

Design and Construction of Canadian Advanced PHWRs

Dr. Ala Alizadeh
Vice President, Marketing & Business
Development

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Outline

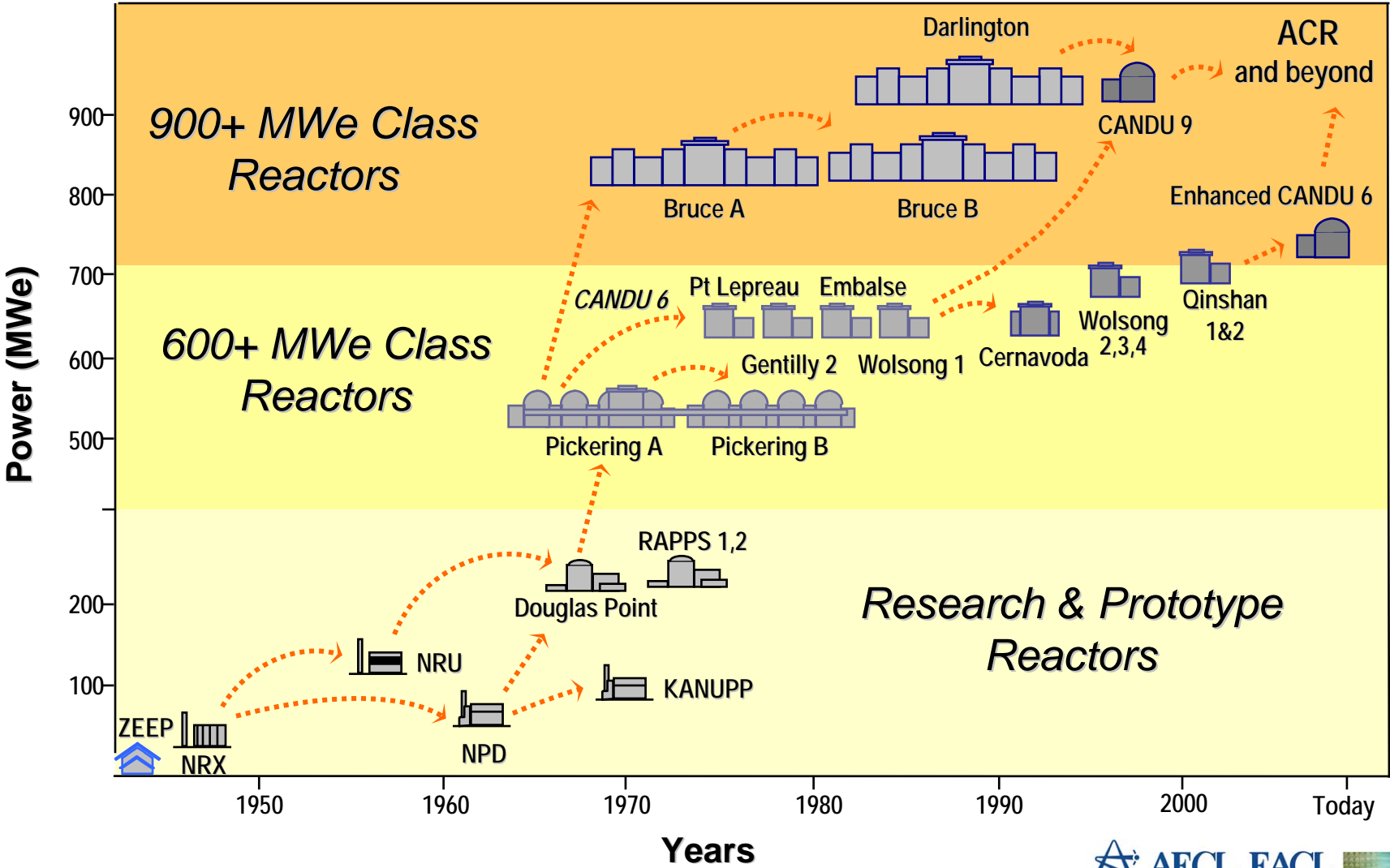
- **Introduction**
- **CANDU Reactor Development History & Recent Projects**
- **New Build Initiatives in Canada**
- **Fundamentals of CANDU Reactor Technology**
- **Overview of Major Features of ACR-1000 Design**
- **ACR-1000 Construction**
- **Summary & Final Remarks**

Atomic Energy of Canada Limited

- **Commercial Crown corporation, established 1952 to lead Canadian nuclear industry**
- **AECL is a fully integrated company: reactor designer, vendor, project management, R&D, nuclear services, refurbishment, waste management, worldwide**
- **Over 5000 staff**



CANDU: Built on a Strong History

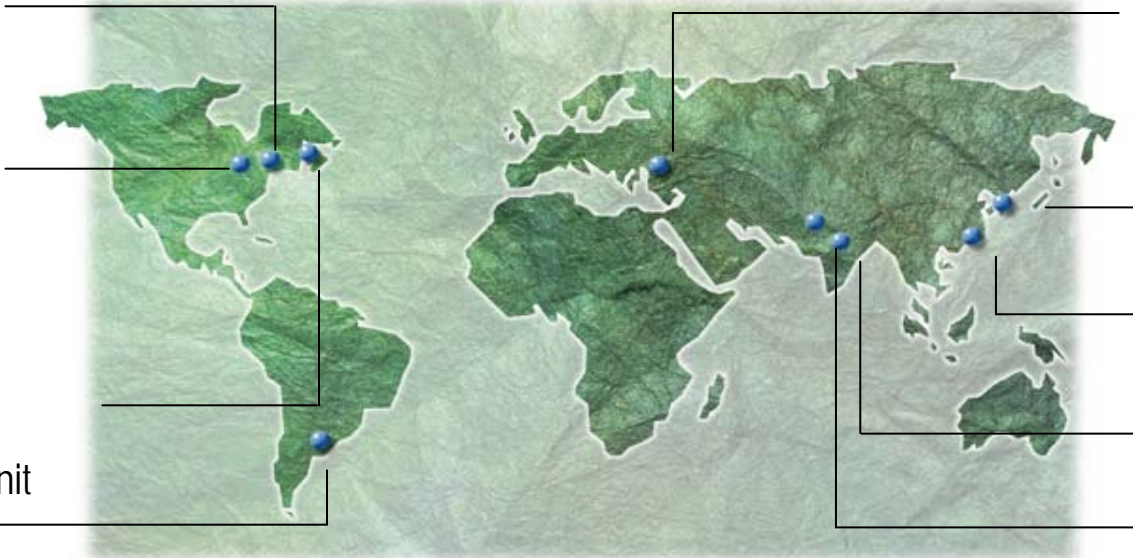


42 CANDU Reactors Worldwide, 6 Under Construction, and 3 in Pre-project Phase = 51 reactors

Quebec, Canada
Gentilly 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 2 unit,

Republic of Korea
Wolsong 4 units

China
Qinshan 2 units

India (CANDU type)
13 units, 5 under construction

Pakistan
KANUPP 1



Point Lepreau, Canada



Pickering, Canada



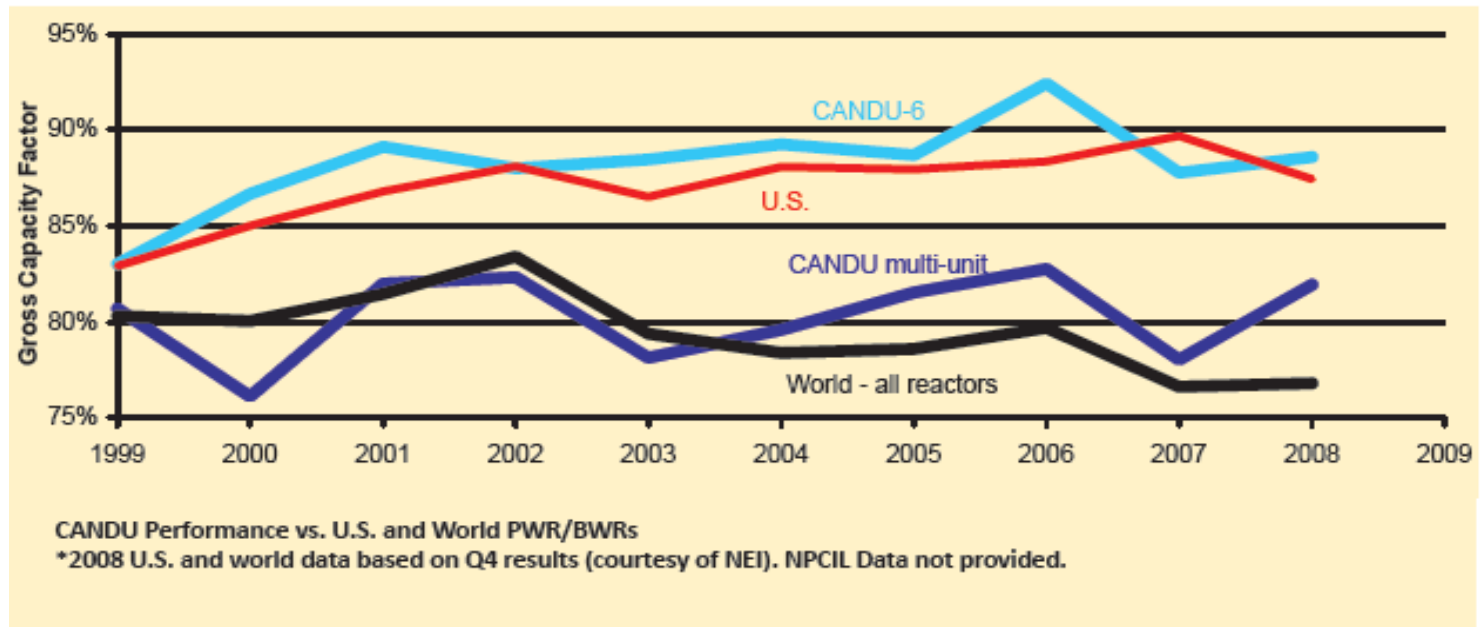
Qinshan, China

AECL Track Record on New Projects

In-Service Date	Plant	Status
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	Completion Project

CANDU 6 Lifetime Capacity Factors

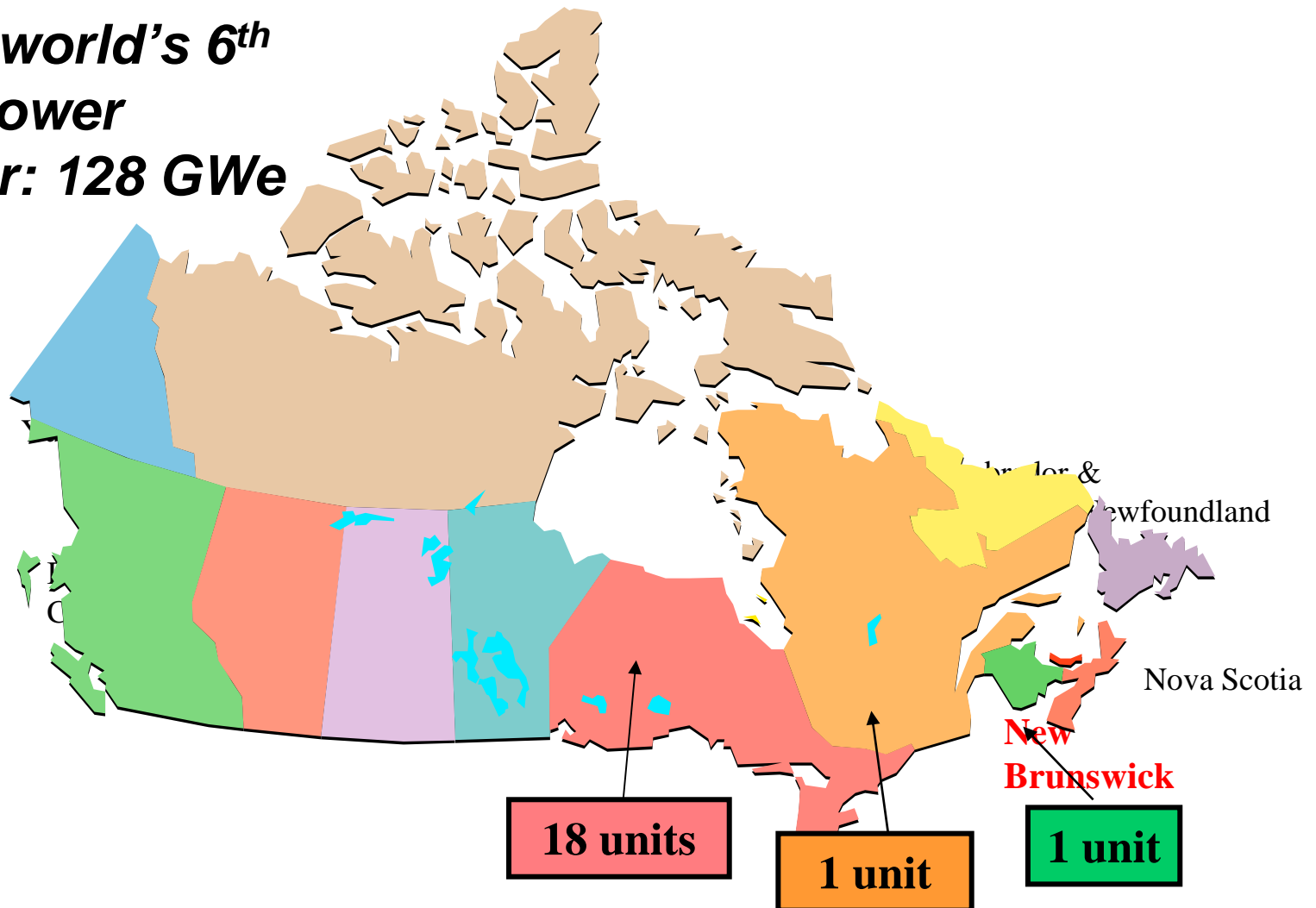
- For all CANDU 6s: 88.8%
- For CANDU 6s entering service in the last decade: 90.2%
- 6 of 9 exported CANDU 6s are in global top decile



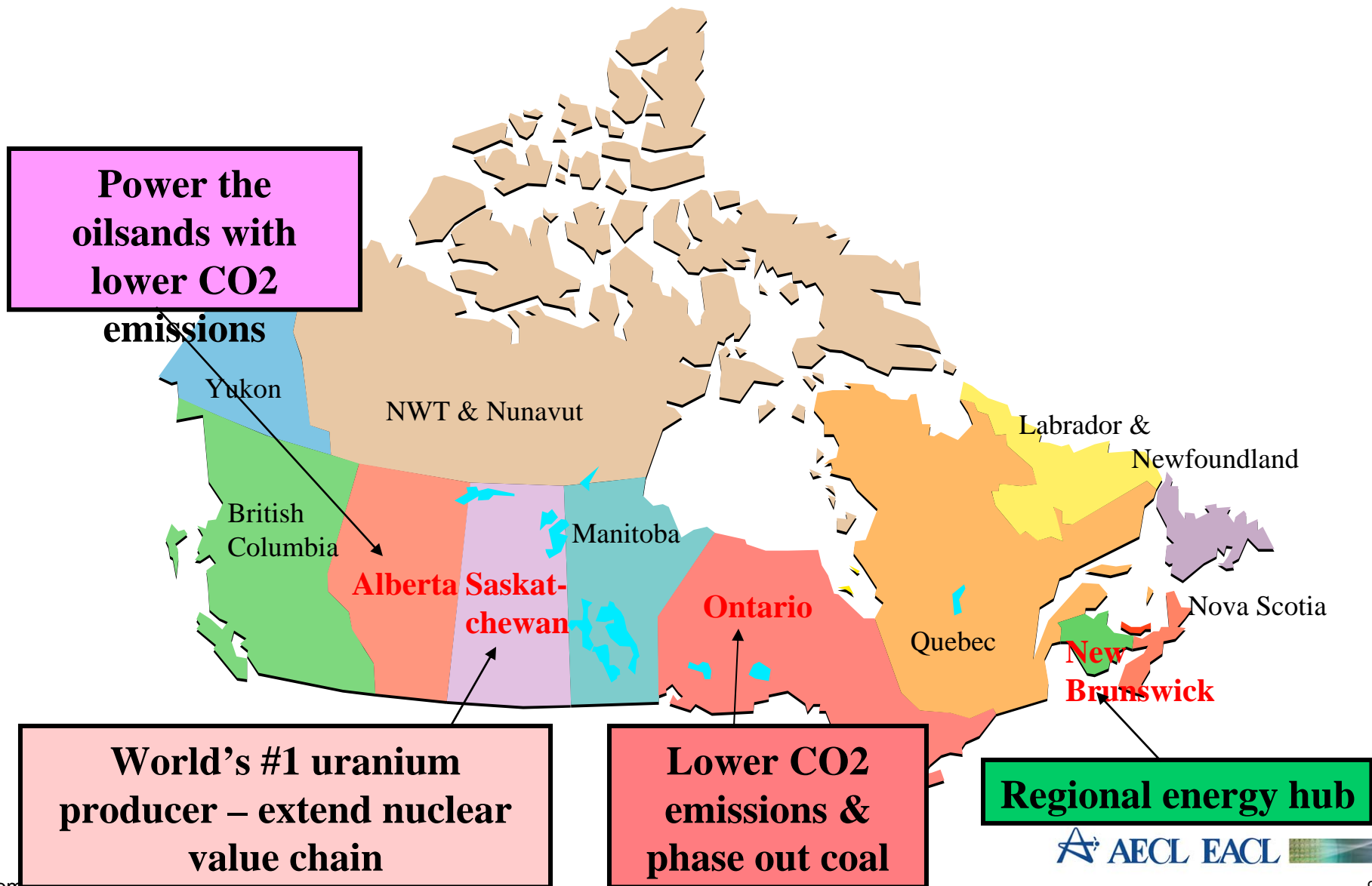
Source: COG 2009

Nuclear power in Canada

**Canada: world's 6th
largest power
generator: 128 GWe**



Canadian new build nuclear power markets & their drivers



New Build in Ontario

- **Ontario committed to phase out 7,000 MW coal fired capacity by 2014**
- **Infrastructure Ontario (IO) new build procurement process is on-going**
- **IO declared AECL proposal for 2 - 4 ACR-1000 units as the “best offer” in June 2009, with two caveats**
 - all offers are higher priced than IO expected
 - need for discussions between Canadian & Ontario governments
- **Power demand drop allows more time for development of new build program**

New Build in Alberta

- **Public consultation on nuclear option is expected to be concluded in 2009**
- **Oil sands and electricity generation in Alberta are major carbon emitters in Canada**
 - carbon capture and nuclear are under study
 - the current oil market has slowed demand for major expansion in the oil sands
- **Bruce Power Alberta is investigating a site at White Mud**
 - site licence application is expected once government policy is published

New Build in Saskatchewan

- **World's largest uranium producer**
- **Pro-nuclear public**
- **Political desire to extend the nuclear value chain**

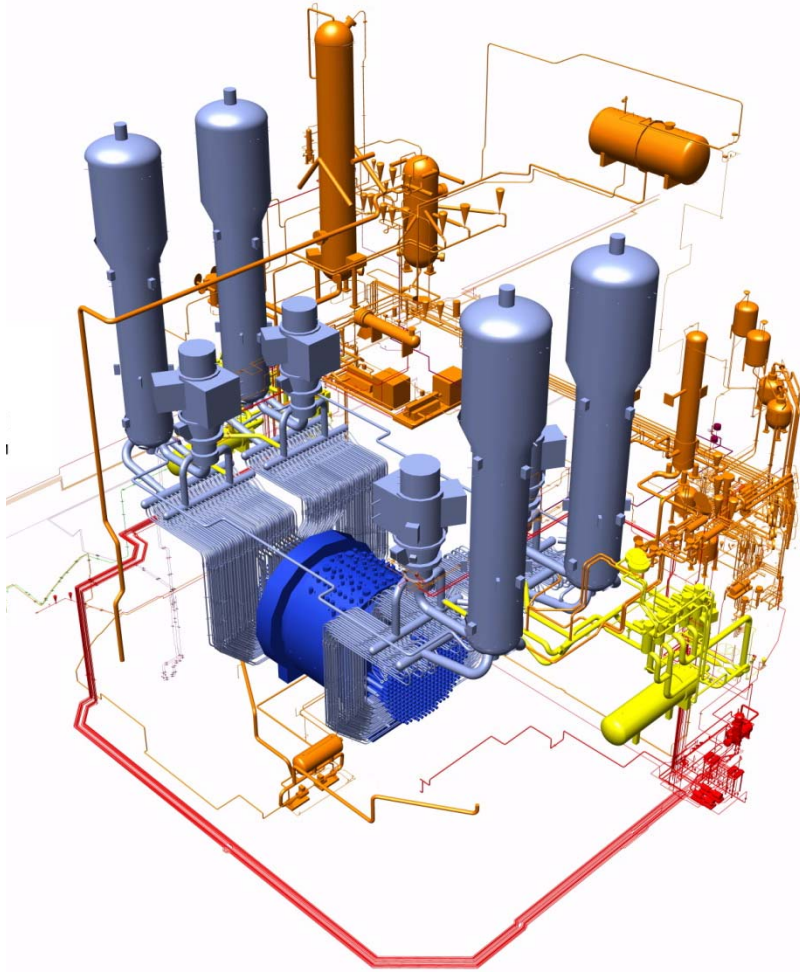
New Build in New Brunswick

- **NB government plans ACR-1000 new build at Lepreau NPP site as part of its planned Regional Energy Hub development**
- **A private sector driven model is under consideration for markets in**
 - **US: New England and Maine**
 - **Canada: Maritime provinces**
- **The current economic downturn has slowed the initiative**

CANDU: Canadian PHWR Technology

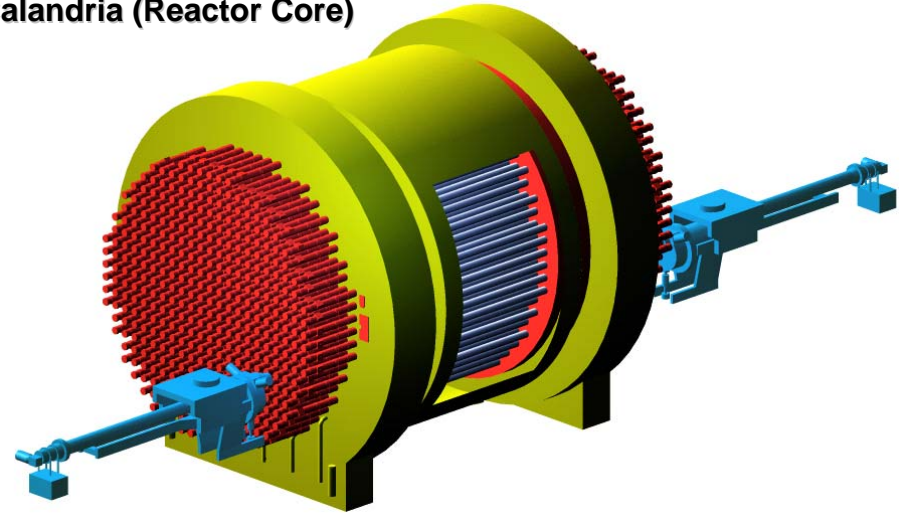
- **AECL developed the design concept on which all currently commercial PHWRs are based**
 - **CANDU = Canada Deuterium-Uranium**
- **Key CANDU characteristics**
 - **Pressure tubes containing fuel bundles located in cylindrical, low pressure moderator tank or “calandria”**
 - **Heavy water moderated**
 - **Natural Uranium CANDUs are heavy water cooled**
 - **Advanced CANDU Reactor ACR-1000 is light water cooled**
 - **43 units based on the CANDU design operate in 7 countries**

CANDU Fuel Channel Reactor



Calandria and HTS System

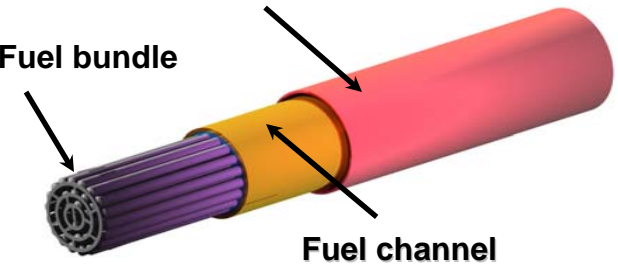
Calandria (Reactor Core)



Fuelling Machine

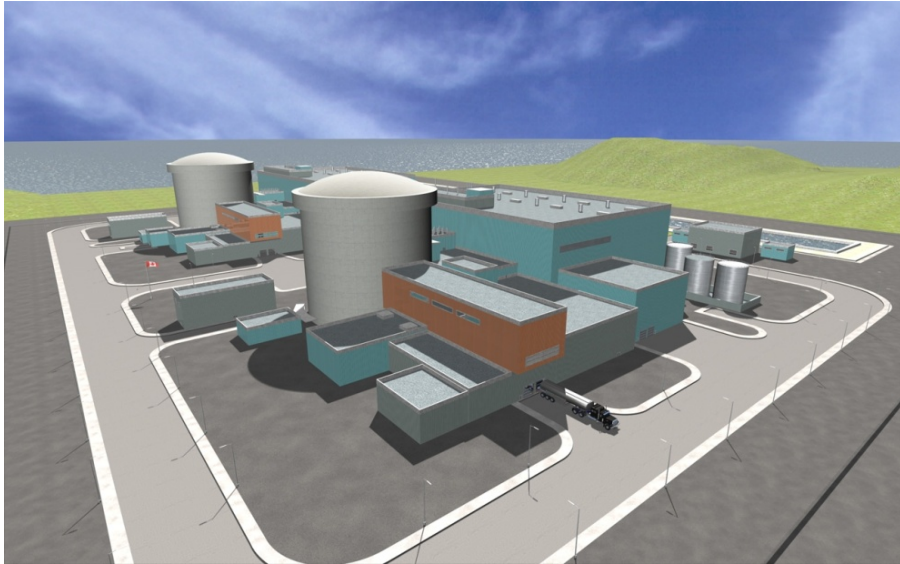
Calandria tube

Fuel bundle



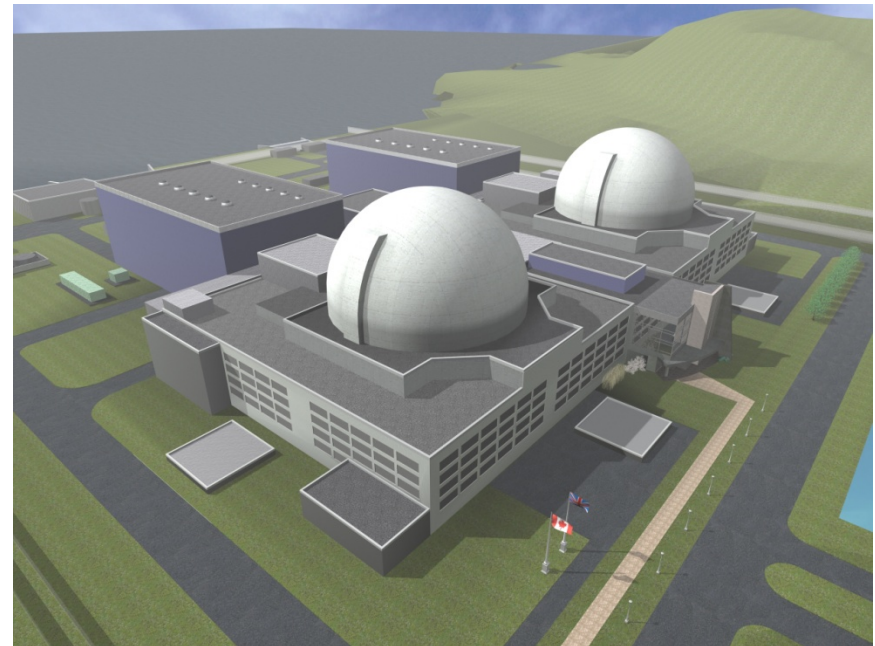
Fuel channel

Today's CANDU Nuclear Power Reactors

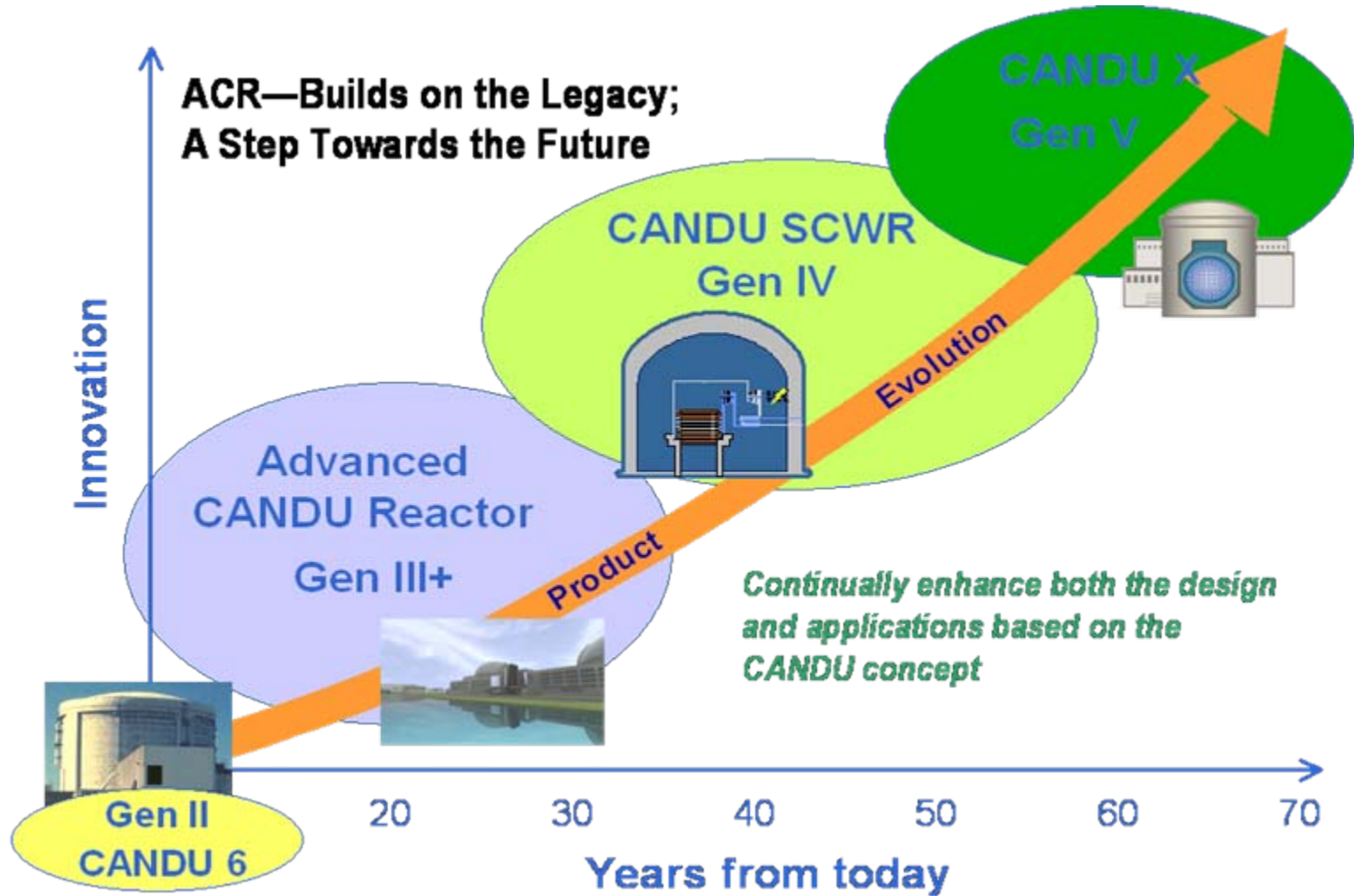


**Natural Uranium 700 MW Class
Enhanced CANDU 6**

**Low Enriched Uranium 1200 MW
Class ACR-1000**



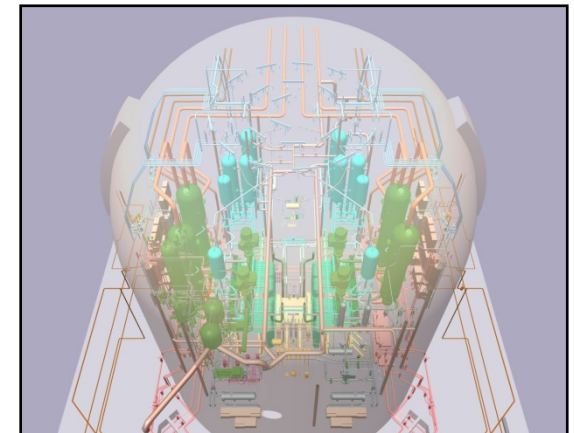
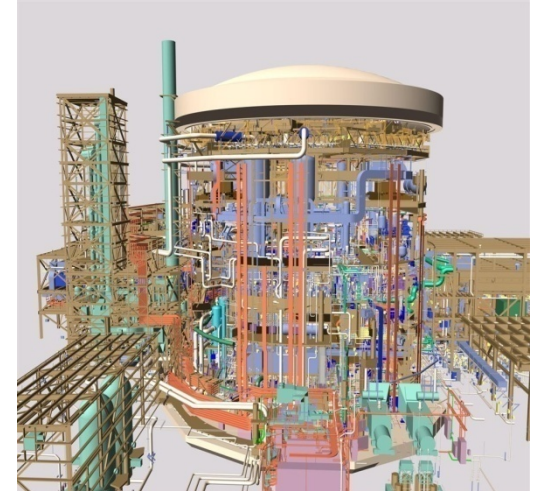
From Present to Future



Advanced CANDU Reactor Products

EC6: Evolutionary Enhancements

- Smallest proven design on the market
 - Meets current requirements, including Generation III safety
 - Reference CANDU 6 design basis maintained
 - Ideal platform for advanced fuels – Recovered U & thorium
- **ACR-1000: Full scope design and development**
 - Meets and exceeds Generation III plus requirements
 - Major design simplifications
 - Competitive economic and operational performance
 - Designed-in constructability



Enhanced CANDU 6

- **Evolution of CANDU 6 Design:**
 - continuously improved by incorporating lessons learned from projects, OPEX, and technology development
- **Enhanced CANDU 6 – EC6**
 - enhanced to meet today’s Gen III licensing requirements in Canada
 - enhanced operability, reliability, life management
 - meets today’s customer expectations while maintaining proven CANDU 6 design basis and track record
 - unique fit to markets interested in medium-size units, localized fuel economics of natural uranium, and alternative and recycled fuels

“EC6 – the natural choice”

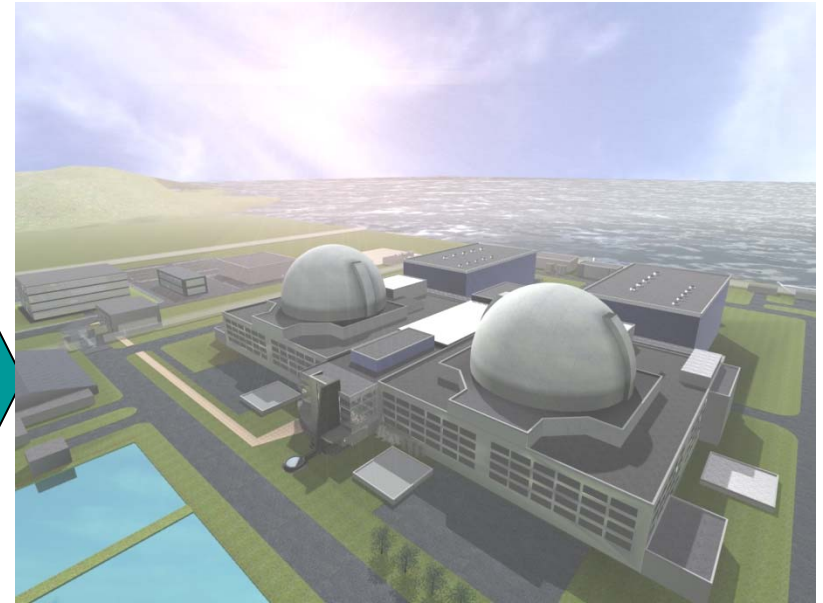
ACR-1000 Design Evolution: advanced design, a large performance gain

CANDU 6: heavy water cooled



2 x 728 MWe

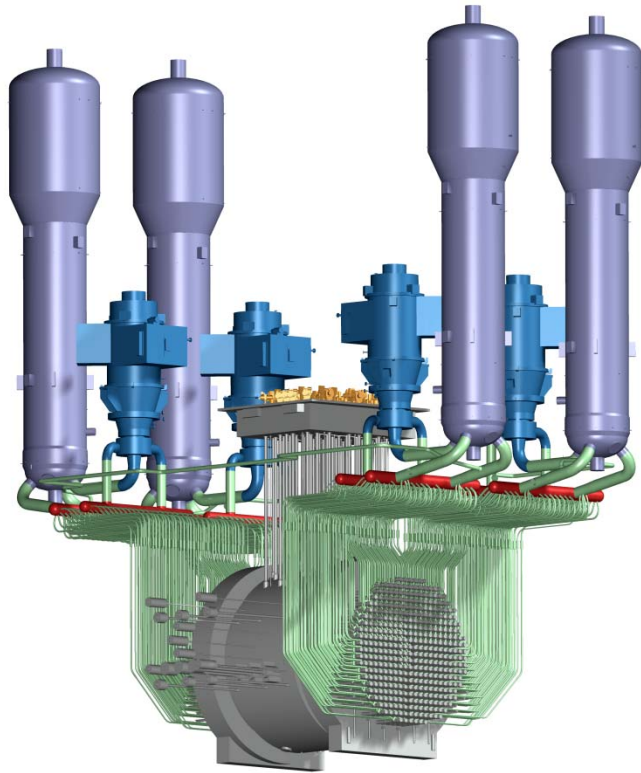
ACR-1000: light water cooled



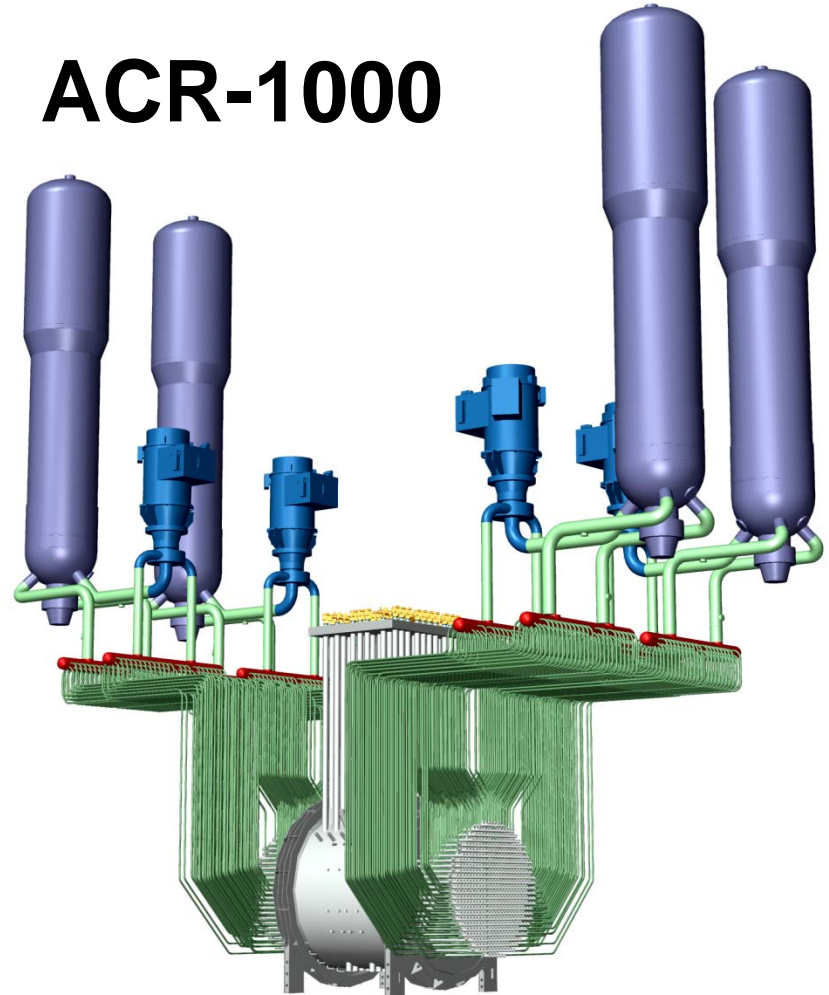
2 x 1165 MWe

Similar coolant system configuration

CANDU 6

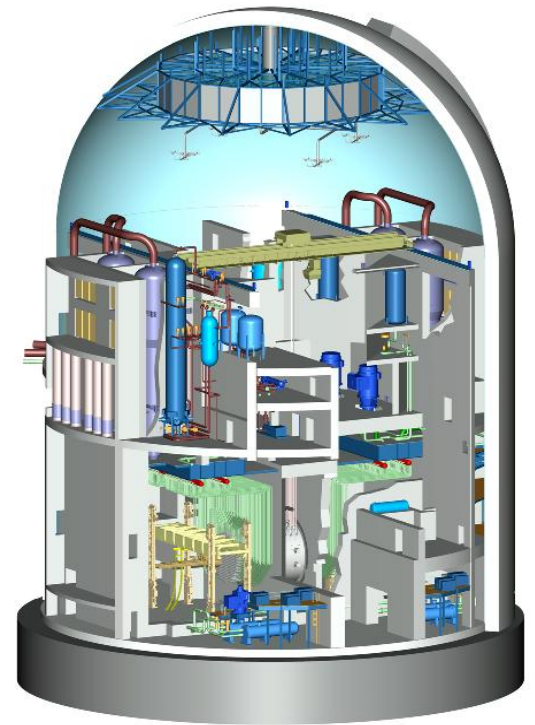


ACR-1000



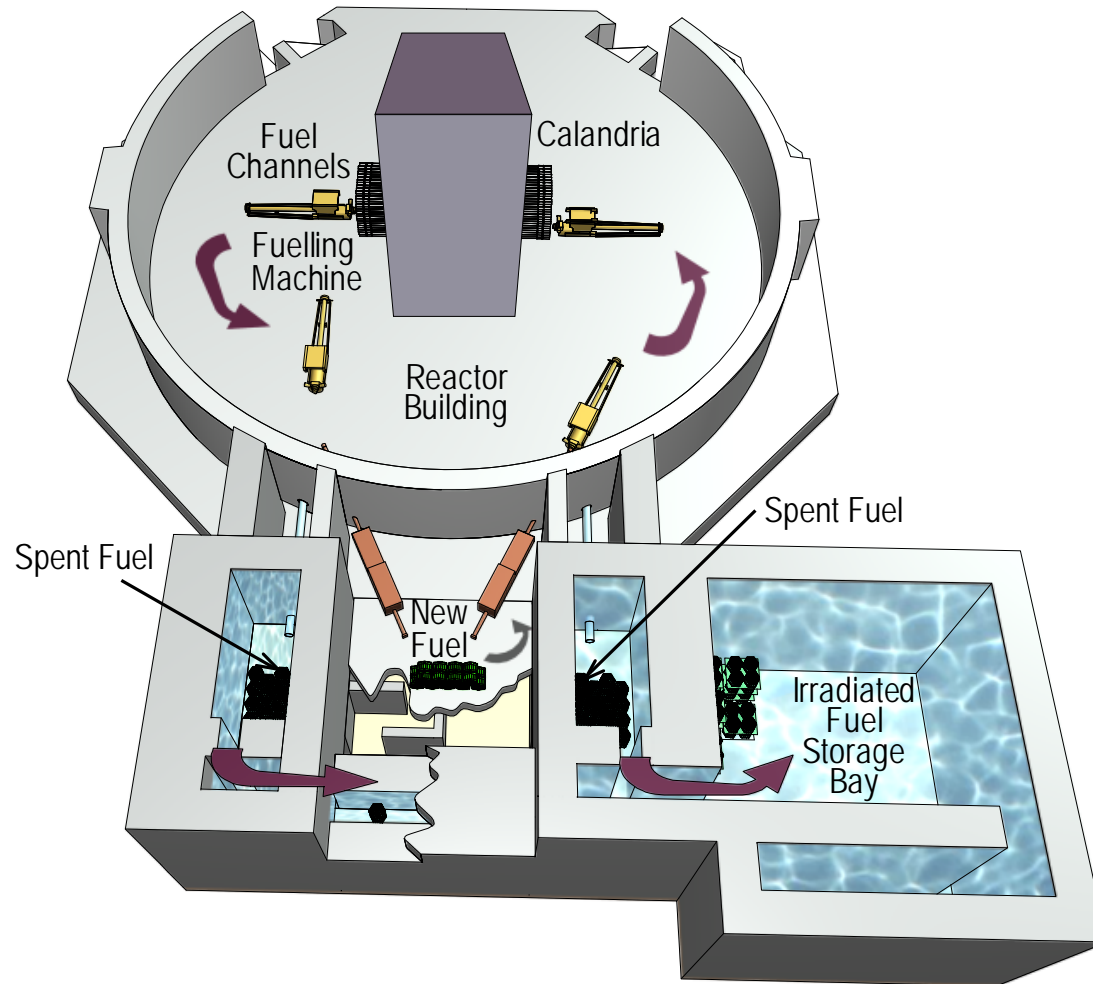
ACR-1000 key features

- **1165 MWe gross output**
- **Light water cooled, heavy water moderated**
- **60 year design life**
- **Similar configuration/equipment as CANDU 6**
- **Load following capability**
- **On power refuelling**
- **Unique fuel cycle flexibility**
- **Standard design product**



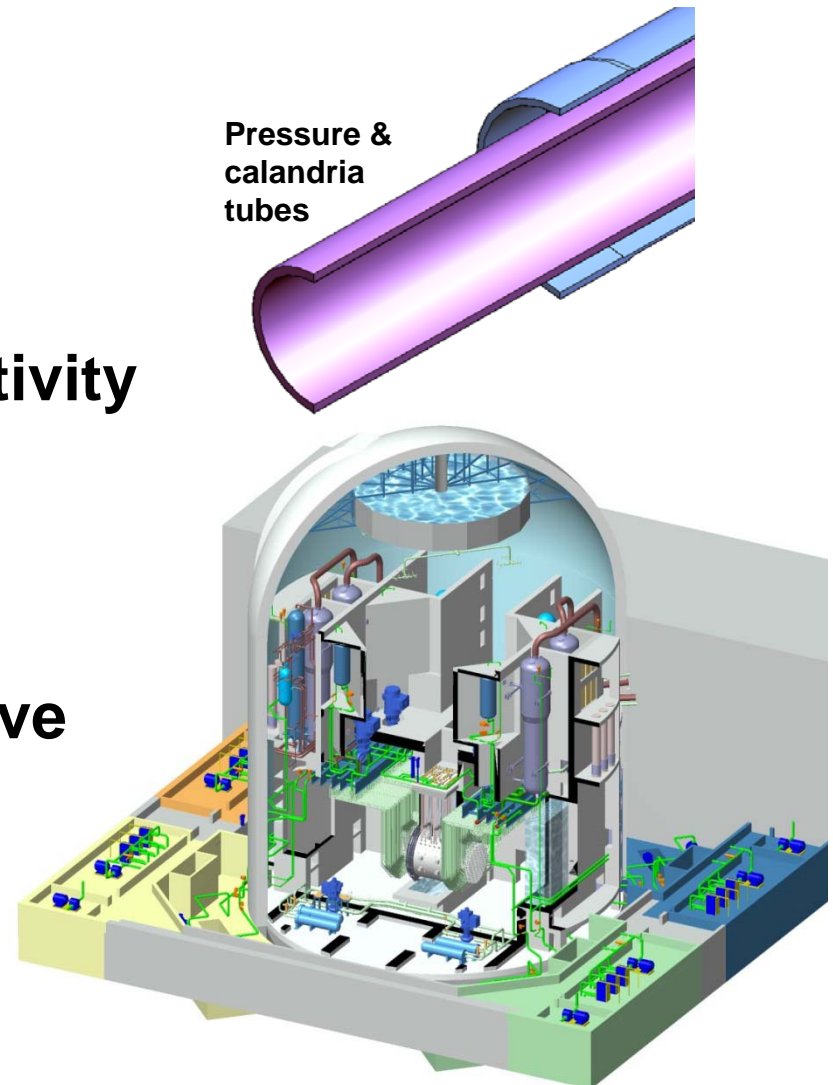
ACR-1000 Reactor Building
Cutaway

On-Power Fueling Sequence



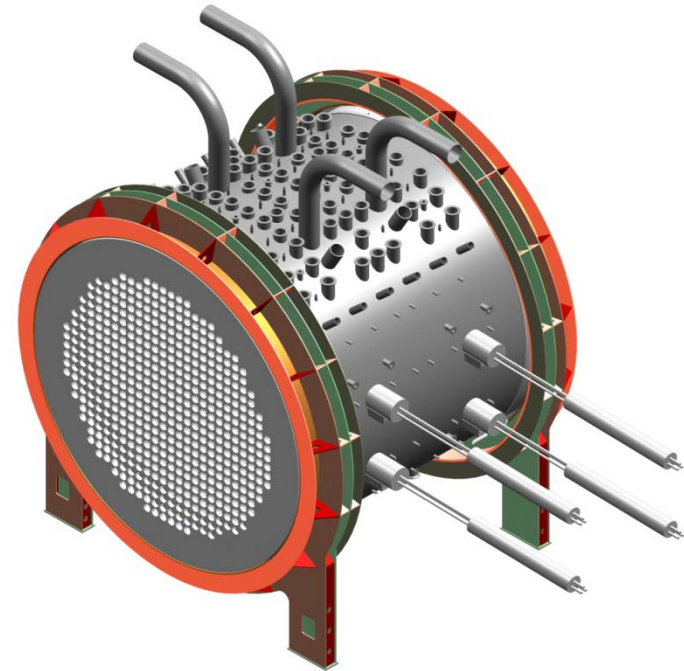
ACR-1000: Innovations

- **Low Enriched Fuel**
- **Light water coolant**
- **Thicker pressure tubes**
- **Negative coolant void reactivity**
- **Higher thermal efficiency**
- **Robust reactor building**
- **Quadrant layout**
- **Enhanced active and passive safety**

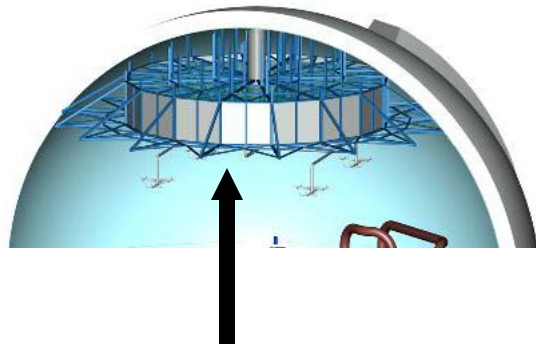


ACR-1000: Traditional CANDU Features

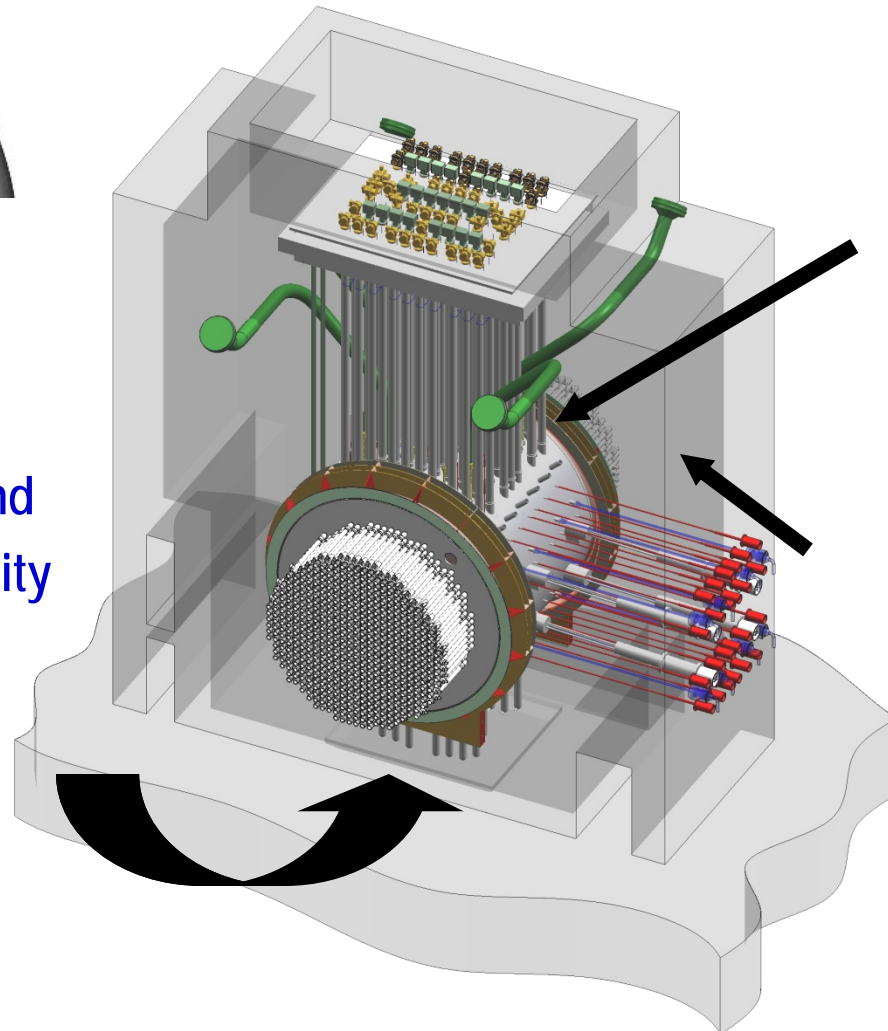
- **Modular, horizontal fuel channels**
- **Water-filled reactor vault**
- **Reactivity mechanisms operate in low temperature, low pressure environment**
- **Two independent, fast, passively driven safety shutdown systems**
- **Reactor building accessible for on-power maintenance**



Large Passive Heat Sinks for Severe Accident Mitigation & Management



3. Water from Reserve Water Tank fills fuel channels, calandria, and shielding vault by gravity

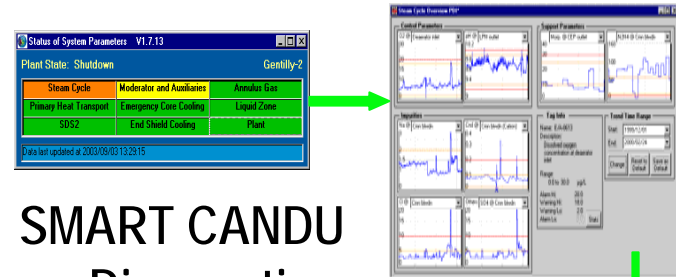


1. Calandria Water

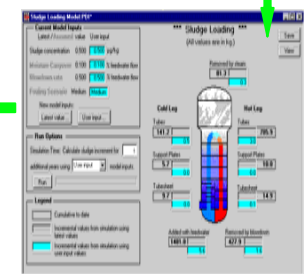
2. Shielding Vault Water

Operations & Maintenance

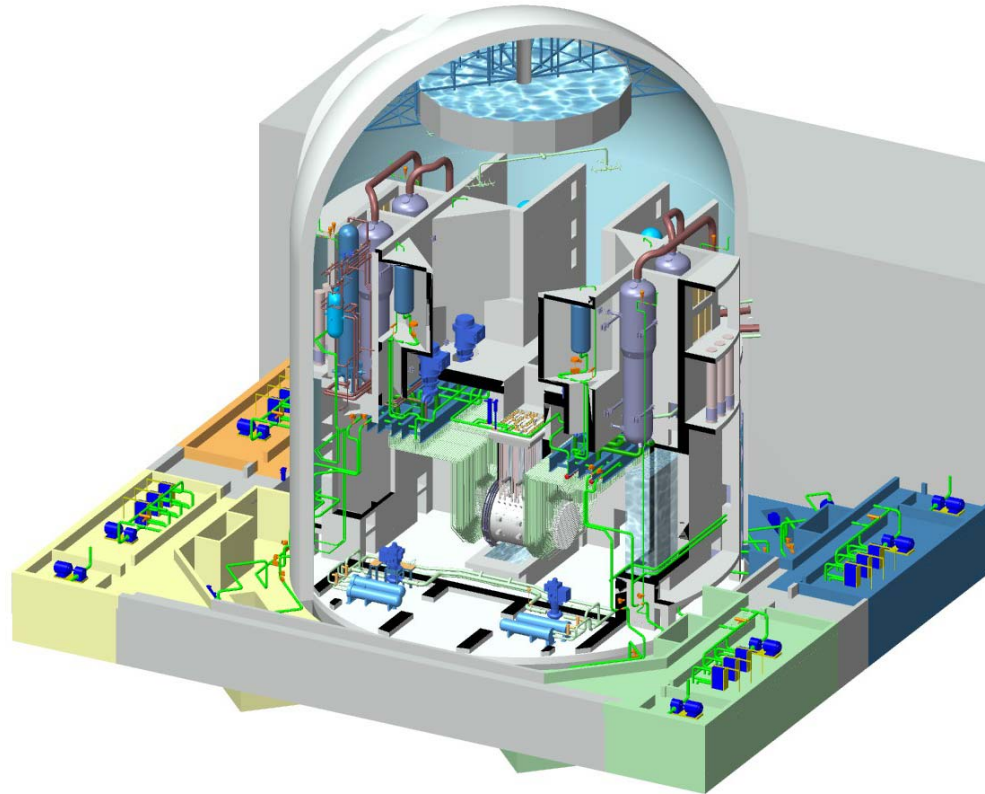
- Advanced control centre
- Computerized safety system testing
- Improved, long-life materials and experience-based plant chemistry specs
- SMART CANDU diagnostics
- Increased shielding in radiologically controlled areas



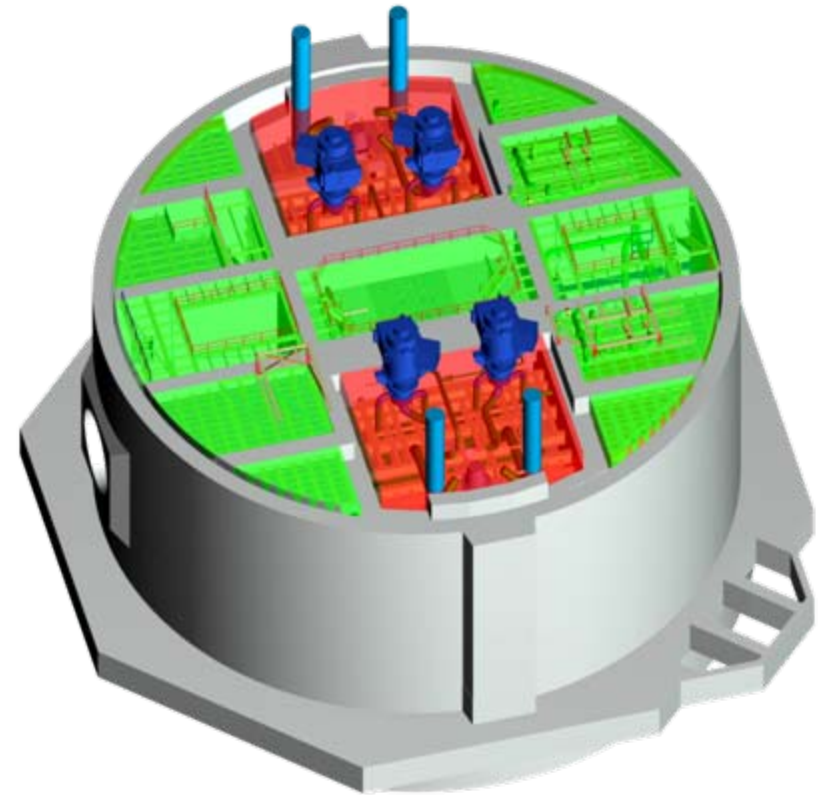
SMART CANDU
Diagnostics



One 21-day outage every three years



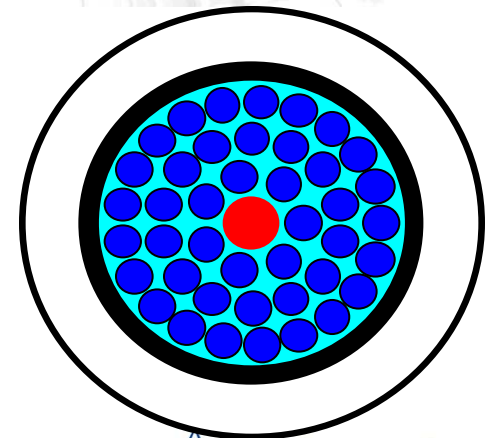
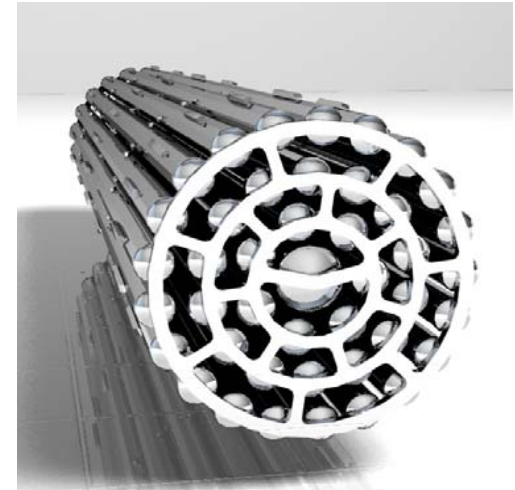
Quadrant Design allows On-Power
Maintenance of safety related systems



On-Power Access to Containment
for Maintenance

ACR-1000 Fuel

- **Simple to manufacture, easy to handle**
- **2.4% uniform enriched UO_2**
- **CANFLEX 43-element bundles**
 - 10 cm dia x 50 cm long
- **20,000 MWd/te burnup**
 - will be increased with experience
- **Two Canadian fuel suppliers**
- **Readily localized**



ACR-1000 Design Status

- **Basic Engineering Program**
 - Integrated design, licensing construction, commissioning, operations, supporting development/qualification
 - Technical and project risk management build into the program from the start
 - Program has completed basic design documentation, comprehensive 3-D CADDs model, major equipment specifications, full safety case documented in PSAR
- **Project Ready**
 - Fully priced turnkey bid was submitted to Ontario in 2009
 - Ontario government described AECL proposal as the “best” bid

Licensing

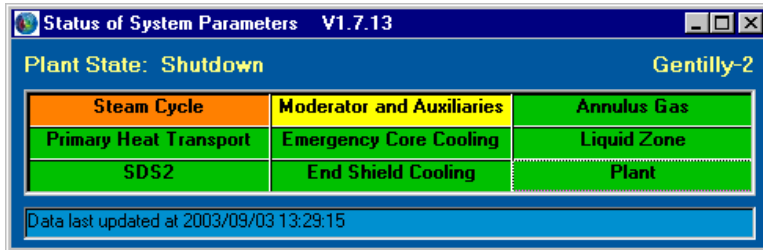
- **Safety and licensing driven design**
 - oriented to CNSC’s new RD-337 requirements
 - meets IAEA’s NS-R-1
 - CNSC pre-project review identified “no fundamental barriers to licensing ACR-1000 in Canada”
- **UK Generic Design Assessment Steps 1 & 2**
 - Joint Programme Office report in March 2008 announced
 - “no impediments to licensing ACR-1000” in UK

Technology

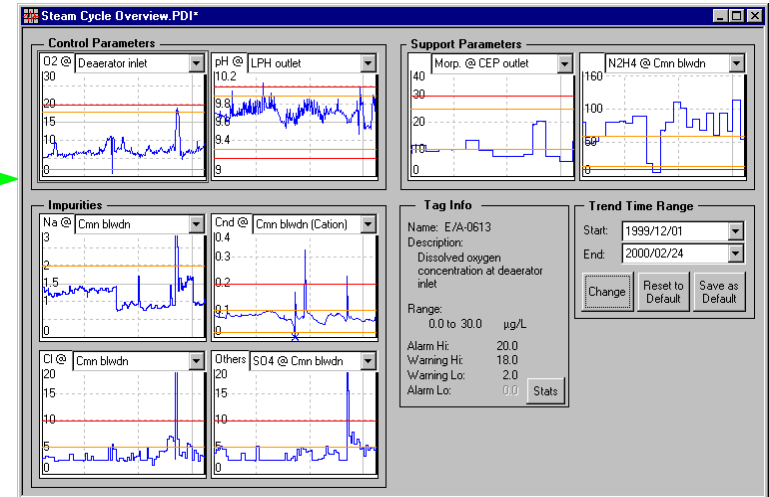
- **Fuel and reactor operating parameters**
 - within experience envelope of CANDU and Fugen HWR operations to allow robust safety code verification
- **Innovation risks were reviewed and assessed**
 - light water coolant, LEU fuel, reduced lattice pitch
- **R&D integrated to design process to:**
 - confirm component designs & verify manufacturing routes
 - confirm design margins for safety analysis
 - validate design and safety codes

New "SMART" Technologies

INFORMATION



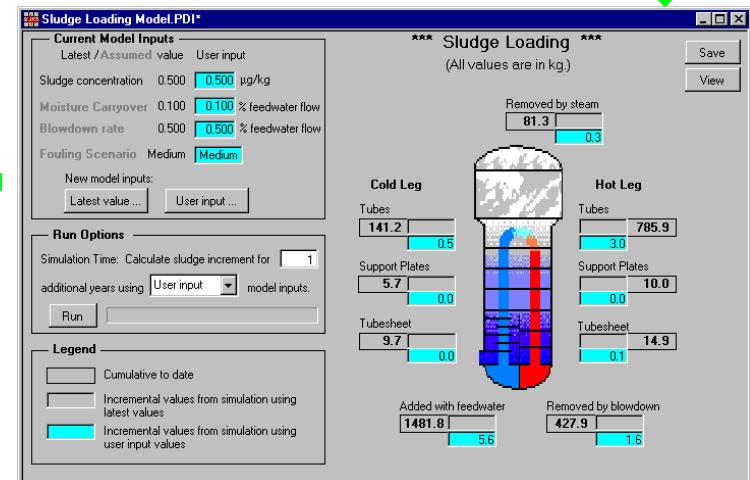
DATA



KNOWLEDGE



ACTION



Supply

- **Supply chain**
 - 5 CANDU new builds, 2 completions over last 15 years
 - refurb/life extensions include fuel channel replacements
 - excellent supplier performance
 - multiple supply sources for many key components, including largest forgings
 - Exploring potential for supply from China & India
- **Equipment size, type & manufacture**
 - most core components comparable to CANDU 6 or Darlington units

Calandria

- Largest nuclear component
- 25 mm shell thickness
- Design pressure ~1 atm
- Similar size as for CANDU 6
- No very large forgings

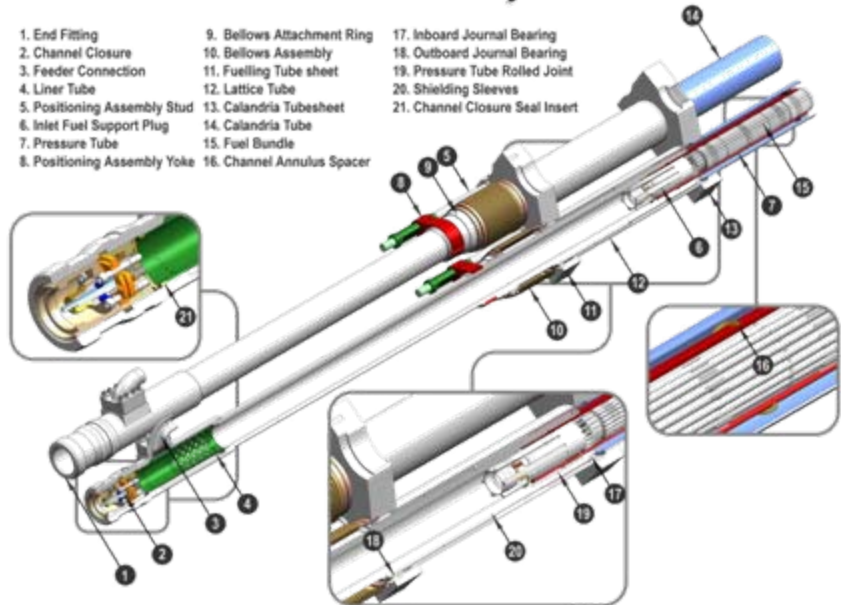
Calandria shell



Supply

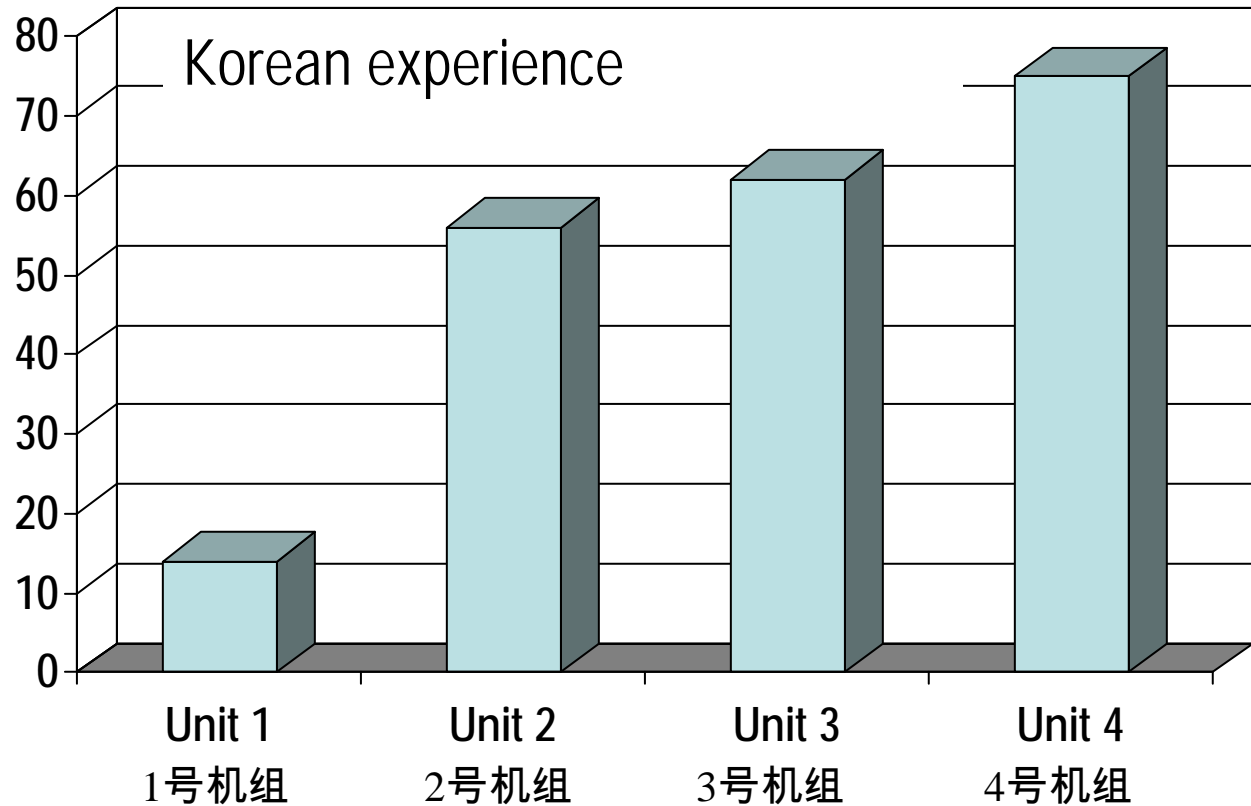
- **Many small, identical nuclear components**
 - require small fabrication shops
- **Example: for 2 unit plant**
 - 1040 fuel channels
 - 2080 end fittings

ACR-1000 Fuel Channel Assembly



CANDU Localisation

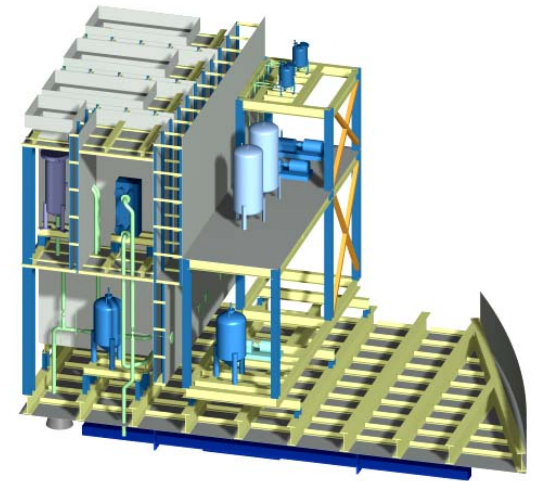
**Local
Content, %**



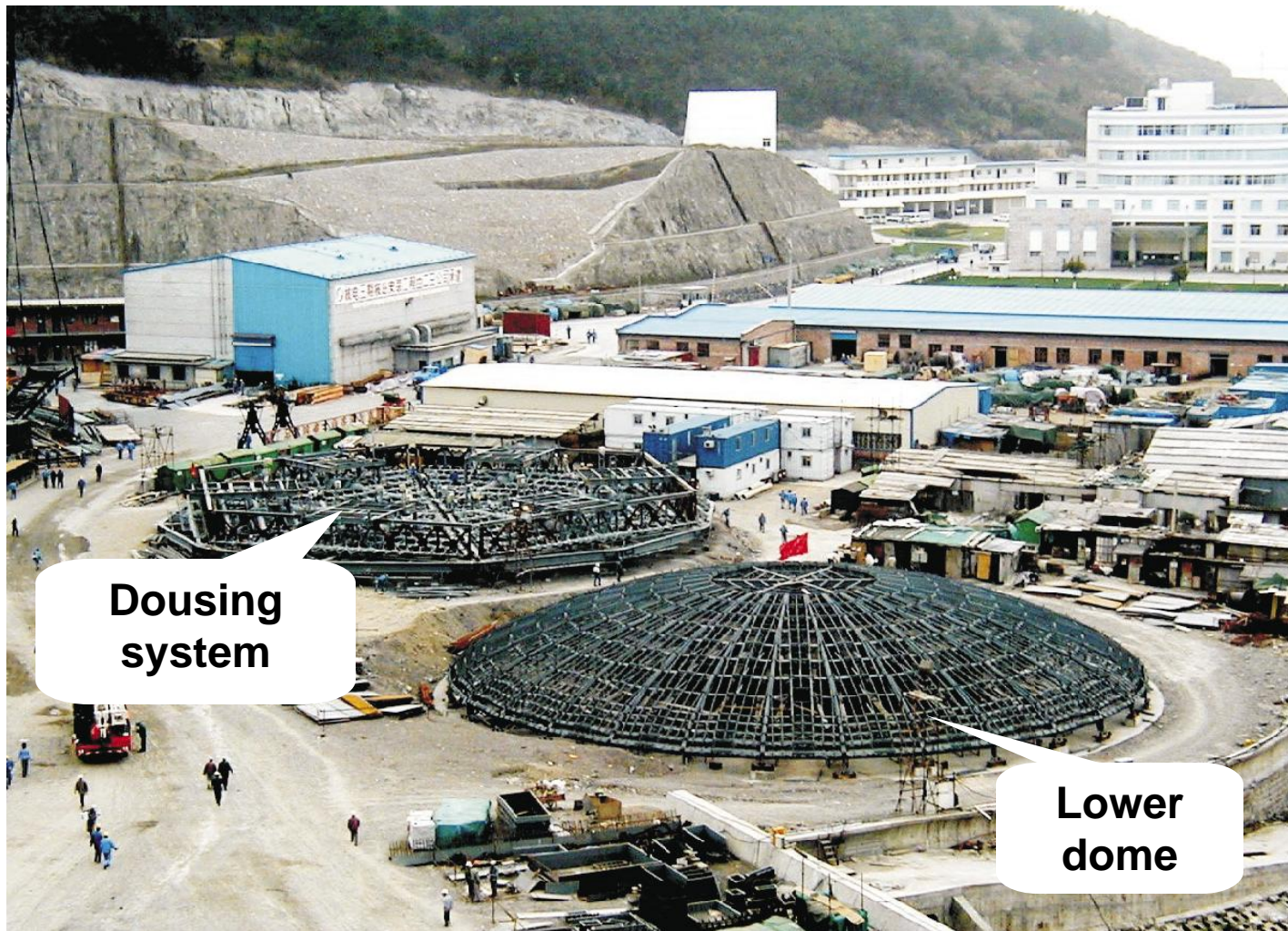
**ACR-1000 has similar supply & construction
localization potential**

Construction

- **Constructability embedded in design**
 - experienced constructors on design team
- **Modularization**
 - 200 reactor building modules
 - strategy developed by multi-discipline team and reviewed with Hitachi
- **NSP similar to existing CANDUs**
 - layout, equipment size & type



Qinshan III on-Site Modules Fabrication



**Dousing
system**

**Lower
dome**

Qinshan III Modules Installation

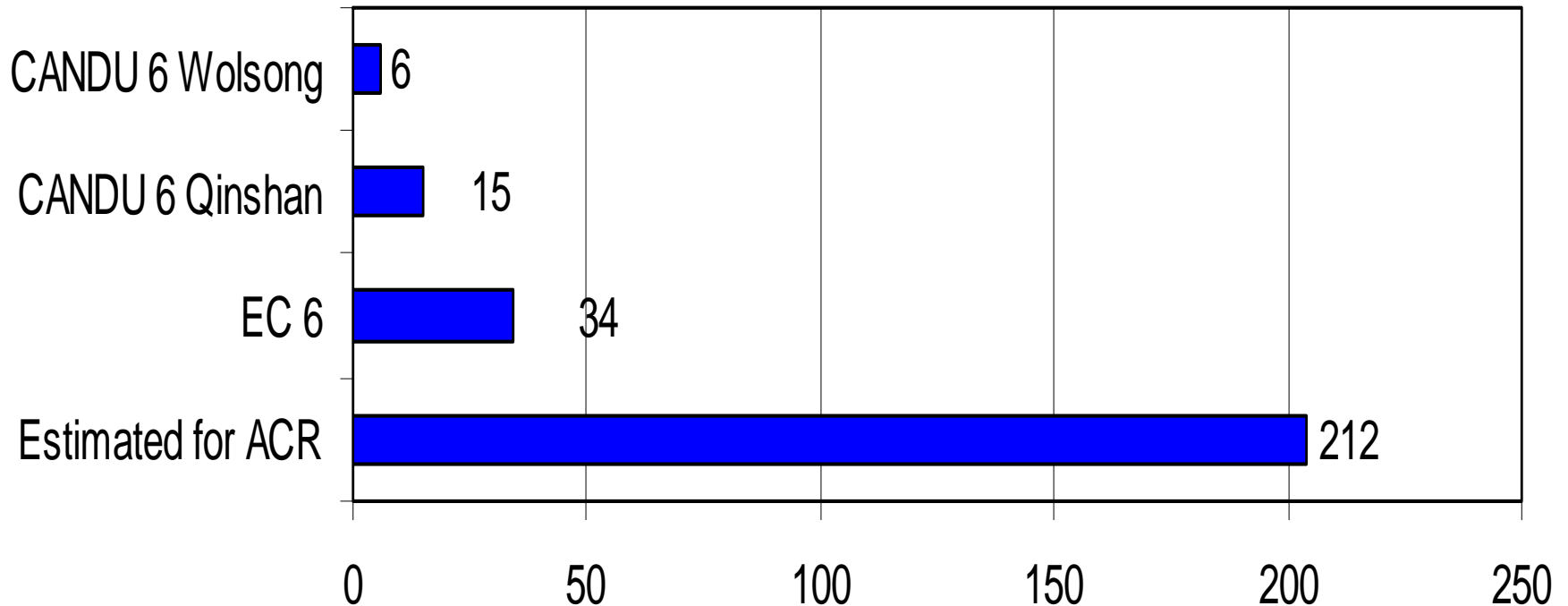


**Dousing system modules
installed in 5 days vs. 120
days using old approach**

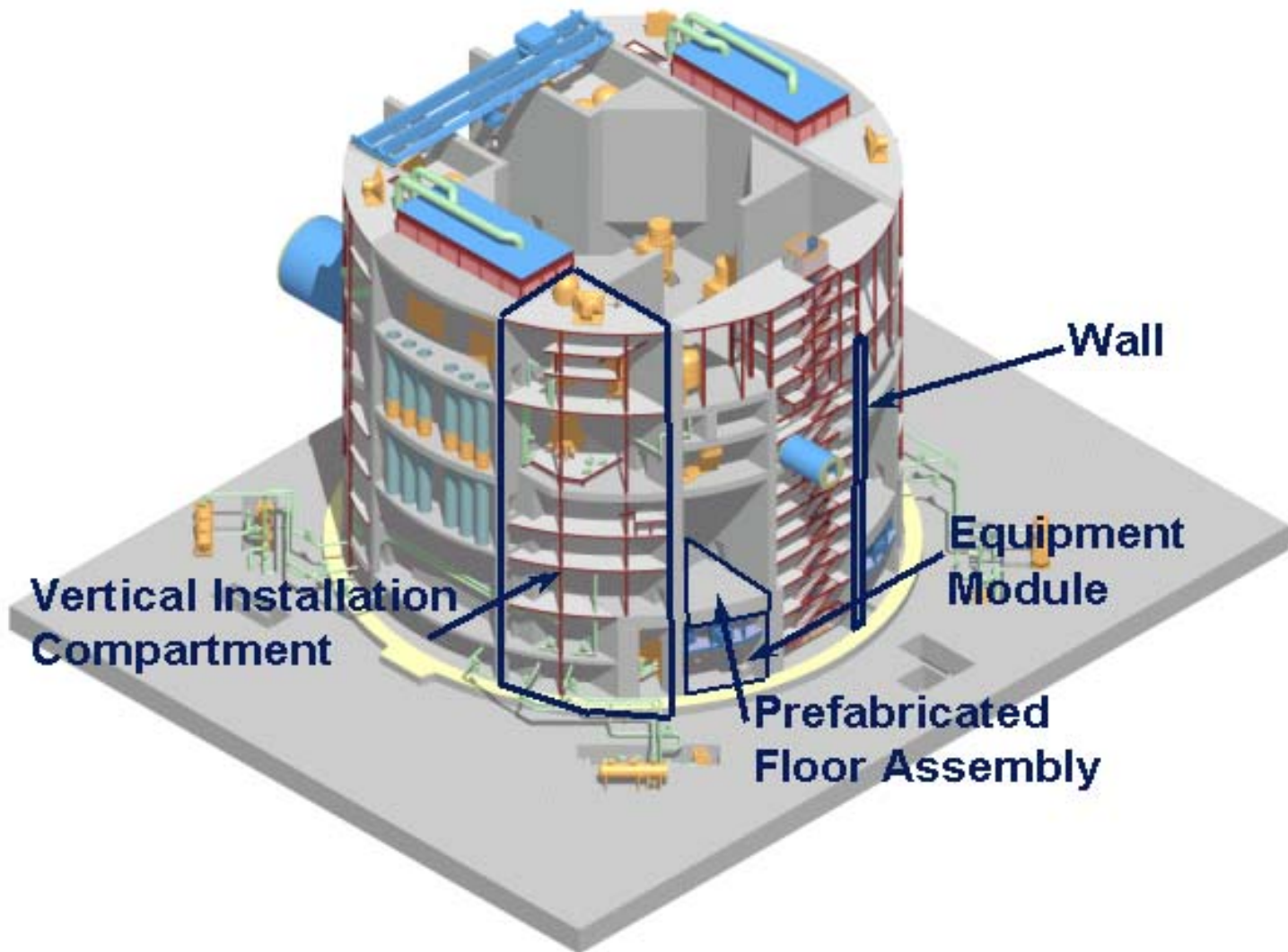


Module Implementation

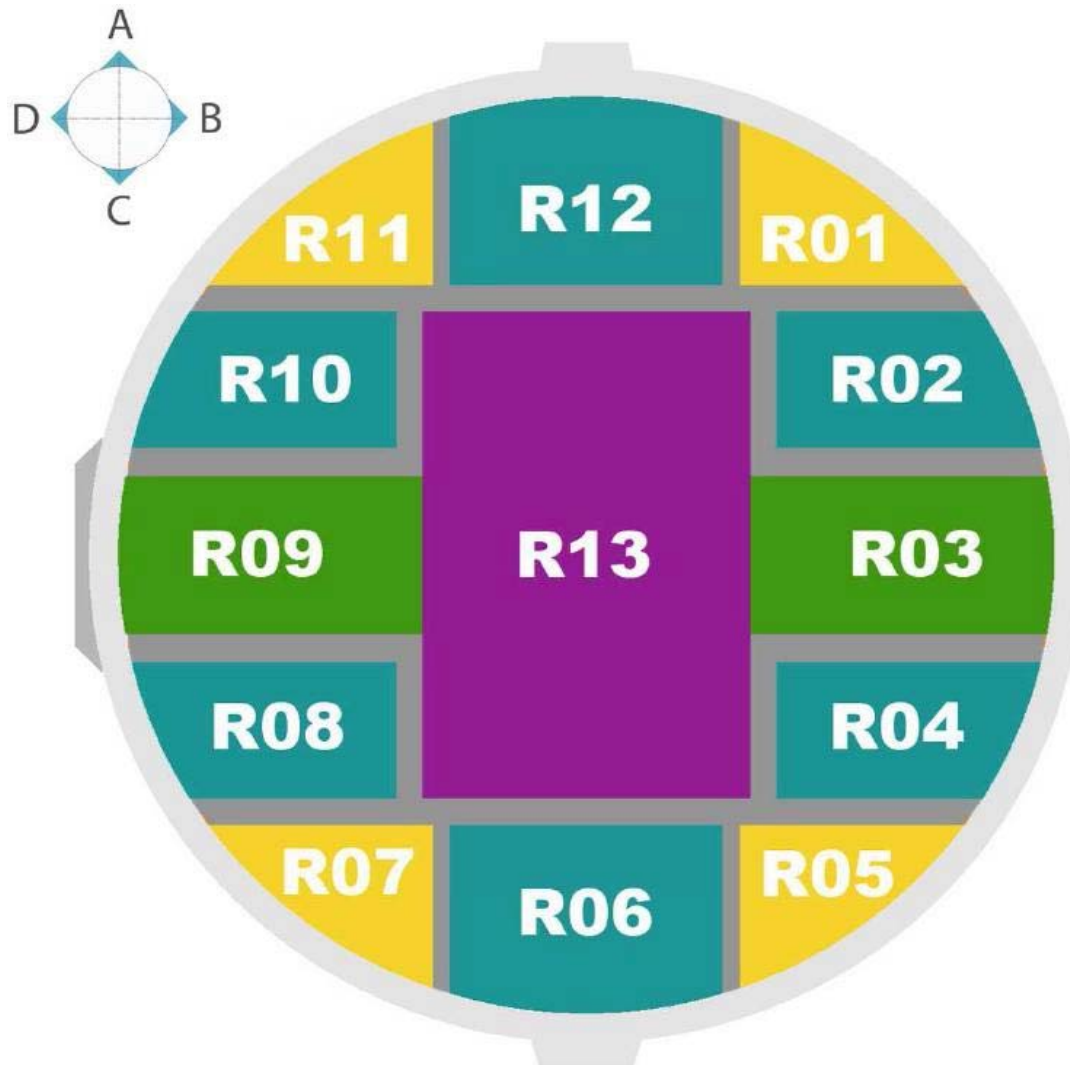
Number of Reactor Building Modules per Unit



Reactor Building Construction Strategy



ACR-1000 RB Compartments



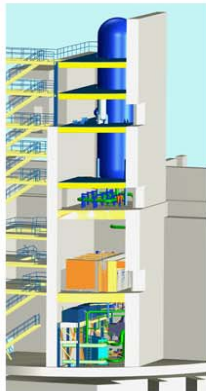
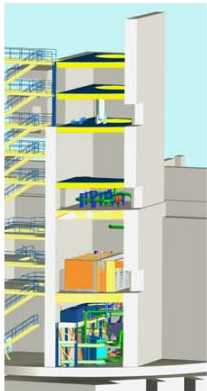
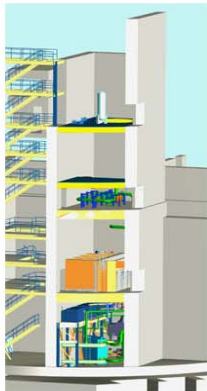
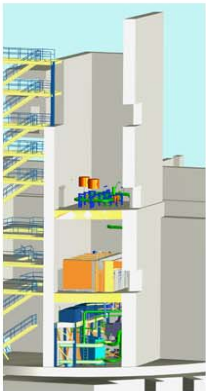
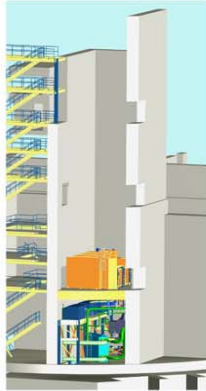
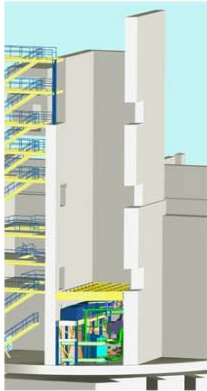
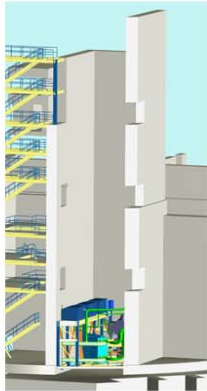
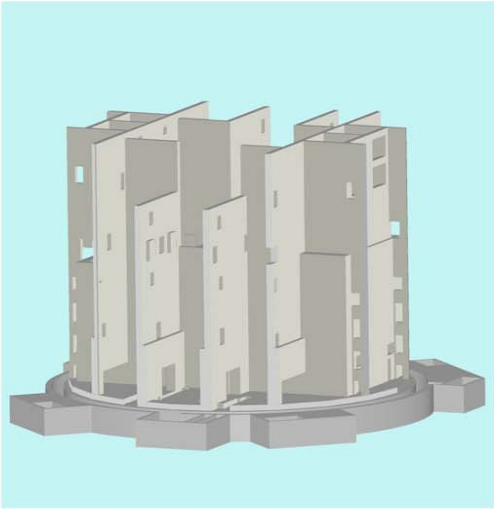
Vertical Installation Compartment

- **Implemented in the civil design from the start**
 - could not be “back-fitted” to an existing design
- **Creates manageable self contained work areas**
 - each compartment can be completed independently
- **Schedule flexibility**
 - late delivery of a module impacts only one compartment
- **Reduces schedule risk by maximizing paralleling of activities**

Internal Structure Design

- **Seismically qualified**
- **Independent from the containment wall**
- **Vertical installation compartment concept**
- **Pre-Fabricated Permanent Formwork (PPF)**
- **Improve constructability of structures**
- **Jumpform or Slipform systems**

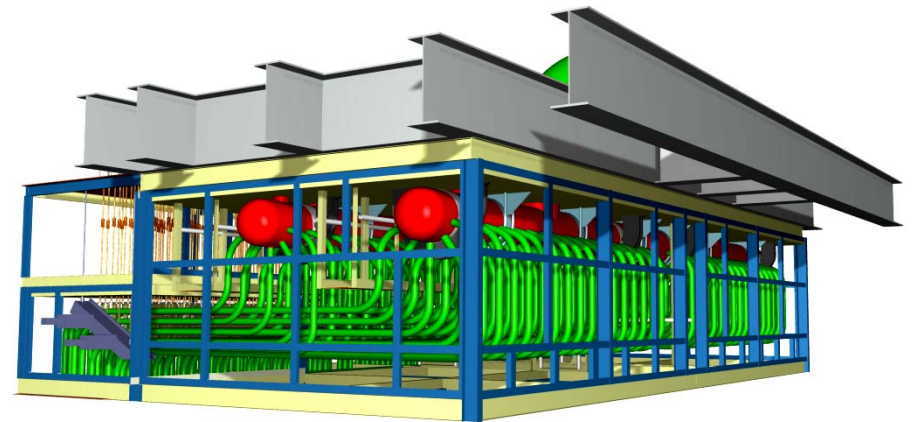
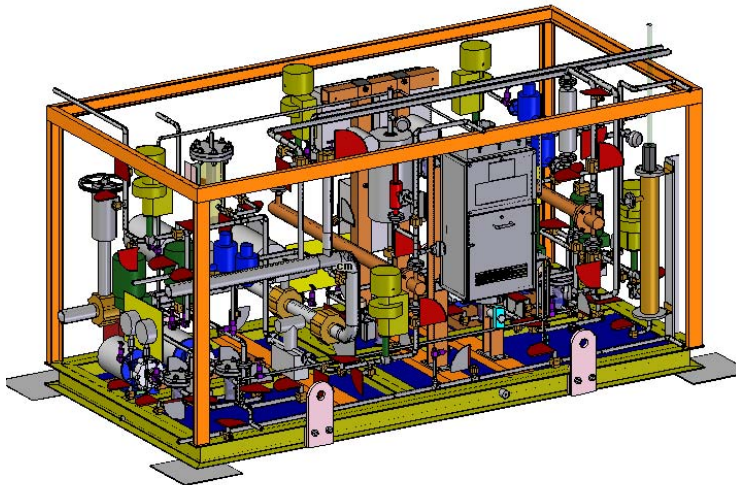
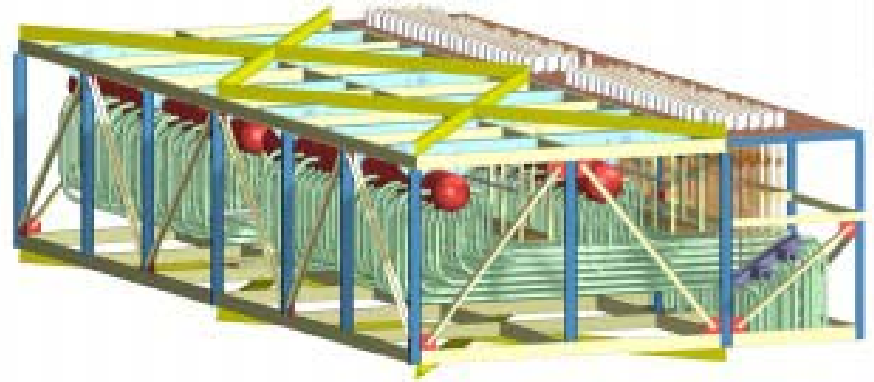
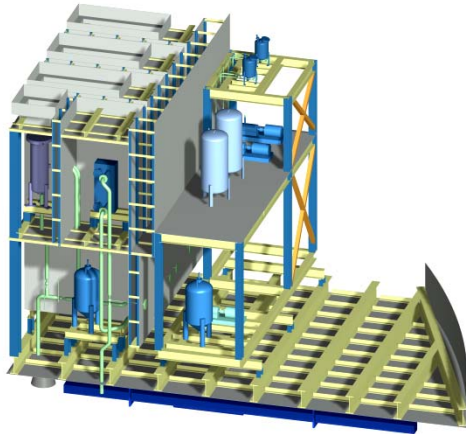
ACR-1000 Module Sequence



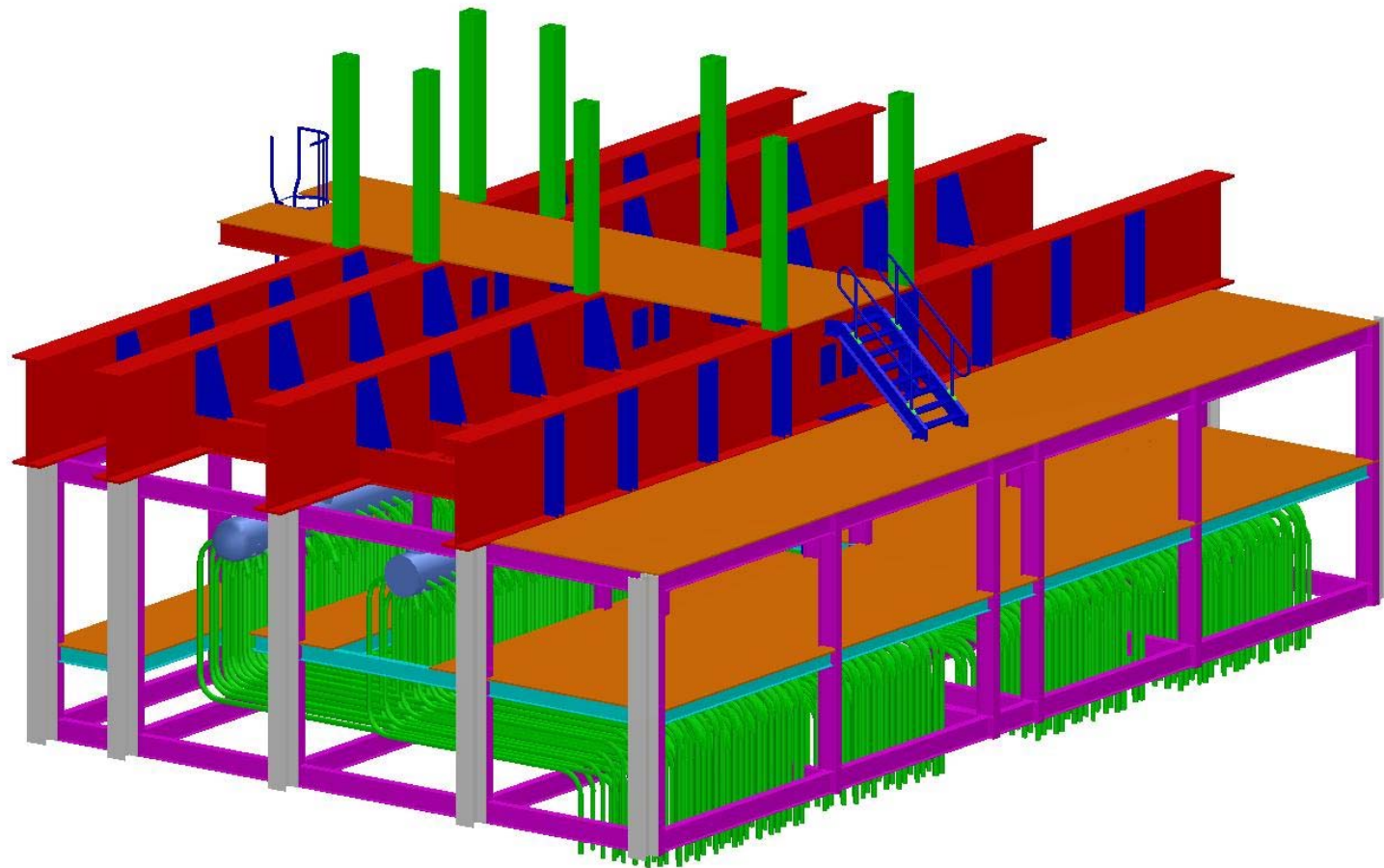
Conventional Slab Construction



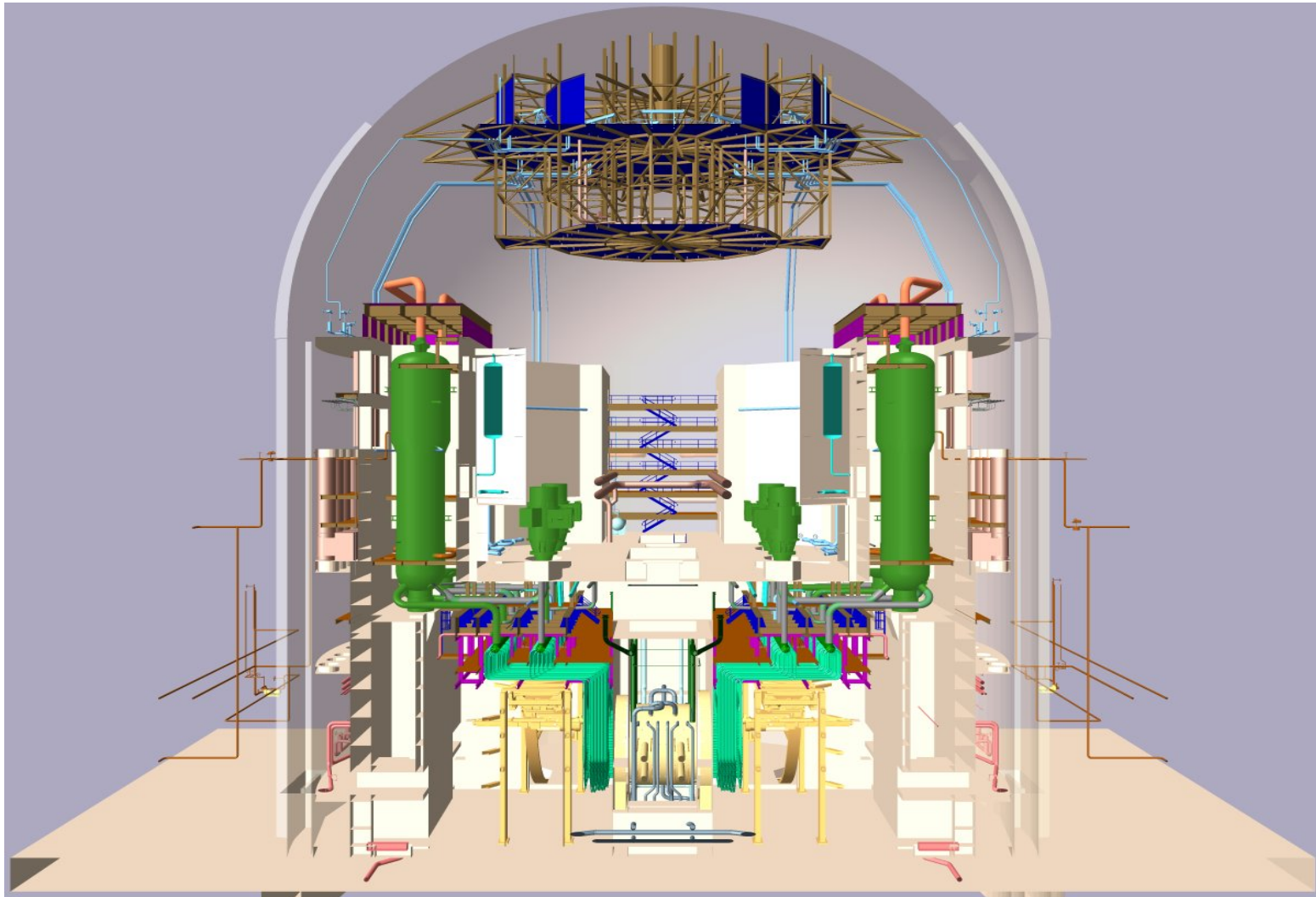
Large ACR-1000 Modules



Feeder Header Module

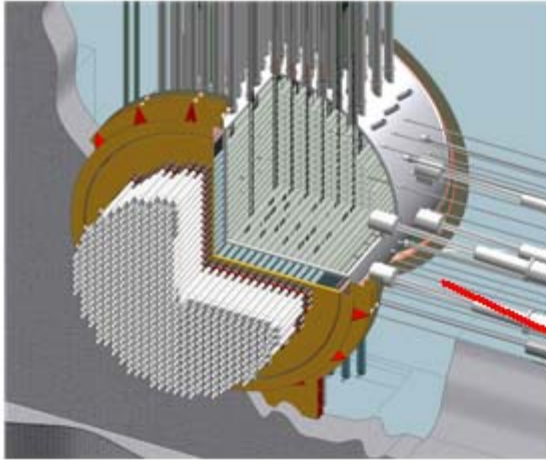


Reactor Building Cutaway

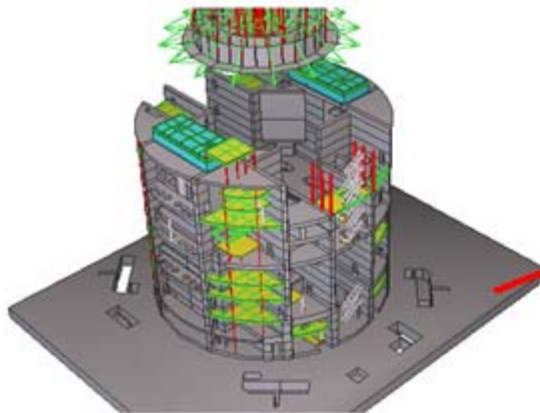
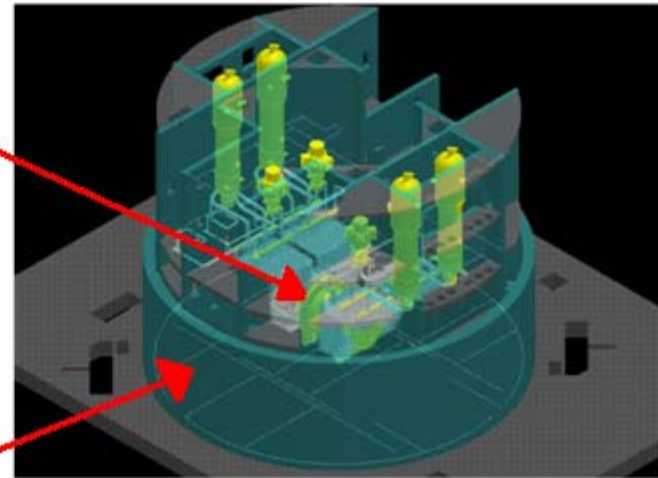


CADDS – Design Integration

Systems and Equipment Model

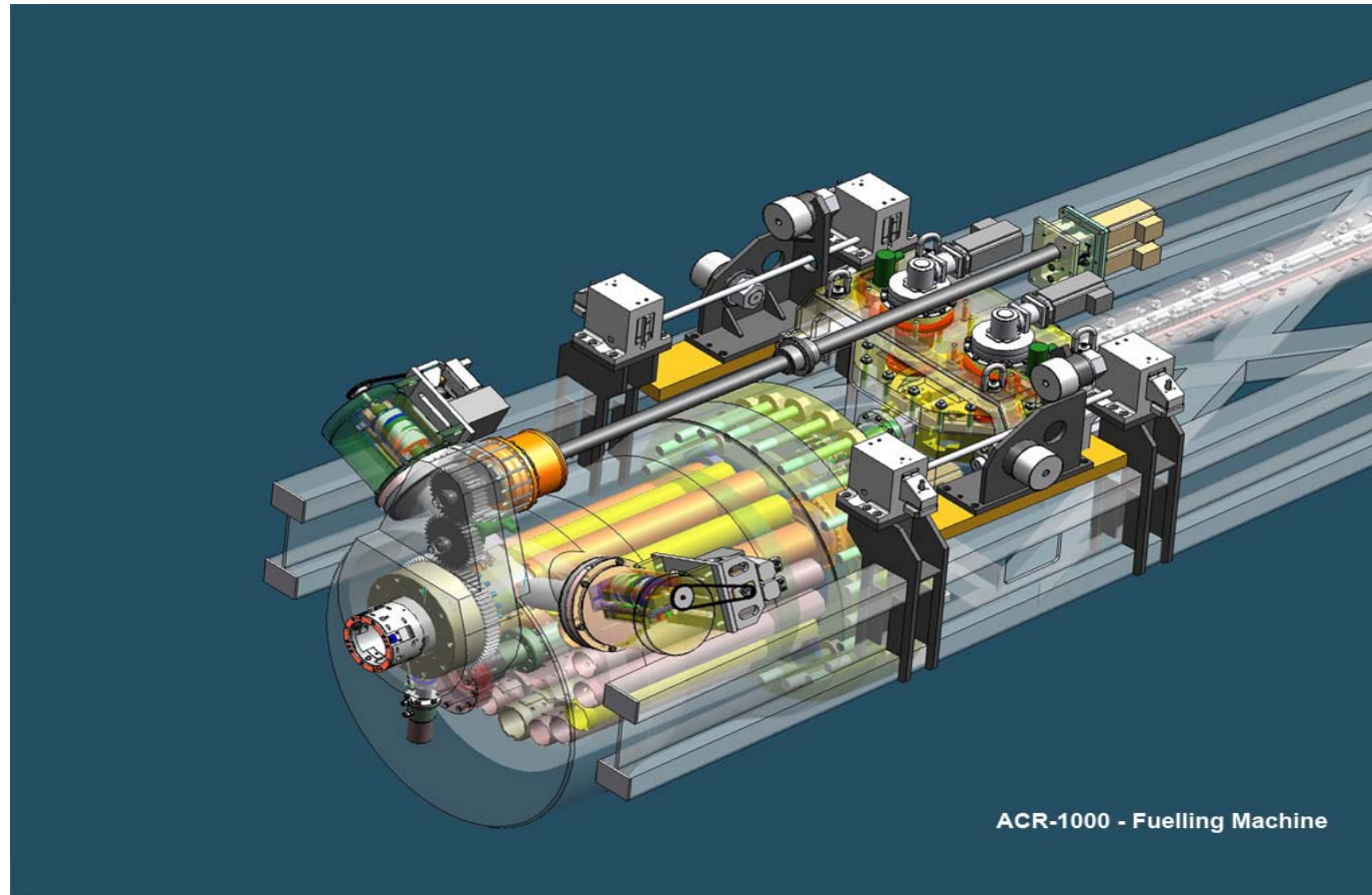


Smart Plant Model



Structural Models

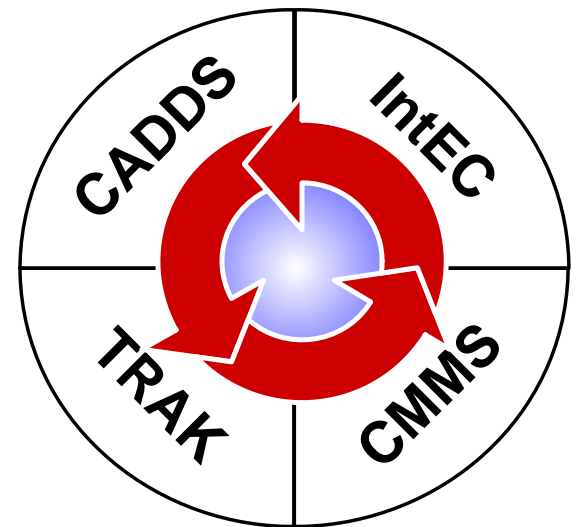
Fueling Machine Head



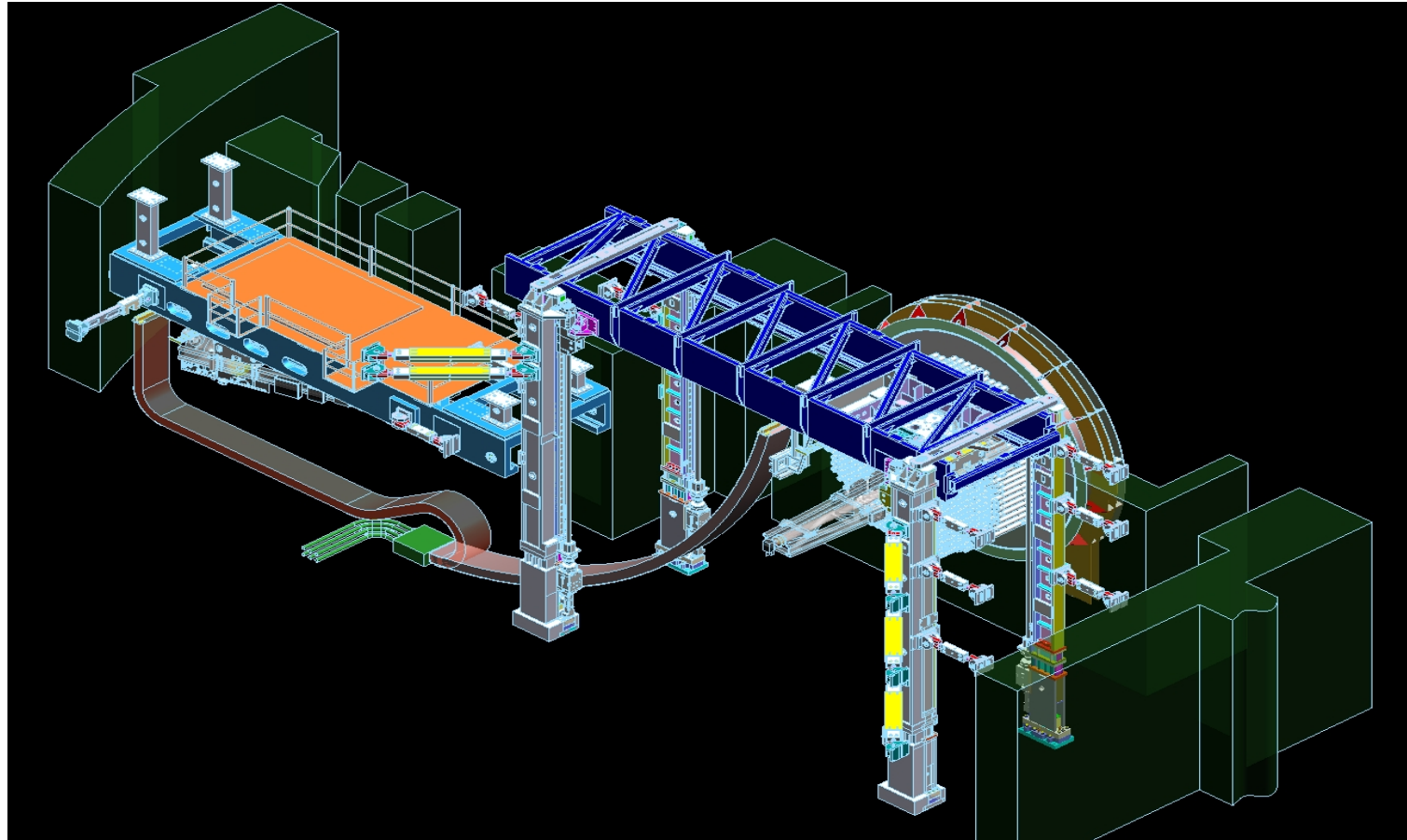
**CADDS models are used to develop bill of material
for complex components**

State-of-the-Art Project Technologies

- **Integrated Project Management Tools**
 - Intergraph 3D plant modelling and design
 - AECL's CMMS supply chain & materials management system
 - AECL's TRAK electronic document management system
 - AECL's IntEC equipment wiring design and management
- **Proven in recent “paperless” projects**

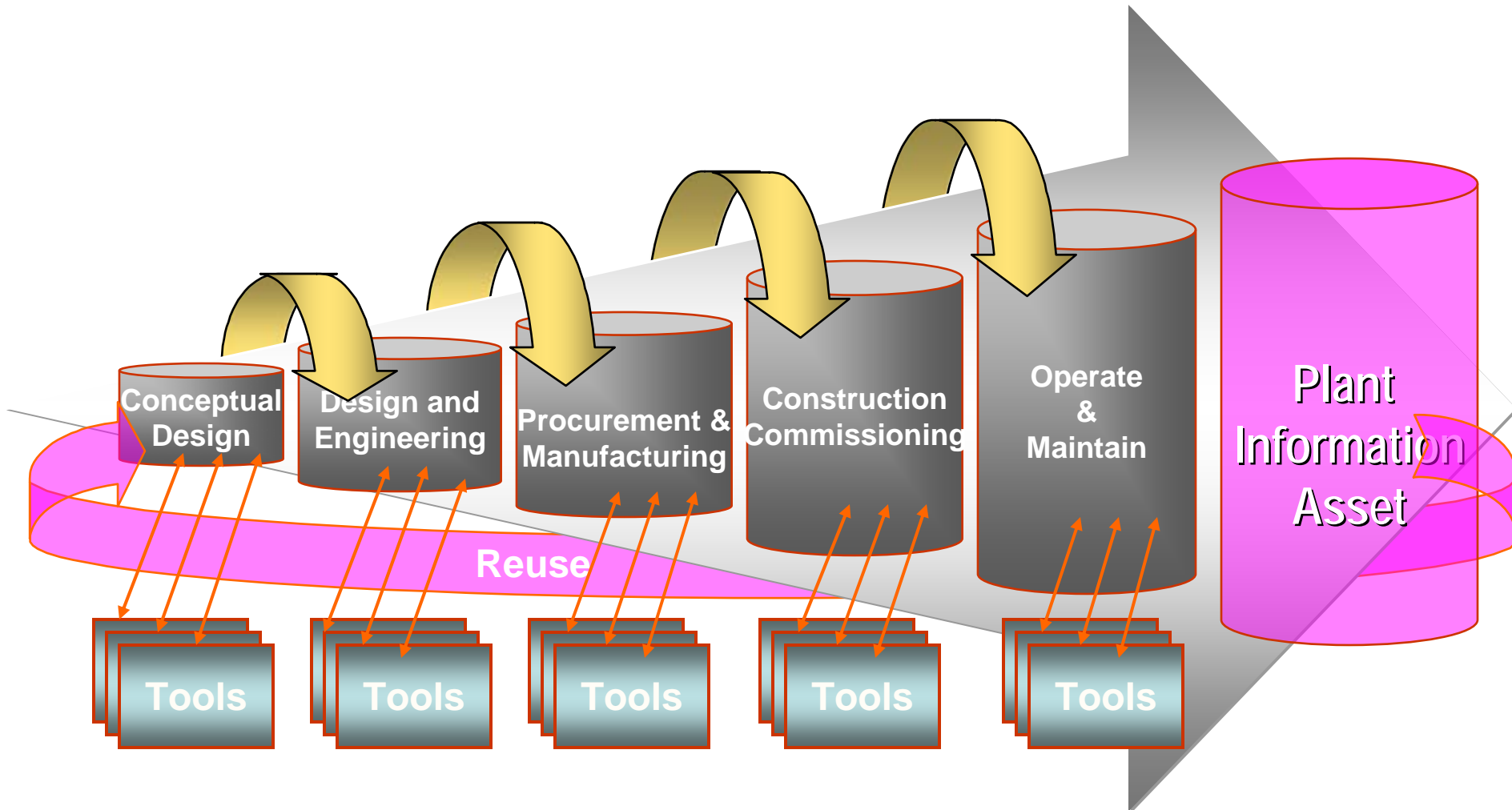


ACR Fuelling System



CADDs Models are used extensively in manufacturing and assembly of the equipment

Integrated Information Cycle



Summary of ACR Design

- **AECL has invested significantly in the “Generic ACR Technology Development” Program for the ACR-1000**
 - Generic ACR program ongoing since 2000
 - The ACR design has undergone extensive program review to serve as a foundation for ACR-1000 basic engineering and pre-licensing
- **Activities being carried out:**
 - Design
 - Licensing
 - Development and Testing
 - Supply Chain Management
 - Commissioning and Operations assessment



Summary of ACR Design

- The ACR technology base is strongly established, using the successful CANDU 6 experience in construction and operation
- Significant design enhancements have been made for the benefit of the Customer:
 - Safety
 - Performance
 - Operability
 - Maintainability
 - Constructability
- The ACR-1000 is ready for pre-project planning and pre-licensing



ACR-1000 - a Gen III+ competitor

- **We started with the highly competitive Gen II+ CANDU 6**
 - lowest installed unit cost foreign technology in China – despite being the smallest
- **And achieved major cost improvements**
 - economies of scale – 60% higher output
 - heavy water – 64% less/kW
 - thermal efficiency – 36.6% vs. 33%
 - simplification & system elimination
 - higher capacity factor
- **ACR-1000 will be fully competitive with all Generation III designs**