ACR Workshop
-Core Design & Reactor Physics-

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Office of Nuclear Reactor Regulation
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Outline

• Overview of ACR Characteristics
• Major differences between current CANDU and ACR
  – Coolant
  – Fuel
  – Lattice Pitch
• Core Physics of ACR
  – Negative Coolant Void Reactivity
  – Negative Power Feedback Reactivity Coefficients
  – Enhanced Control & Safety Characteristics
  – Stable Operation at All Power Levels
• Summary
# Reactivity Effects in ACR-700

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moderator Temperature (including density) effect</td>
<td>-0.013 (mk/°F)</td>
</tr>
<tr>
<td>Coolant Temperature (including density) effect</td>
<td>-0.006 (mk/°F)</td>
</tr>
<tr>
<td>Fuel Temperature effect</td>
<td>-0.008 (mk/°F)</td>
</tr>
<tr>
<td>Power Coefficient (95% -105% full power)</td>
<td>-0.07 mk/% power</td>
</tr>
<tr>
<td>Reactivity change from 0% to 100% full power</td>
<td>-8.0 mk</td>
</tr>
<tr>
<td>Boron effect in Moderator</td>
<td>-2.1 (mk/ppm)</td>
</tr>
<tr>
<td>Full-Core Coolant-Void Reactivity</td>
<td>-3.0 mk</td>
</tr>
</tbody>
</table>
## ACR –700 Core Characteristics

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of fuel channels</td>
<td>284</td>
</tr>
<tr>
<td>Reactor thermal power output</td>
<td>1982 MW</td>
</tr>
<tr>
<td>Gross Electrical Power output</td>
<td>731 MW</td>
</tr>
<tr>
<td>Lattice Pitch (square)</td>
<td>22 cm (8.7 inches)</td>
</tr>
<tr>
<td>Coolant</td>
<td>H₂O @ 300 °C (572 °F)</td>
</tr>
<tr>
<td>Moderator</td>
<td>D₂O @ 80 °C (176 °F)</td>
</tr>
<tr>
<td>Enrichment of CANFLEX SEU Fuel</td>
<td>2.0%SEU (42 pins) + NU/Dy</td>
</tr>
<tr>
<td>Core-Average Fuel Burnup</td>
<td>20.5 MWd/kg(U)</td>
</tr>
<tr>
<td>Max. Fuel Element burnup</td>
<td>26 MWd/kg(U)</td>
</tr>
<tr>
<td>Fuel Bundles Required per FPD</td>
<td>5.8</td>
</tr>
<tr>
<td>Channel Visits per FPD (2-bundle-shift scheme)</td>
<td>2.9</td>
</tr>
<tr>
<td>Max. Time-Average Channel Power</td>
<td>7.5 MW(th)</td>
</tr>
<tr>
<td>(power form factor 0.93)</td>
<td></td>
</tr>
<tr>
<td>Max. Time-Average Bundle Power</td>
<td>874 kW(th)</td>
</tr>
<tr>
<td>Max. Instantaneous Linear Element Rating</td>
<td>51 kW/m</td>
</tr>
</tbody>
</table>
ACR-700 Reactor Control & Safety Systems

Control System

- 9 Mechanical Control Assemblies with 2 segments per assembly
  - 9 mk worth for bulk- and spatial-control functions
  - 12 minutes of xenon override time
  - Power cycling from 100% -75% -100%,
  - Reactivity for about 7 full-power days without refueling.
- 4 Mechanical Control Absorbers for fast power reduction

SDS1

- 20 Mechanical Absorbers

SDS2

- 6 liquid-poison injection nozzles in reflector region
End-View of ACR-700

ACR-700 Reactor Core
284 Fuel Channels

upper ZCU absorbers parked above core
ZCU 4, 5 & 6 (upper)
ZCU 7, 8 & 9 (upper)
ZCU 1, 2 & 3 (upper)
ZCU 1, 2 & 3 (lower)
ZCU 4, 5 & 6 (lower)
ZCU 7, 8 & 9 (lower)
reflector 500 mm

Pg 7
ACR-700 Reactivity Mechanisms Plan View

- **Shutoff Units (SU)**
- **Zone Control Units (ZCU)**
- **Control Absorber Units (CAU)**

Fuel Bundle Positions:
- SDS-2 Injection Nozzles
- Vertical Flux Detector Units

Legend:
- Red: SHU - Shutoff Units
- Green: ZCU - Zone Control Units
- Blue: CAU - Control Absorber Units
### Safety Parameters in ACR-700 and CANDU 6

<table>
<thead>
<tr>
<th>Parameter</th>
<th>ACR-700</th>
<th>CANDU 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Delayed Neutron Fraction (β)</td>
<td>0.0056</td>
<td>0.0058</td>
</tr>
<tr>
<td>Prompt Neutron Lifetime (millisecond)</td>
<td>0.33</td>
<td>0.92</td>
</tr>
<tr>
<td>Full-Core Coolant Void Reactivity</td>
<td>-3 mk</td>
<td>+15 mk (Approx.)</td>
</tr>
<tr>
<td>Power Coefficient</td>
<td>-0.07 (mk per % power)</td>
<td>~0</td>
</tr>
<tr>
<td>SDS1</td>
<td>20 Absorber Rods</td>
<td>28 Absorber Rods</td>
</tr>
<tr>
<td>SDS2</td>
<td>6 Poison Nozzles (reflector region)</td>
<td>6 Poison Nozzles (core region)</td>
</tr>
</tbody>
</table>
## Characteristics of ACR-700 and CANDU 6

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<tr>
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<th>ACR-700</th>
<th>CANDU 6</th>
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<tbody>
<tr>
<td><strong>Fuel Channels</strong></td>
<td>284</td>
<td>380</td>
</tr>
<tr>
<td><strong>Reactor Thermal Power (MW)</strong></td>
<td>1982</td>
<td>2064</td>
</tr>
<tr>
<td><strong>Gross Electrical Power (MW)</strong></td>
<td>731</td>
<td>728</td>
</tr>
<tr>
<td><strong>Fuel Enrichment</strong></td>
<td>2.0% in 42 pins Central NU/Dy pin</td>
<td>37 NU pins</td>
</tr>
<tr>
<td><strong>Core-Averaged Burnup (MWd/kgU)</strong></td>
<td>20.5</td>
<td>7.5</td>
</tr>
<tr>
<td><strong>Fueling Rate (Bundles per Day)</strong></td>
<td>5.8</td>
<td>16</td>
</tr>
<tr>
<td><strong>Channel Visits/Day</strong></td>
<td>3</td>
<td>2</td>
</tr>
</tbody>
</table>
Major Differences between CANDU 6 and ACR

- Coolant
  - CANDU 6 (D$_2$O )
  - ACR (H$_2$O)

- Fuel
  - CANDU 6 (NU in 37-element bundle)
  - ACR (2.0 % SEU in 42 pins, Central Pin Dy/NU, CANFLEX bundle)

- Lattice Pitch
  - CANDU 6 (28.575 cm, 11.25 inches)
  - ACR (22.0 cm, 8.66 inches)
CANDU Fuel Bundle Designs

37-Element Bundle
C6 Fuel Channel

CANFLEX
Bundle (43 elements)
ACR Fuel Channel
Effects of CANFLEX SEU Fuel in ACR

- Enables the use of H$_2$O Coolant
- Allows the reduction of moderator to reduce Coolant Void Reactivity (CVR)
- Allows the use of neutron absorber in the central fuel pin to further reduce CVR to target of $-3$ mk
- High fuel burnup
- Reduction in maximum fuel element rating
- Inlet skewed axial power profile improves thermal hydraulic margin
Axial Power Profiles in ACR and in C6

Bundle Position from Inlet End (Channel Power = 7.5 MW)
Effect of Coolant Void in ACR

- ACR lattice is under-moderated with normal H$_2$O coolant
- H$_2$O acts as both coolant and moderator
- LOCA further reduces moderation from the lattice
- Coolant Void Reactivity (CVR) is a combined effect due to loss of absorption (positive) and loss of moderation (negative) from H$_2$O
- Increase in fast flux and decrease in thermal flux upon LOCA
- U238 and Pu239 generate negative components in CVR
  - Increase in Resonance Absorption (1 eV to 100 keV) in U238
  - Decrease in Fission (0.3 eV resonance) in Pu239
Physics Innovations to achieve slightly negative CVR (H₂O Coolant)

- Large Moderator/Fuel ratio (Vm/Vf) means high CVR
- Current Lattice Pitch (LP) 28.575 cm (11.25 inches)
  \[ Vm/Vf = 16.4 \quad CVR = +60\ mk \]
- Target CVR = -3 mk requires Vm/Vf < 6.0, LP < 20 cm (7.87 inches)
- Minimum LP = 22 cm (8.66 inches) required to provide space for feeders between channels
  \[ Vm/Vf = 8.4 \]
- Use larger CT, OR = 7.8 cm (3.07 inches) to displace more moderator
  - Vm/Vf = 7.1
  - Add Dy (4.6%) to central NU pin CVR = -3 mk
Comparison of CANDU 6 and ACR Lattices

CANDU 6 Lattice

ACR Lattice
Core Size Comparison

CANDU 6
728 MWe
380 channels
Diameter = 760 cm
(299 inches)

ACR
731 MWe
284 channels
Diameter = 520 cm
(205 inches)

Calandria volume reduced by a factor of 2.5 (smaller lattice pitch).
By using H₂O coolant, less than 25% of D₂O used in C6 is required.
Effect of Trip Time & CVR on LOCA Transients in ACR

- LOCA power transients in ACR
  - Not sensitive to trip time (1 to 3 seconds)
  - Not sensitive to the magnitude of the negative CVR
    (-1 mk to –6 mk)
Effect of Trip Time on LOCA Transient

ACR 100% RIH LOCA Transient

- CVR -3 mk, Trip at 1 s, 1.36 FPS
- CVR -3 mk, Trip at 2 s, 2.11 FPS
- CVR -3 mk, Trip at 3 s, 2.81 FPS

Relative Power vs. Time after break (second)
Effect of CVR on LOCA Transient

ACR 100% RIH LOCA Transient

- CVR -1 mk, Trip at 3 s, 3.13 FPS
- CVR -3 mk, Trip at 3 s, 2.81 FPS
- CVR -6 mk, Trip at 3 s, 2.45 FPS
Unique LOCA Features in ACR

• Power in reactor core region drops upon LOCA due to negative void reactivity
• Rapid rise in thermal neutron flux in the reflector region due to migration and subsequent thermalization of fast neutrons from the core region
• Fast neutronic trip is available from neutron detectors in the reflector region
Thermal Neutron-Flux Distributions in ACR-700 after LOCA

Thermal Flux (10E14 )

Distance from Edge of Reflector (cm)
Thermal Flux Profile upon LOCA at t=0 s
Thermal Flux Profile upon LOCA at t=0.015 s
Thermal Flux Profile upon LOCA at t=0.02 s
Thermal Flux Profile upon LOCA at $t=0.03$ s
Thermal Flux Profiles in ACR-700 upon LOCA

(click picture to start animation)
Thermal Flux Ratios in ACR-700 upon LOCA

(click picture to start animation)
Summary

- ACR is an evolutionary design of current CANDUs

- Common features between ACR and current CANDUs:
  - Horizontal fuel channels
  - D$_2$O moderator
  - On-power fueling
  - Simple fuel bundle design

- ACR specific features:
  - H$_2$O coolant
  - High burnup SEU fuel
  - Smaller lattice-pitch and compact reactor core
  - Negative coolant void reactivity enhances safety margins
  - Negative power feedback coefficients enhances reactor stability