PHWR Group of Countries

Implementation of Lessons Learned from Fukushima Accident in CANDU Technology

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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
Outline/Objectives

• CANDU Design Overview
• Inherent Robustness of CANDU/PHWR Design to Severe Accident
• Status of Fukushima Actions in CANDU Countries
  – Strengthening Defence-in-Depth
  – Enhancing Emergency Response
• 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

- Opens automatically
  - Boiler makeup water isolation valves fail open on loss of power or instrument air
- Emergency water supply
  - (simplified)
- Main Steam Safety Valves (MSSVs)
  - Opens 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
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 due to natural circulation cooling.
Suspended Debris Bed

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

- Calandria Vessel Rupture Disc
- 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
Status of Fukushima Actions in CANDU Countries

- **Strengthening Defence-in-Depth**
  - Protect Fuel
  - Prevent Severe Core Damage
  - Protect Containment
  - Protect Spent Fuel Pools
- **Enhancing Emergency Response**
  - Protect Public
Response to Fukushima Accident

Assessments equivalent to stress tests

• Argentina – performed stress test similar to EU
• Canada, China, India, Korea and Pakistan completed independent comprehensive safety assessment
  – Wolsong-1 (Korea) Continued Operation is contingent upon implementation of results from ‘Augmented Stress Test’
• Romania – performed EU Stress Test

CANDU safety improvements through lessons learned
Protect Fuel (1/3)

Planned or Implemented Design Improvements

• Emergency Mitigating Equipment (EME)
  – Mobile water pumps and diesel-generators

• Water makeup connections to:
  – Steam Generators (pumped/gravity feed from Dousing Tank/Deaerator)
  – Primary Heat Transport System (PHT)
  – Emergency Core Cooling (ECC) System
  – Emergency Water Supply System

• Provision to open Main Steam Safety Valves after station blackout

Strengthening defence-in-depth
Protect Fuel (2/3)

Planned or Implemented Design Improvements (cont’d)

• Improvements to safety related systems to enhance capability and reliability to better cope with accidents
• Upgrades of power systems to improve reliability, longevity of battery supply, improved backup for critical loads
  – Improved load shedding to extend battery availability
  – Battery charging capability and UPS system backup
  – Upgrades to power supply for key instrumentation (e.g., Local Air Cooler)
• Protection against flooding (barriers, water-tight doors, sealing penetrations)
Protect Fuel (3/3)

Analyses and Reassessments

- Re-evaluation of site-specific magnitudes of external events, including multi-unit events:
  - High winds
  - Seismic margin assessment / Seismic PSA
  - Tsunami / Storm Surges
  - Flooding
  - Significance of station blackout event on spent fuel bundles inside fueling machine
Prevent Severe Core Damage (1/2)

Planned or Implemented Design Improvements

• Water makeup connections to:
  – Calandria vessel (moderator)
  – Calandria vault (shield tank)

• Improve pressure relief capability of calandria/vault

• Instrumentation upgrades arising from qualification for Severe Accident (SA) conditions
  – Installation of seismic trip system

Strengthening defence-in-depth
Prevent Severe Core Damage (2/2)

Analyses and Reassessments

- Severe accident studies including modelling for multi-unit plant events
- Reassessment of Main Control Room & Secondary Control Room habitability
- Instrumentation qualification for Severe Accident conditions
Protect Containment (1/2)

Planned or Implemented Design Improvements

• Installation / enhancement of Containment Venting
• Installation of Passive Autocatalytic Recombiners (PARs)
• Instrumentation to measure hydrogen in containment
Protect Containment (2/2)

Analyses and Reassessments

• Enhancement of **Filtered** Containment Venting System
• Severe Accident Management Guidelines (SAMGs)
• Instrumentation for SA conditions monitoring
  – qualify existing or new
• Control Facilities habitability during SA
• Improved modelling of SAs for multi-unit plants

**Strengthening defence-in-depth**
Protect Spent Fuel Pools

Planned or Implemented Design Improvements
- Instrumentation to measure water level and temperature
- Piping and connections for external addition of water
- Develop and implement *Abnormal Operating Procedure* for loss of cooling

Analyses and Reassessments
- Structural integrity check for temperatures above design values

Strengthening defence-in-depth
Protect the Public (Onsite)

Planned or Implemented Design (or Procedural) Improvements

• Enhancing On-site / Off-site emergency preparedness and response
  – Training for severe accidents
  – Provision of satellite phones and improved on-site emergency communication

• Enhancing preparedness and execution of station emergency drills
  – Improvement of Abnormal Operating Procedures for specific scenarios

• On-site emergency management facility capable of withstanding extreme events
  – Maintaining site self-sufficiency through availability of water and emergency power
Protect the Public (Offsite)

Planned or Implemented Procedural Improvements

- Establish/Confirm national level oversight process for offsite nuclear emergency response
- Reassessment of emergency management, in particular for multi-unit events
- Emergency drills up to full scale involving all levels of government
  - Review and increase in frequency and scope as necessary
Summary

Safety Enhancements

- **Protecting Fuel**
  - Deployment of back-up mitigation equipment
  - Makeup water capability to SG/PHT/ECC/Dousing Spray

- **Preventing Severe Core Damage**
  - Makeup water capability to moderator system and calandria vessel/vault

- **Protecting Containment**
  - Passive Recombiners and containment venting
  - SAMG validation/exercise

- **Protecting Spent Fuel Pools**
  - Makeup water capability and instrumentation

- **Protecting the Public**
  - Containment filtered venting
  - Integrated emergency plans and full scale emergency exercises
Summary

Safety Benefits

• Enhanced accident prevention
  – Risk reduction by a factor of 2 to 10, depending on accident scenarios

• Improved accident mitigation
  – Potential radiological consequence reduced to as low as practicable

• Improved public protection
  – Effective strategies for sheltering and evacuation
Thank You

PHWR Group of Countries
Argentina, Canada, China, India, Korea, Pakistan, Romania