CANDU Safety #18: Safety Research and Development Programs

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Overview

- Large-scale multi-channel burst tests
- Small-scale burst tests
- Loss-of-coolant accident in the Blowdown Test Facility
- In-cell fission-product release tests
- Contact boiling tests and molten material-pressure tube tests

Large Scale Multi-Channel Burst Tests (MCBT)

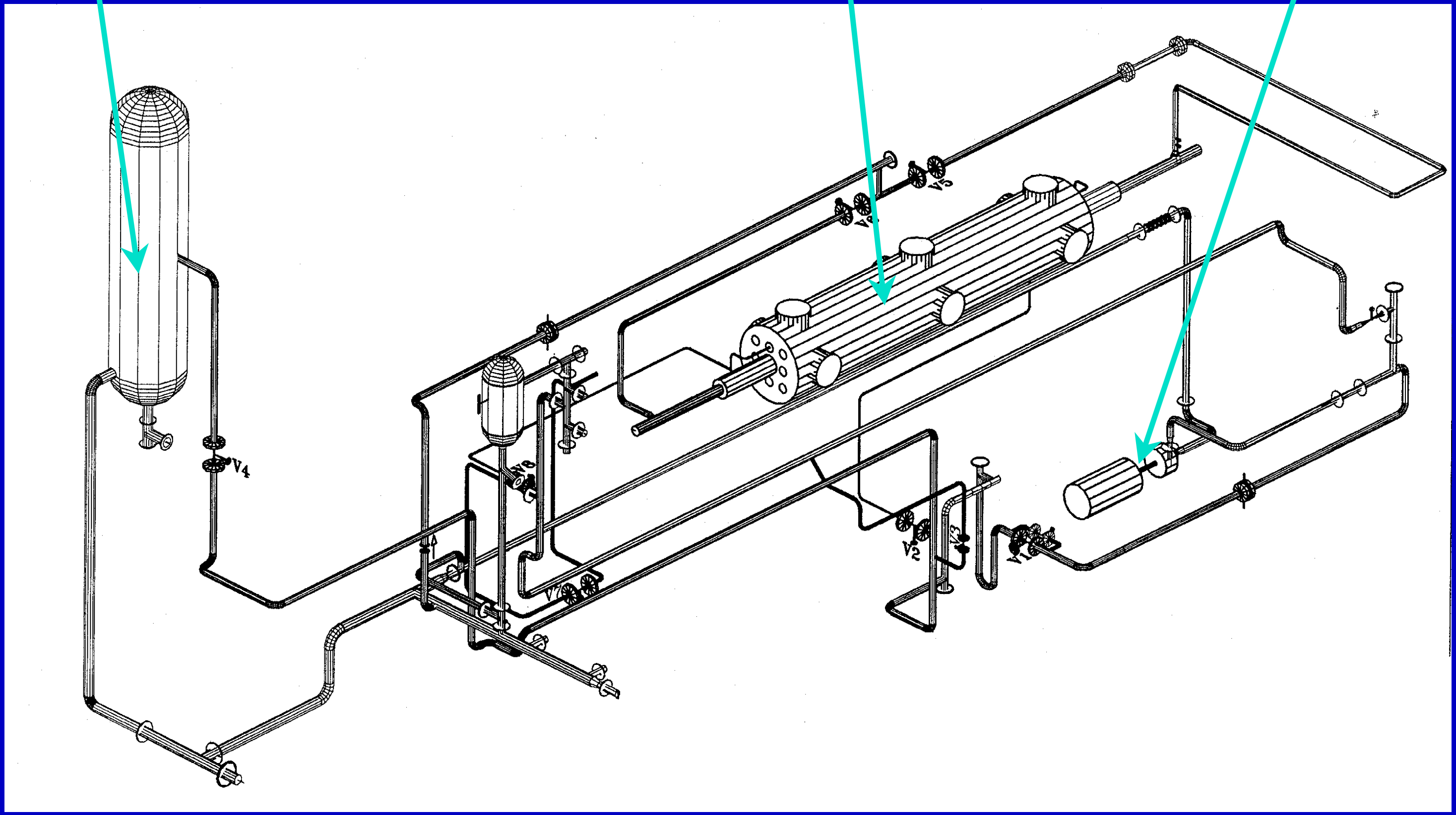
- **Test Objective: To study the effect of fuel-channel burst on in-core structures such as adjacent channels and shut-off rod guide tubes**
- **Test Facility consists of:**
  - **a full scale 9-channel array (3 x 3 matrix) mounted inside of a steel containment vessel**
  - **the burst channel contained 37-element simulated fuel bundles (actual fuel sheaths with copper pellets)**
  - **end-fittings and feeders mounted on the burst channel**
  - **target channels consisted of full-length pressure tubes and calandria tubes, garter springs, simulated fuel bundles,**
  - **remaining channels consisted of full-length steel tubes (to simulate pressure tube and calandria tube); simulated bundles**
  - **test loop consisting of a pump, water supply vessel, piping**

MCBT Facility

Water in Supply Vessel;
Hot Water at 259ºC to 305ºC;
Pressurized to approx. 11 MPa

Containment Vessel;
holds the 3 x 3 channel array;
typically central channel is ruptured

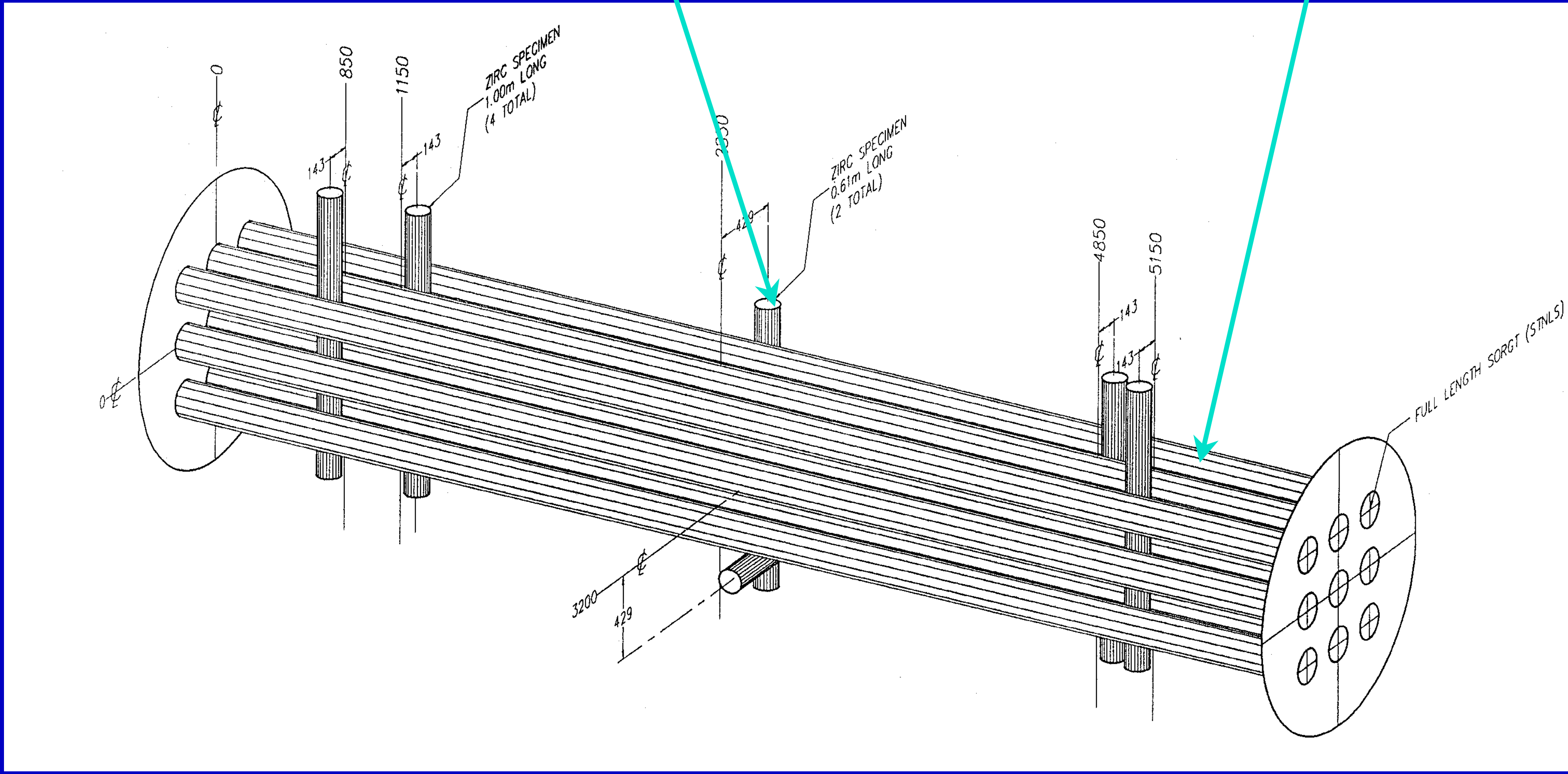
Pump



MCBT 3 x 3 Channel Matrix

Shut off rod guide tubes

9 Full-length channels in a 3 x 3 matrix configuration



MCBT Defect, Procedure, Instrumentation

- Defect
  - A defect in the pressure tube and calandria tube is manufactured so that it will rupture under coolant pressure
- Test Procedure
  - Heat the loop to the desired temperature, ranging from 259 to 296°C, and pressure 10 MPa
  - Vent the pressurized annulus gas to initiate the rupture of the pressure tube
- Instrumentation
  - pressure in containment vessel water
  - strain gauges on the containment vessel
  - crack-propagation gauges
  - system pressures and temperatures; various other instruments

Application of MCBT Results

- Code validation: prediction of the hydrodynamic pressure in the containment vessel
- Address licensing safety issues (i.e., integrity of adjacent channels etc)
- Understanding: experiments provide insight into in-core rupture phenomena

AECL Whiteshell Small-Scale Burst Tests

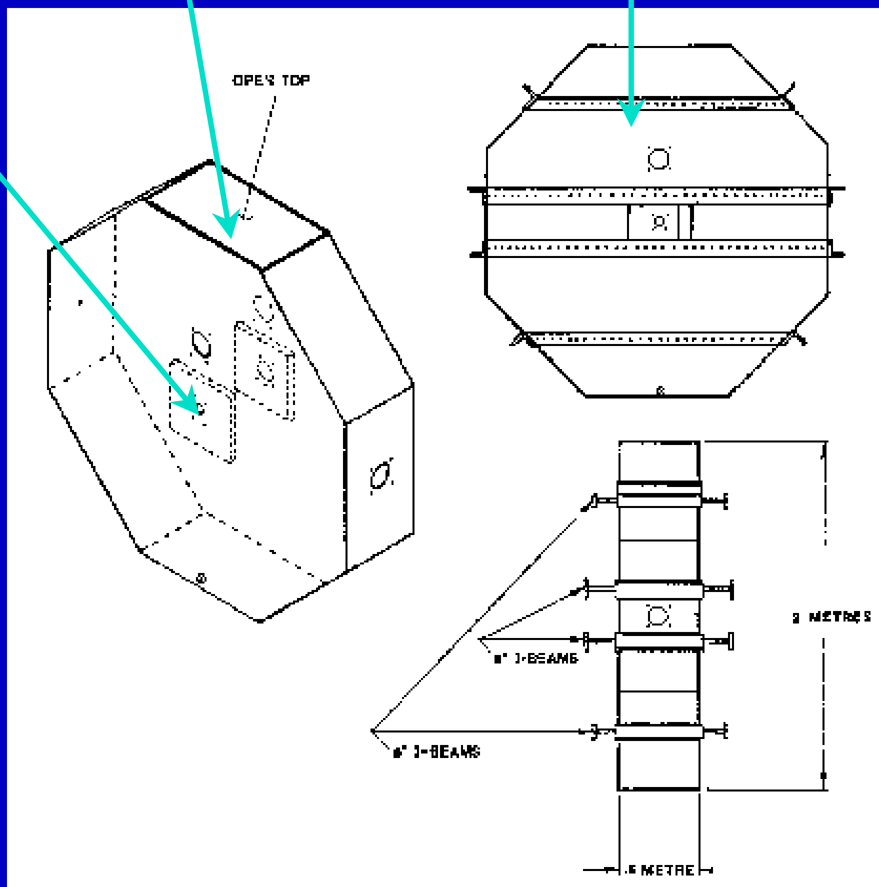
- Objective:
  - to investigate the parameters affecting guillotine-failure of the pressure tube
  - Concern: pressure tube guillotine failure may result in end-fitting ejection and subsequent loss of moderator water
- Facility
  - Steel containment vessel filled with water
  - A fuel sheath, mounted in the centre of the vessel, with a manufactured defect
  - Hot-water reservoirs to supply water to the ruptured sheath

Whiteshell Burst Test Facility

Relief opening at top

Stainless-steel vessel

Location of Ruptured tube



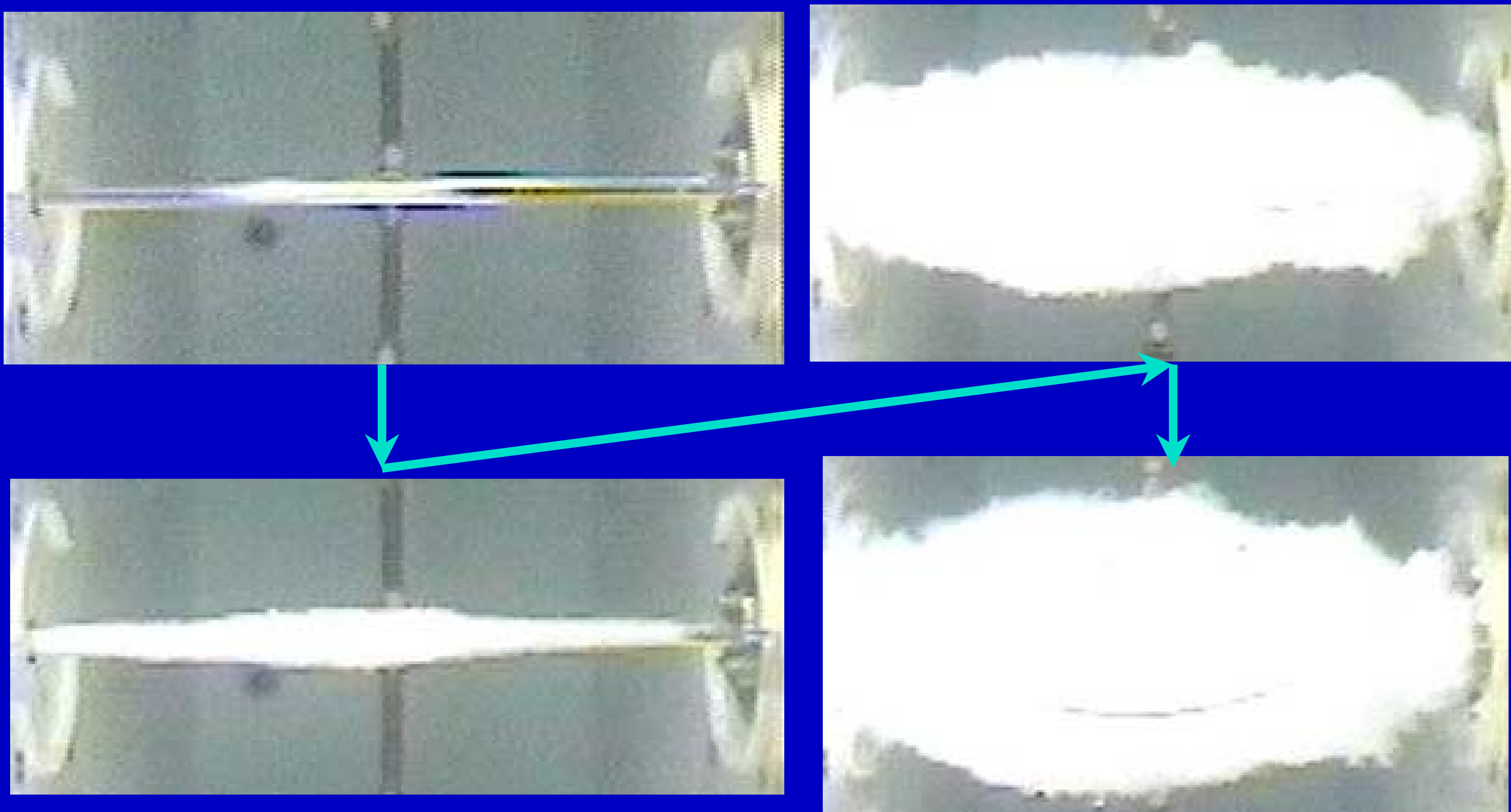
Variation of Several Parameters in WL Tests

- Coolant burst temperature (up to approximately 300^{o}C),
- Coolant burst pressure,
- Defect length,
- Surrounding water temperature,
- Collapsible volumes (i.e., various matrix sizes, 3x3, 5x5, 11x11 etc.),
- Small and large water reservoirs.

Various Instrumentation in WL

- Measure
  - Element coolant pressure,
  - Element coolant temperature,
  - Water pressure in containment vessel at various locations,
  - Crack extension speed,
  - Bubble growth through high-speed video, and
  - Vessel wall strain

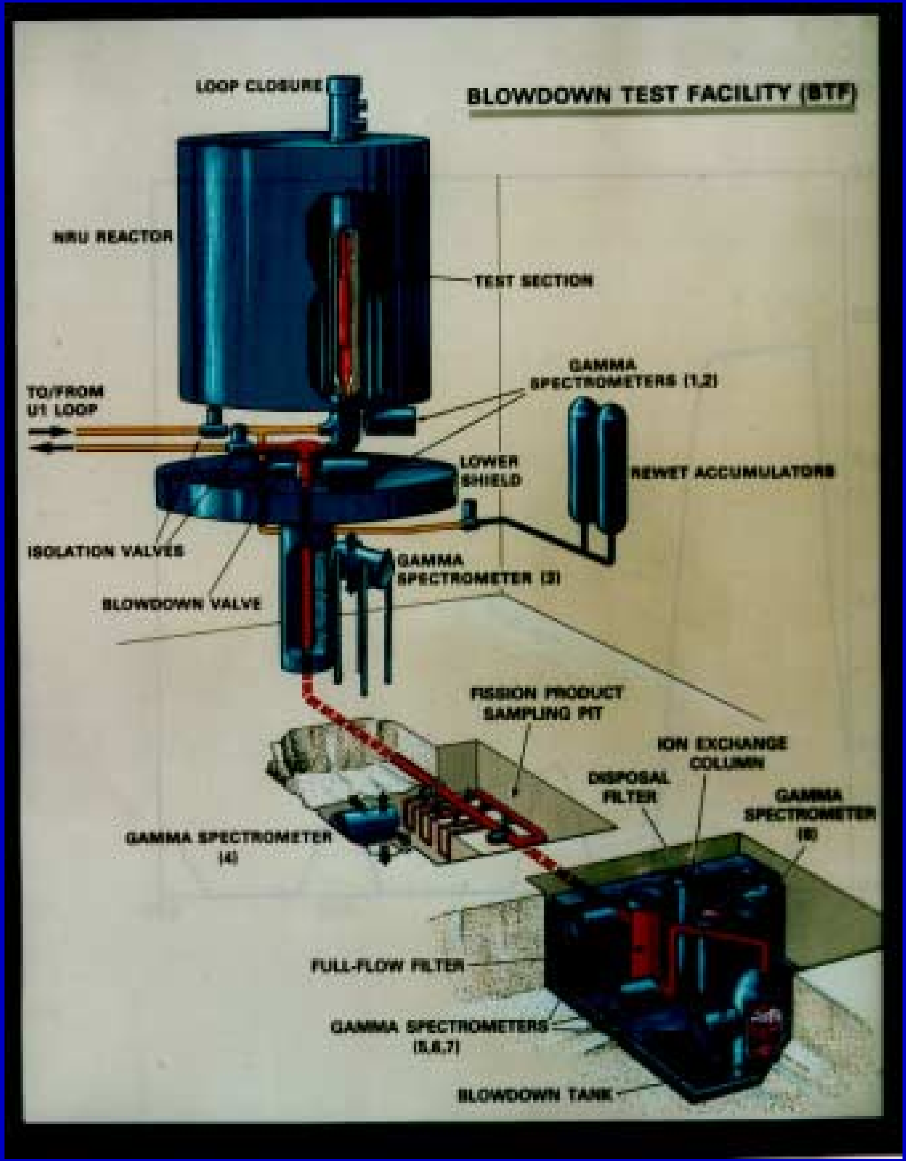
Bubble Dynamics After Rupture



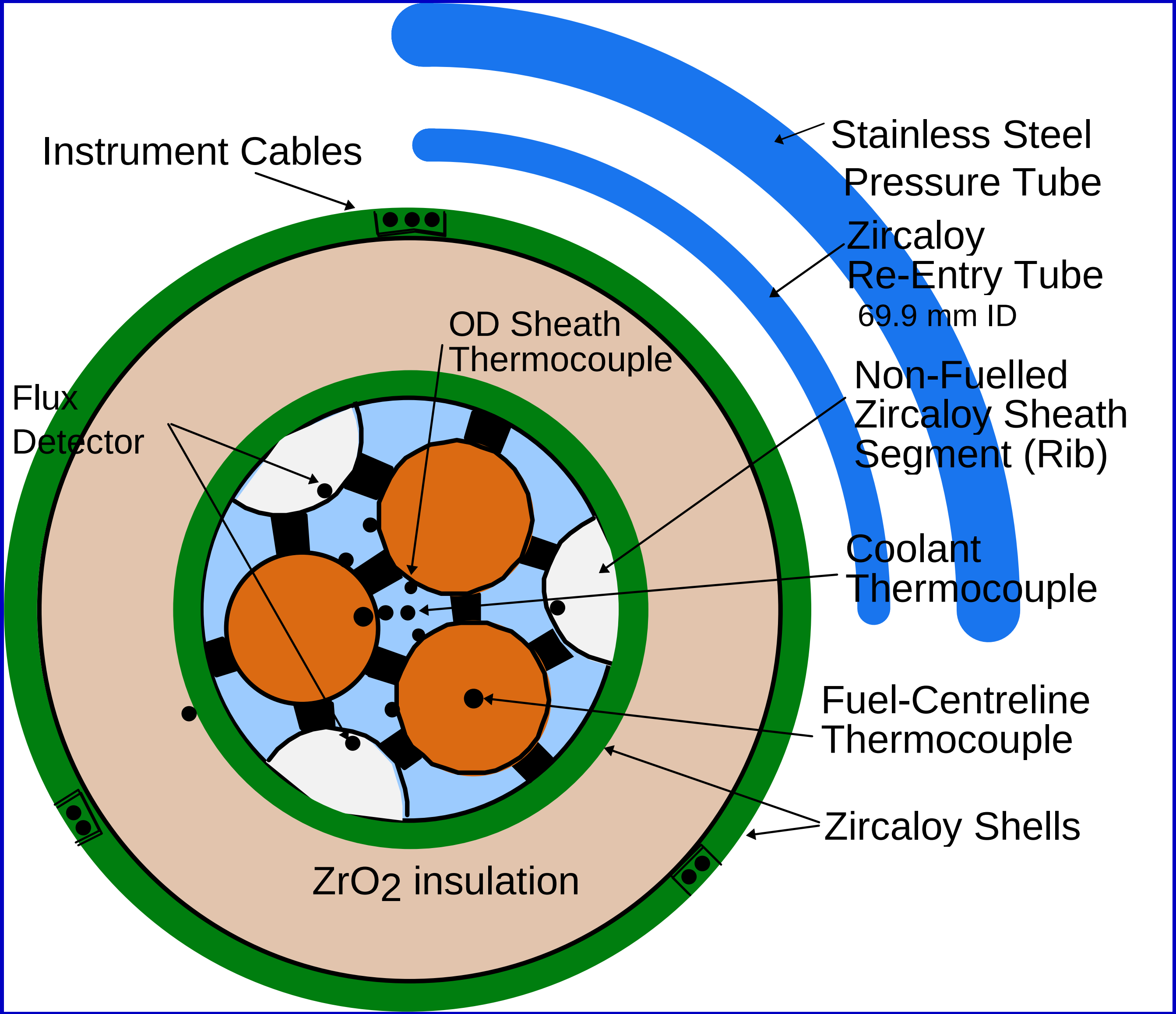
Blowdown Test Facility (BTF)

- Tests performed at the AECL-Chalk River Laboratories Research Reactor
- Capable of simulating a loss-of-coolant accident with or without emergency core cooling
- Measurements include fission product release, fuel and system temperatures

BTF Test Facility



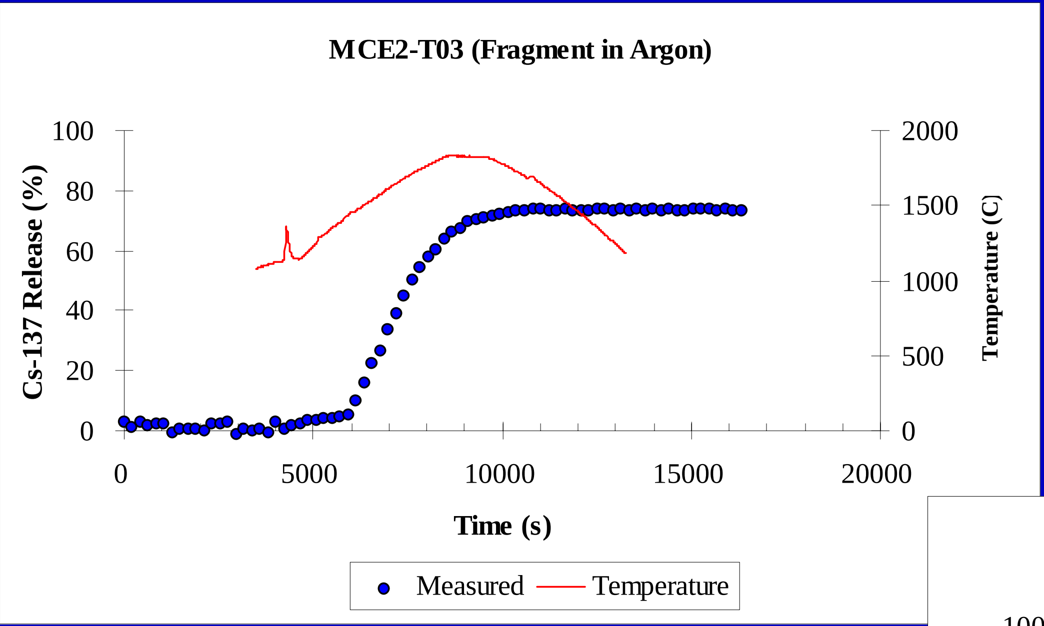
Cross-Section of the BTF Test String

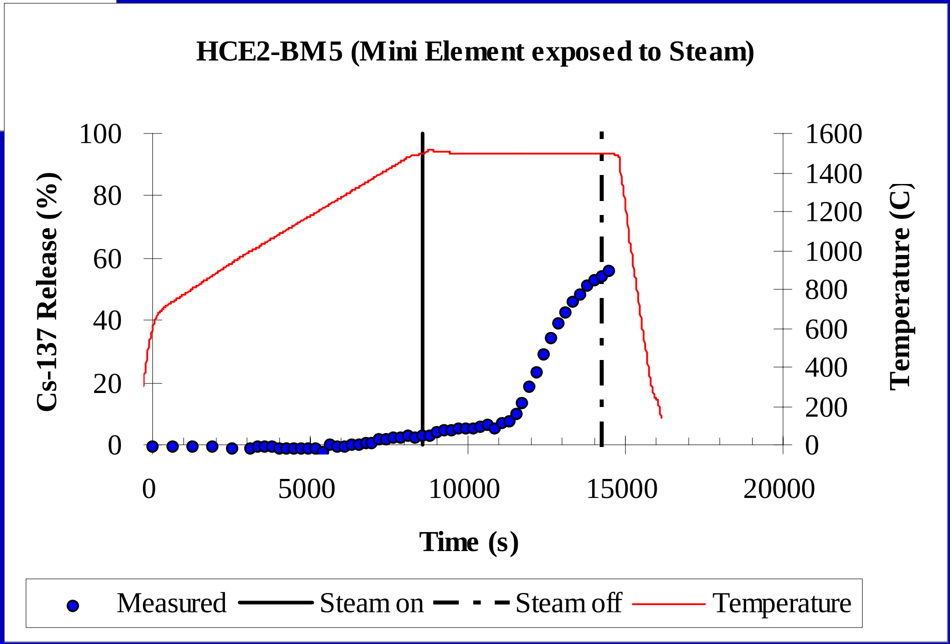


In-cell fission-product release tests

- **Objective: 1) understand fission product release under various conditions; 2) provide data for code development and validation**
- **100's of tests performed**
- **Varied parameters include:**
  - **Fuel type (CANDU fuel, research reactor fuel, light water reactor fuel)**
  - **Fuel sample design (bare UO_2 fuel fragments, fuel pellet inside a sheath)**
  - **Environmental conditions (inert, air, steam)**
  - **Various heating rates**
  - **Various steady state temperatures**
  - **Various hold times at steady state temperature**

Experiment Result

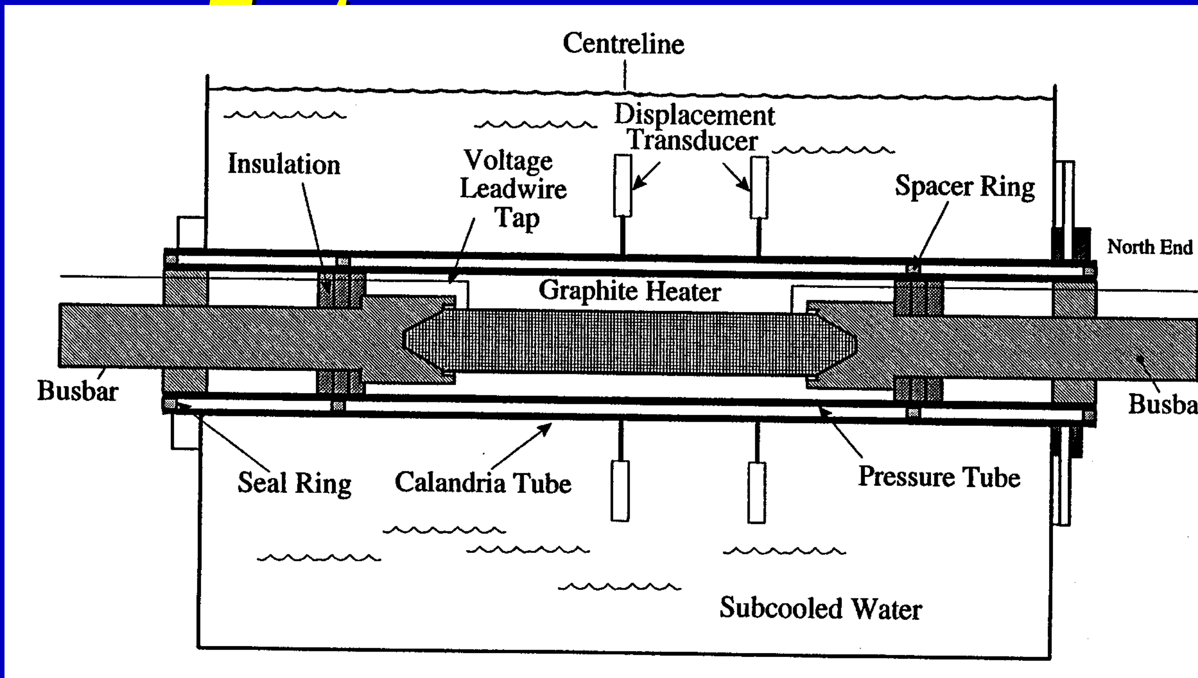




Some Channel Integrity Experiments

- Pressure tube-calandria tube contact boiling tests
  - Objective: determined the conditions for calandria tube dryout (applied in LOCA and LOCA/LOECC analysis)
- Induced temperature gradient around pressure tube tests
  - Objective: determine conditions for localized pressure tube strain and potential failure of pressure tube
  - i.e., applicable for flow blockage type conditions
- Local hotspot on pressure tube tests
  - fuel bearing pad-pressure tube contact tests
  - fuel element-pressure tube contact tests
  - molten material falling onto inside surface of pressure tube tests

Circumferential Temperature Gradient in PT Test



- Graphite heater used to heat up channel
- Tests induce a temperature gradient in the PT during heatup
- Internal pressure applied
- Assembly contained in cool water tank

- Non-uniform pressure tube temperature leads to non-uniform deformation
- Depending on the severity of the gradient, the pressure tube may fail due to local straining before it balloons into contact with its calandria tube

Molten-Material Contacting PT Tests

- Hole machined in the middle of graphite heater
- Zircaloy-4 ingot is machined to fit into hole
- Heater power increased to melt ingot
- Molten matarial drops onto PT
- Local PT temperatures increase rapidly
- Local PT deformation

Photograph of outside of failed PT