CANDU 9 Safety & Licensing Requirements

- licensable in Canada
  - “up-front” review by the AECB to ensure no fundamental barriers
- licensable in customer’s country
  - example of dual licensability: desire for Exclusion Area Boundary <500m led to dry high-pressure steel-lined containment and two independent ventilation isolation systems
- meet IAEA Standards and Guides
- meet utility requirements for modern evolutionary plant
- enhanced safety
Heat Transport System

- one loop design (Bruce B) chosen for simplicity
- alternating channels connected to different inlet headers to increase margins for large LOCA power transient (interlacing)
- pressurizer volume handles change from zero power cold to full power hot
  - greater assurance of thermosyphoning in accidents
Feeder Connections

- To outlet header
- To inlet header 1
- To inlet header 2

Same
480 channel
core as Darlington
ECC System

Gas ~8MPa

Floating Ball Shut-Off

One-Way Rupture Disc

Heat Transport System

Support Flange

Foil
ECC System
Grouping & Separation

- defence against common cause & external events
- each group must on its own:
  - shutdown the reactor
  - remove decay heat & contain radioactivity
  - monitor state of the plant
- either Main Control Room (MCR) or Secondary Control Area (SCA) can perform the above safety functions including earthquakes
- SCA needed only for major fire in MCR or hostile takeover
**Calandria Tubes**

- Increased heat transfer under accident conditions
- Shot-peening of the outside surface, for Qinshan project
- Black oxide on the inside surface, added for CANDU 9
- Reduces required moderator subcooling, and therefore the size of moderator heat-exchangers or risk of summer derating
Effect of Increased Heat Transfer in Accidents

nucleate boiling on peened surface  film boiling on smooth surface
Reserve Water Tank

- large high-elevation tank similar to CANDU 6 dousing tank supplying:
  - ECC water, directly to sumps
  - steam generator emergency feedwater
- for severe accident mitigation
  - makeup to shield tank (added)
  - makeup to moderator (added)
  - makeup to heat transport system
Containment

- prestressed concrete with steel liner for increased leaktightness & robust severe accident performance
  - design leak rate 0.2%/day at design pressure
- no pressure suppression via dousing (simplification)
- two redundant, separated, fully independent ventilation isolation systems
- reduced exclusion area boundary (less than 500m.)
- hydrogen mitigation for severe accidents
Exclusion Area Boundary

CANDU 9 < 500 m.

Point Lepreau 914 m.
Hydrogen Control

- small hydrogen source term (cool moderator)
- natural convection flow patterns
- no hydrogen traps
- large containment volume
- dispersed igniters
- passive recombiners
Hydrogen Mixing

- Normal Operation
- Accident mode

Local Air Cooler
Hydrogen Mixing Duct
Blow-out panels
Wetproofed Catalyst
Pt on Charcoal

Substrate

Teflon Layer

Hydrogen Flow

Water Flow

\[ H_2 \]

\[ H_2O[g] \]

\[ HD \]

\[ HDO[g] \]
Severe Accident Goals

- stop severe accident at the channel boundary using the moderator (no fuel melting)
- stop severe core damage at calandria boundary using the shield tank (no melt-through)
Severe Accident Prevention and Mitigation

- **Shutdown**
  - three methods: control system & two shutdown systems

- **Decay heat removal**
  - normal & auxiliary feedwater (Group 1)
  - full-pressure & temperature shutdown cooling system
  - emergency high-pressure feedwater (Group 2)
  - makeup from reserve water tank to steam generators
  - moderator as emergency heat sink
  - shield tank / end shield cooling

- **Electrical power**
  - normal Class IV
  - emergency Group 1 Class III
  - seismically-qualified Group 2 Class III
CANDU Fuel Channel Cross-Section

- Fuel
- Pressure Tube
- Gas annulus
- Calandria tube
- Moderator
Heat Rejection to Moderator in Severe Accident

Normal Heat flow

Low Pressure (Sag) High pressure (Expand)

Fuel
Pressure Tube
Gas annulus
Calandria tube
Moderator
Calandria as Core Catcher

Concrete Structure

Calandria

Fuel Channels

Shield Tank
Specific Water Volumes Near the Fuel

Moderator
Can remove 4.4% decay power
Has 8 litres of water per kW
at 1% decay power
Takes >5 hours to heat up and boil off with no heat removal

Shield Tank
Can remove 0.4% decay power
Has 32 litres of water per kW
at 0.5% decay power.
Takes >20 hours to heat up and boil off with no heat removal
Calandria as Core Catcher

Water makeup & boiloff

Shield Tank

Calandria

Collapsed Channels

Possible Molten Centre

Heat flux < CHF

Crust
CANDU 9 - Severe Core Damage Mitigation

Reserve Water Tank

Level Control

Head Tank

Calandria

1.4 m

0.6 m

1.4 m

0.6 m
Demonstration of Licensability in Canada

- two year formal review by AECB
- > 200 documents
- acceptance of Licensing Basis Document (Canadian and foreign requirements)
- review of design requirements, design methods, safety analysis, probabilistic safety analysis, QA, decommissioning, safeguards etc.
- address Generic Action Items
- 13 key issues identified and eventually resolved
Review Focussed on Thirteen Issues

- Large LOCA analysis
- PT rupture/Moderator
- In-core LOCA/SDS1
- Digital control system
- Plant Display System/Control Centre
- Containment design
- Backup heat sinks
- Moderator temperature predictions
- Post-accident monitoring
- Experience feedback
- Safety critical software
- Grouping and Separation
- Severe accident programme
Licensability in Country of Origin

- “The CANDU 9 design complies or can be made to comply with licensing requirements in effect, in Canada, on January 1, 1995;
- “AECL's proposals to address Generic Action Items for the CANDU 9 design are acceptable. In all cases the proposed method for addressing Generic Action Items is equivalent to or an improvement with respect to what is currently accepted on operating CANDU reactors in Canada, and
- “AECL has adequately addressed the major issues identified in the June 1996, “AECB Staff Interim Statement on CANDU 9 Licensability”.”
- “AECB staff therefore concludes that there are no fundamental barriers to CANDU 9 licensability in Canada”
Conclusions

- CANDU 9 incorporates:
  - emerging international safety standards
  - utility requirements for modern evolutionary plant
  - severe accident prevention and mitigation using inherent CANDU characteristics and passive systems
  - licensability in Canada through formal AECB review
  - lessons learned from licensing CANDU 6 in Asia
- CANDU 9 designed to be an internationally licensable product