ACR-1000 Design Overview

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Presentation to PEO / CNS
Chalk River, 2008 May 21

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Nuclear New Build – Generation III+ Design

• Enhanced Safety
  - Improved safety margins
  - Improved core damage prevention & mitigation
    ✓ Reduction in Large Release Frequency
    ✓ Station Blackout Capability
    ✓ Systematic approach to assessing Beyond Design Basis Accidents – Severe Core Damage Accidents
      ✓ Reduction in Severe Core Damage Frequency
    ✓ Use of passive design features

• Reduction in Plant Capital Cost

• Reduction in Construction Schedule
  - 54/48 months for 1st/nth plant

• Improved Plant Reliability & Maintainability
  - Increased capacity factor, reduced outage duration, reduced outage frequency

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ACR 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
On-power Fuelling

- No re-fueling outage (flexibility in planned outage timing)
- Permit reduced planned outage frequency
- Can detect and remove failed fuel on-power
Evolutionary NSSS Design

- Same reactor coolant system as CANDU 6 and Darlington
ACR-1000 Evolution
(Updating approved C9 features)

- Steel lined large containment and testable penetrations
- Reserve water tank for accident coolant make-up
- ECC accumulator tanks inside containment
- Moderator improved circulation
- High pressure feedwater system
- Distributed control system / plant display system including fuel handling control
- Modern control centre / human factors
- New fuel and spent fuel transfer and storage system
- Modularization
ACR-1000 Product Drivers

• Licensing - Meets Canadian regulatory requirements and regulations including RD-337

• Economics - Improved performance over current CANDU – improved thermal efficiency with higher operating pressure & temperature

• Design changes to improve operational and environmental performance including customer feedback
  - Reduced use of heavy water – reduced tritium emissions
  - Use of low enriched uranium (LEU) to extend fuel life – reduced wastes

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Quad-Unit ACR-1000
ACR-1000 Reactor

- Standard size fuel channel
- Reactor assembly same size as CANDU 6 with more fuel channels
- Simple bundle design with low enriched uranium (LEU) Fuel
  - 20,000 MWd/te reference burnup
CANFLEX-ACR Fuel Bundle

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ACR Fuel Bundle

- Based on 43-element CANFLEX geometry
  - Same diameter and length as CANDU 6
  - 42 elements containing uniform 2.4 wt% LEU
  - Larger centre element contains Yttrium stabilized matrix of Zirconium oxide plus a mix of Dysprosium and Gadolinium oxides to reduce coolant void reactivity

- Lower linear element rating and higher critical heat flux ratio compared to 37-element CANDU 6 fuel bundle
  - improve thermal margins (designed for end of life conditions) for normal operation and accident conditions
ACR-1000 Improved Fuel Channels

- Zr 2.5wt% Nb alloy
- PT wall 50% thicker for 30 year operation:
  - Lower creep and sag
  - Increased strength to improve safety margins
- CT is larger diameter (160mm), thicker and stronger
- Failure of a pressure tube will not lead to CT failure

Pressure Tube
- 104 mm ID x 6.5 mm thick wall x Approx 6.5 m long

Calandria Tube
- Body: 2.5 mm thick wall
- Ends: 4.5 mm thick wall
- Length: approx 6m
Fuel Channel End Fitting

- Material: modified Type 403 stainless steel CSA Standard N285.6.8 per CANDU 6
- ACR-1000 EF length is 33% longer than CANDU 6 to accommodate the feeder bank
- ACR EF incorporates a double set of rolled joint grooves
ACR Pressure Tube Rolled Joint

- PT wall thickness is 6.5 mm compared with 4.19 mm CANDU 6
- EF wall thickness is thinner at 22.5 mm & 20 mm (out and in-board joints) as compared with 25.4mm (C6)
- Two sets of rolled joints in the EF to facilitate retention of one EF during retubing (requires verification)
- Zero-clearance rolled joint limits the tensile residual stresses per C6
ACR Feeder Arrangement

Feeders spaced along center portion of end fitting
End Fitting FM Bayonet & Feeder Connection

- Bayonet Fitting for fuelling machine connection, similar to Bruce/Darlington
  - Required to provide clearance for FM snout in tight lattice pitch
- Feeder connection uses transition elbow instead of straight connection and Graylok in C6
New Fuel Transfer System
Bridge & Carriage
ACR-1000 Fuelling Machine Head

4 disconnect latches for carriage junction

Stiff cradle to support pressure boundary

Redundant electric drives
FUELLING MACHINE HEAD

Separator Assembly
Snout Assembly
Magazine Assembly
Cradle
Ram Assembly
Spent Fuel Transfer
Receiving Bay
ACR-1000 Enhancements

• Reactor Coolant System
  – Stainless steel feeders and headers

• Reactivity Devices
  – No adjusters; liquid zone control replaced with mechanical zone control rods

• Safety Systems
  – Simplified and more reliable emergency coolant injection
  – Long-term cooling system to perform long term ECC and maintenance cooling
  – High pressure emergency feedwater system
Emergency Core Cooling (ECC) System

- Passive injection from pressurized ECI tanks located inside Reactor Building
- Passive Core Makeup Tanks ensure thermosyphoning
- Passive supply of water from Reserve Water System
- Long Term Cooling system for makeup and recovery cooling
- LTC pumps are powered by seismically and environmentally qualified Class III (Emergency Power) electrical system.
Powerful Emergency Core Cooling System
Long Term Cooling (LTC) System

- LTC system provides fuel cooling in the long term recovery stage of a LOCA.
- Comprised of 4 redundant divisions located in 4 separate quadrants of the RAB.
- The LTC system also provides maintenance cooling after a normal shutdown.
Four Quadrant Separation

- Essential cooling water and Long Term Cooling system equipment separated into four divisions
- Four electrical buses supply electrical power to safety system
- Four channels used for instrument and logic for safety systems.
- Quadrant layout and separation, allows on-line maintenance, and more flexibility in outages
ACR-1000 Quadrant Layout

4 emergency diesels/unit
2 SB diesels per plant
Electrical Equipment Rooms

(Section of RAB looking from side C)

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Key Regulatory Requirements

• The key CNSC requirements (RD-337) on severe accidents can be categorized as follows:
  – Safety Goals
    ▪ CDF should be $<10^{-6}$ and shall not exceed $10^{-5}$ ev. / plant year
    ▪ LRF should be $<10^{-7}$ and shall not exceed $10^{-6}$ ev. / plant year
    ▪ The design shall be balanced such that no particular event or design feature makes a disproportionately large or significantly uncertain contribution to the frequency of severe accidents.
  – Containment Performance
    ▪ It shall be demonstrated that the containment will maintain its role as a leak tight barrier for a period of at least 24 hours following the onset of core damage.
    ▪ After this period, the containment must prevent uncontrolled releases of radioactivity.
Passive Features – Water Inventory

- Large amounts of water inside RB; RWT, ECI, GLT, CMT, Calandria Vessel, and Reactor Vault to absorb decay heat
  - Calandria – 220 m³
  - Reactor Vault – 1400 m³
  - RWT – 2500 m³
  - ECI – 440 m³
  - GLTs – 1600 m³
  - CMTs – 100 m³
  - Total > 6000 m³
ACR-1000 Enhancements

- **Heat Sinks & Severe Accident Mitigation**
  - Reserve Water Tank for passive makeup to Reactor coolant system, steam generators
  - Continue shield cooling system to keep reactor vault cool
  - Containment sprays also available from reserve water tank
  - Hydrogen passive recombiners
  - Vault cooler long term containment heat sink
1. Calandria Water
2. Shielding Vault Water

3. Water from Reserve Water Tank fills calandria, and reactor shielding vault by gravity
Containment Cooling System

• Layout promotes natural circulation to aid in hydrogen mixing and avoid local regions of high temperature.

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Operations

• **Build on existing performance**

• **Important to integrate operations goals into the design**
  
  – Example: on-power maintenance

• **Input from operations during design**
ACR-1000’s heritage: CANDU 6
-- a consistent performer

Gentilly 2 shut down during spring runoffs & Embalse load followed during early operation

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Source: COG, data to end 2006
One 21-day outage every three years

Quadrant Design for On-Power Maintenance

On-Power Access to Containment for Maintenance

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Improved Operations/Maintenance

- On-power maintenance strategy
- Improved plant layout: permanent elevator, walkways, platforms; provision for electrical, water, air to facilitate maintenance
- Increased shielding in radiologically-controlled areas: reduced worker exposure
- Customer-driven improvements in operability and maintainability e.g. Mechanical zone control rods; solid-rod guaranteed shutdown state
- Computerized testing of major safety systems/automatic calibration of in-core detectors
- Four quadrant separation of systems
Evolution of Main Control Room (MCR)

• Features of the Advanced Control Room
  – Extensive use of Large Screen Displays (LSDs)
  – Highly Integrated Main Operator Console and Shift Interrogation Console
  – “Soft” Controls & Computerized Procedures
  – CANDU Alarm Message List System (CAMLs)
  – Automated Safety System Testing and Startup Sequences
  – Hardwired backup for Safety Functions
  – Seismic Qualification of Main Control Room
  – Smart CANDU Diagnostics
Evolution of Main Control Room

• Human Factors Program and close association with operating utility personnel
  – Continuous feedback through systematic processes
  – Periodic reviews of current practices and problems at operating stations
  – Formalized Function Analysis, Task Analysis & Validation
  – Control Centre Mock-up and Validation with experienced operators
    ▪ Completed for CANDU9
    ▪ In progress for ACR-1000
CANDU Control Centre Mock-up
ACR-1000 Main Control Room

Backup & Safety Panels

SSM Soft Wall Displays

Backup Annunciation

Soft Annunciation

PDS Soft Wall Displays

SSM Displays

PDS Displays

Backup Annunciation
Plant Information, Diagnostics and Analysis

**Status**
- Current value and trend of most recent values compared to user-defined limits
- Colour indicates status of all monitored parameters

**Trends**
- Trends of correlated parameters help with diagnostics and analysis
- Support proactive decisions

**Analysis**
- Activity transport
- SG fouling
- Thermal performance
- Deuterium ingress
- Thermal fatigue
Demonstrated Project Delivery

• Robust and experienced supply chain
• Project delivery experience and capabilities
• New delivery technologies
CANDU Supply

Calandria

• Largest nuclear component
• 2.5cm shell thickness
• Design pressure ~1 atm
• Similar size as for CANDU 6
• No forgings
ACR Construction

- Qinshan demonstrated large potential for significant schedule and cost reduction using modules & open top construction
- ACR extends use of modules for increased parallel construction
- Extensive modularization coupled with “Vertical Installation Compartments”
- Approximately 200 modules in Reactor Building
- Input from module fabricators and constructors incorporated into module designs
Qinshan Open Top Modular Construction

- Faster installation
  - Steam generators installed in 8 hours
  - Dousing system installed in prefabricated segments

- Logic improvements
  - 1 month not waiting for inner dome formwork
  - 6 months not waiting for SGs prior to feeder headers

- Etc …
Large Civil Structure Modules

• Structural Steel shipped to site
• Fabricated adjacent to Reactor Building
• Installation using VHL Crane
ACR-1000 Equipment/Systems Modules

- Piping/Valve Modules Pre-Assembled on Skids
- Instrumentation Racks/Pre-assembled Panels Modules
- Shipped to site

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State-of-the-Art Project Delivery Technologies

• Integrated Project Management and Delivery Tools
  – Intergraph SmartPlant 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-1000 Integrated Information Management

- Engineering Data Centered Model with Integrated Engineering Tools Suite.
- ACR output continues to be deliverables based.
- ACR Master Plant Database (UDL):
  - Defines nominal design values
  - Integrate data from various engineering processes
  - Version Management of single source data
  - Control of UDL/SADL Interfaces and PSA interfaces
- Document Database Publisher:
  - Production of deliverables by importing data from single source
Key ACR-1000 Information Systems

SP Foundation (Data Management)

- SolidEdge Mech Design
- IntEC CIE Design
- P3e Proj Mgmt
- IntEC Equip Spec
- CMMS Material Mgmt
- SP3D 3D Model
- SPPID 2D Process Design
- REMS Req’t Mgmt

TRAK (Document Management)

- Fabricators
- Constructors
- Suppliers
- CNSC
- Client

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ACR Program

• ACR program established in 2001
• AECL moved to the ACR-1000 to meet market requirements
• Organization, scope, cost, schedule, risk and quality assurance project elements are well-defined for basic engineering
• 3 years of pre-project review with CNSC
• Design freeze to support safety analysis March 2007
• Preliminary Safety Case Package milestone for ACR-1000 complete 2008 May
• Generic Safety Case Report under preparation.
ACR-1000 Summary

• ACR evolved from successful proven CANDU 6
• CANDU 9 design features have been adapted into the ACR-1000
• ACR-1000 specific design features have been incorporated in response to new build regulatory requirements, OPEX issues and desired increased plant reliability
• Many enhancement including passive safety features meeting current Canadian regulatory requirements
• Pre-project design review underway with CNSC