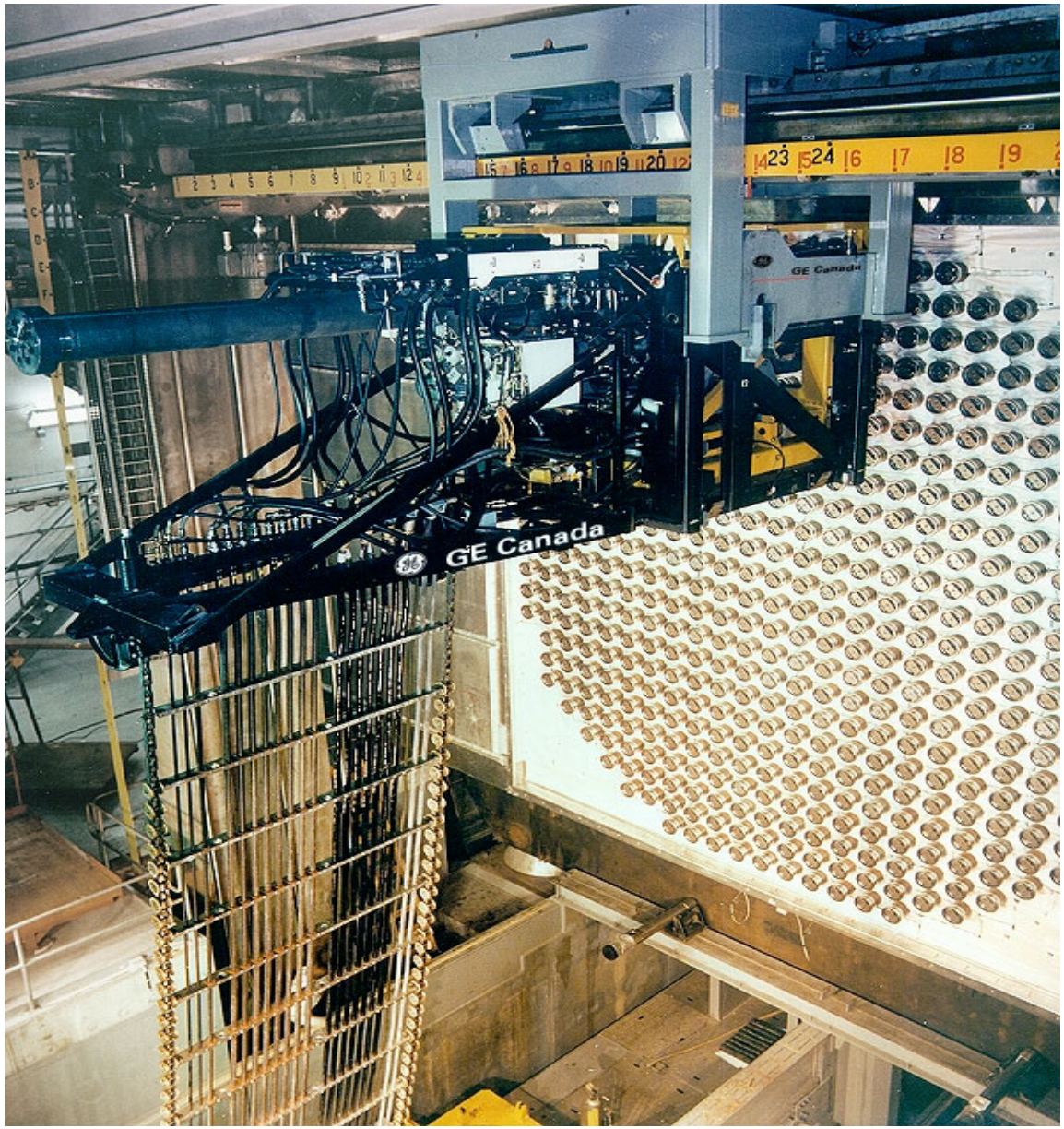
Please note: Pickering 7 - 894 days of continuous operation (26-04-1992 till 7-10-1994 = ~2.5 years)

CANDU Fuel Bundle

- Length 50 cm
- Diameter 10 cm
- Mass ~20 kg

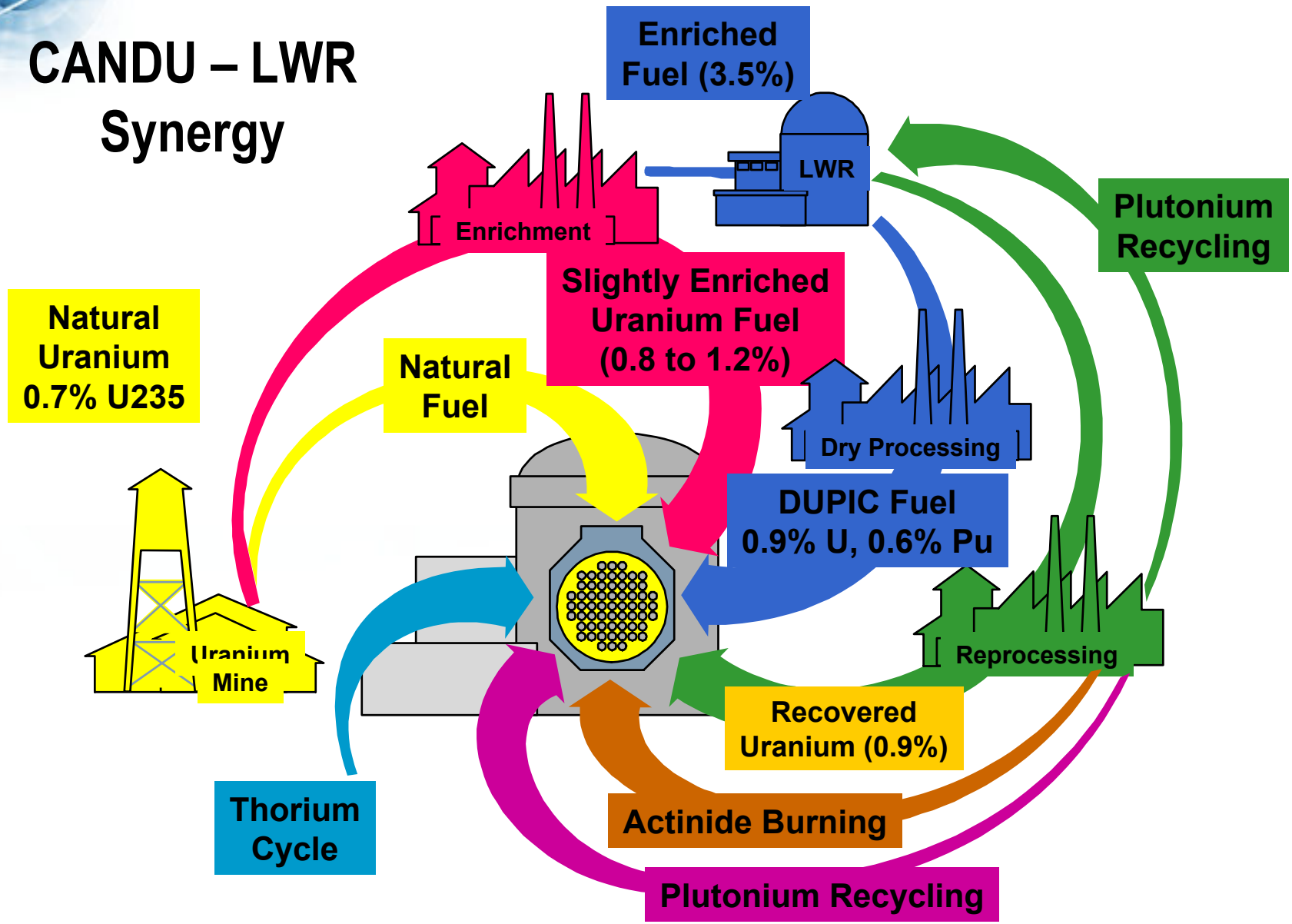
Countries with CANDUs manufacture their own fuel

Bruce Plant – Fuelling Machine



CANDU Fuel Cycles

CANDU – LWR Synergy

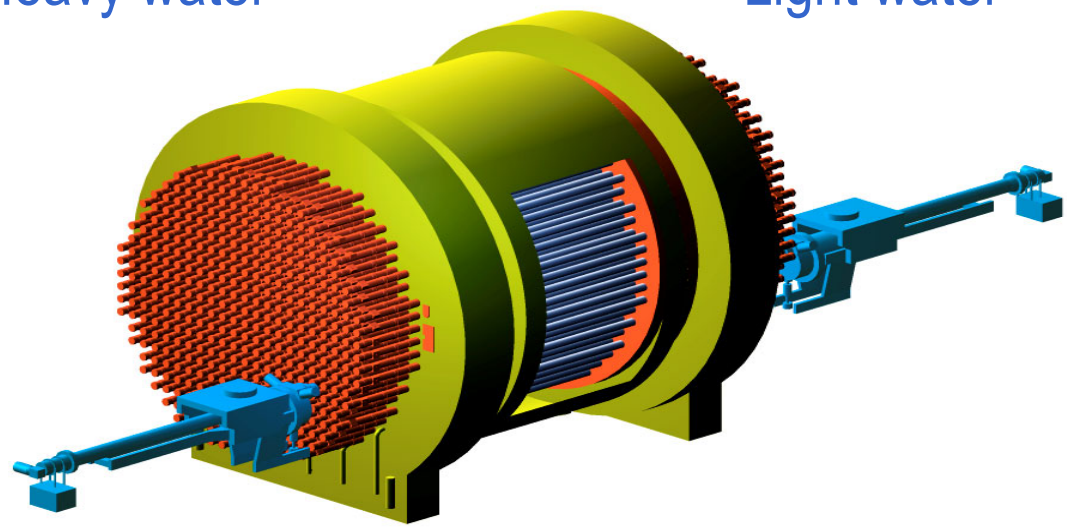


CANDU – PWR Comparison

CANDU 6

380 small dia channels

Heavy water

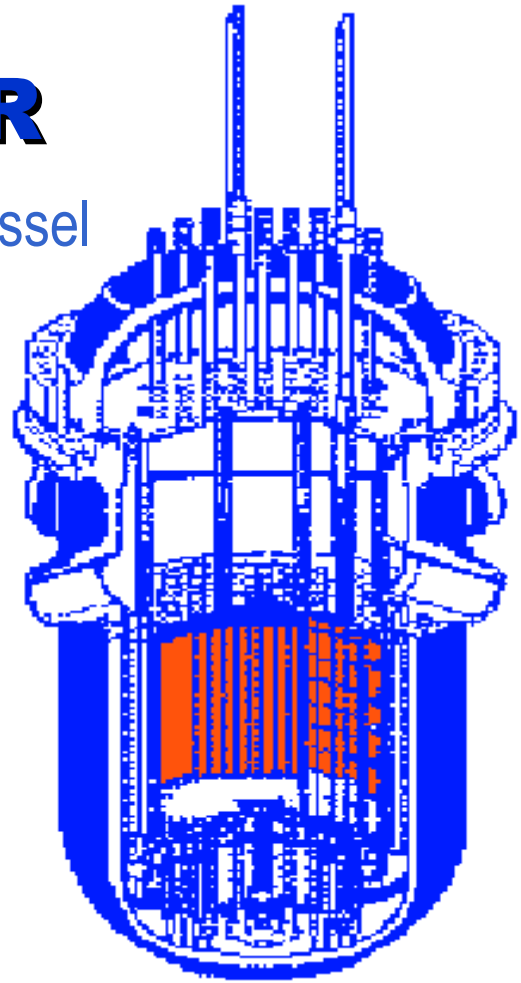


Two separate systems (coolant & moderator) (no Boron)

PWR

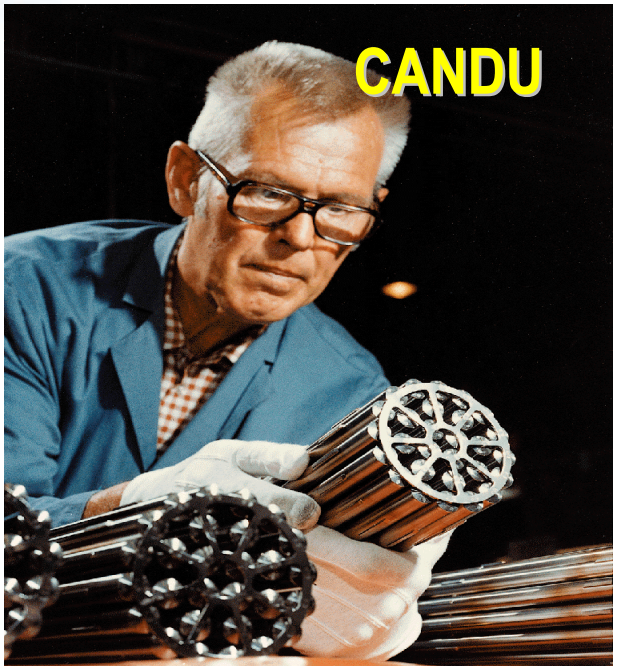
One large dia vessel

Light water

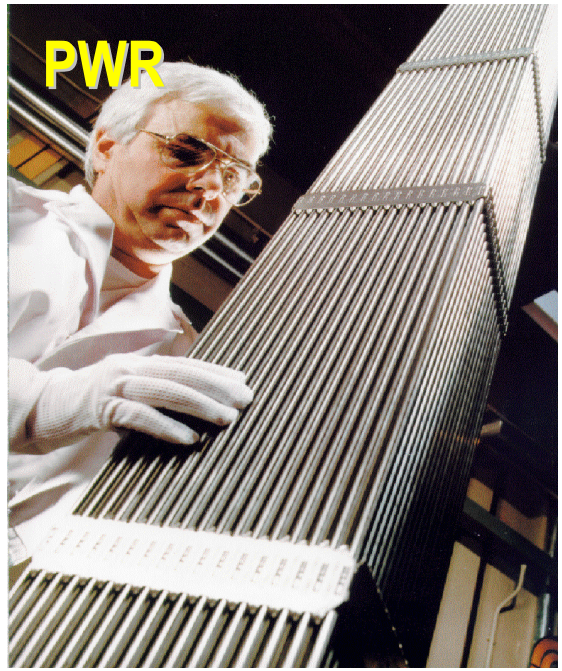


One system (coolant = moderator) (Boron present)

Fuel Comparison

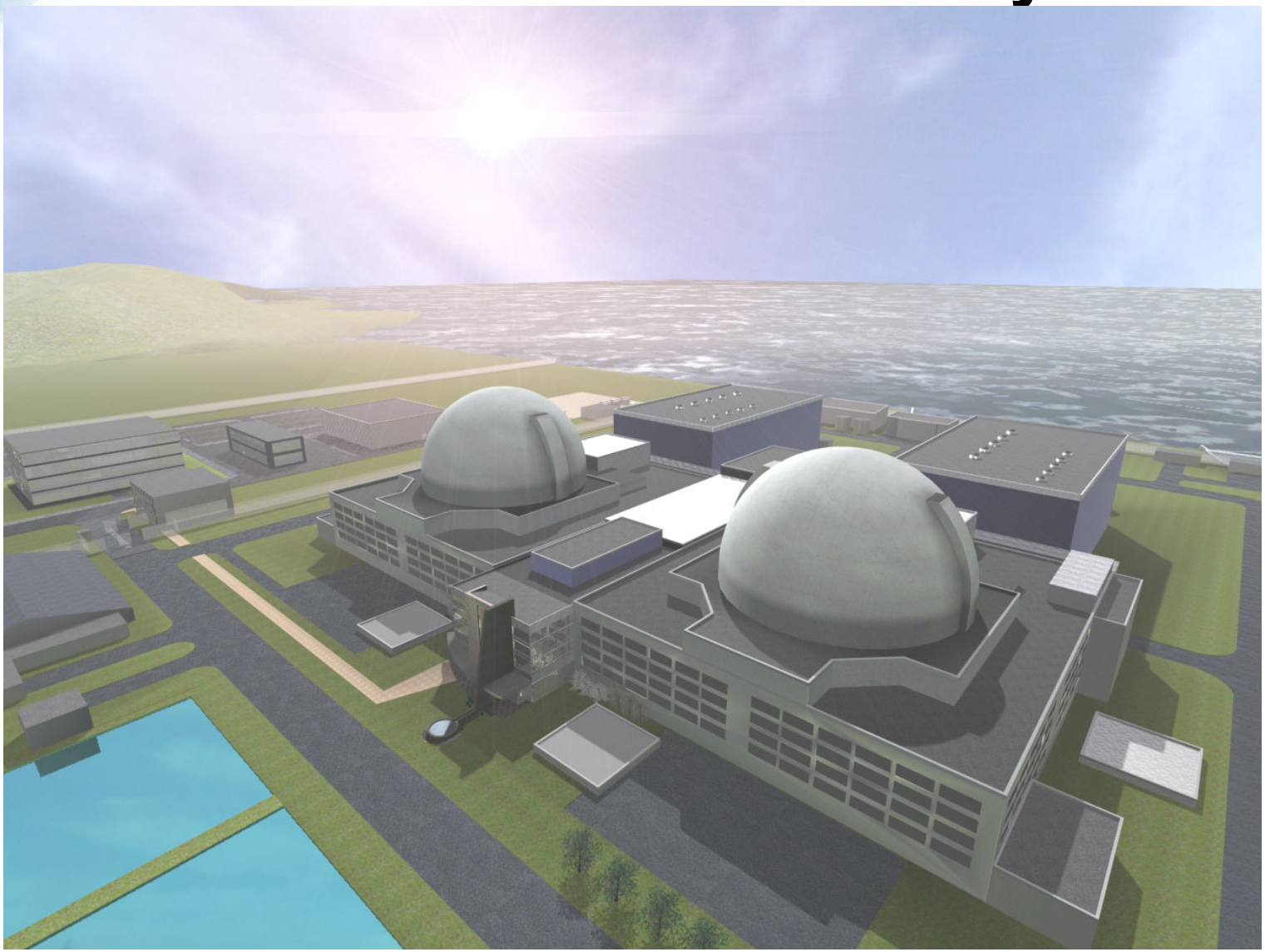


- natural uranium
- low burnup
- short bundles (0.5 metres)
- on-power refuelling
- remove defected fuel during operation



- enriched uranium
- high burnup
- long bundles (3.8 metres)
- shut down to refuel
- remove defective fuel only when shut down to refuel

ACR-1000 - Twin Plant Layout



Keeping the CANDU Tradition…

ACR-1000 evolved from the successful CANDU 6

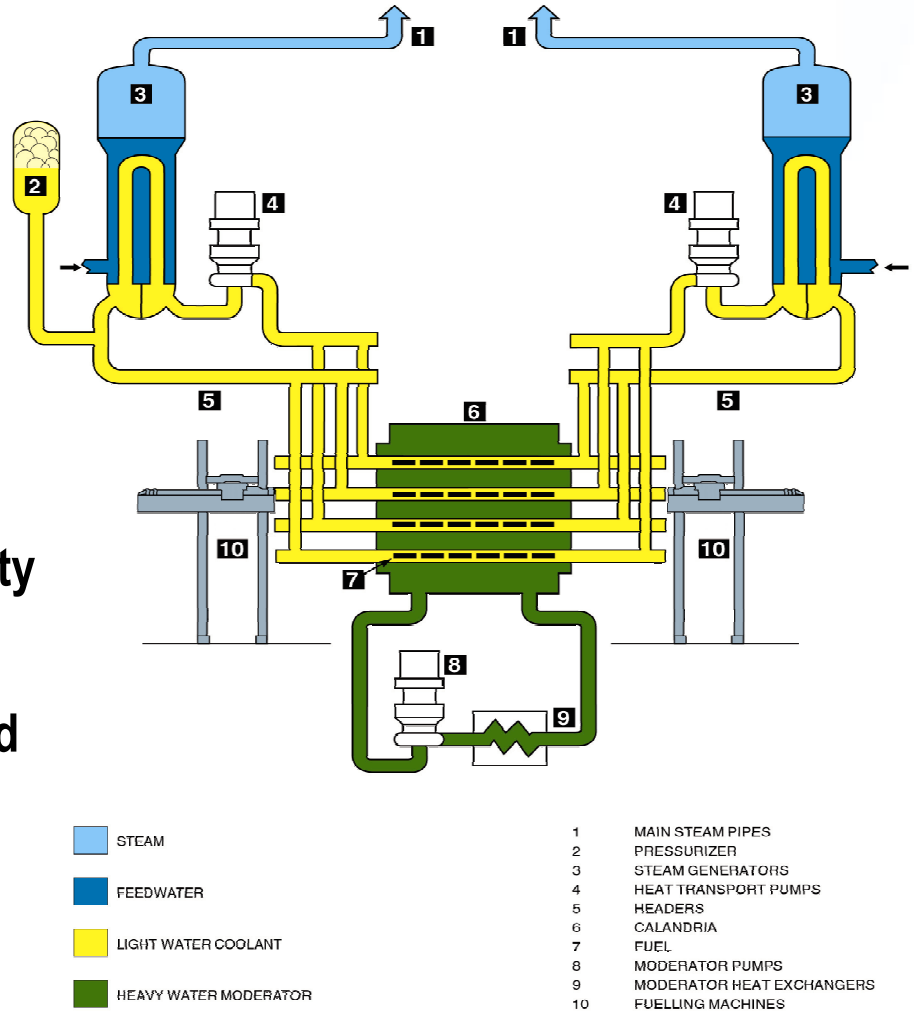
- modular horizontal fuel channels
- simple, economical fuel bundle design
- cool, low pressure heavy water moderator
- high neutron efficiency
- on-power fuelling
- passive shutdown systems

The most recent CANDU 6 plant completed in 2002 and 2003.

- Twin-unit 728 MW each, in Qinshan Phase III, China
- Built ahead of time and under budget

….While Embracing Innovation

- Enriched fuel
- Light water coolant
- Optimized plant arrangement
- Higher thermal efficiency
- Enhanced passive safety features
- Smaller reactor core with improved stability and output
- Design features for simpler operations and maintenance
- Advanced construction methods



Further improved safety, performance and cost

Generation III+ Improvement Areas

- **Safety Enhancements**
  - Reduce core damage probability by 10 times
  - Enhanced passive safety
- **Cost Reductions**
  - Reduce cost by 25% or more
- **Improved Operations**
  - Capacity Factor 95% year over year, >93% over 60-year lifetime

ACR-1000: designed with customer input

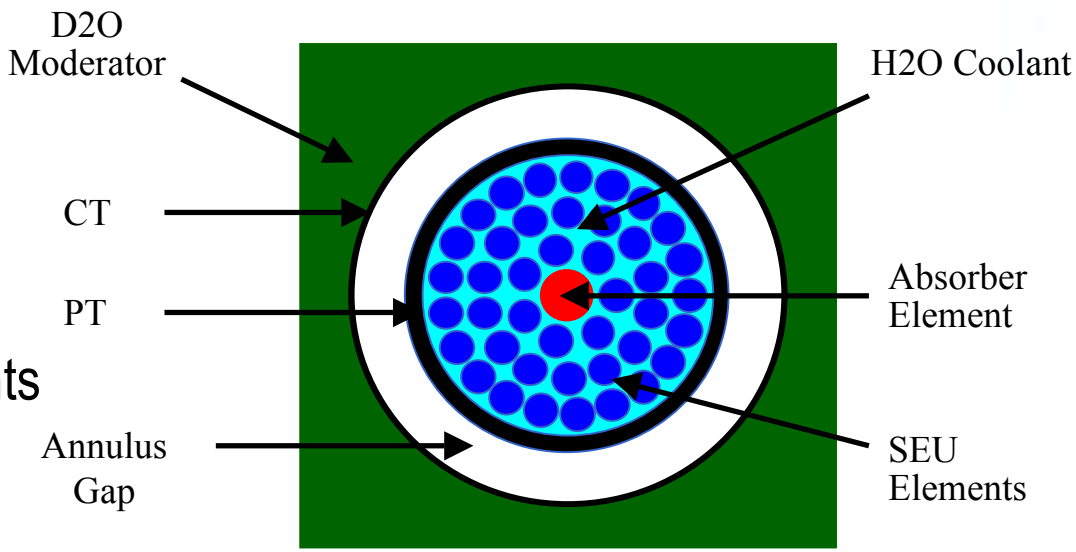
Typical Reactor Characteristics

	CANDU 6	ACR-1000
• Number of channels [-]	380	520
• Calandria diameter [m]	7.6	7.5
• Thermal Output [MWt]	2064	3187
• Gross/net output [MWe]	728/666	1165/1085
• Cycle Efficiency [%]	35.3	36.6
• Steam temperature [Cº]	258	273
• Steam quality [-]	0.9975	0.999
• Steam pressure [MPa]	4.6	5.9
• Feed water temperature [Cº]	187	217
• ROH pressure [MPa]	9.9	11.1
• RIH temperature [Cº]	260	275
• Total D_2O inventory [Mg]	457	250

Reactor Core Characteristics

The ACR-1000 reactor core characteristics:

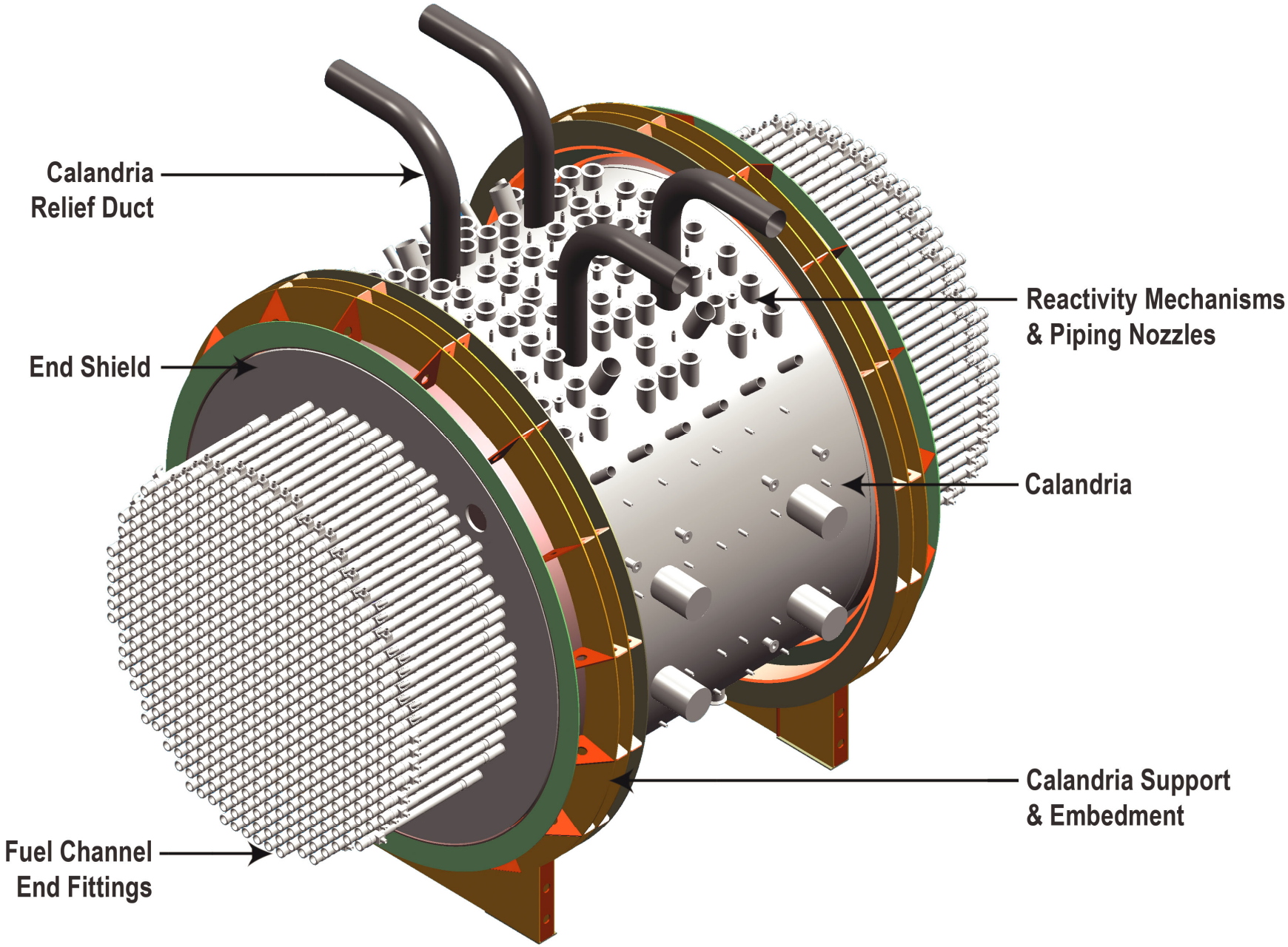
- Compact size
- Small negative coolant-void reactivity
- Reduced heavy water requirements due to compact core size and the use of light water as the coolant
- Simplified reactor control through negative feedback in reactor power
- High radial power form factor and a relatively flat axial power shape
- Lower linear element ratings and enhanced thermal margins



ACR-1000

- No. of channels 520
- Lattice Pitch 240 mm
- Core diameter 7. 5 m
- Moderator volume 23 m^3

ACR-1000 Reactor Assembly



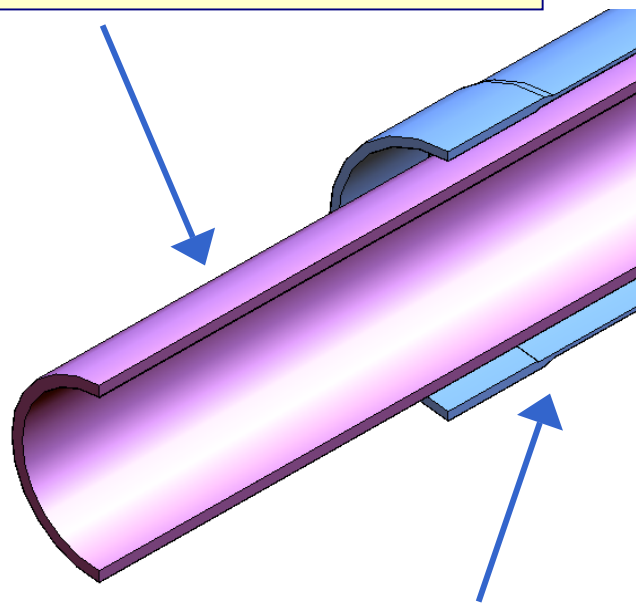
ACR Fuel Channel & Feeder Design Improvements

- Pressure Tube (PT) is improved zirconium 2.5wt% niobium alloy
- PT wall is designed to provide at least 30 years operation:
  - ➢ Increased strength to improve safety margins
- Calandria tube is Zr-4, designed to withstand PT rupture
- Designed and manufactured for easy replacement of PTs at mid-life (30 years)

- Feeder materials has been changed from carbon steel to stainless steel to ensure longer life
- Feeder hot bending to reduce number of welds
- Improved accessibility and significant reduction of feeder inspections

Pressure Tube

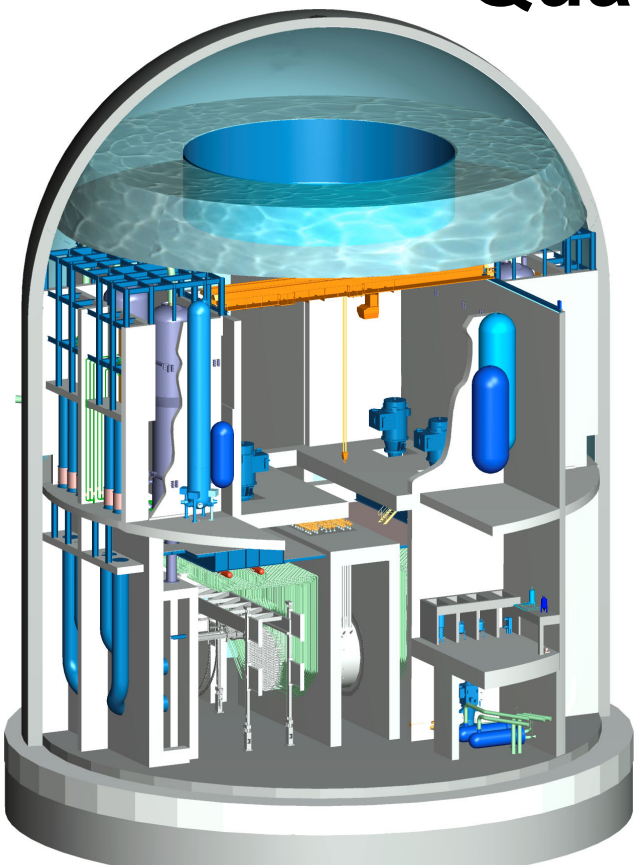
104 mm ID x 6.5 mm thick wall x Approx 6.5 m long



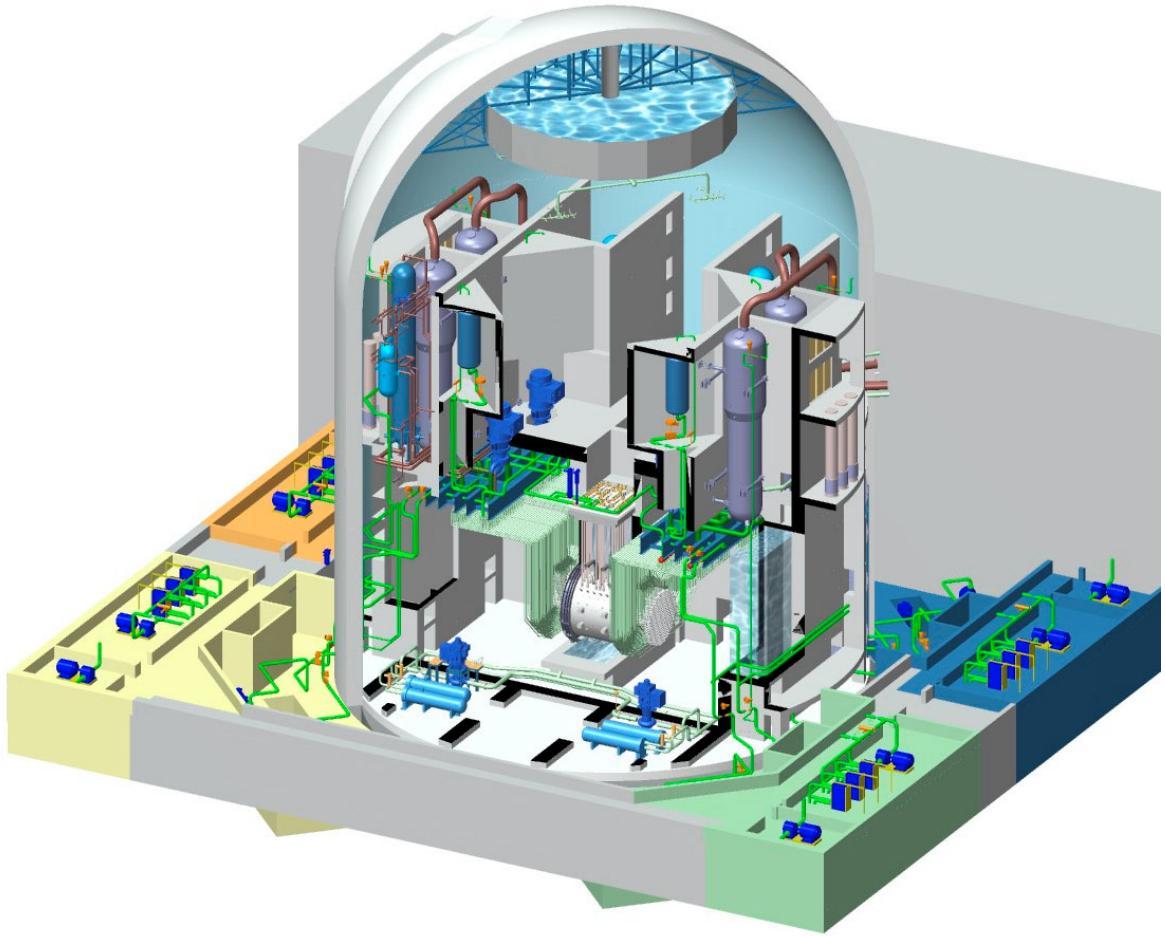
Calandria Tube

Body: 160 mm ODX
2.5 mm thick wall
Ends: 4.5 mm thick wall
Length: Approx. 6m

Safety: Strong Containment with Quadrant-based Design



Steel-lined, 1.8 meter thick pre-stressed concrete walls



Four-Quadrant Separation

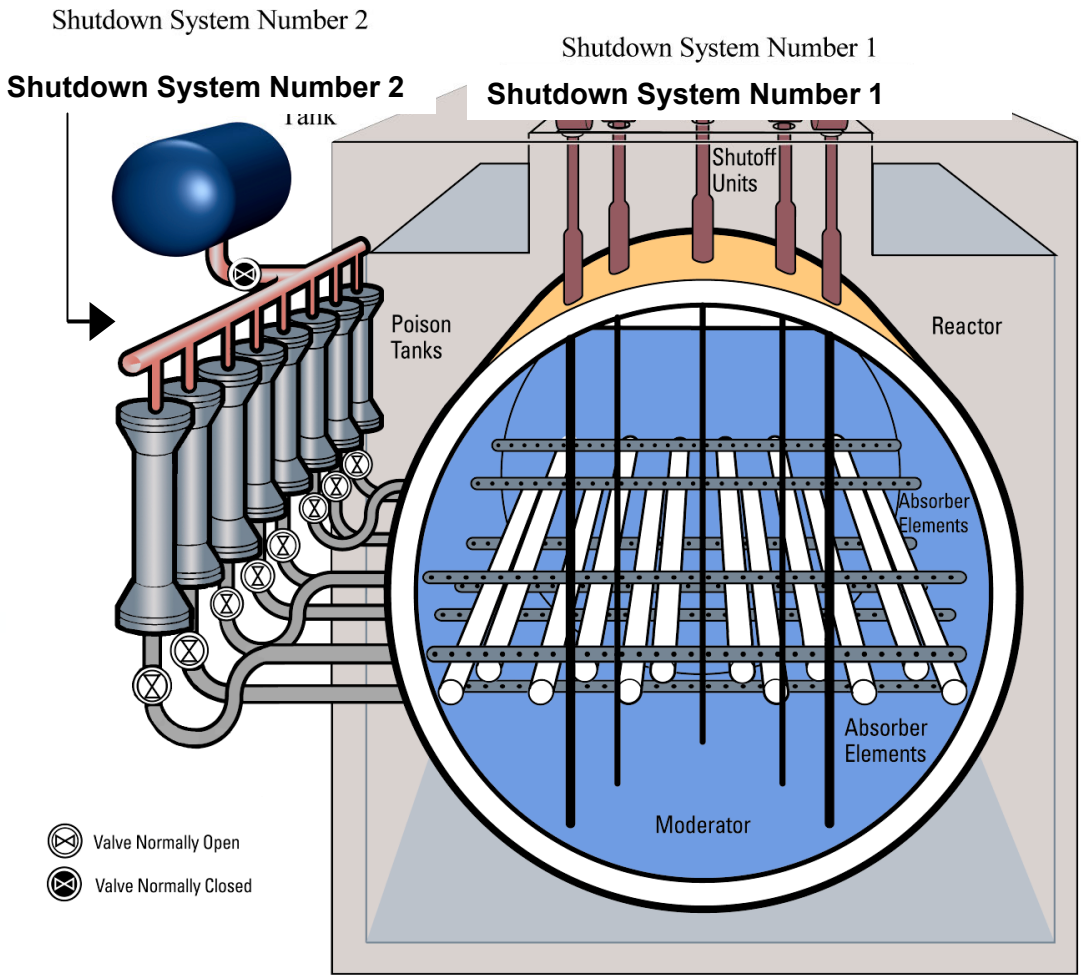
- 4 divisions of major safety related systems provide additional redundancy and reliability to allow on-power maintenance of one division
- 3 of 4 divisions required for a normal operation
- 2 of 4 divisions required for accident mitigation
- 4 channel instrumentation provides additional redundancy and reliability to allow individual channels to be taken out for maintenance.

Dual Passive Independent Shutdown Systems

- Shutdown system 1 (SDS1)
  - ➢ Shut-off rods fall vertically into the low pressure moderator by gravity drop
- Shutdown system 2 (SDS2)
  - ➢ Liquid neutron absorber injected horizontally by gas pressure into the moderator

Please note:

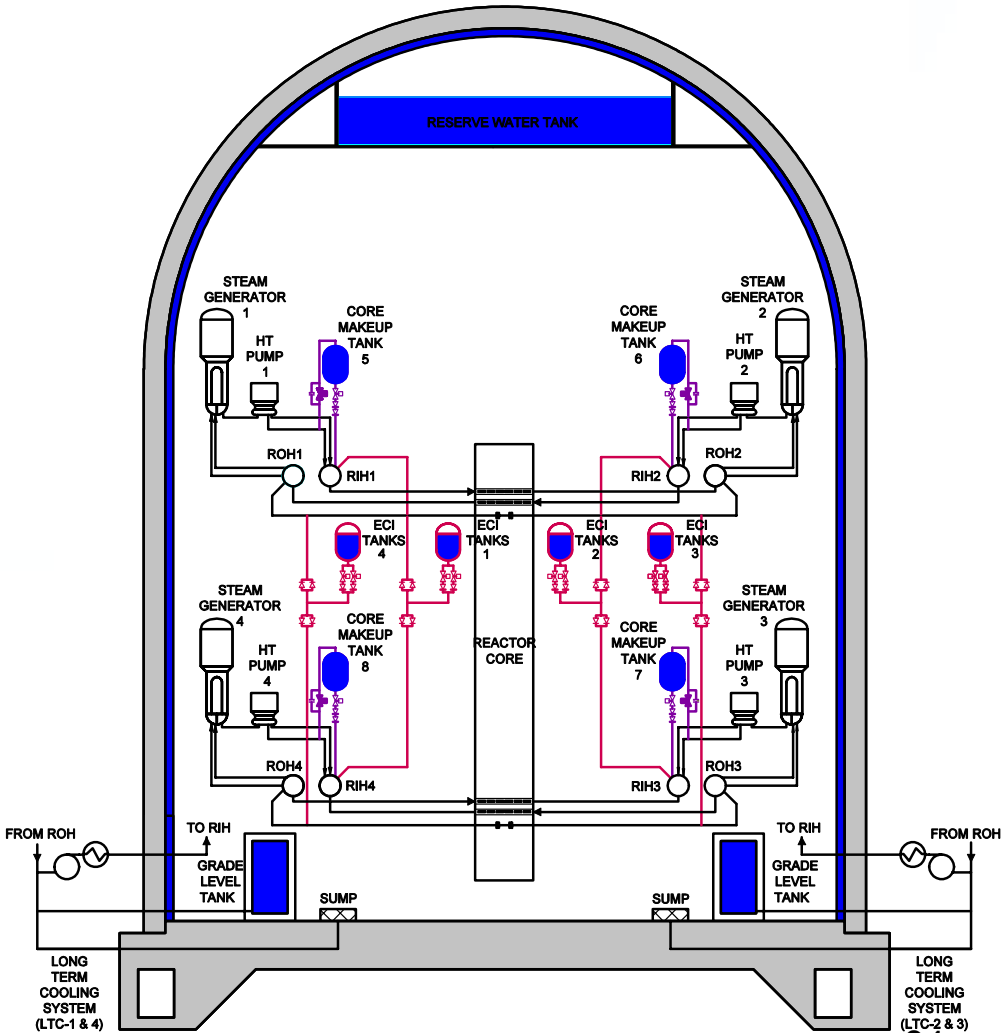
- ➢ All reactivity devices in the cool, low pressure moderator,
- ➢ Independent from reactor control system



ACR-1000 Shutdown Systems 1 and 2

Emergency Core Cooling (ECC) System

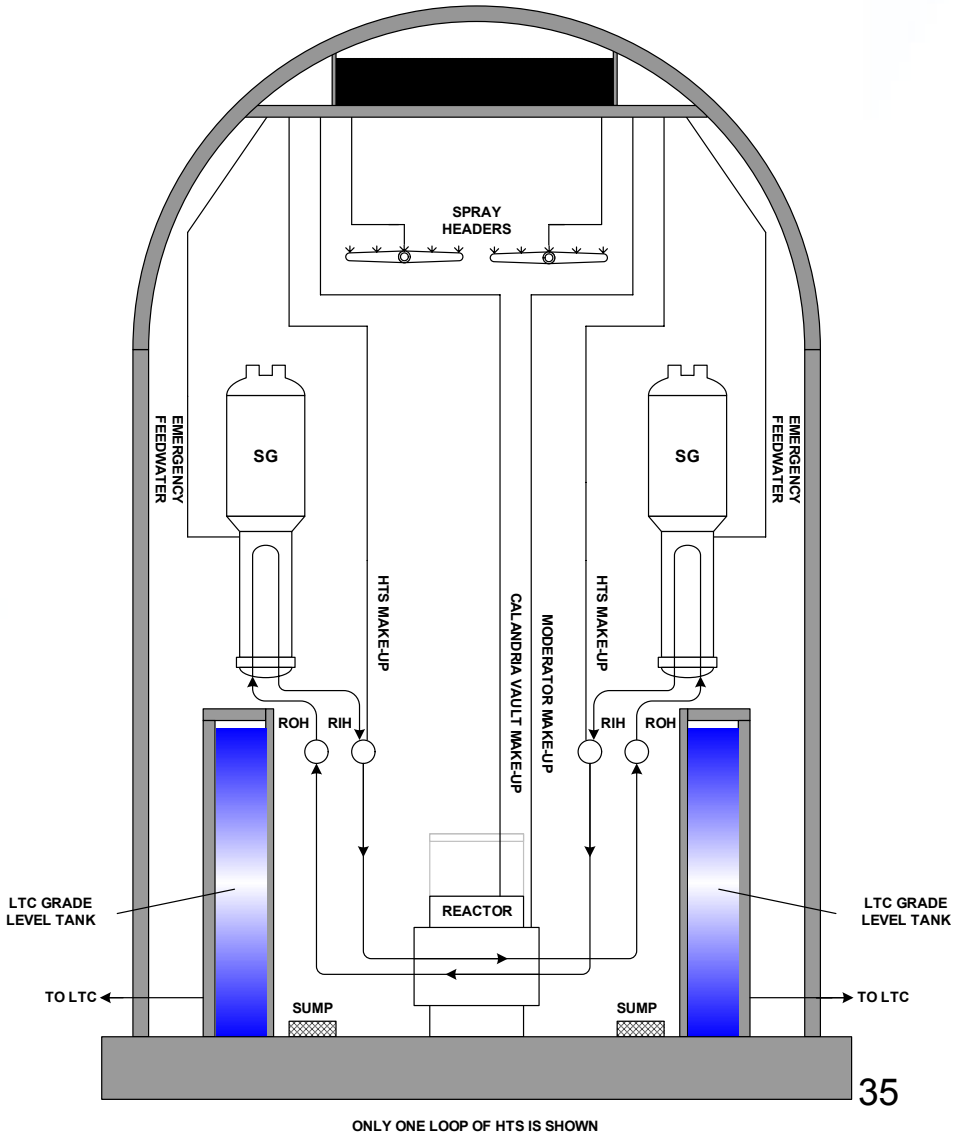
- **Two Stage ECC System**:
  - Passive initial injection from pressurized ECI tanks located inside Reactor Building (RB)
  - Long Term Cooling (LTC) System provides pumped recovery
  - LTC System also provides maintenance cooling after normal shutdown
  - LTC pumps and heat exchangers located in Reactor Auxiliary Building (RAB) adjacent to RB sumps



Reserve Water System

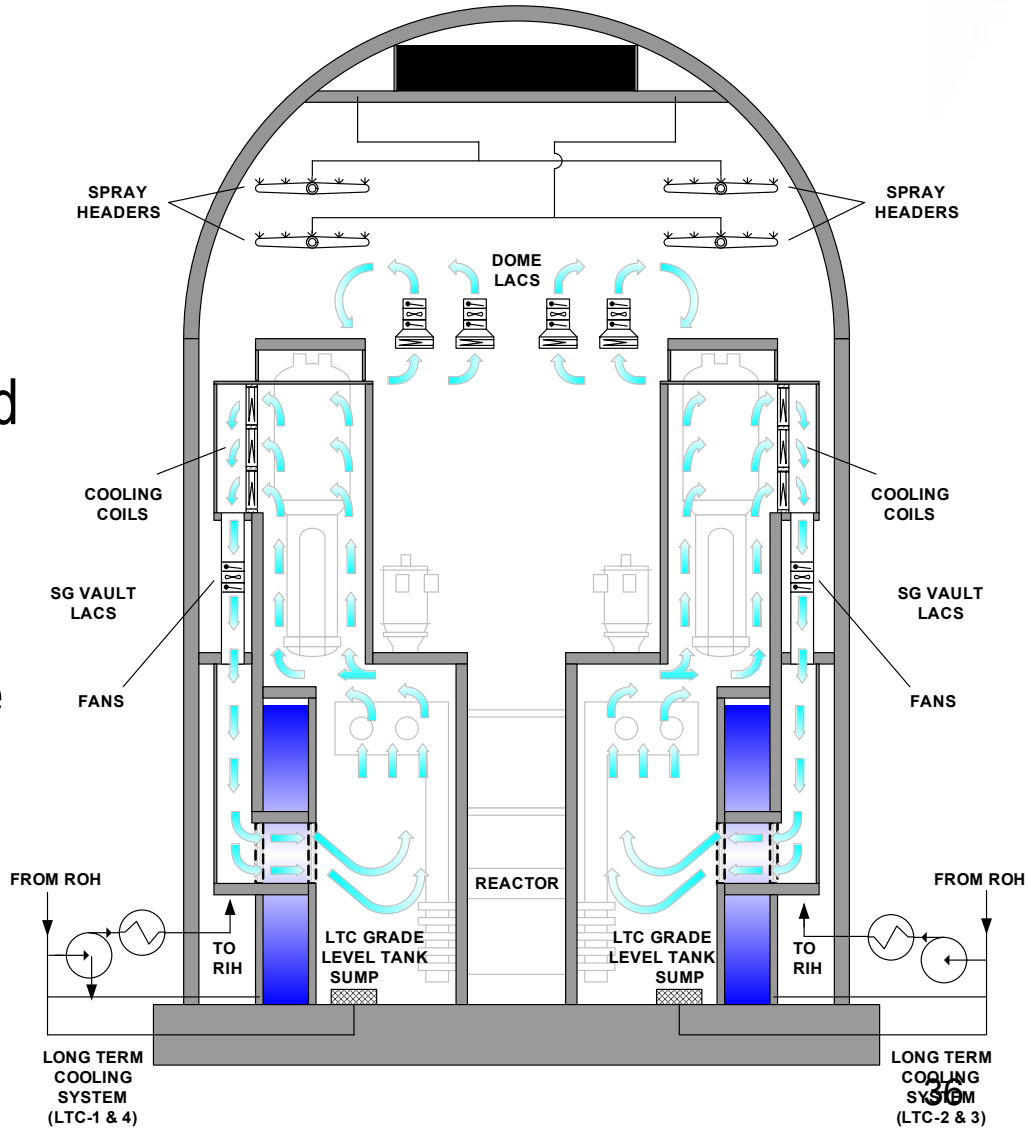
- Elevated Reserve Water Tank passively supplies water to:
  - Reactor Coolant System
  - Secondary SG side
  - Moderator System
  - Shield Tank Vault
  - Reactor Building Spray

- LTC Grade Level Tanks passively supply water to RB sumps.
- Reserve Water System provides cooling to reactor core for severe accident events



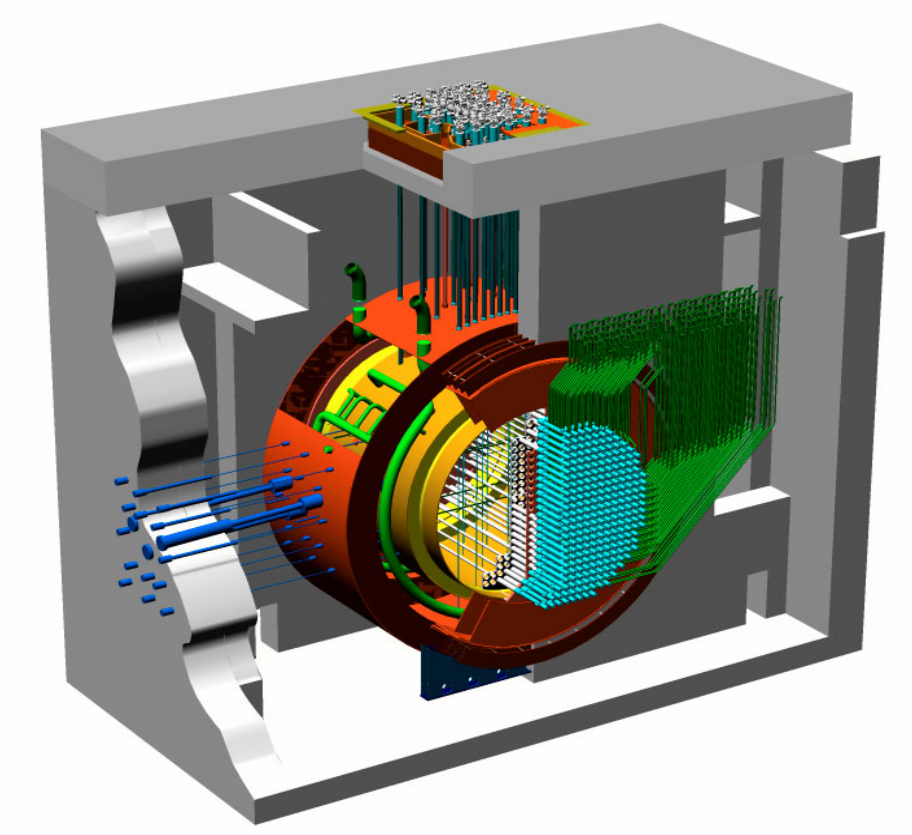
Containment

- Steel-lined containment
- Auto isolation on high pressure / high radiation signals
- Containment cooling system, comprised of local air coolers and spray system supplied by the Reserve Water Tank
- Passive autocatalytic hydrogen recombiners and ignitors for core damage accidents
- RB equipment is accessible on-power through 2 airlocks

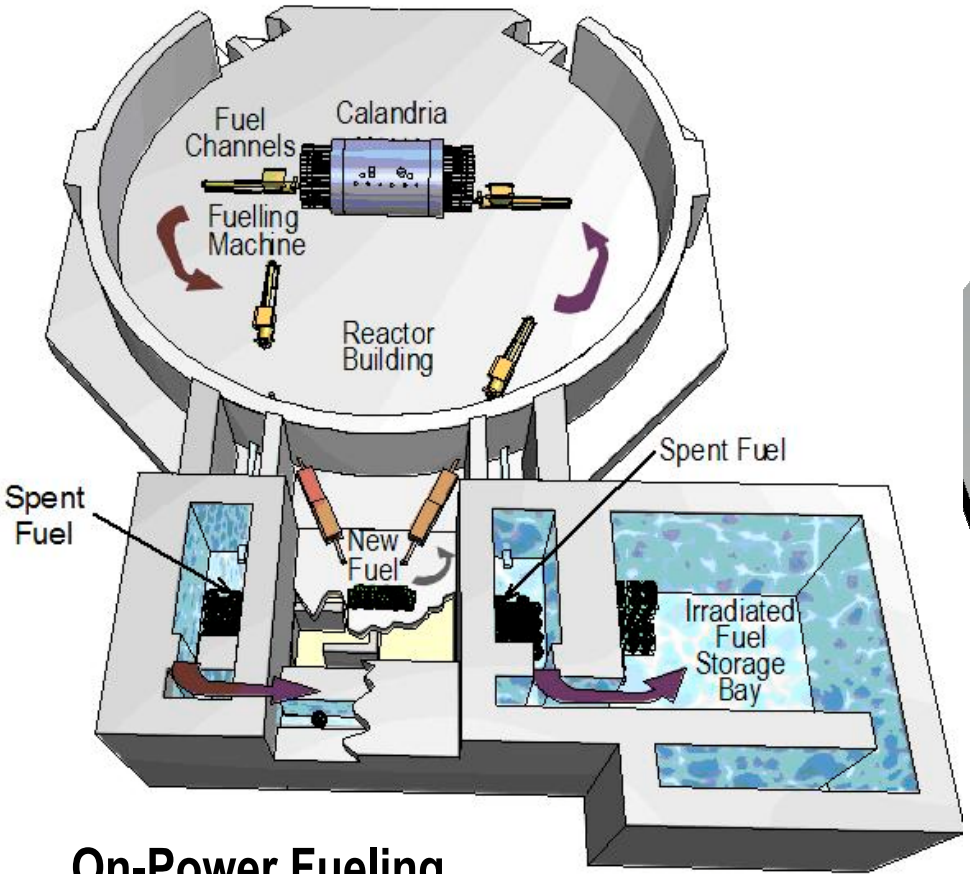


ACR-1000 Additional Passive Heat Sinks

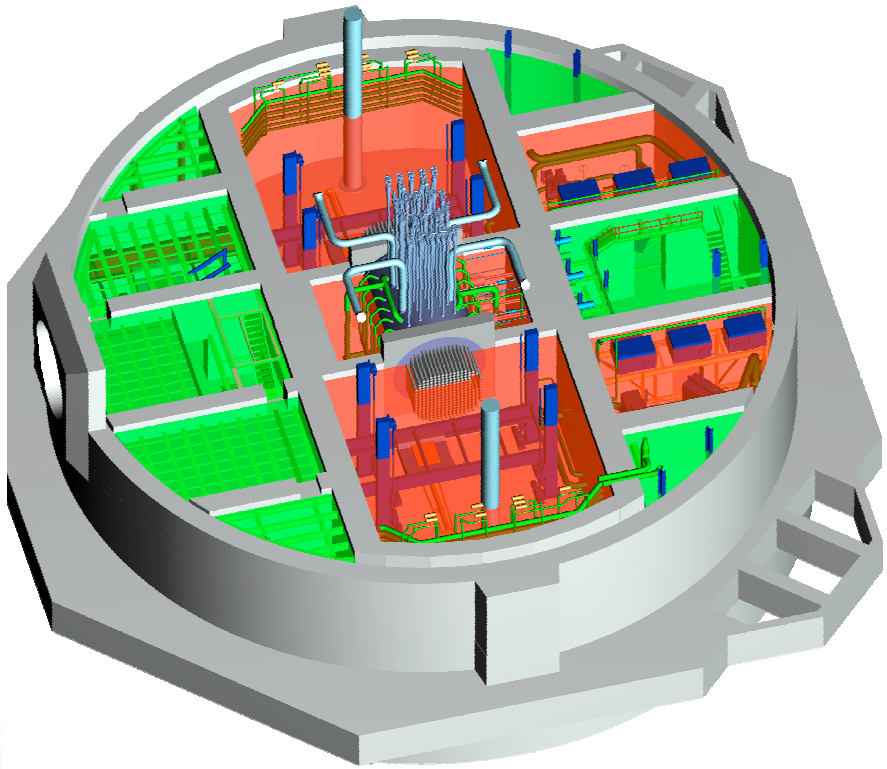
- Cool, low pressure moderator, and
- Large concrete reactor vault surrounding the core in the calandria vessel filled with light water to further slow down the severe core damage progression



Improved Operations: One planned 21 day shut-down every three years



On-Power Fueling



On-Power Access for Maintenance

Innovation: Constructability

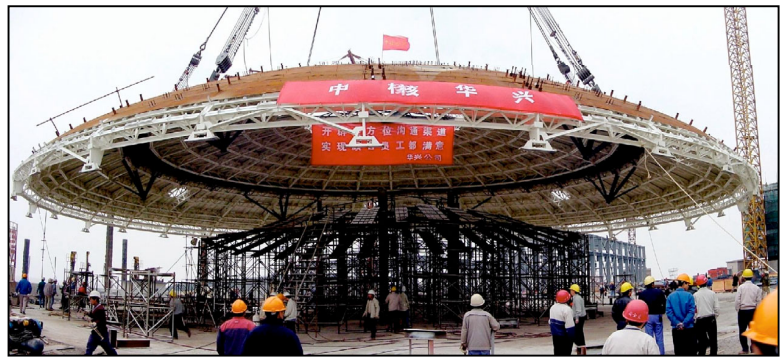
ACR-1000 Construction Strategy:

- Prefabrication
- Modularization
- Very Heavy Lift Crane (VHL)
- Open Top construction
- Parallel Construction
- Advanced engineering tools
- Proven at Qinshan

Qinshan - Dousing System Modules

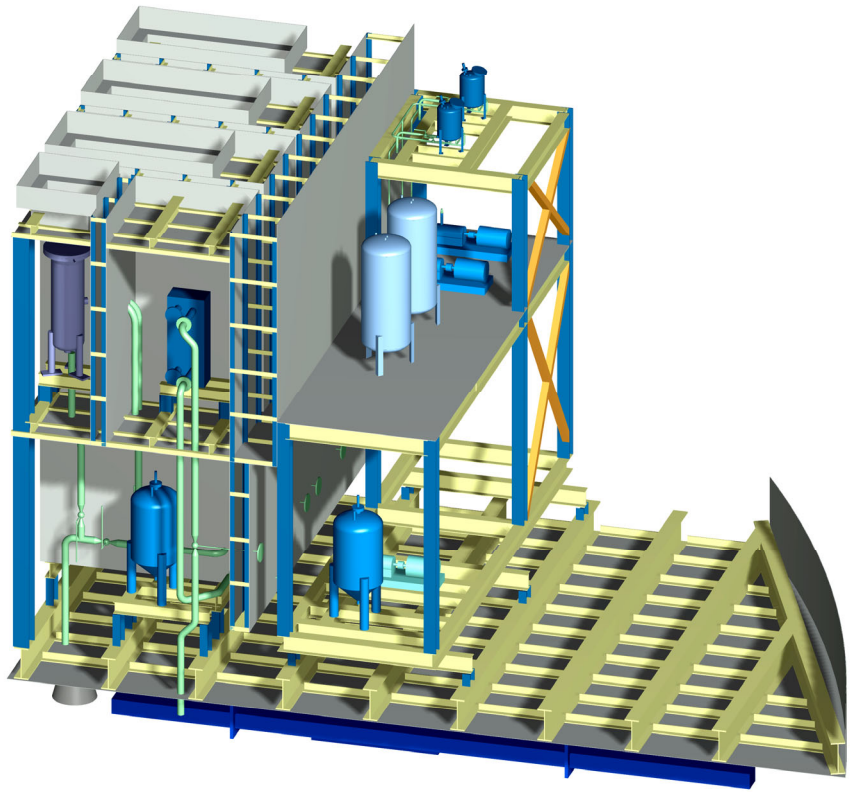
ACR Module Types

ACR is designed to employ more than 165 modules in the Reactor Building



ACR Module Types (cont'd)

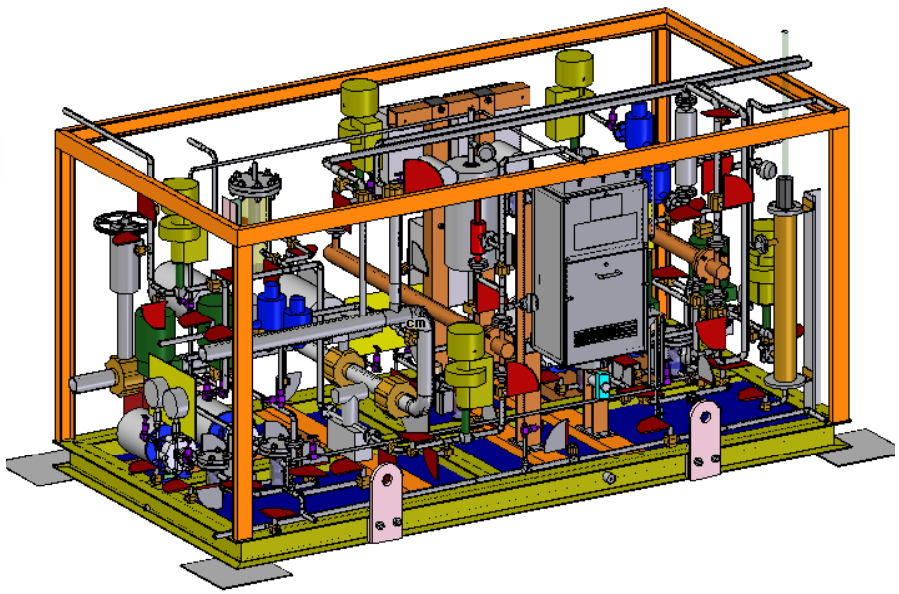
- **Large Multi-Discipline Modules**
  - Too large for shipment to site by road/rail
  - Assemble either adjacent to site (outside construction site) or
  - Assemble in shipyard/ fabrication shop with access to water and ship to site via water transportation
  - Shipping costs versus saving in shop fabrication costs need to be assessed

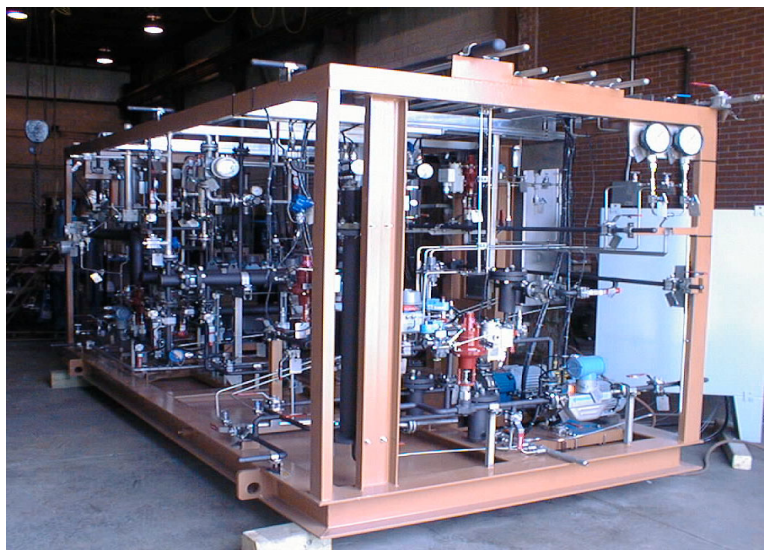


ACR Moderator Purification System Module

ACR Module Types (cont'd)

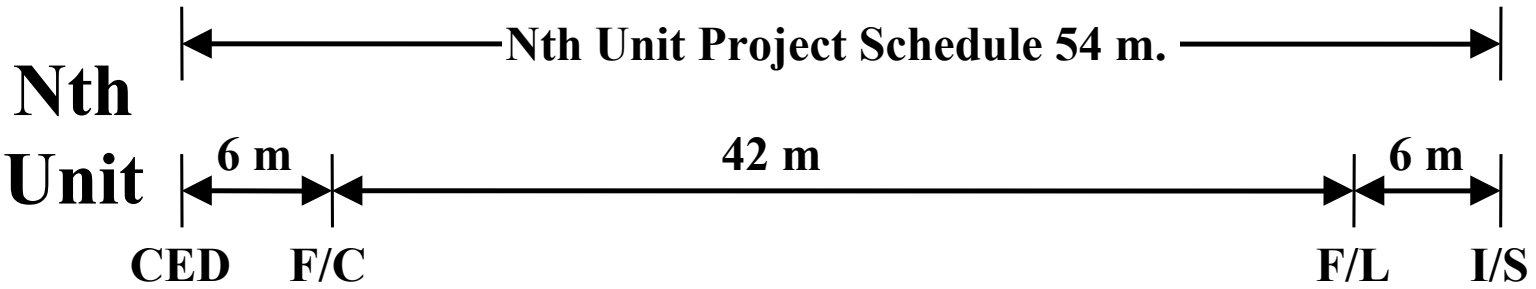
- Piping Valve/ Modules Pre-Assembled on Skids
  - Pre-assembled in Supplier/ Fabricators shop
  - Shipped by road/ rail/ sea
- Instrumentation Racks/ Pre-assembled Panels
  - Pre-assembled in Suppliers shop
  - Shipped by road/ rail/ sea





- Images taken from 3L Filters

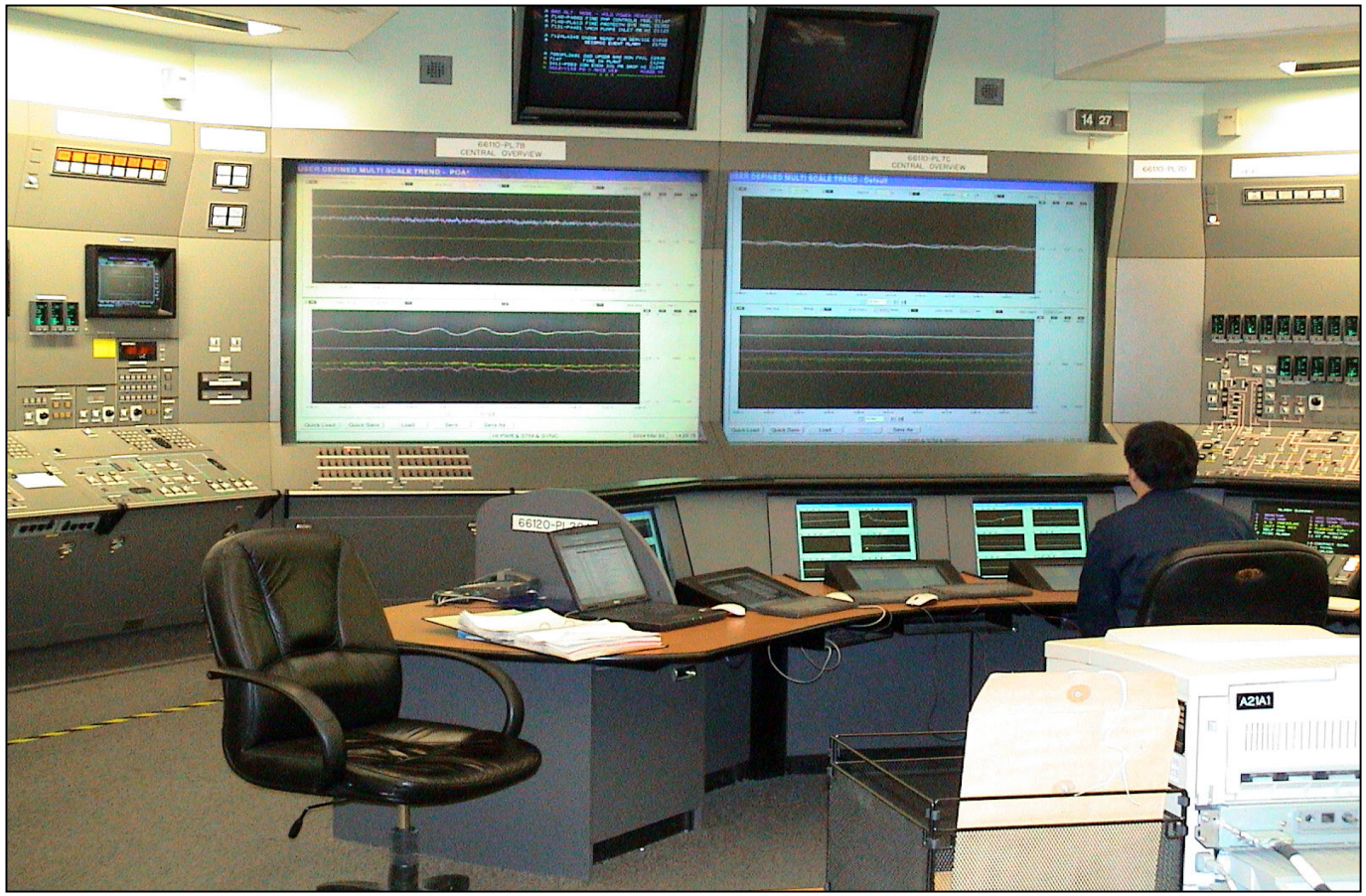
ACR-1000 Project Schedule



CED: Contract Effective Date
F/C: First Concrete
F/L: Fuel Loading
I.S: In Service

- First units will require up to one year longer schedule

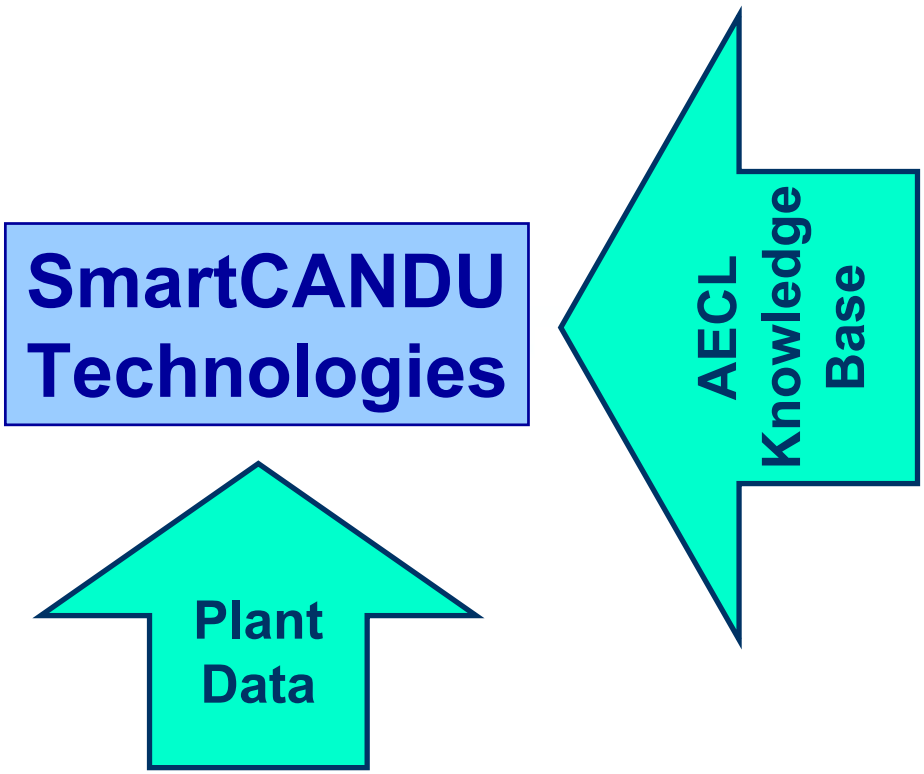
ACR-1000 Control Centre



Ergonomic operator console, touch displays, large screens, smart annunciation….

Smart CANDU Modules

High Capacity Factors And Long-Life



CAMLS

Intelligent CANDU Annunciation Message List System that assists operators to cope with events such as blackouts.

ChemAND

Health monitor for plant chemistry. Predicts future performance of components, determines maintenance requirements and optimal operating conditions.

ThermAND

Health monitor for heat transfer systems & components. Ensures optimal margins and maximum power output.

MIMC

Maintenance Information Management Control system that links health monitor data to the plant work management system.

Summary & Final Remarks

AECL has and offers advanced reactor technologies:

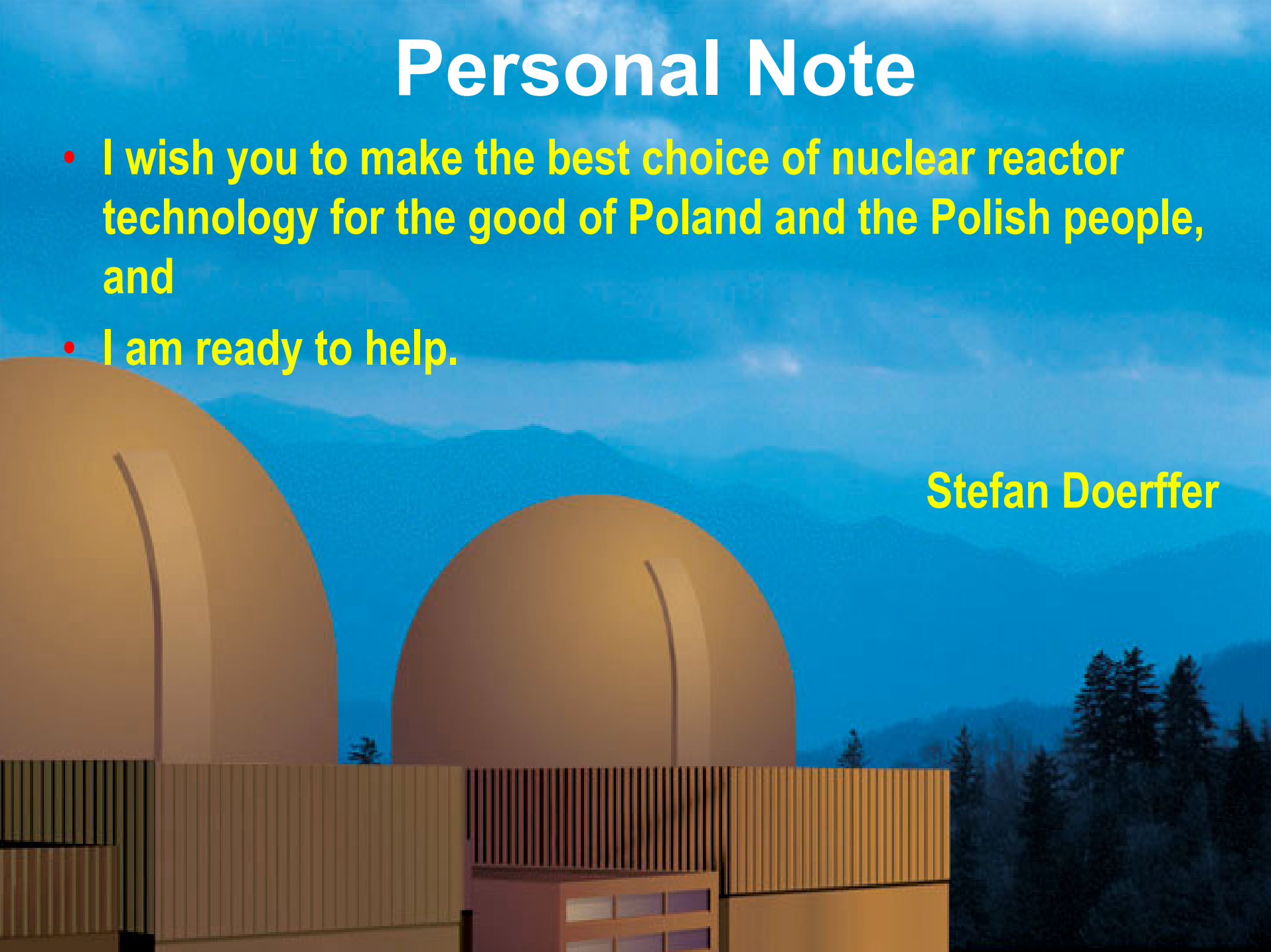
- Enhanced CANDU 6
  - ready for near-term deployment, and
  - meets Gen III criteria
- ACR-1000
  - Generation III+ technology
  - Current evolution of CANDU
  - Combines experience of CANDU 6, domestic and offshore programs

AECL ready to help Poland to meet its energy needs

Personal Note

- I wish you to make the best choice of nuclear reactor technology for the good of Poland and the Polish people, and
- I am ready to help.

Stefan Doerffer

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