5. ACR Fuel Qualification

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Outline

- Objective and approach
- In-reactor tests
- Out-reactor tests
- Analyses

Objective

- **To confirm that all configurations permitted by design tolerances in fuel and reactor will maintain fuel within specified acceptable design limits during normal operations and anticipated operational occurrences so that General Design Criterion 10 is met**

Approach

- Systematically evaluate impact of all significant operating and damage mechanisms, individually and in combination
- Confirm consequences are within acceptable limits via combination of
  - in-reactor tests,
  - out-reactor tests,
  - analyses, and
  - engineering judgment.
- Envelope all permitted operational and design configurations
- Ensure sufficient margins exist that account for burnup, peak element rating, coolant temperature and flow rate

Four Groups of Assessments

- **Thermal integrity**
  - confirm temperatures in critical parts remain within design allowances
  - CHF, end temperature peaking, etc.
- **Structural integrity of fuel element**
  - confirm all parts of fuel element retain structural integrity with sufficient margins
  - stress corrosion cracking, internal gas pressure, longitudinal ridging, etc.
- **Structural integrity of fuel bundle**
  - confirm that all parts of the fuel bundle operate with sufficient margins against cracking or breakage
  - endplate during refueling loads, fatigue, etc.

Four Groups of Assessments

- Dimensional compatibility
  - confirm that all parts of the fuel bundle stay within available clearances and do not damage each other or interfacing systems
  - dimensional compatibility with fuel channel and fuel handling systems
    - bowing, droop, etc.

Fuel Design Criteria

- Establish fuel design criteria to cover ACR conditions
  - e.g. maximum internal gas pressure < coolant pressure
  - limits on clad strain, clad oxidation, etc.
- Confirm that limiting operating values are within criteria
  - e.g. for gas pressure confirm by ELESTRES analysis
    - calculate gas pressure during irradiation
    - calibrate ELESTRES code against all available pertinent data for fission gas release and internal pressure
    - ensure coverage for ACR conditions (power, burnup, etc)
    - simulate all permitted combinations of power histories, fuel design tolerances, coolant temperature, etc.
  - likewise, combinations of tests and analyses as appropriate for all credible damage mechanisms

In-Reactor Tests

- Objective: to confirm satisfactory irradiation performance of fuel
- Integral and separate-effects tests
- Already have many irradiations in the range of interest
  - previous presentation
- Additional qualification tests planned in NRU reactor for ACR-specific detailed internal design

In-Reactor Tests

- High power envelope
  - overall "health" during irradiation, including Dy-doped fuel
  - envelope operating power in ACR
  - also measure important data for calibrating computer codes such as ELESTRES and BOW
    - fission gas release, cladding ridge strain, fuel element bowing, UO_2 grain growth, etc.
- Power-ramp test
  - confirm tolerance to ACR power ramps
- Separate-effects tests
  - Dy-doped fuel

Out-Reactor Tests

- Direct qualification, plus data for scaling to in-reactor conditions via follow-up analyses
- Thermal performance
  - CHF, pressure drop, post-dryout temperatures
- Strength
  - bundle strength, refueling impact, endurance, cross-flow, longitudinal ridging, clad corrosion, stress-corrosion cracking
- Dimensional compatibility
  - fuel handling compatibility, spacer interlocking, bent tube gauge (confirm passage through sagged channel), sliding wear

CHF Tests

- **Objectives**
  - produce CHF data for incorporation into ASSERT, NUCIRC and CATHENA computer codes to calculate critical channel power
- **Conditions**
  - axial and radial flux distributions typical of ACR
  - flow conditions typical of ACR
  - variety of pressure tube creep
  - accident conditions
    - flow oscillations (loss of power to class IV bus)
    - power increases (loss of reactivity control)
  - both water and freon tests

Pressure-Drop Tests

- Objective
  - measure pressure drop across ACR fuel string for use in ASSERT, NUCIRC and CATHENA computer codes to calculate coolant flow
- Conditions
  - testing in full-scale channel
  - temperature, pressure, and flow to represent highest rated channel

Post-Dryout Temperatures

- **Objectives**
  - determine clad temperatures in dry-patches following dryout
  - determine heat-transfer coefficients in dry-patches
  - these will be used in thermal hydraulic codes to calculate clad temperatures in appropriate accident scenarios
- **Conditions**
  - typical of those expected in ACR

Bundle Strength

- **Objective**
  - confirm ACR fuel bundle has adequate strength under axial static loads for normal and abnormal conditions of support
- **Conditions**
  - 12-bundle fuel string
  - typical supports from side-stops (single and double)
  - applied loads will reflect expected hydraulic drag and sliding friction forces
  - operating temperature and pressure of the coolant

Refueling Impact

- **Objective**
  - confirm ability of ACR fuel to withstand expected impact loads during refueling
- **Conditions**
  - acceleration distance representative of ACR conditions
  - acceleration velocity representative of flow

Endurance and Fretting in Axial Flow

- **Objectives**
  - confirm that fretting in fuel bundle and in pressure tube will be within design allowances
  - confirm integrity of fuel bundle weld and of endplate due to fatigue
- **Conditions**
  - 12-bundle fuel string in a full-scale ACR fuel channel
  - support from shield plug representative of ACR
  - flow conditions typical of ACR for coolant temperature, pressure and mass flow rate

Endurance in Cross-Flow

- **Objectives**
  - confirm structural integrity of fuel bundle during passage through cross-flow region
  - develop guidelines for maximum permissible residence period in cross-flow region under unusual circumstances
- **Conditions**
  - tested in a full-scale channel
  - flow conditions typical of ACR for coolant temperature, pressure and mass flow rate
  - typical duration of cross-flow in reactor is a few minutes, but longer tests are planned to help determine fuel integrity limits

Longitudinal Ridging

- **Objective**
  - confirm extrapolation of existing correlation for longitudinal ridging to ACR conditions of temperature and pressure
- **Conditions**
  - autoclave tests
  - test conditions will reflect normal operating conditions and hydrostatic tests, and go beyond them to establish critical collapse pressures

Clad Corrosion

- **Objective**
  - determine oxidation rate and hydriding under ACR conditions
- **Conditions**
  - autoclave tests
  - temperature ranges to exceed temperatures expected in ACR at metal/oxide interface
  - coolant chemistry to be maintained per ACR conditions (e.g. for pH and LiOH concentration)
  - possible in-reactor tests

Stress Corrosion Cracking

- **Objective**
  - obtain data on transient stress corrosion cracking to fully cover ACR conditions, including transient power-ramps during refueling
- **Conditions**
  - ACR conditions of dwell time, stress, CANLUB, radiation effects

Fueling Machine Compatibility

- **Objective**
  - confirm that ACR bundle's dimensions are compatible with fueling machine, cavities and end fitting
- **Conditions**
  - test in a prototype fueling machine
  - test conditions representative of typical reactor conditions of pressure, temperature and flow

Spacer Interlocking

- **Objective**
  - confirm absence of spacer interlocking when the fuel bundle passes through the reactor
- **Conditions**
  - this test is very similar to previous test on fueling machine compatibility, except that this also covers the magazine of the fueling machine

Bent Tube Gauge

- **Objectives**
  - confirm ability of the fuel bundle to traverse the rolled-joint region of the end fitting
  - develop an ACR bent tube gauge for GO-NO GO inspection of fuel bundles during large-volume fabrication (similar to current CANDU practice)
- **Conditions**
  - bent tube gauge will be designed to reflect dimensions of
    - rolled joint upset region of the end fitting
    - aged fuel channel: pressure tube sag and diametral creep
    - irradiated bundle diameter

Sliding Wear

- **Objective**
  - determine wear rate of pressure tube and bearing pads due to periodic sliding of the fuel bundle during fueling operations
  - confirm that wear of pressure tubes is within allowance
- **Conditions**
  - setup will reflect end of the fuel channel, where highest wear is expected
  - test conditions will reflect conservative representations of refueling scheme (e.g. in number of passes of fuel bundle) and bundle orientation

Analyses

- **To systematically confirm that ACR fuel meets all design criteria for all damage scenarios**
- **In some cases, measurements from preceding tests will be used as inputs, and scaled from test conditions to in-reactor on-power conditions**
  - out-reactor tests need scaling for effects such as dimensional changes in fuel due to in-reactor creep
  - in-reactor measurements require scaling to convert post-irradiation measurements (off-power) to on-power operating values
- **Test conditions necessarily cover limited combinations, analyses extend to full range of specs**

Examples of Planned Analyses

- Thermal performance
  - peak pellet temperature (including end temperature peaking), clad temperature (including oxidation, crud, braze voids)
- Structural integrity of fuel elements
  - internal gas pressure, stress-corrosion cracking from multiple power ramps
- Structural integrity of fuel bundle
  - bundle fatigue for full residence period
- Dimensional compatibility
  - on-power bowing, sag, and droop including creep, axial expansion of fuel bundle string

Tools

- Qualified computer codes, e.g.
  - ELESTRES, BOW, FEAT, FEAST, INTEGRITY, BEAM, etc.
- Qualified facilities
- Qualified staff
- Full qualification to ISO 9001-2000 and CSA 286.7

Summary: Fuel Qualification

- Ensure ACR has full thermal integrity, structural integrity, and compatibility with interfacing systems by checking that all parts of ACR fuel will meet pre-defined design criteria in above areas
- Comprehensive, integrated set of in-reactor tests, out-reactor tests, and analyses
- Qualified computer facilities, codes, and staff
- Will confirm that fuel performance will continue to be excellent in ACR for all configurations permitted by design and operational tolerances

Overall Summary

- ACR fuel design follows >50 years of CANDU fuel design and operating performance experience
- CANFLEX and Bruce Low Void Reactivity Fuel provide recent experience for qualifying a new fuel design
- ACR fuel is based on 3 underlying, well established fuel technologies
  - CANFLEX, enriched uranium with extended burnup, and Low Void Reactivity Fuel
- The qualification plan being developed for ACR fuel will confirm that all configurations permitted by design tolerances in fuel and reactor will keep fuel within design allowances

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