



# 3. ACR Fuel Qualification

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## Purpose

- **To confirm that all configurations permitted by design tolerances in fuel and reactor conditions will maintain fuel within specified acceptable design limits during normal operations (NOC) and anticipated operational occurrences (AOO).**

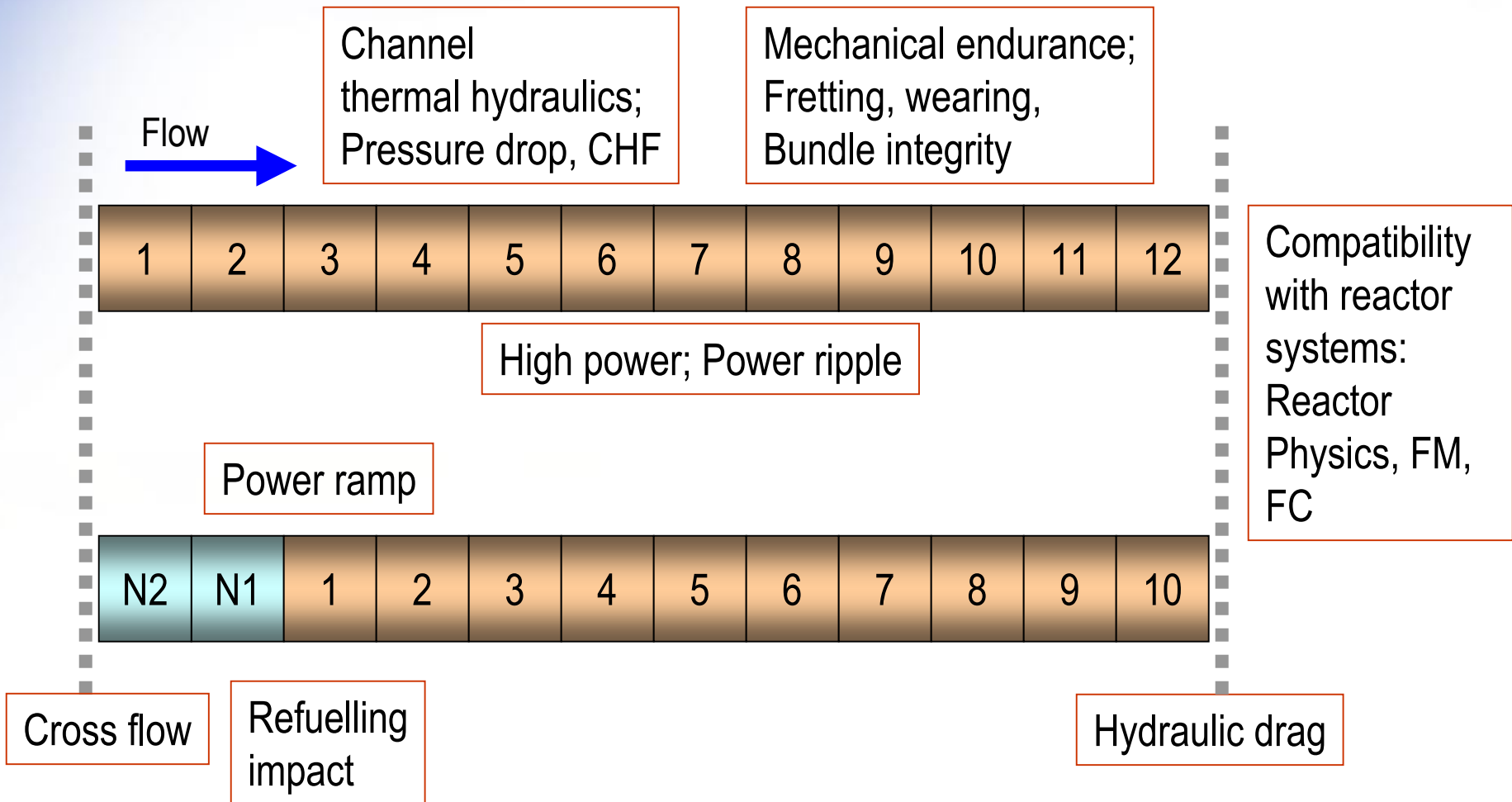


# Outline

- **To address expected verification methods for ACR**
- **Scope**
  - Design requirements
  - General considerations (grouping activities, verification methods, conservatism)
  - Thermal integrity
  - Structural integrity: element
  - Structural integrity: bundle
  - Compatibility with reactor systems
  - Expectation from US NRC
  - Conclusions



# Design Requirements





# General Considerations: Three Performance Aspects

- **Thermal integrity**
  - confirm that fuel clad and pellet will not overheat
- **Structural integrity**
  - confirm that critical components of the fuel bundle will not crack or break, nor will fuel bundle geometry lose geometric stability
- **Compatibility with reactor systems**
  - ensure that critical parts fit and that they have acceptable interactions with neighbours and other interfacing systems



# General Considerations: Verification Methods

- Overall features of ACR fuel design are supported by operating experience
  - proven design features (e.g., thin wall clad, small diametral gap)
    - cumulative element failure rate of about 0.001% since 1997
  - CANDU utilities have ongoing fuel surveillance program
  - experience to extended burnups
    - about 230 bundles in the Bruce A power reactor, exceeding 17 MWd/kgU (about 20 bundles were examined in hot cell)
    - about 870 fuel elements in NRU, exceeding 17 MWd/kgU
      - 15 irradiations with bundle avg burnups greater than 21 MWd/kg
- New design features are verified by
  - prototype testing; available data plus planned tests
  - analytical predictions or
  - combination of both



# Previous Irradiations for CANFLEX SEU and Dy-Doped Fuel

- Dimensionally acceptable for ACR fuel element verification
- Power
  - high powers for SEU; five CANFLEX SEU bundles had peak ratings above 60 kW/m
  - powers for Dy-doped fuel comparable to ACR conditions
- Burnup
  - two CANFLEX SEU test bundles (AJM, AJN) were irradiated to burnups exceeding 20 MWd/kgU
- Will be used in the qualification of ACR fuel design

# CANFLEX-SEU Fabrication Dimensions





# Dy-doped Fuel Fabrication Dimensions





# ACR Element High Powers, Compared to Irradiations in NRU



# Planned Irradiation Tests



# Planned Out-Reactor Tests

- CHF test
- Pressure drop test
- Mechanical fretting endurance test
- Cross flow test
- Refueling motion test
- Sliding wear test
- Bent tube gauge test
- Bundle strength test



# Planned Out-Reactor Tests

- **Spacer interlocking test**
- **Frequency sweep test and pressure pulsation test**
- **Fueling machine compatibility test**
- **Seismic testing**
- **Axial collapse test**
- **Longitudinal ridge test**



# General Considerations: Conservatism

- **Envelope operational and design configurations**
  - most representative elements/bundles
  - bounding power envelopes
  - appropriate thermal hydraulic conditions
  - appropriate consideration for design parameters and uncertainties



# Thermal Integrity



# Pellet Melting





# Clad Dryout



# Structural Integrity: Element



# Structural Integrity: Element



# Internal Gas Pressure



# Fission Gas Release



# Clad Collapse into Axial Gap



# Clad Strain at Circumferential Ridges



# Clad Collapse into Diametral Gap (Longitudinal Ridging)





# Power-Ramp Behaviour

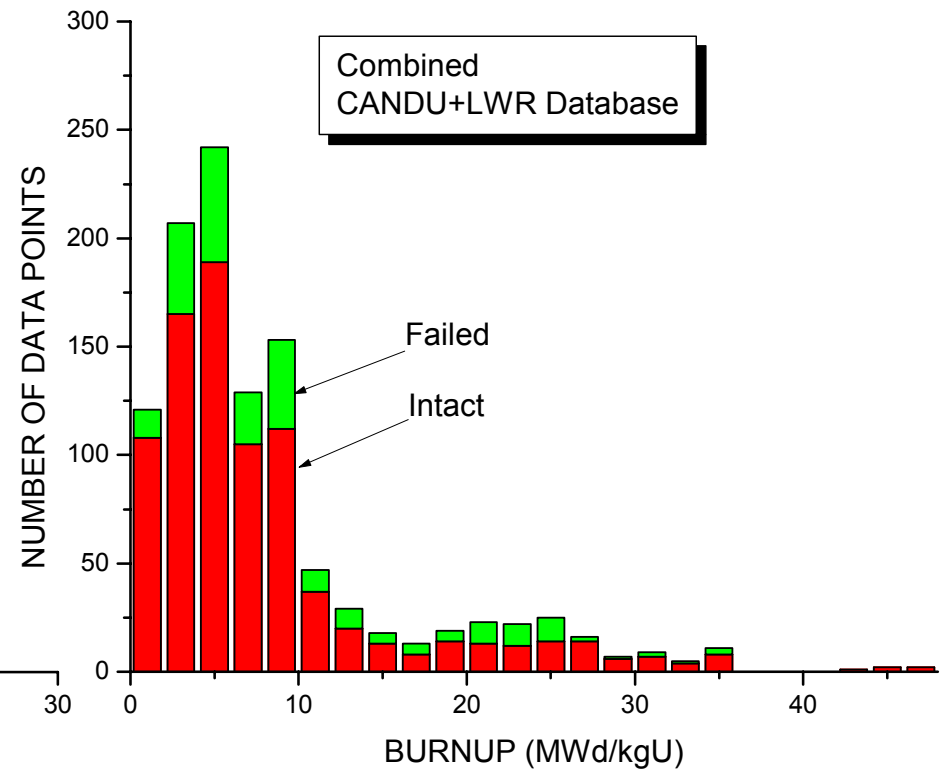
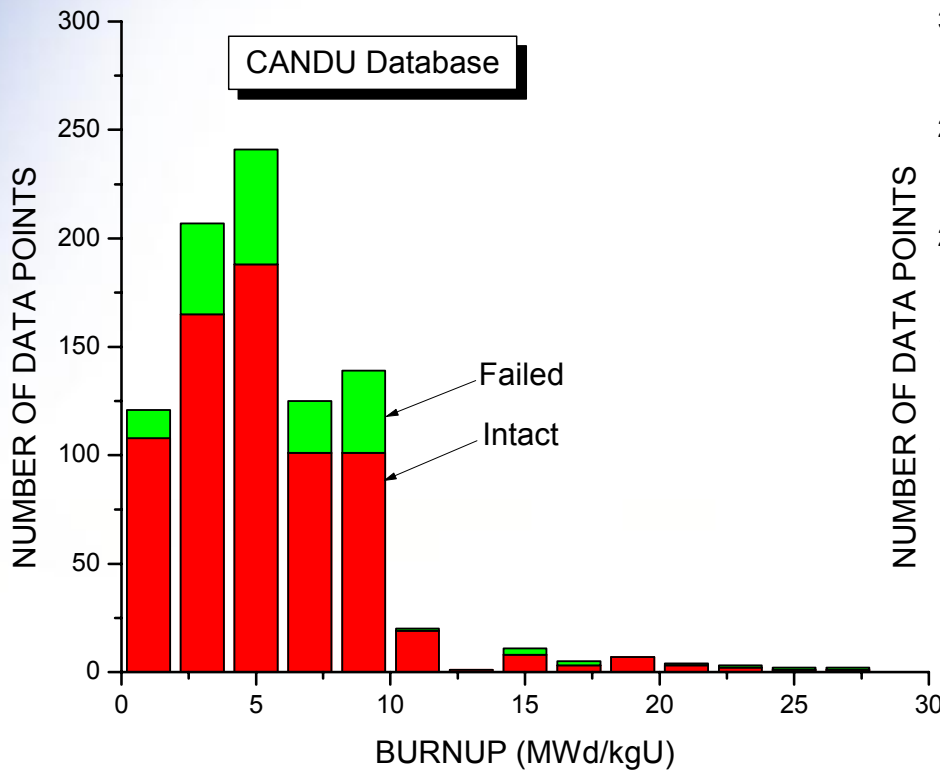


# Power-Ramp Database





# Distribution of Data





# Power-Ramp Failure Threshold



# Hydriding



# Clad Oxidation and Crud



# Structural Integrity: Bundle



# Structural Integrity: Bundle





# Static Refueling Loads



# Typical Side Stop Design



# Secondary Stresses/Strains in Endplate



# Buckling



# Typical Bundle Compression Test Result vs. Prediction



# Refueling Motion



# Typical Bundle Velocity vs. Distance (Cold, Flow Visualization Test)



# Fatigue Caused by Lateral Vibrations of Fuel Elements





# Fatigue Caused by Axial Vibrations



# Cross-Flow Endurance



# Compatibility with Reactor Systems



# Compatibility with Reactor Systems



# Length Changes



# Fretting



# Fretting vs. Time



# Sliding Wear





# Bowing, Sag and Droop



# Dimensional Compatibility with FC and FH Systems



# Conclusions

- **Fuel design criteria established consistent with SRP requirements**
- **Verification plan will show how criteria are met**
- **Verification plan consistent with previous qualification of CANDU fuel**
- **Extensive CANDU power reactor experience supports key ACR fuel design features**
- **Various incremental qualification activities for ACR fuel planned**
  - testing, analysis, and combination
  - takes advantage of available existing test results (e.g., CANFLEX qualification results)



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