PHWR Group of Countries
Implementation of Lessons Learned from Fukushima Accident in CANDU Technology

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Vienna, August 2013
Countries Operating CANDU
Pressurized Heavy Water Reactor (PHWR)

CANDU reactors have operated for over 700 reactor years across 34 reactors in 7 countries

Source: CANDU Energy Inc.

No major events in CANDU reactor history

PHWR Group of Countries
Outline/Objectives

• CANDU Design Overview
• Inherent Robustness of CANDU/PHWR Design to Severe Accident
• Safety Reviews by CANDU Countries in light of Fukushima Event
  – Response to Fukushima Accident
  – CANDU Design Enhancements
  – Severe Accident Management
• Summary
CANDU Design Overview
Based on the CANDU-6 design
Primary and secondary circuits are separated (unlike Fukushima Dai-Ichi)
CANDU Design Overview
Based on the CANDU-6 design

- Boiler makeup water isolation valves fail open on loss of power or instrument air.
- Emergency water supply (simplified).
- Main Steam Safety Valves (MSSVs) open automatically to depressurize primary and secondary sides.
- Feedwater supply.

Source: CANDU Energy Inc.
CANDU Design Overview
Passive Heat Removal

~ 500 Mg H₂O in calandria vault
~ 200 Mg D₂O calandria vessel

~ 100 Mg D₂O in heat transport system

Calandria Tube
Heavy water coolant
Pressure tube
Annulus Gas
Fuel
Annulus Spacer
Inherent Robustness of CANDU Design to Severe Accident

Scenario: Unmitigated Total Loss of Heat Sinks
Core Heat-up Leading to In-core Fuel Channel Ruptures

Channel rupture at high pressure can be delayed by ~ 1-7 days by gravity feed using existing dousing tank water inventory.

~ 4 hours for unmitigated total loss of heat sinks.
Suspended Debris Bed

Core debris from disassembled channels held up by intact channels
Core Collapse

Core collapses into residual water pool in calandria vessel

Residual water pool boil-off continues

Calandria vessel

Reactor vault water subcooled at this point

Porous terminal debris bed quenches
Corium In-vessel Retention

~ 40 hours to calandria vessel failure for unmitigated total loss of heat sinks

Calandria vessel failure not expected until calandria vault water level is below corium level inside calandria vessel

A design change to permit water makeup to calandria vault will maintain calandria vessel integrity
Safety Reviews by CANDU National Regulatory authorities in light of Fukushima Event
Response to Fukushima Accident

Assessments equivalent to stress tests

- Canada, India and Korea completed independent comprehensive safety assessment, and started implementation
- Argentina – performed stress test similar to EU
- Romania – performed EU Stress Test and started implementation
- China – comprehensive safety assessments nearing completion
Response to Fukushima Accident

1. External events
2. Design issues
3. Severe accident management / recovery
4. National organizations
5. Emergency preparedness
6. International cooperation

CANDU “Stress Test”
External Events

Seismic

• NPPs were designed or assessed for at least 0.1g and
• Re-assessed for 0.2g or higher by Seismic Margin Assessment (SMA), or PSA based SMA
• Margins enhanced for more severe events
  – some seismic upgrades performed or planned
  – Certain countries are installing or considering seismic trip
• Higher seismic requirements for new plants
  – typically 1 in 10,000 years for design basis

Sufficient seismic margins.
External Events (con’t)

Flooding

- Adequate safety margins against tsunami for affected NPPs
  - upgrades have been identified for one of India’s reactors
- All NPPs are improving defences
  - e.g. raised barriers, additional pump out capability, strengthened sea defences

Other enhancements

- Additional fire defences needed have been identified and are being installed.

Increased protection against wide range of hazards.
Design Enhancements - Water Supply

Existing Passive Heat Sinks
• CANDU has large inventory of water
  – many hours of passive cooling
  – no reactivity or structural concerns with rapid cool-down and depressurization

Added Makeup Water Sources
• Installing accessible connection points to:
  – steam generators
  – calandria vessel
  – calandria vault
• Deploying portable pumps
  – on and off-site

Making CANDUs safer.
Design Enhancements – Power Supply

Existing Electrical Systems
• CANDU’s have good diversity and redundancy
  – standby and emergency power has many days supply of fuel

Added Power Sources
• Providing mobile Diesel Generators
  – stationed on- or off-site
  – accessible connection points
  – adequate fuel
• Considering additional battery capacity or charging capability
  – may be limited to specific purposes, e.g. accident management related I&C
  – may add portable charging generators

Strengthening defence-in-depth.
Design Enhancements – Spent Fuel

Existing Spent Fuel Cooling

- Slow heat-up
  - low heat load
  - large water inventory
- Pools are robust
  - in-ground and seismically qualified
  - pools are not in reactor building
  - accessible
  - steam can be vented
- No criticality issue

Added Safety Features

- Accessible pool makeup connections
- Better instrumentation – for monitoring water level

Spent fuel pools are safe.
Design Enhancements – Containment

Hydrogen Control
- All CANDUs installing or evaluating passive recombines
  - complementary to igniters
- Hydrogen concentration monitoring under consideration or already installed

Venting
- All CANDUs have filtered containment venting
  - in place and adequate for DBA – Design Basis Accident
  - Additional filtered system are being considered or already have been installed

Enhancements to ensure containment integrity.
Severe Accident Management

SAMGs (Severe Accident Management Guidelines)

- Enhancements are being developed:
  - to address credible worst case scenario including multi-unit sites
  - In some countries implementation underway

Instrumentation

- Survivability of equipment and instrumentation in severe accident conditions:
  - hardening of key I&C
  - additional instrumentation to support severe accident management

Even well designed and well built systems may fail.
Summary

• CANDU has inherent safety features
• Enhancements to strengthen Defence-in-Depth:
  – Preventing Fuel Failure
    • Back-up Mitigation Equipment
  – Preventing Severe Core Damage
    • Makeup capability to calandria vessel
  – Arresting Severe Core Damage
    • Makeup capability to calandria vault
  – Preventing Containment Failure
    • Containment venting/Passive Recombiners