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What if?

Implementation of Lessons Learned from the Fukushima Dai-ichi Accident – Canadian Experience

US NRC 27th Annual Regulatory Information Conference
North Bethesda, Maryland, USA
March 11, 2015

Ramzi Jammal
Executive Vice-President & Chief Regulatory Operations Officer

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Chronology

Mar 2011
Fukushima nuclear event in Japan

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Chronology

- Apr 2011: CNSC Task Force convened
- Jul 2011: Safety Review Criteria – Canadian 'Stress Test' issued
- Oct 2011: CNSC Task Force Report – Issued for public comment
- Dec 2011: IRRS Mission conducted
- Mar 2012: CNSC Staff Action Plan – Issued for public comment
- Apr 2012: External Advisory Committee Report issued
- Jun 2012: CNSC Action Plan – Approved by CNSC Commission
- Dec 2013: Short-term Actions completed

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Chronology

Dec 2014
Mid-term Actions completed

Dec 2015
Closure of CNSC Action Plan

Reassessment of external hazard of higher magnitudes and consequences

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CNSC Action Plan

Integrates reviews and recommendations

- CNSC Fukushima Task Force
- External Advisory Committee
- IAEA/IRRS follow-up mission

Applies to all nuclear facilities and CNSC

- Strengthening reactor Defence-in-Depth
- Enhancing emergency response
- Improving regulatory framework and processes
- Enhancing international collaboration
- Enhancing communications and public education

Shift in regulatory focus from accident prevention to accident prevention and mitigation

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CNSC Action Plan

McMaster University
Emergency Preparedness Exercise

CANDU Extreme
Event Simulation

CNSC ONLINE Extreme Event Simulation,
Communications, and public education

International collaboration

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CNSC Defence-in-Depth Accident Prevention and Mitigation based on solid foundation established by INSAG

Level	Implementation
1. Prevent deviations from Normal Operation (NO) and prevent failures of structures, systems and components (SSCs) important to safety.	<ul style="list-style-type: none"> Conservative safe design High quality construction (e.g., appropriate design codes and materials, design procedures, equipment qualification, control of component fabrication and plant construction)
2. Prevent Abnormal Operational Occurrences (AOOs) from escalating to accident conditions and to return the plant to a state of NO.	<ul style="list-style-type: none"> Inherent and engineered design features to minimize or exclude uncontrolled transients to the extent possible
3. Minimize the consequences of Design Basis Accidents (DBAs), and prevent escalation to Beyond Design Basis Accidents (BDBAs)	<ul style="list-style-type: none"> Inherent safety features Fall-safe design Engineered design features, and procedures to minimize consequences
4. Ensure that radioactive releases caused by RDBAs are kept as low as practicable, and prevent progression to Severe Accidents (SAs)	<ul style="list-style-type: none"> Equipment and procedures to manage RDBAs and mitigate their consequences as far as practicable Robust containment design Complementary design features to prevent accident progression to SAs Accident management procedures
5. Mitigate the radiological consequences of potential releases of radioactive materials that may result from accident conditions.	<ul style="list-style-type: none"> Emergency support facilities Onsite and offsite emergency response plans

Strengthening all levels of Defence-in-Depth

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Reactor Defence-in-Depth

CONTROL COOL CONTAIN

1st and 2nd levels - Design Provisions

3rd to 5th levels - Defence-in-Depth

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Reactor Defence-in-Depth

~ 500 Mg H₂O in calandria vault
 ~ 200 Mg D₂O calandria vessel
 ~ 100 Mg D₂O in heat transport system

Levels 1 and 2 Defence-in-Depth Through Design Provisions

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Reactor Defence-in-Depth Prevent Severe Core Damage

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Reactor Defence-in-Depth

Analyses and Reassessments

- Site-specific magnitudes of external events
 - High winds, Seismic, Tsunami, Storm Surges, Flooding
- Re-evaluation of multi-unit events

Design Improvements

- Emergency Mitigating Equipment (EME)
 - Mobile water pumps and diesel-generators
- Water makeup connections to:
 - Steam Generators and Primary Heat Transport System
 - Provision to manually open Main Steam Safety Valves
- Upgrades to improve reliability of battery supply
- Protection against flooding

Strengthening 3rd and 4th level of Defence-in-Depth

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Reactor Defence-in-Depth Protect Fuel Licensee Met CNSC Requirements

Water Supply Connection Points

Bruce, Battery

GPG Flood Protection

Strengthening 3rd and 4th level of Defence-in-Depth


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Reactor Defence-in-Depth



Analyses and Reassessments

- Severe accident studies including modelling for multi-unit plant events
- Reassessment of Main Control Room and Secondary Control Room habitability during emergencies
- Instrumentation qualification for Severe Accident conditions

Design Improvements

- Water makeup connections to
 - Calandria vessel (moderator) and Calandria vault (shield tank)
- Improve pressure relief capability of calandria/vault
- Instrumentation upgrades for Severe Accident (SA) conditions

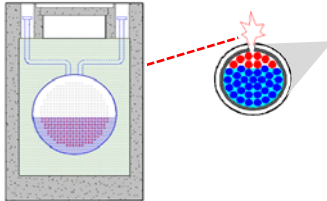
Strengthening 4th level of Defence-in-Depth

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Assessment Was Completed 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

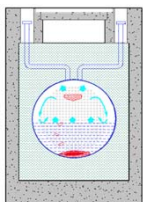
~4 hours for unmitigated total loss of heat sinks due to natural circulation cooling

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Assessment Was Completed Suspended Debris Bed - Core Collapse



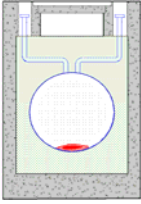
- Calandria Vessel Rupture Disc
- Core collapses into residual water pool in calandria vessel
- Residual water pool boil-off continues
- Reactor vault water subcooled at this point
- Porous terminal debris bed quenches

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Assessment Was Completed Moderator Complete Boil-off



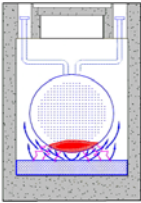
- ~ 8 hours to moderator boil-off for unmitigated total loss of heat sinks
- Shield tank water level well above level of debris
- Dry hot debris in calandria vessel
- A design change to permit water makeup to calandria vessel from outside RB will maintain water level and quench core debris

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Assessment Was Completed Corium In-vessel Retention



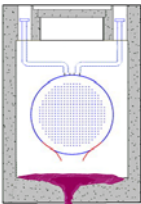
- ~ 40 hours to calandria vessel failure for unmitigated total loss of heat sinks
- Calandria vessel failure not expected until calandria vault water level is below corium level inside calandria vessel
- A design change to permit water makeup to calandria vault will maintain calandria vessel integrity

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Assessment Was Completed Corium In-vessel Retention




- After 56 hours, molten fuel debris fall into the basement of the reactor building for unmitigated total loss of heat sink.
- Controlled venting protects containment from high internal pressure and cracking.

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Mitigation Implemented Prevent Severe Core Damage



- Design change to permit water makeup to calandria vessel from outside RB will maintain water level and quench core debris
- Design change to permit water makeup to calandria vault will maintain calandria vessel integrity

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Reactor Defence-in-Depth Prevent Severe Core Damage Licensee Met CNSC Requirements



Bruce Power Fire trucks provide cooling water. New emergency water pumping equipment procured and on site.

Darlington Emergency water supply.

Darlington Emergency portable pumps further strengthen emergency preparedness.

Strengthening 3rd and 4th level of Defence-in-Depth

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Reactor Defence-in-Depth Protect Containment

Analyses and Reassessments

- Enhancement of Filtered Containment Venting System
- Severe Accident Management Guidelines (SAMGs)
- Instrumentation for SA conditions monitoring
- Control Facilities habitability during SA
- Development of site-wide Probabilistic SA

Design Improvements

- Installation / enhancement of Containment Venting
- Installation of Passive Autocatalytic Recombiners (PARs)

Strengthening 4th level of Defence-in-Depth

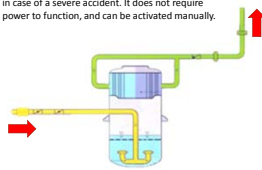
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Reactor Defence-in-Depth Protect Containment

Emergency Containment Filtered Ventilation

The system is designed to provide additional filtering in case of a severe accident. It does not require power to function, and can be activated manually.







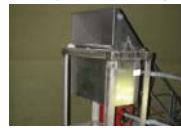
Hydrogen Control and Mitigation

Passive Autocatalytic Recombiners (PARs) are designed to remove hydrogen in non-flammable atmospheres. Self-starting. It does not require power to function.

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Reactor Defence-in-Depth Protect Containment

Point Lepreau Emergency filtered vent stack **Containment cooling enhancement to SAMG or through repowering Containment Air Coolers (plant specific approach based on design)** **Hydrogen Control and Mitigation with licensees have enhanced hydrogen control through installation of Passive Autocatalytic Recombiners.**

Strengthening 3rd and 4th level of Defence-in-Depth

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Reactor Defence-in-Depth Protect Spent Fuel Pools

Analyses and Reassessments

- Structural integrity check for temperatures above design values

Design Improvements

- Instrumentation to measure water level and temperature
- Piping and connections for external addition of water
- Operating Procedure for loss of cooling

Strengthening 4th level of Defence-in-Depth

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Reactor Defence-in-Depth
Protect Spent Fuel Pools
Licensee Met CNSC Requirements








Bruce Power CME Drills Point Lepreau, Crew Fuel Storage Tank Farm Drill Permanent piping to spent fuel pool


Strengthening 4th level of Defence-in-Depth

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Implemented Safety Enhancements
Enhancing Emergency Preparedness (Onsite)



Onsite emergency preparedness

- Incorporating Severe Accidents Management into Emergency Plans

Backup Power and Telecommunications


- Implementation of backup power to emergency facilities and telecommunications equipment
- Formalized *Mutual Aid Agreement* for external support


Station Boundary Monitoring and Dose Modelling

- Installation of automated real-time boundary radiation monitoring
- Development of source term estimation capability





Strengthening 4th and 5th level of Defence-in-Depth

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Implemented Safety Enhancements
Enhancing Emergency Preparedness (Onsite)








Bruce Power New emergency response command and control facilities was demonstrated during Huron Challenge emergency exercise in Oct. 2012 OPG Command centre McMaster (Research Reactor) Emergency Exercise

Strengthening 4th and 5th level of Defence-in-Depth

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Implemented Safety Enhancements
Enhancing Emergency Preparedness (Offsite)


Integration of Federal and Provincial Nuclear Emergency Plans

- Establishing formal, transparent, national-level oversight process for offsite nuclear emergency programs
- Reviewing planning basis of offsite arrangements
 - Developing capability for predicting offsite effects – needs for sheltering and evacuation
 - Simple instructions to public in case of nuclear emergency
- Monitor performance of full scale emergency drills involving multi-levels Federal/Provincial/Municipal
- Study of Consequences of a Hypothetical Severe Nuclear Accident

Strengthening 4th and 5th level of Defence-in-Depth

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Implemented Safety Enhancements
Enhancing Emergency Preparedness (Offsite)




Evacuation




Decontamination station





Potassium iodine (KI) Pills

Protecting the public through sheltering and evacuation

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Concluding Remarks
Safety Benefits


Enhanced accident prevention

- Accident risk reduced by a factor of 2 to 10, depending on accident scenarios


Improved mitigation of accident consequence

- Potential radiological consequences reduced to as low as reasonably practicable

Public protection

- Effective strategies for sheltering and evacuation
- Pre-distribution of potassium iodine (KI) pills to communities

Continuous safety improvements ... no complacency

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Annex 1 Safety Enhancements to Defence-in-Depth

Level /Description	Objectives	Design Upgrades	Guides/ Procedures	Safety Assessments
Level 1: Prevention of abnormal operation and failures	Prevent deviations from normal operation, and to prevent failures of systems, structures, and components (SSC)			
Level 2: Control of abnormal operation and detection of failures	Detect and intercept deviations from normal operation in order to prevent Anticipated Operational Occurrences (AOOs) from escalating to accident conditions, and to return the plant to a state of normal operation			Reassessment of AOOs to confirm adequacy of plant operational safety.
Level 3: Control of accidents within the design basis	Minimize the consequences of accidents by providing inherent safety features, fail-safe design, additional equipment, and mitigating procedures	Irradiated fuel bays (IFBs) make-up water capabilities and instrumentation		Reassessment of design-basis accidents to confirm adequacy of plant design safety.

Level /Description	Objectives	Design Upgrades	Guides/ Procedures	Safety Assessments
Level 4: Control of severe plant conditions, including prevention of accident progression and mitigation of consequences of severe accidents	Ensure that radioactive releases caused by severe accidents are kept as low as practicable	Emergency mitigating equipment (EME) and connections: <ul style="list-style-type: none"> o Provision of an alternate and independent supply of make-up water to Steam Generator/Primary Heat Transport/Calandria/moderator/ Shield Tank o Provision to open Main Steam Safety Valves after station blackout Installation/enhancement of Filtered Containment Venting Installation of Passive Hydrogen Recombiners Installation of Shield Tank (or Calandria vault) overpressure relief Upgrades of power systems to improve reliability, longevity of battery supply, improved backup for critical loads <ul style="list-style-type: none"> o Improved load shedding to extend battery availability o Battery charging capability and uninterruptible power supply (UPS) system backup o Upgrades to power supply for key instrumentation (e.g., Emergency Filtered Air Discharge System) Protection against flooding (barriers, water-tight doors) Instrumentation upgrades for severe accident conditions	Emergency mitigating equipment guidelines (EMEGs) Severe accident management guidelines (SAMGs)	External hazards assessment: re-evaluation of site-specific magnitudes of external events, including main-unit and B events for: <ul style="list-style-type: none"> o high winds, o seismic margin assessment / seismic probabilistic safety assessment, o tsunami, and flooding Demonstration of adequacy or provision of additional relief capacity to the reactor during severe accident Structural integrity assessment of IFBs for temperatures above design values Reassessment of Main Control Room & Secondary Control Room habitability Instrumentation qualification for severe accident conditions Assessment of airplane crash

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Annex 1 Safety Enhancements to Defence-in-Depth

Level /Description	Objectives	Design Upgrades	Guides/ Procedures	Safety Assessments
Level 5: Mitigation of radiological consequences of significant releases of radioactive materials	Mitigate the radiological consequences of potential releases of radioactive materials that may result from accident conditions.	Onsite and offsite emergency response centres Regional Emergency Response Support Centre (RESCC) available to all Canadian NPP operators Emergency Operations Centre	Integrated Emergency Plans Provincial Nuclear Emergency Response Plan Regional and Municipal Emergency Response Plans	Study of Consequences of a Hypothetical Severe Nuclear Accident Plume dispersion and dose modelling

Canadian NPPs are designed to shut down and remain in a safe state.

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