ACR TECHNOLOGY BASE:
FUEL CHANNEL THERMALHYDRAULICS

By Peter G. Boczar, Director

Reactor Core Technology Division

Presented to US Nuclear Regulatory Commission

Office of Nuclear Reactor Regulation

September 26, 2002

AECL

TECHNOLOGIES INC.

Outline

- **Thermalhydraulic parameters**
- **Analytical approaches**
- **Experimental support**
- **ACR qualification**

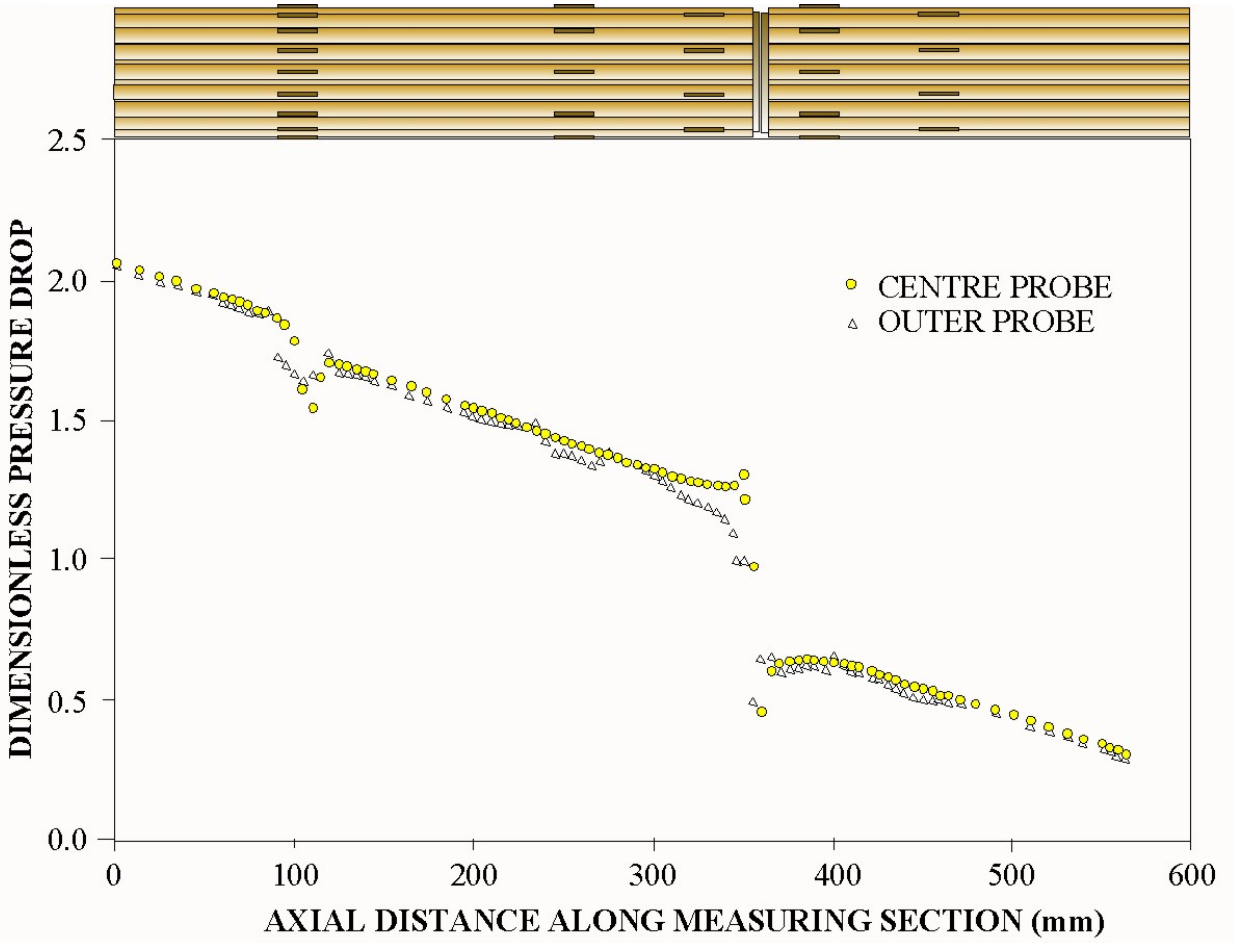
Thermalhydraulic Parameters

- Fuel string pressure drop
  - establishes channel flow based on pump characteristics
- Critical heat flux (CHF)
  - determines trip set-points for
    - Neutron Overpower Protection (NOP) system (loss-of-regulation accident)
    - process trip parameters for other accidents (such as loss-of-flow)
  - a determinant in setting reactor power, operating margins
- Post-dryout (PDO) behavior
  - establishes behavior in operation beyond dryout
    - heat transfer, and drypatch stability and spreading

Fuel String Pressure Drop

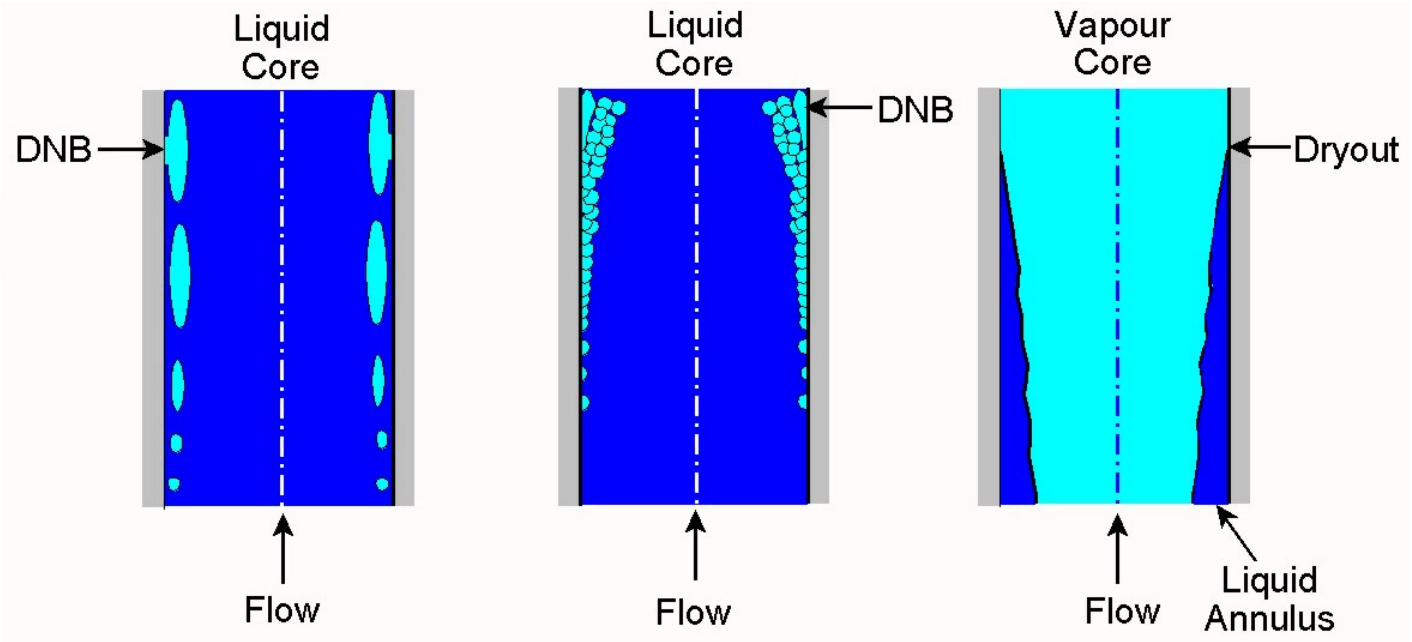
- Part of the overall pressure drop between headers
- Separated into single-phase and two-phase regions
- Pressure-drop components
  - friction
  - bundle junction, spacer & bearing pad planes
  - acceleration
- Sliding probes for pressure drop measurements
  - detailed hydraulic characterization

Axial Pressure Profiles Along 37-Element Bundles



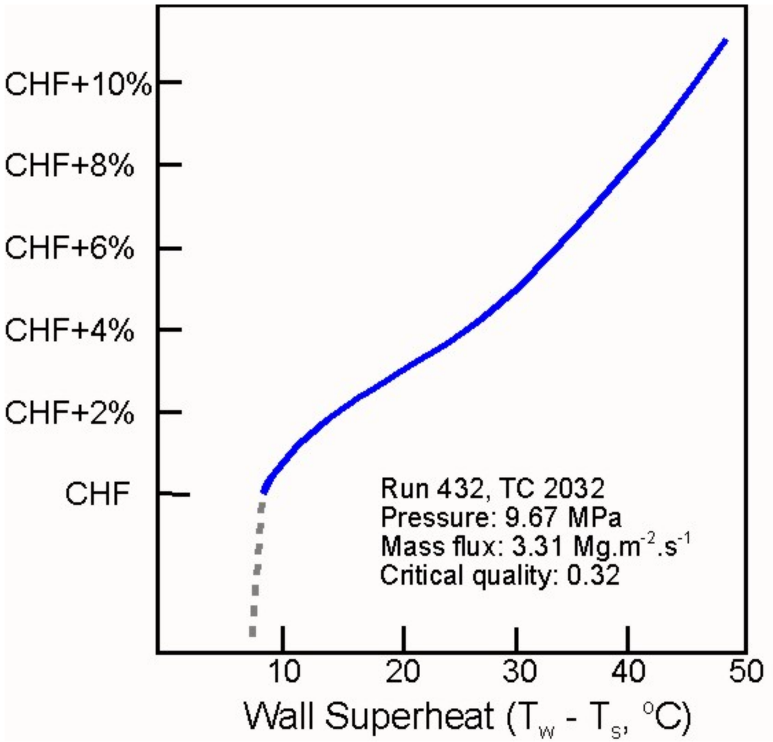
Critical Heat Flux

- **Phenomenon corresponding to point where continuous liquid contact cannot be maintained at the heated surface**
- **CHF mechanism corresponds to dryout at CANDU (& ACR) conditions of interest (high flows and high qualities)**



Dryout Characteristics

- Onset of intermittent dryout criteria is used
  - only a single point of the fuel clad may encounter dryout while the remainder of the bundle remains wet



- Clad temperature increases only slightly beyond dryout

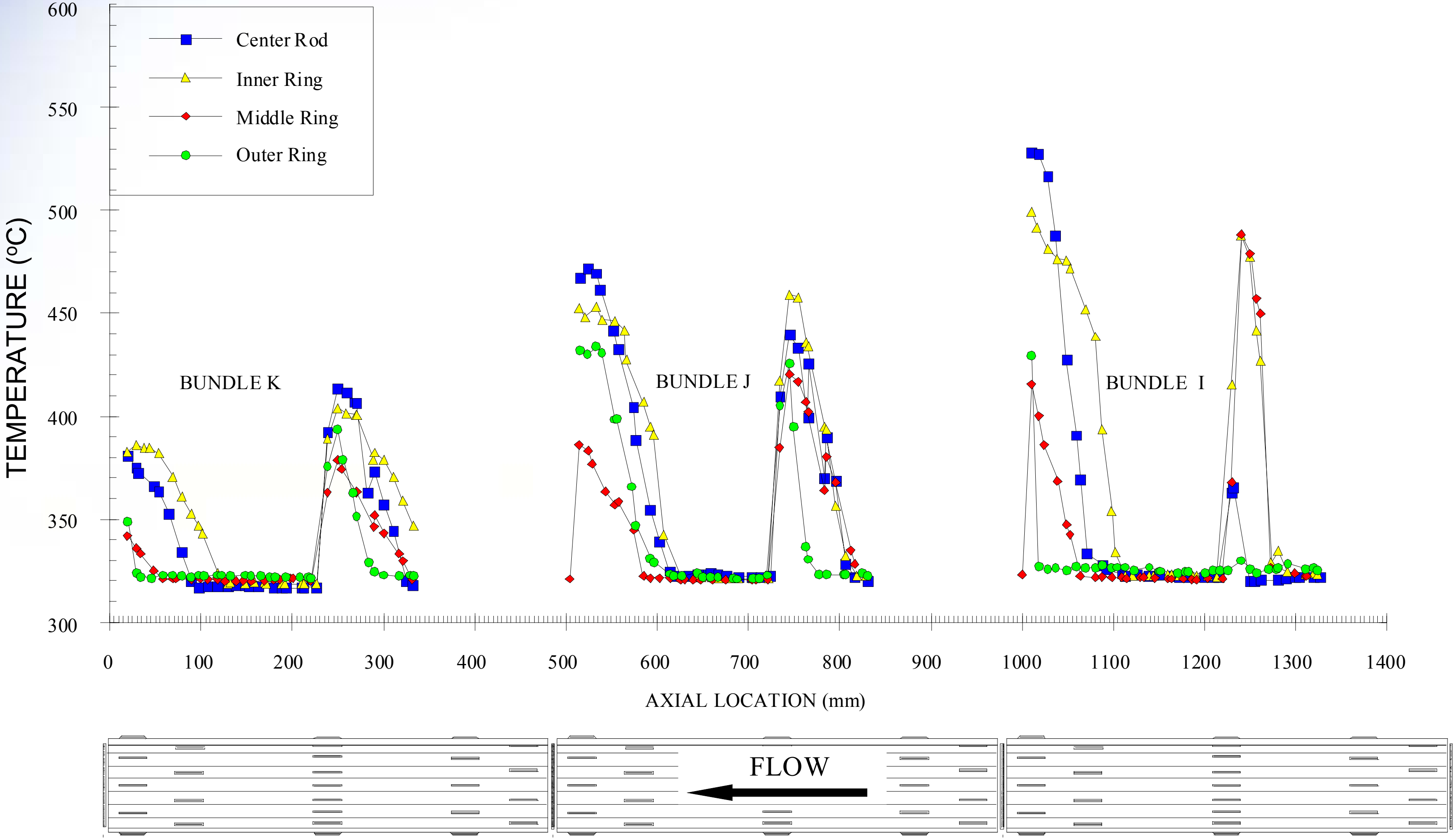
- No severe consequence to fuel or clad integrity

Post Dryout (PDO)

- Heat-transfer regime where the heated surface is cooled by the vapor flow

- At PDO conditions
  - fuel clad temperature rise is gradual and controllable
  - maximum clad temperature is predictable
  - drypatches are stable and propagate gradually with change in flow conditions

PDO Temperature Distribution in 37-element Bundles



Prediction Methods

- Pressure drop
  - friction factor, appendage & bundle junction loss coefficients
  - onset of significant void
  - two-phase multiplier

- CHF
  - bundle CHF look-up table

- PDO
  - tube-based PDO look-up table
    - modification factor to account for effects of bundle & developing flow

Thermalhydraulics Computer Codes

- **NUCIRC**
  - 1-D flow for steady-state applications
  - evaluates critical channel powers (CCPs) for all channels
  - based on reference flow conditions with CHF and pressure drop correlations

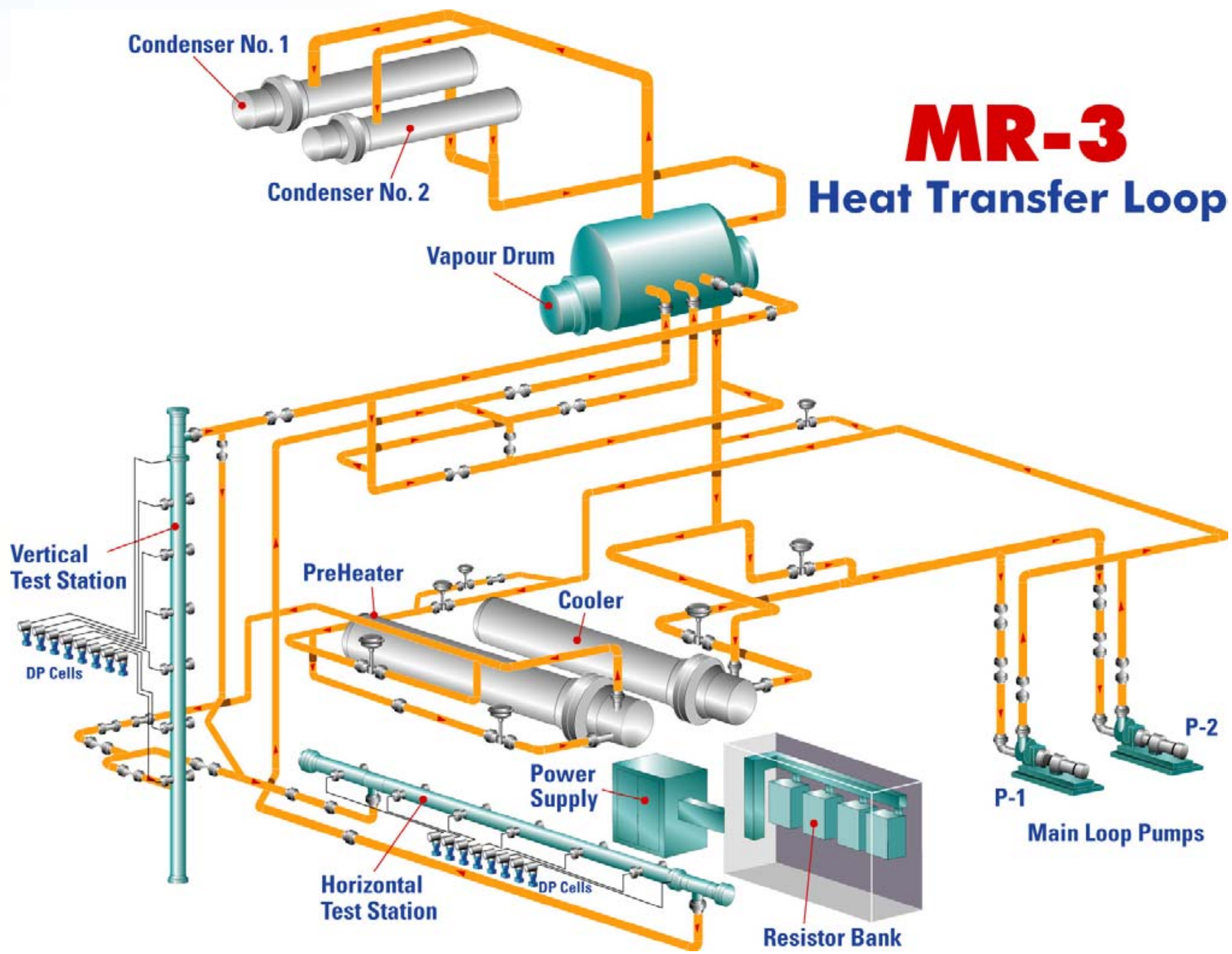
- **CATHENA**
  - 1-D, 2-fluid flow for transient applications
  - safety analyses based on system-flow conditions with correlations for CHF, pressure drop, & PDO heat transfer
  - applicable for all postulated accident scenarios

Experimental Facilities

- **Full-scale high pressure steam-water loop**
  - models CANDU conditions of pressure & temperature
- **Full-scale low pressure Freon-134 loop**
  - simulates high pressure steam-water conditions
  - fluid-to-fluid modeling well established for converting to water-equivalent conditions
- **Small-scale steam-water and Freon-134 loops**
  - simple test sections or bundle sub-assemblies
  - fundamental and separate-effect studies

Water Test Facility

Freon Test Facility



Freon Loop Fuel Bundle Simulator

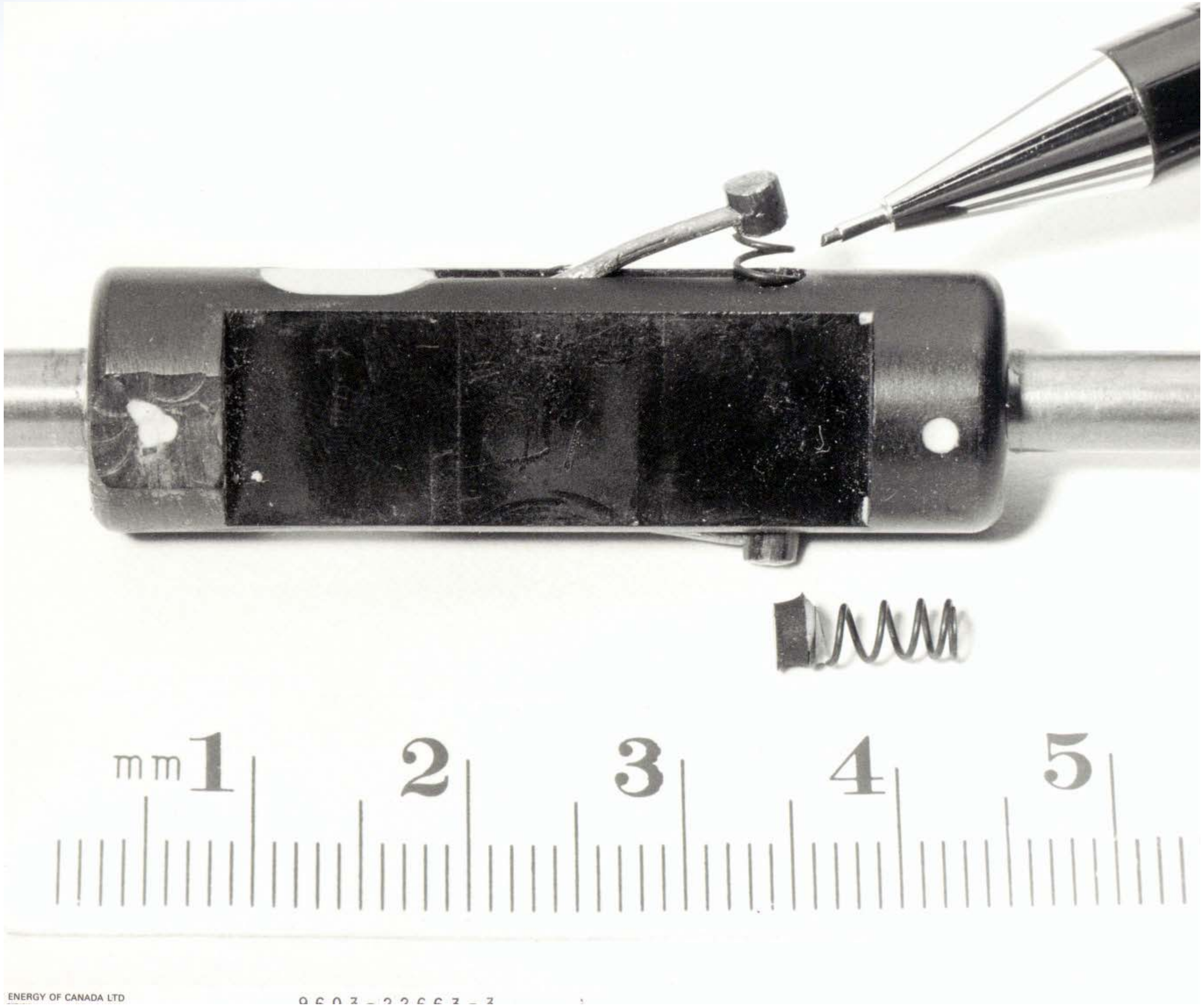
- A 6-m (20 ft) long full-scale bundle string with junction and appendages simulated
- Non-uniform axial and radial power distributions

Advanced Instrumentation

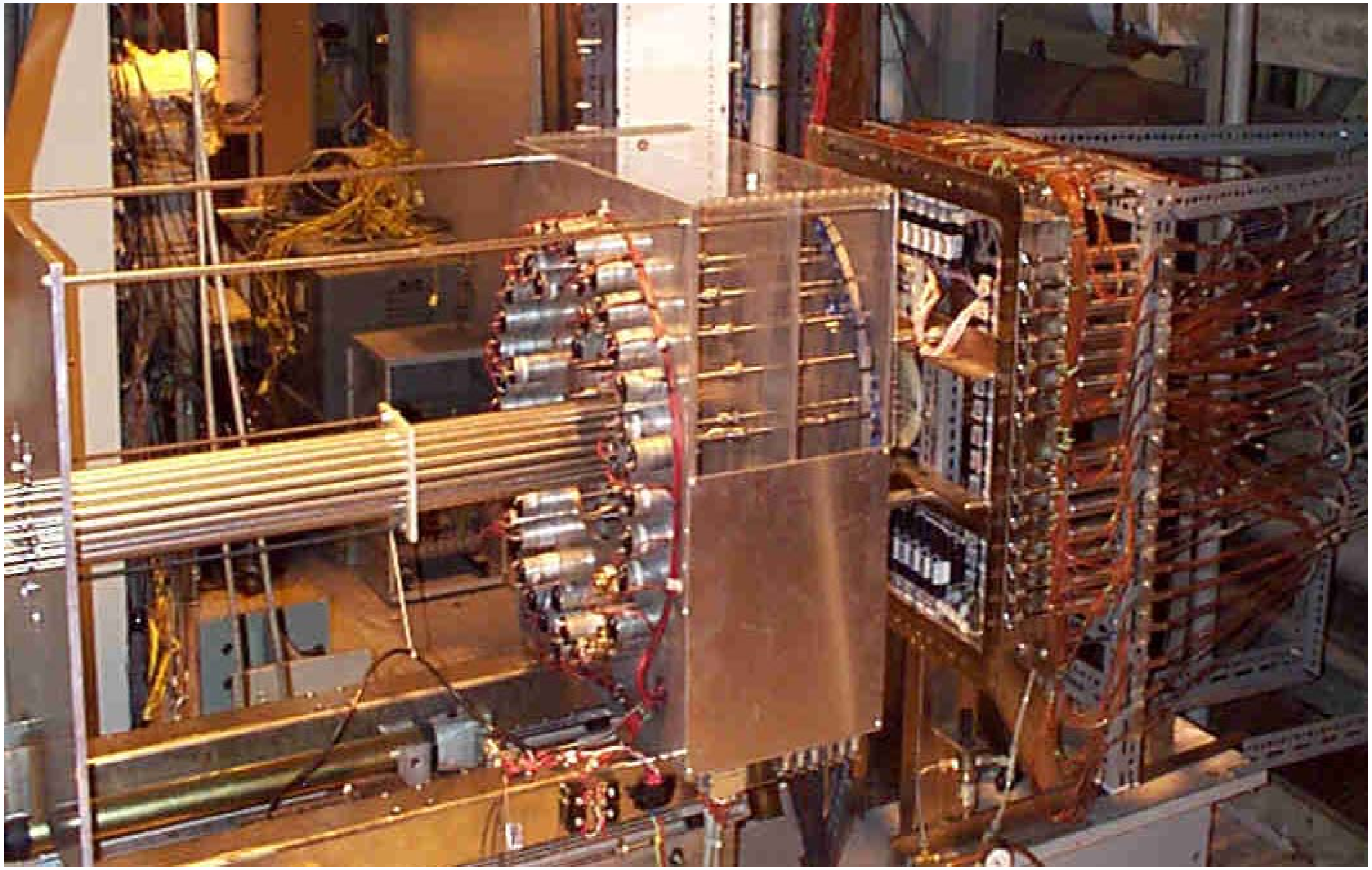
- Sliding probes for pressure drop measurements
  - detailed hydraulic characterization

- Sliding thermocouple assemblies for dryout detection and fuel clad temperature measurements
  - cover almost the entire fuel clad area
  - detects initial & subsequent dryout locations
  - allows 3-D representation of clad temperature

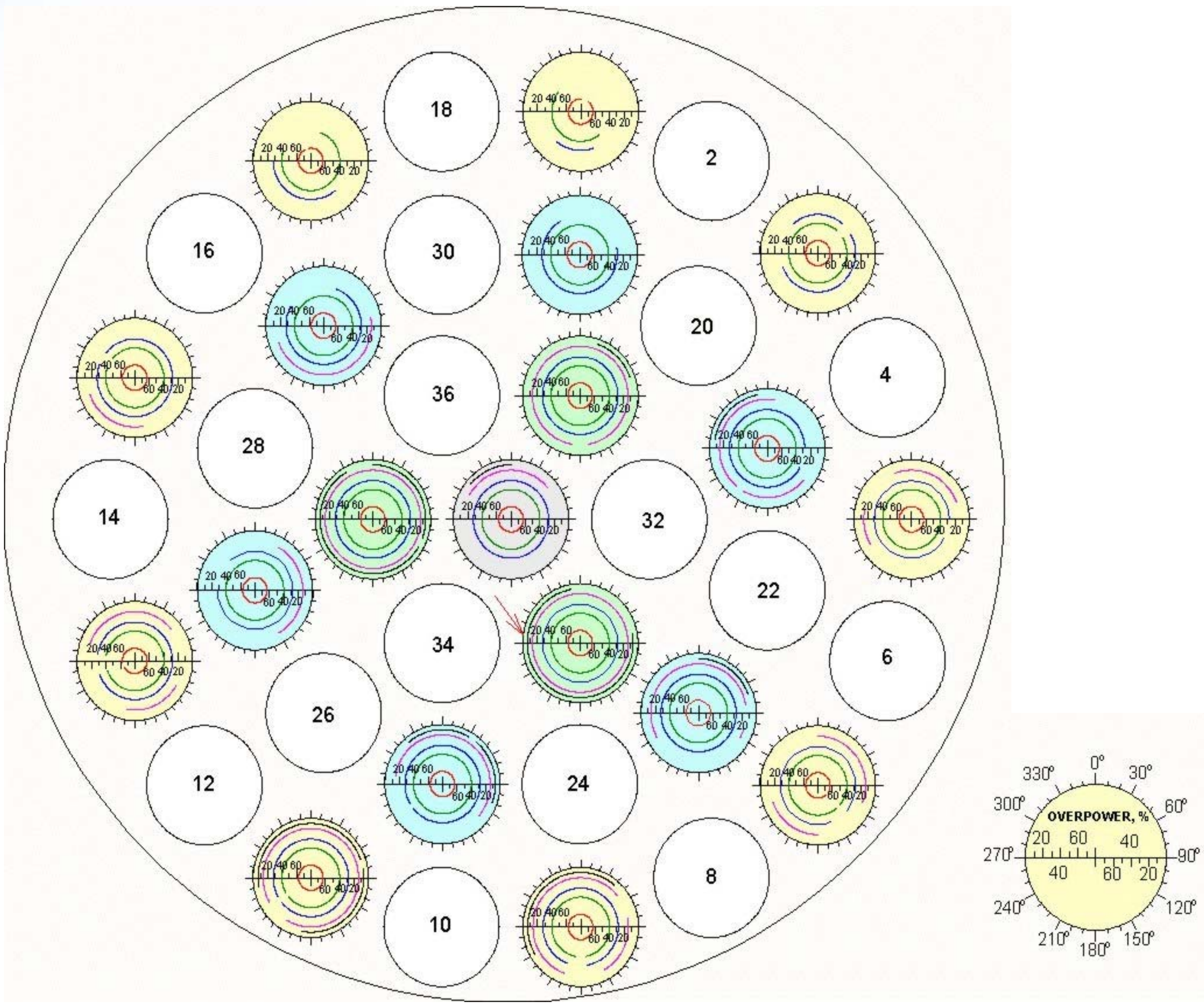
Sliding Thermocouple Assembly



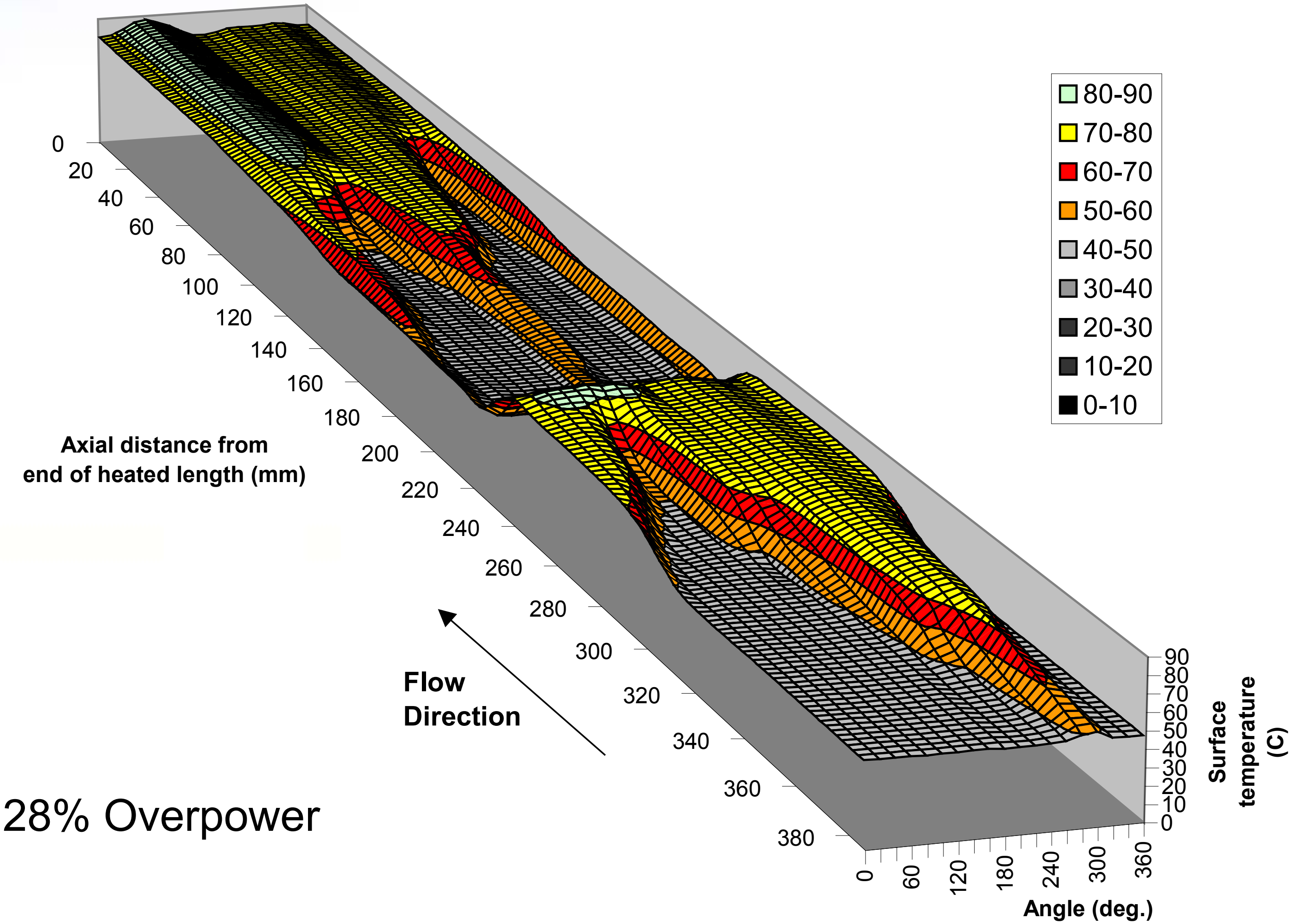
Sliding Thermocouple Drive Unit



Circumferential Drypatch Map



PDO Clad Temperature Profile



Element 35, 28% Overpower

ACR Thermalhydraulic Qualification

- ACR qualification will include CHF, pressure drop, post-dryout measurements in water and freon
  - correlations and models will be tuned to reflect ACR results
- ACR conditions slightly beyond existing database

	Existing database	ACR conditions
Channel outlet pressure	6 to 11 MPa (870 to 1600 psi)	12.5 MPa (1800 psi)
Mass flow rate	7 to 23 $kg.s^{-1}$ (15 to 51 $lb.s^{-1}$)	26 $kg.s^{-1}$ (57 $lb.s^{-1}$)
Inlet subcooling	10 to 75 ^{o}C (18 to 135 ^{o}F)	49 ^{o}C (88 ^{o}F)

Summary

- In-depth understanding of CANDU fuel thermalhydraulic behavior based on extensive experimental data and analytical information directly supports the ACR
- ACR qualification will include measurements in freon and water
- Minor extensions of existing CHF, pressure drop and PDO heat transfer models & correlations will cover ACR

AECL

TECHNOLOGIES INC.