1. Introduction to CANDU Fuel

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AECL TECHNOLOGIES INC.

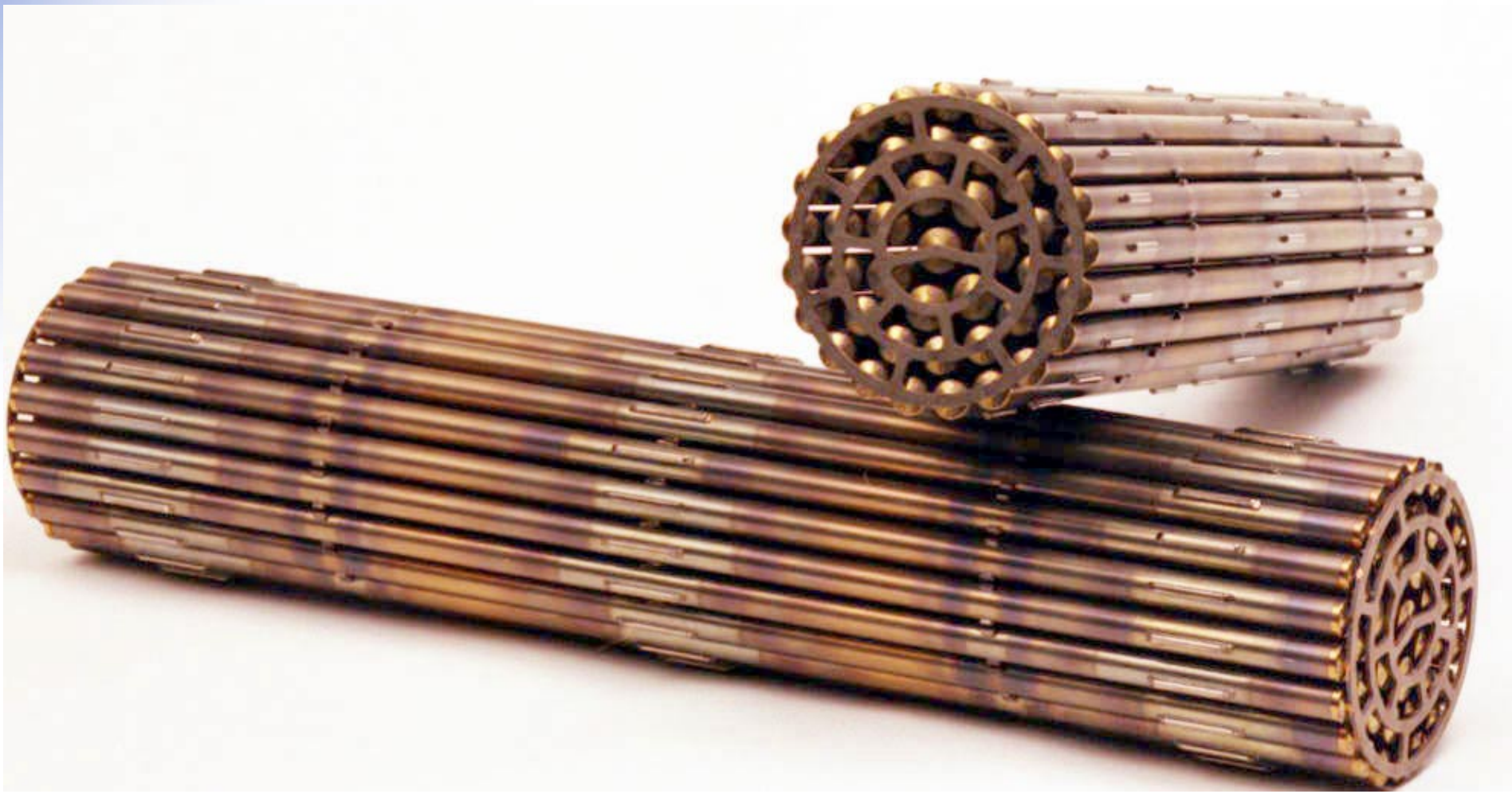
Outline

- CANDU fuel features
- Evolution of CANDU fuel
- CANDU fuel design requirements

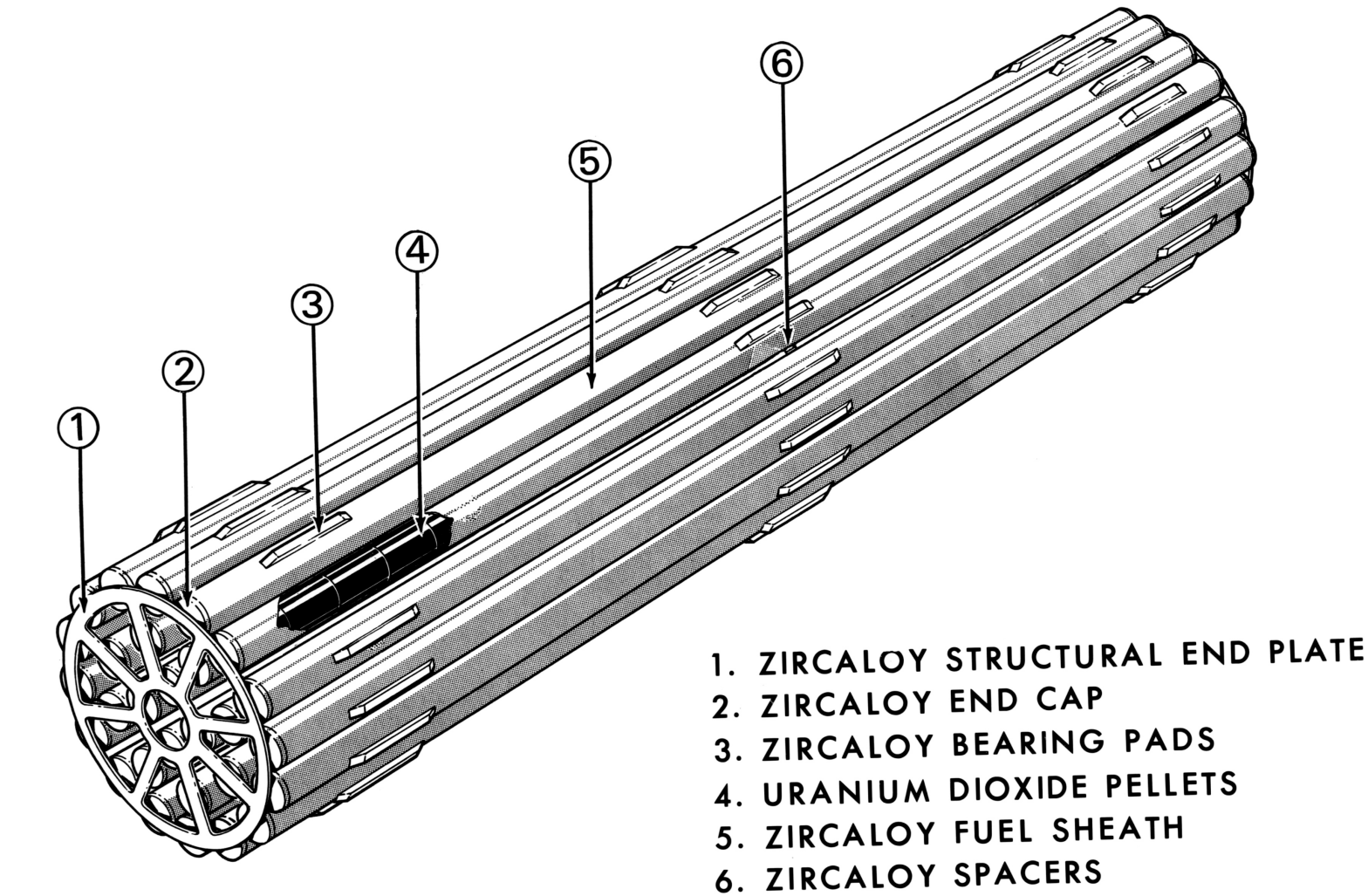
Features of CANDU Fuel

- Small
  - 50 cm (20”) length, 10 cm (4”) dia
- Lightweight
  - ~24 kg (50 lb) / bundle
- Simple in design
  - 7 separate components (8 in CANFLEX)
- Easy to manufacture
  - all countries having CANDU reactors manufacture their fuel
- Excellent performance
  - defect rate ~ 2 defects per million elements
  - ~2 million bundles irradiated

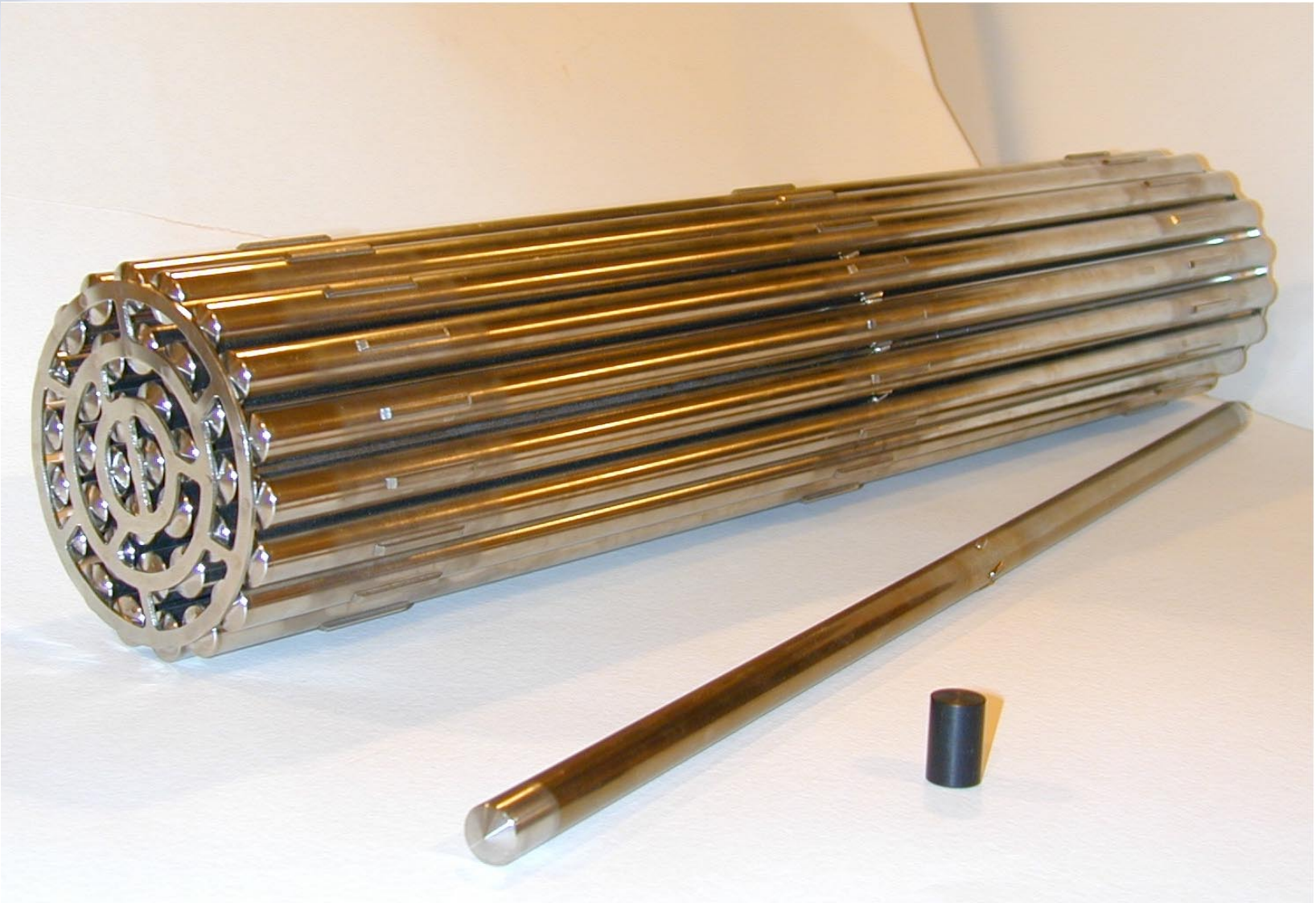
CANFLEX Bundle



37-element Fuel



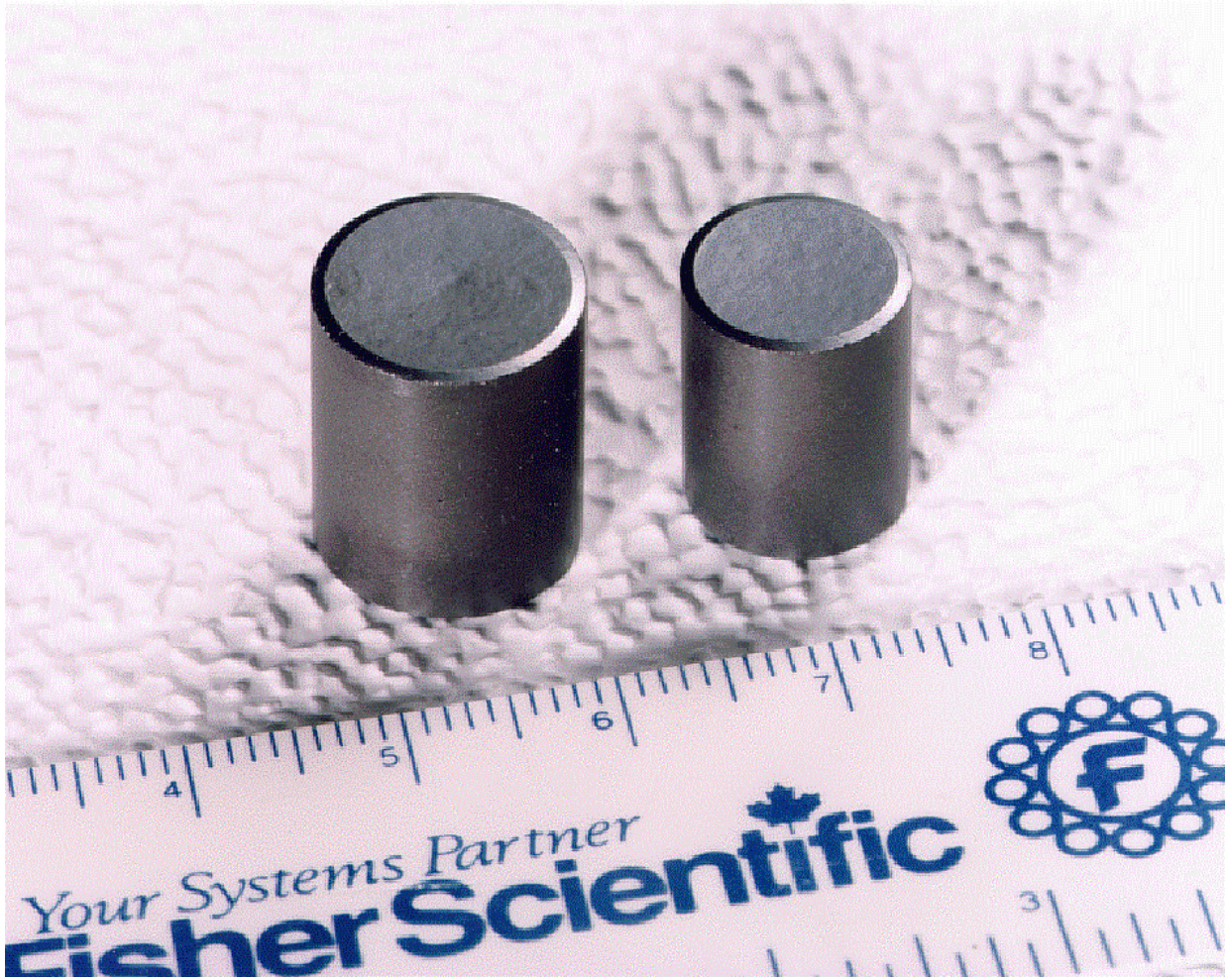
CANDU 6 37-element Fuel



UO_2 Powder

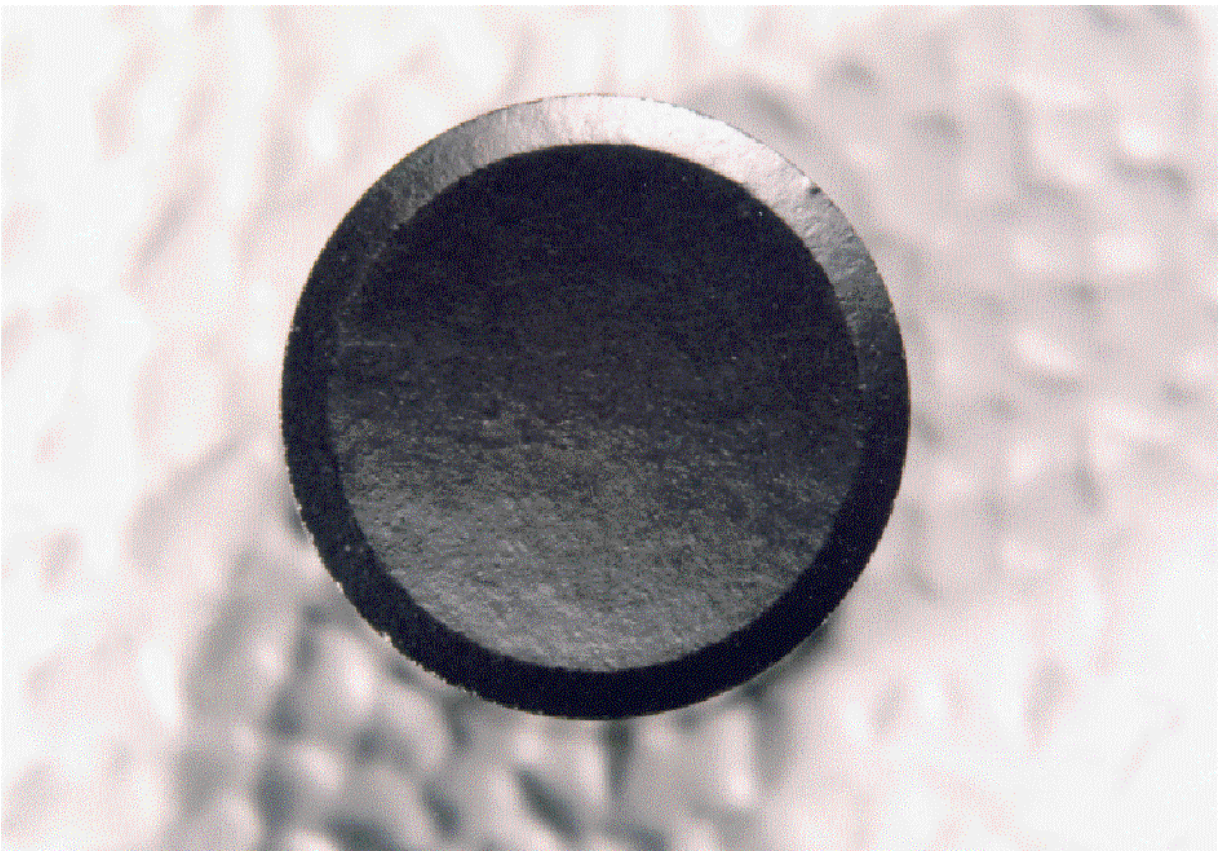
UO_2 Pellets

- UO_2, high density (for dimensional stability)



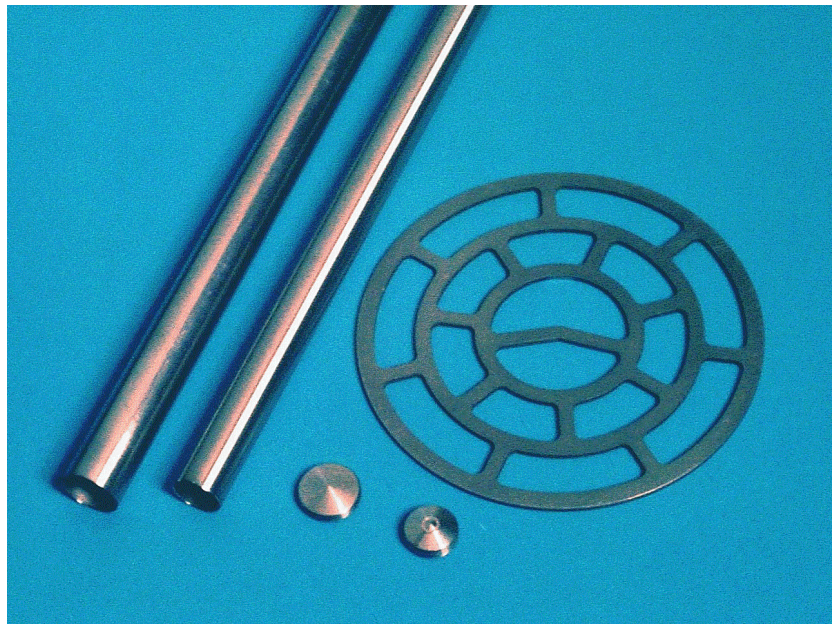
UO_2 Pellets

- Chamfers and end-dishes (reduce inter-pellet stresses on clad, volume for fission gas)



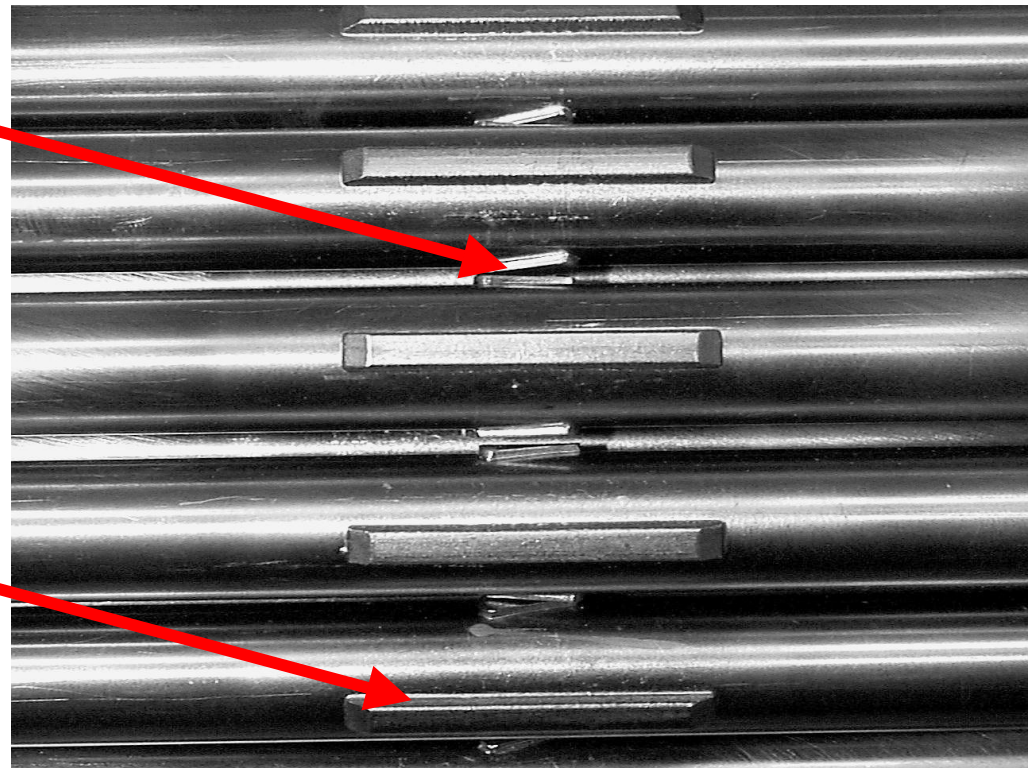
Clad, CANLUB, Endcaps, Endplates

- Clad
  - thin, collapsible (0.4 mm, 0.016”)
  - excellent heat transfer to coolant
  - low neutron absorption, Zr-4
- CANLUB
  - graphite coating applied to inside of clad provides protection against power ramp failures
- Endcaps
  - seal the fuel element
  - thin to reduce neutron absorption, good heat transfer
  - profiled to interact with fuel channel and fuel handling components
- Endplates
  - thin to minimize neutron absorption
  - flexible to accommodate fuel element differential expansion
  - strong to provide structural support and element separation



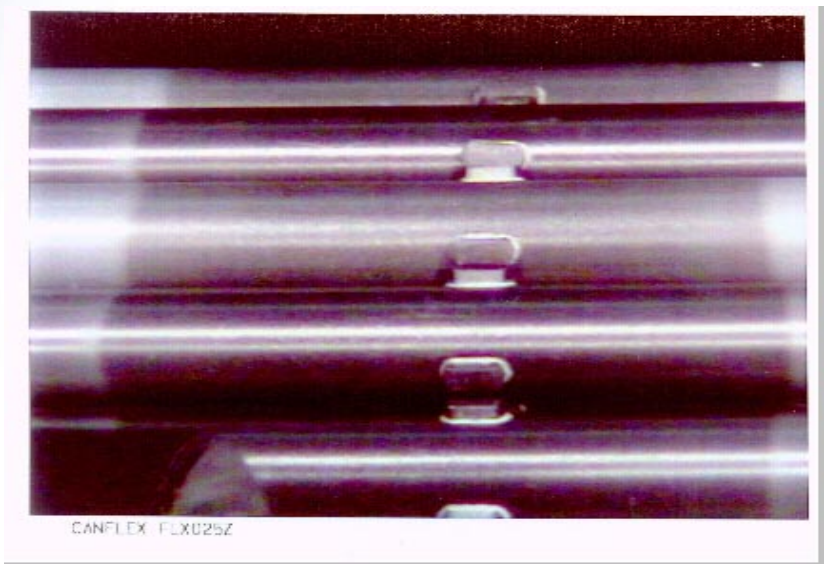
Spacers, Bearing Pads

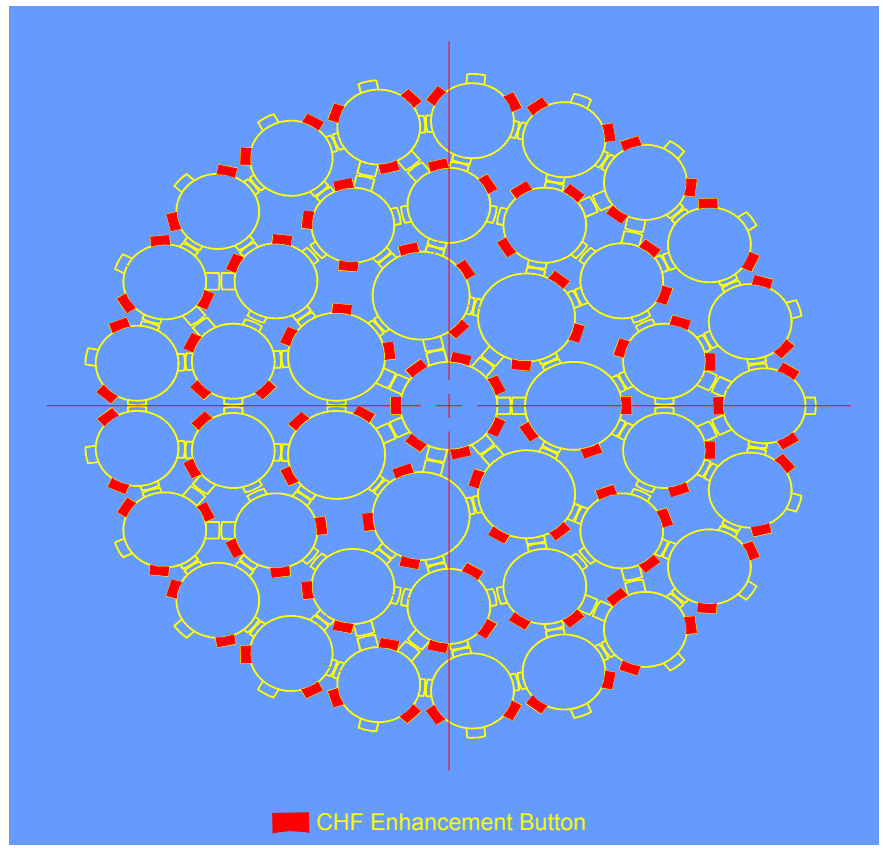
- Inter-element spacers
  - provide element separation at the bundle midplane
- Bearing pads
  - provide element-to-pressure tube separation



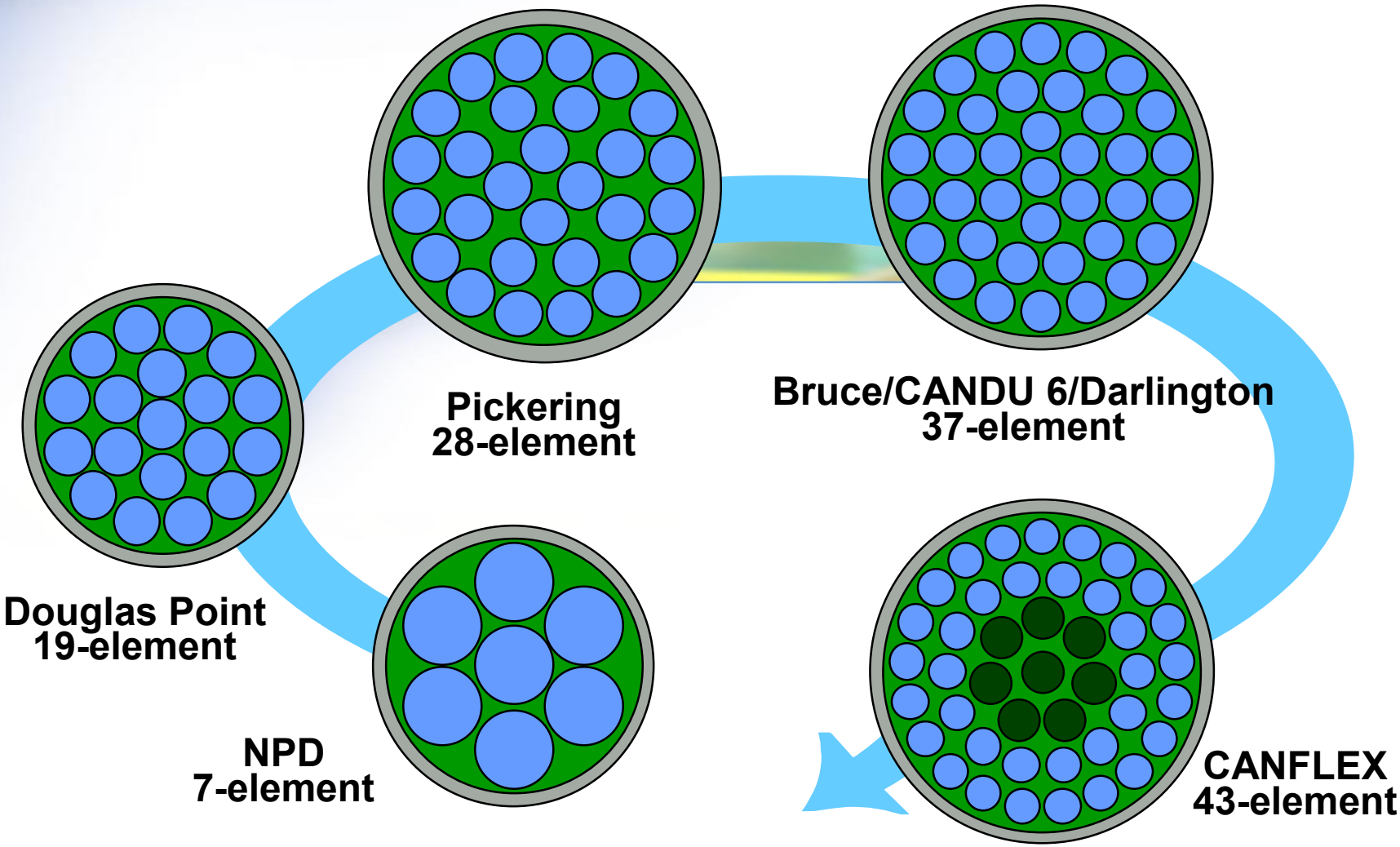
CHF-Enhancing Buttons (CANFLEX)

- Appendages are attached on the 1/4 and 3/4 bundle planes

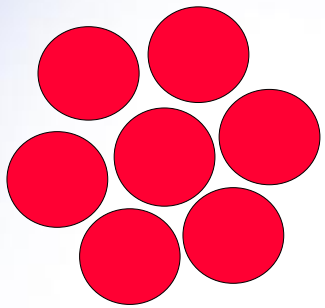




Evolution of CANDU Fuel

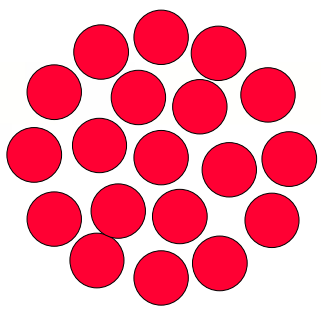


CANDU Fuel Bundle Types



7 element NPD
(1st Charge)

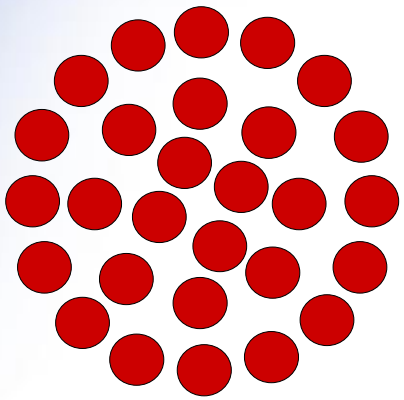
NPD (Nuclear Power Demonstration)



19 element
(>9 reactors)

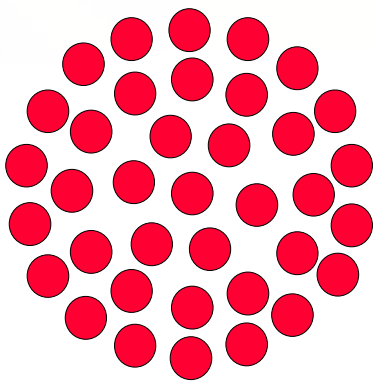
NPD,
Douglas Point,
Reactors in Pakistan,
India

CANDU Fuel Bundle Types



28 element Pickering
(8 reactors)

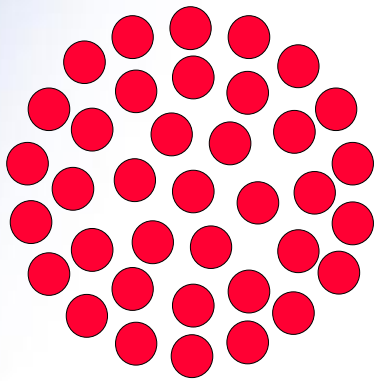
Pickering 1 - 8



37 element Bruce/Darlington
(12 reactors)

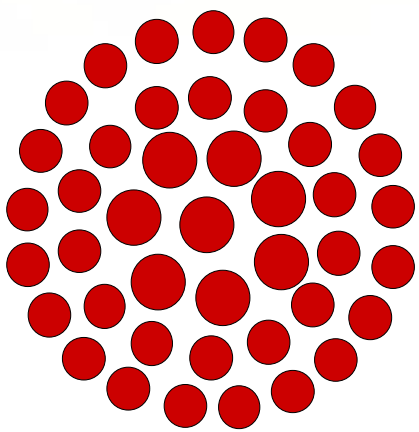
Bruce 1 - 8
Darlington 1 - 4

CANDU Fuel Bundle Types



37 element CANDU 6
(11 reactors)

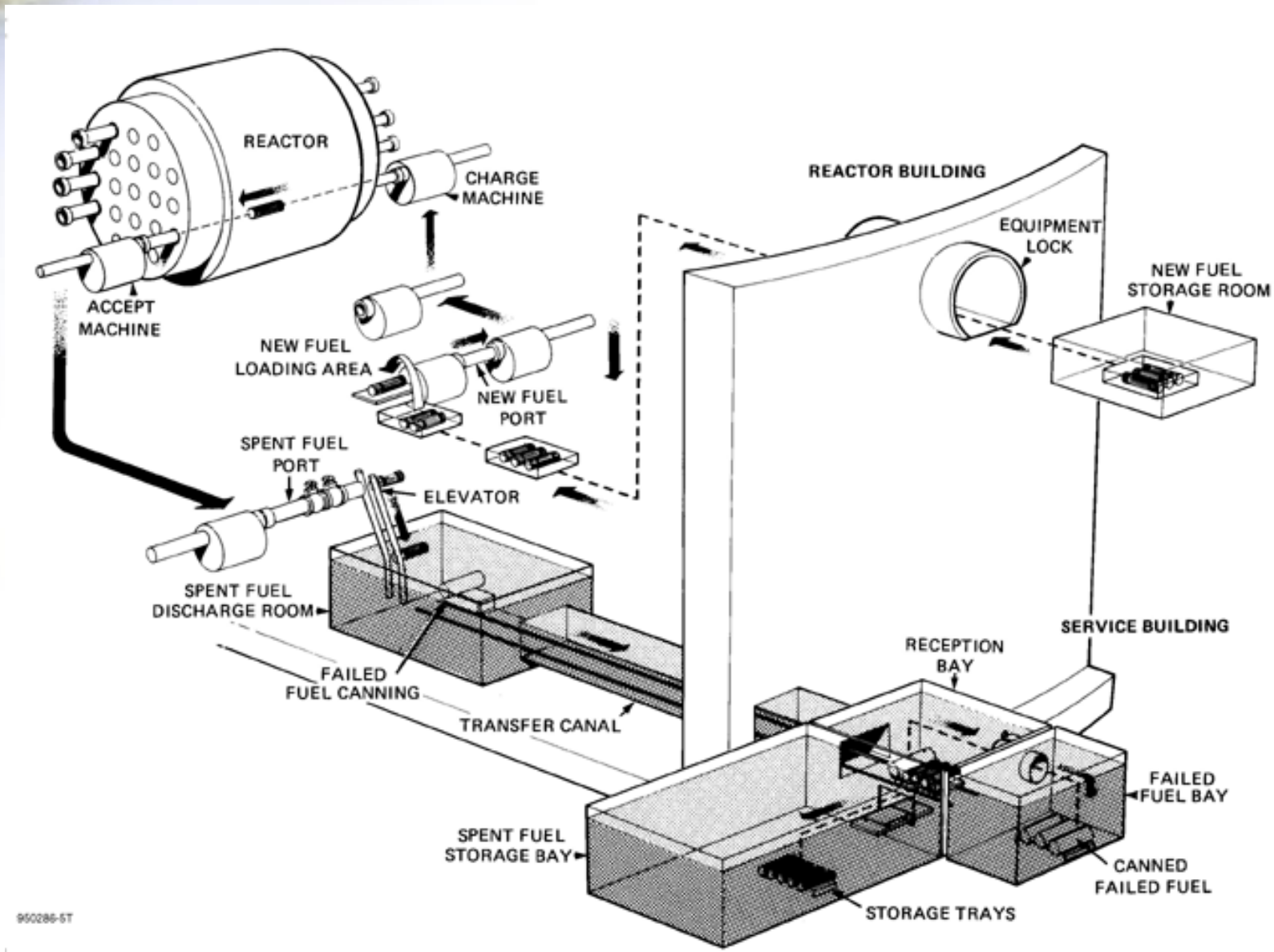
Canada: Pt Lepreau, Gentilly 2
Argentina: Embalse
Korea: Wolsong 1 - 4
Romania: Cernavoda 1, 2
China: Qinshan 1, 2



43 element CANFLEX

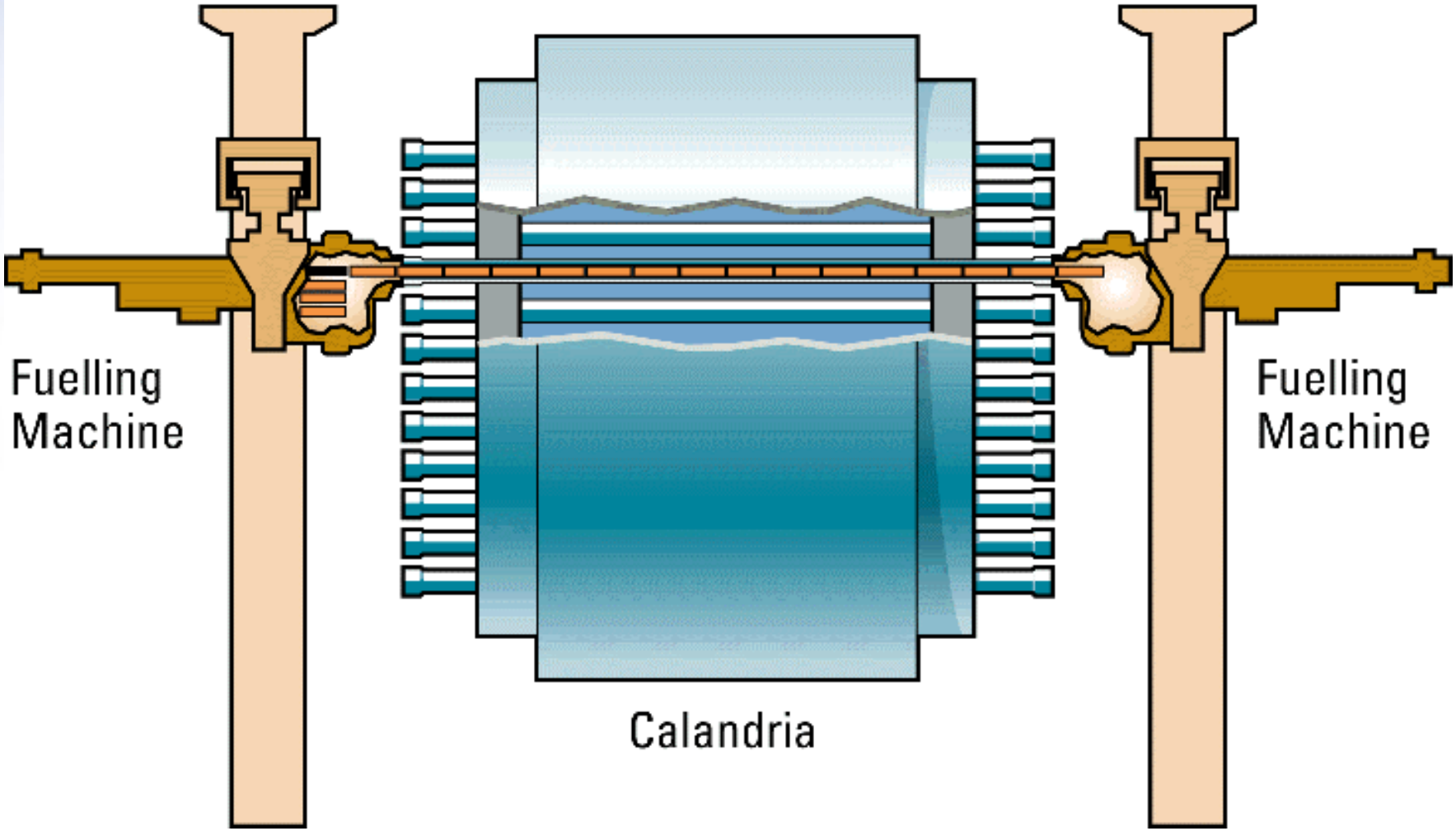
CANDU 6, Bruce,
ACR

CANDU Fuel Duty Cycle

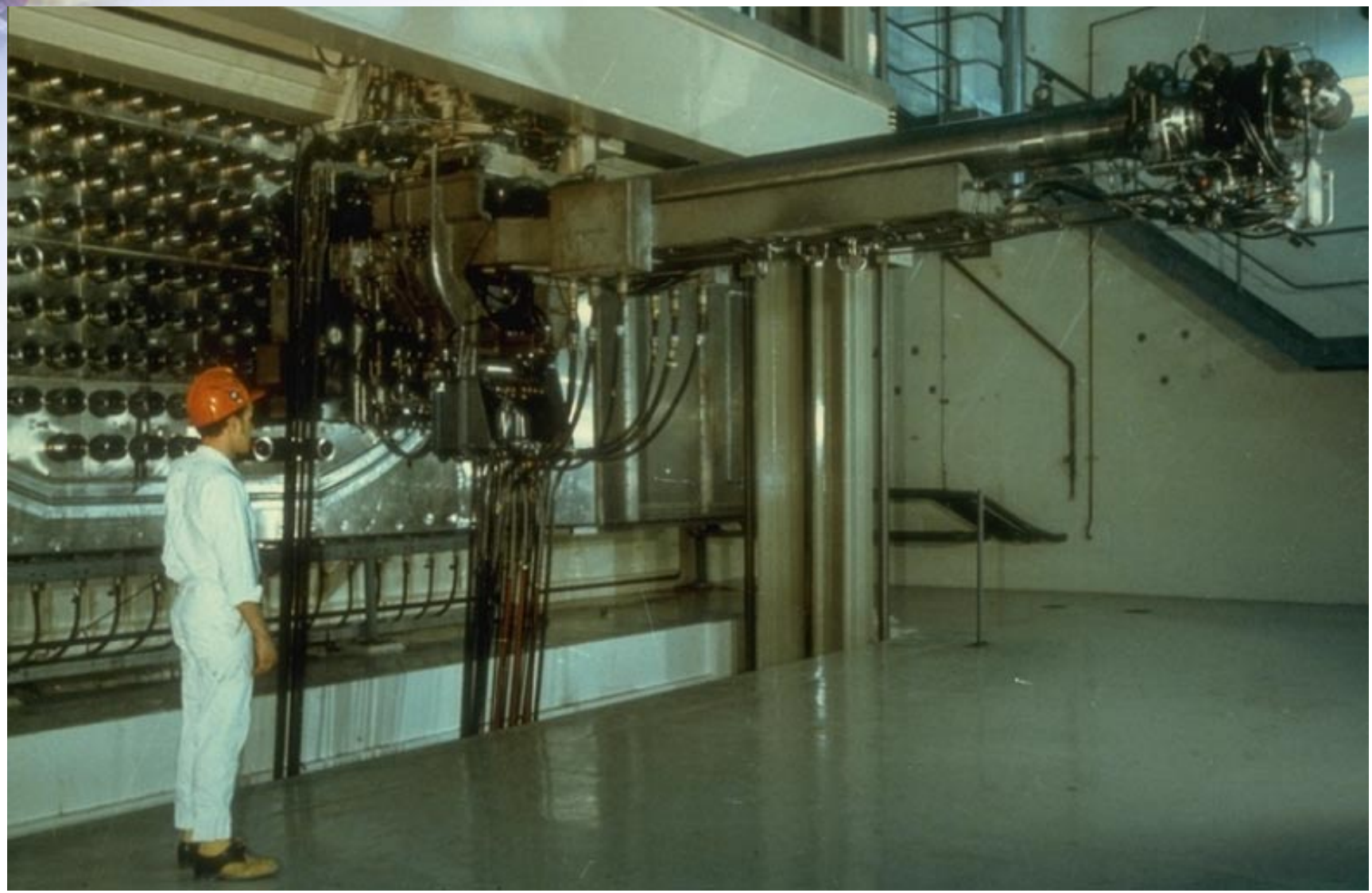


Loading CANFLEX at Point Lepreau in New Fuel Room

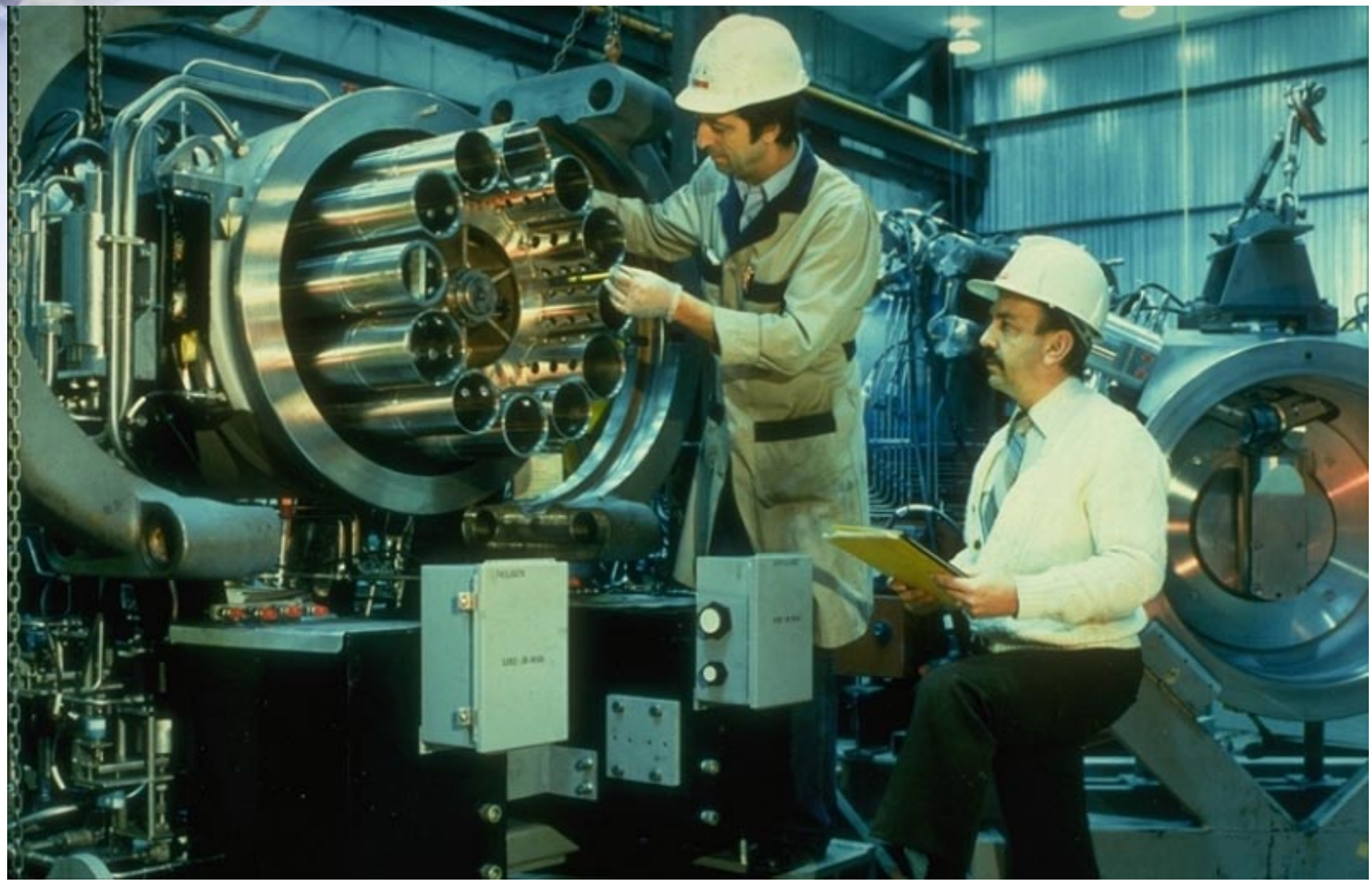
On-power Refueling



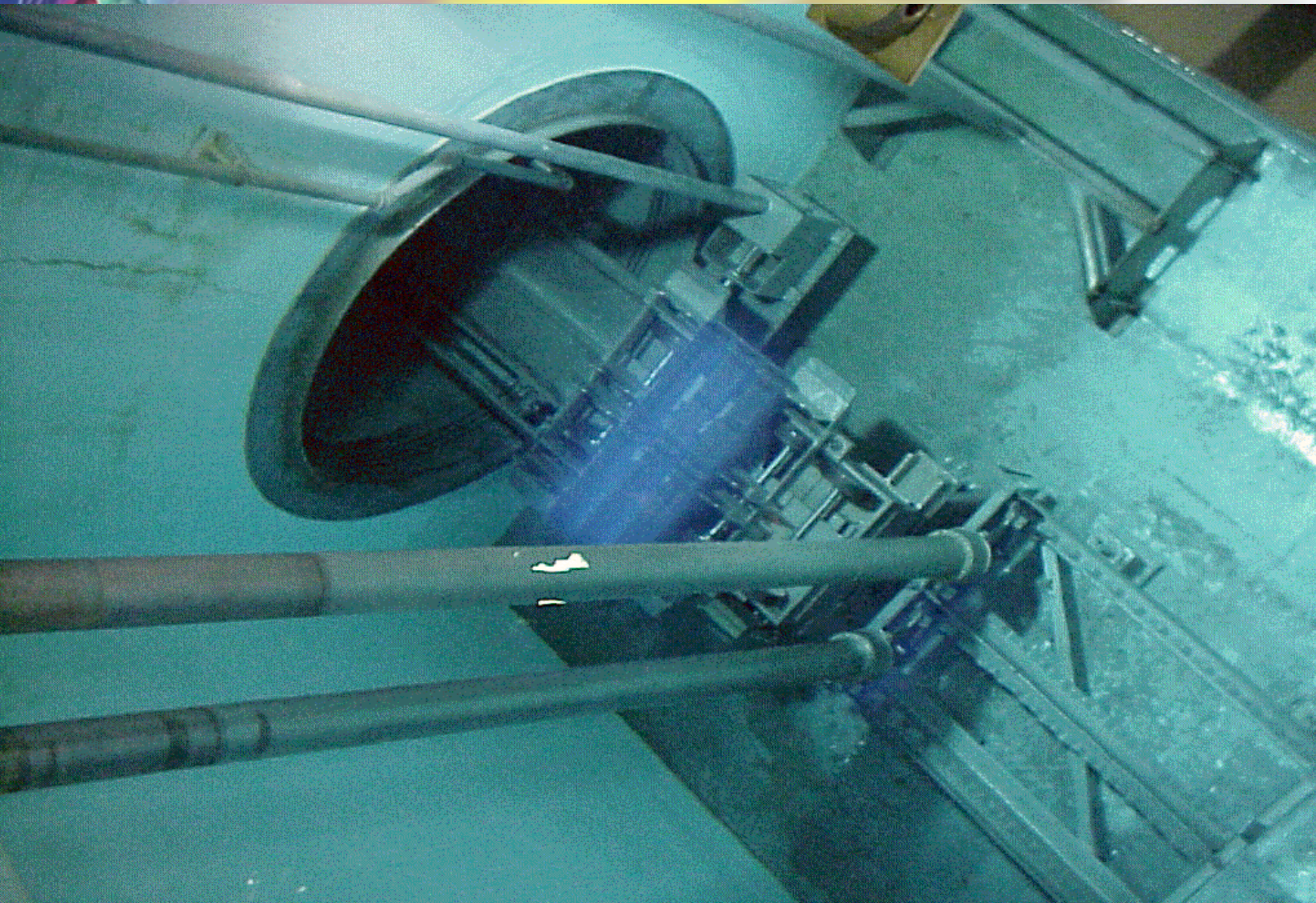
Pickering Fueling Machine



Fueling Machine Magazine



Spent Fuel in Transfer Canal



Spent Fuel in Reception Bay

Original Criteria for Fuel Design (1950s)

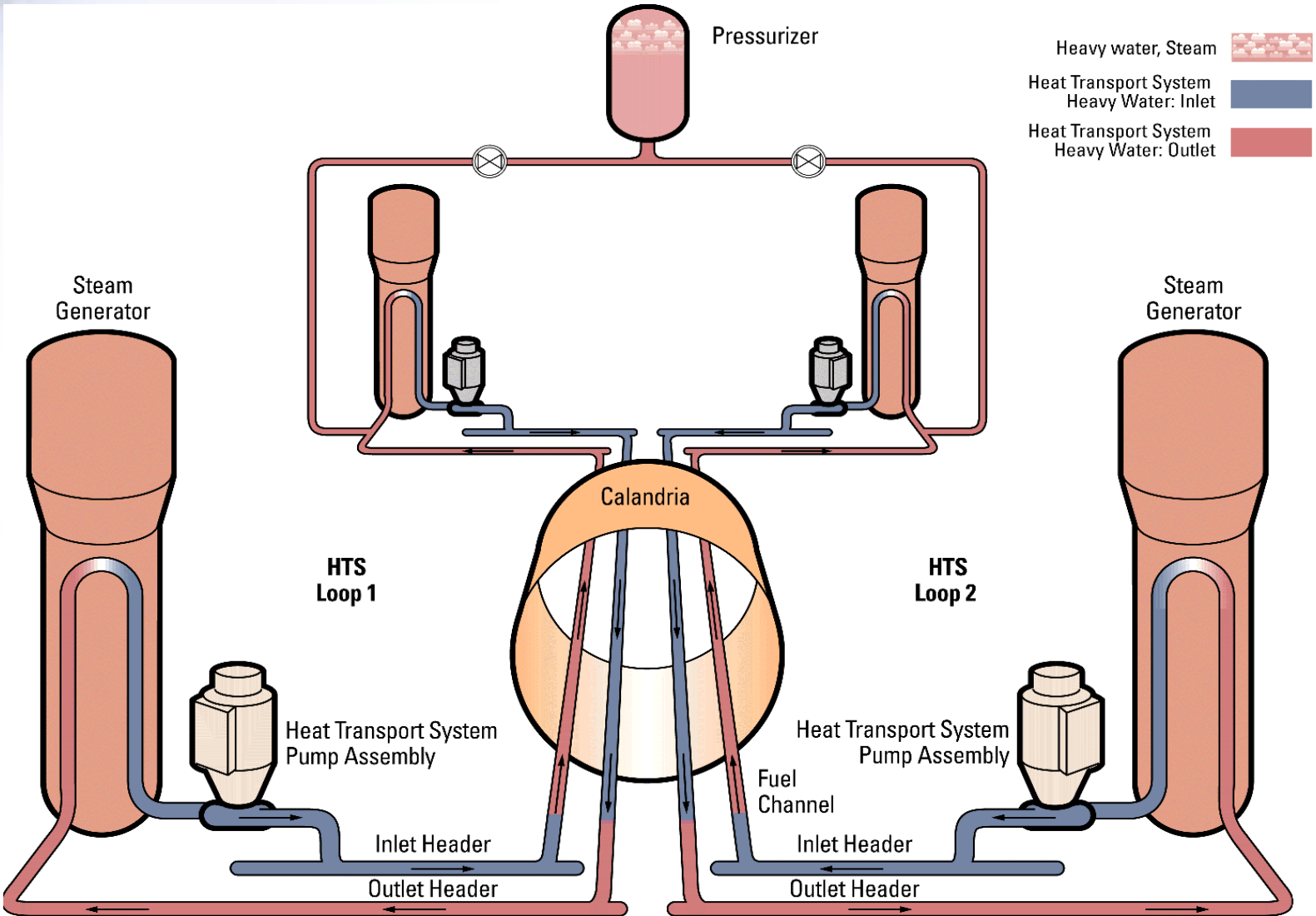
W.B. Lewis stated that CANDU fuel must

- Be safe, reliable, low risk of release of radioactive fission products
- Have good neutron economy
  - low neutron absorption materials / natural uranium
- Meet power specifications
  - 1 MW per bundle
  - no distortion in 1-4 years in-reactor
- Be easily handled
- Be inexpensive
  - at that time, 1 mils/kWh

CANDU Fuel Design Requirements

- CANDU fuel must meet the requirements imposed by the reactor interfacing systems
  - reactor coolant system (RCS)
  - fuel channels
  - fuel handling systems
  - fuel management (nuclear design or reactor physics)

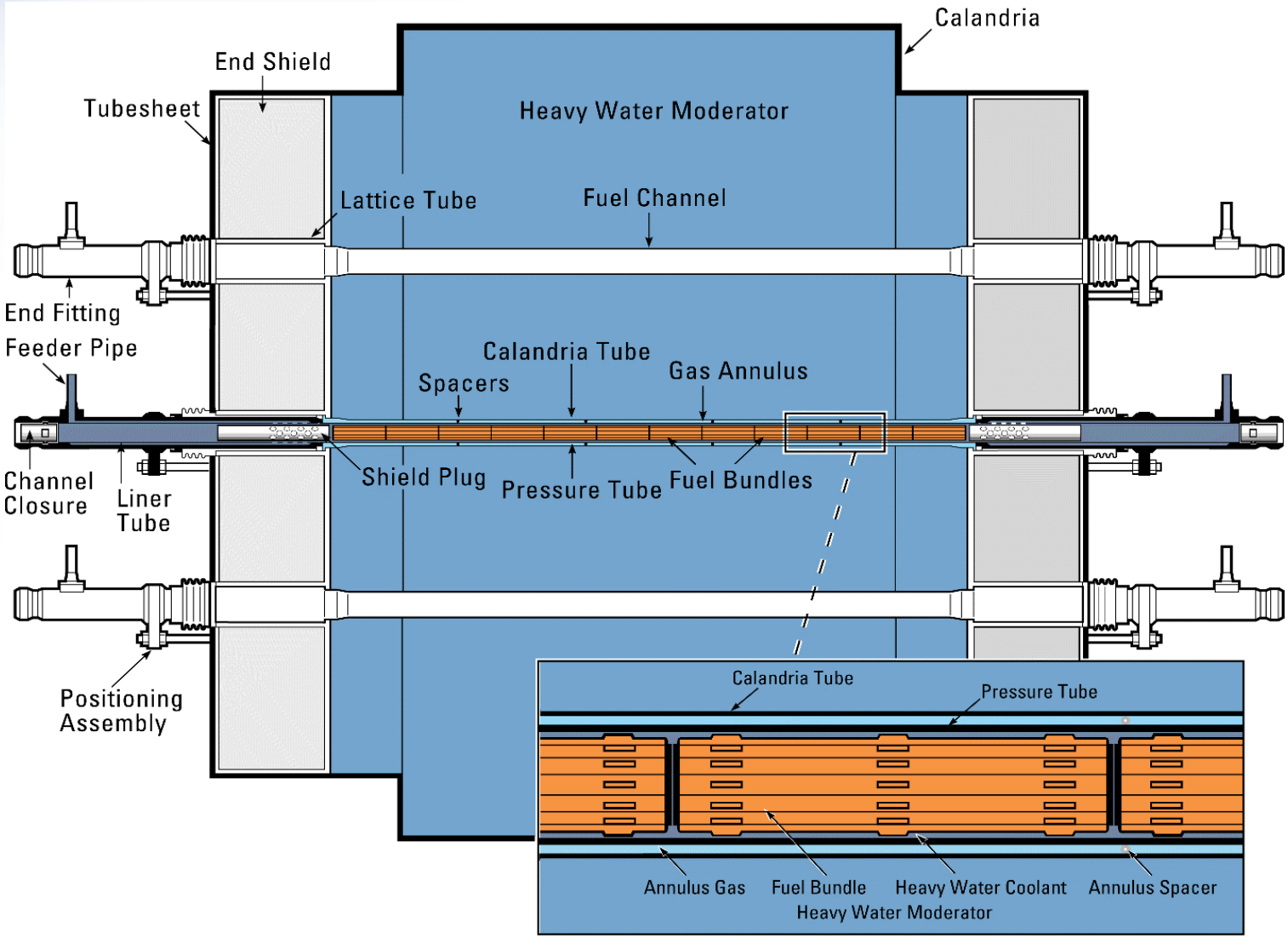
Reactor Coolant System



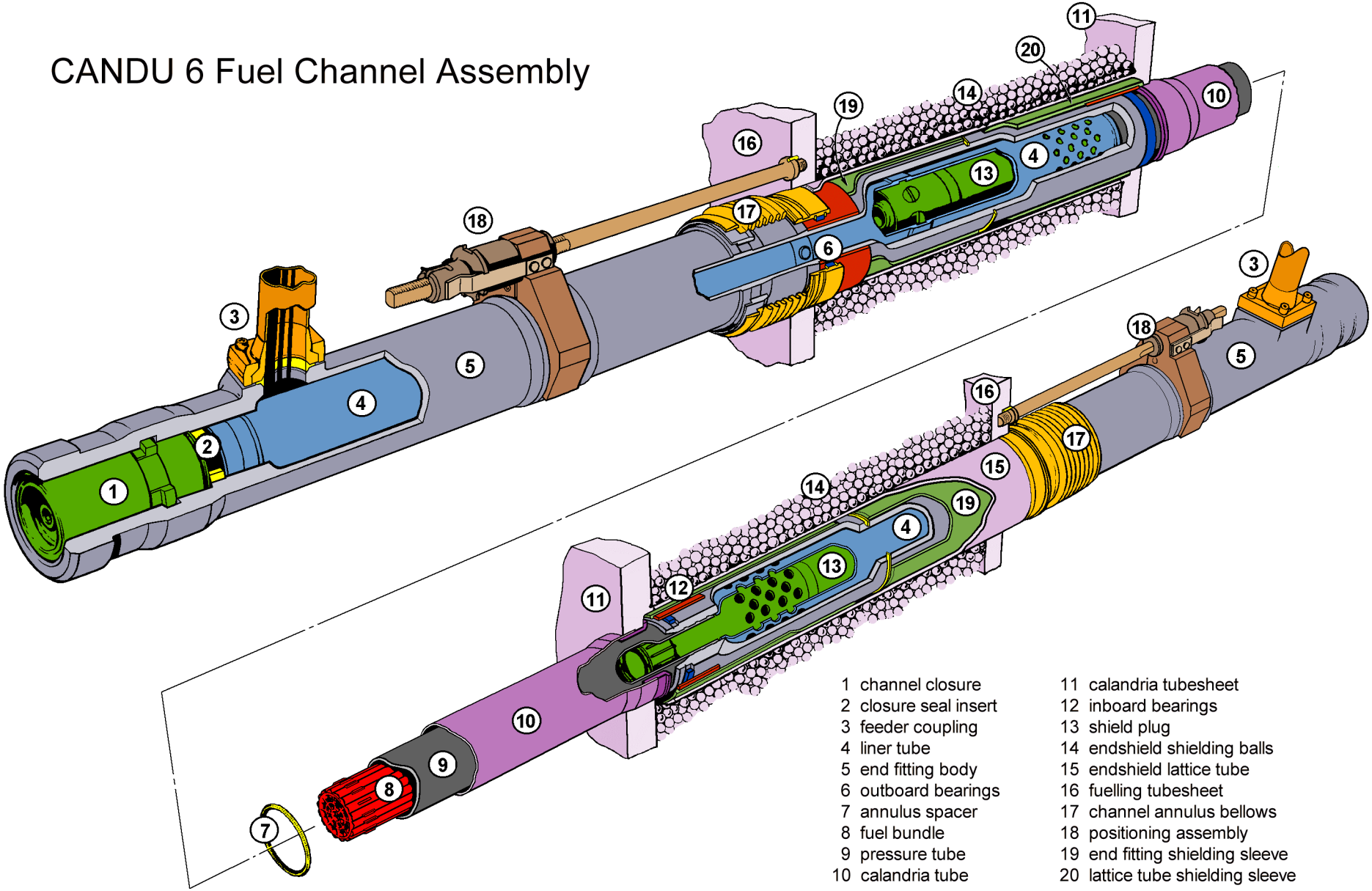
RCS Requirements on Fuel

- Pressure drop across the fuel compatible with RCS design allowance
- Adequate thermal hydraulic performance during NOC
- Fuel element withstands entire range of flows and pressure pulsations
  - inter–element spacer height to remain above acceptable levels required to prevent damage of the fuel clad
- Fuel element contains fission products during NOC
- Sufficient margin on critical channel power for expected range of axial flux shapes, flows, and flow area increases resulting from radial pressure–tube creep up to the end of the pressure–tube life

Calandria Assembly, Fuel Channel Arrangement



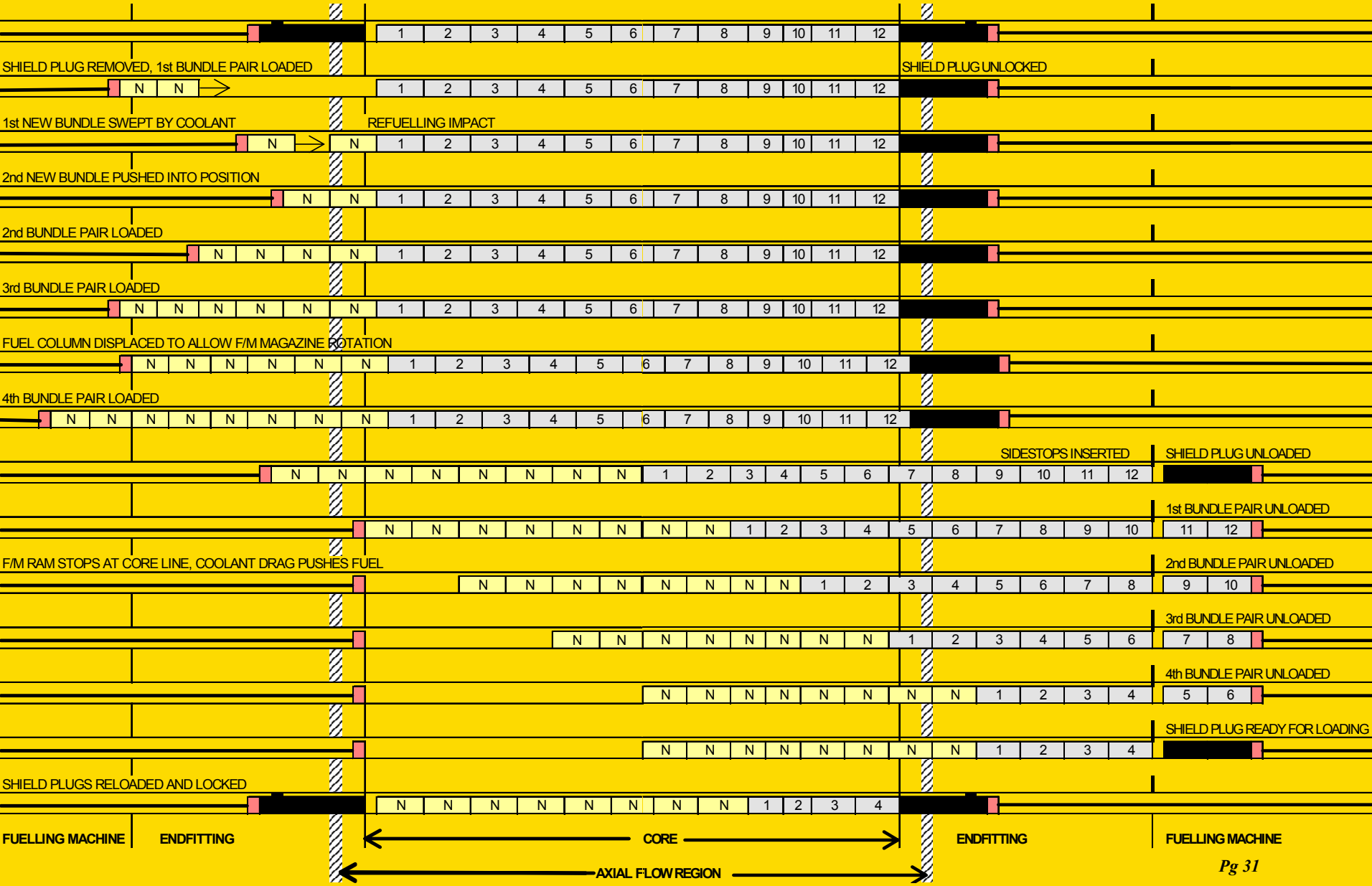
CANDU 6 Fuel Channel Assembly



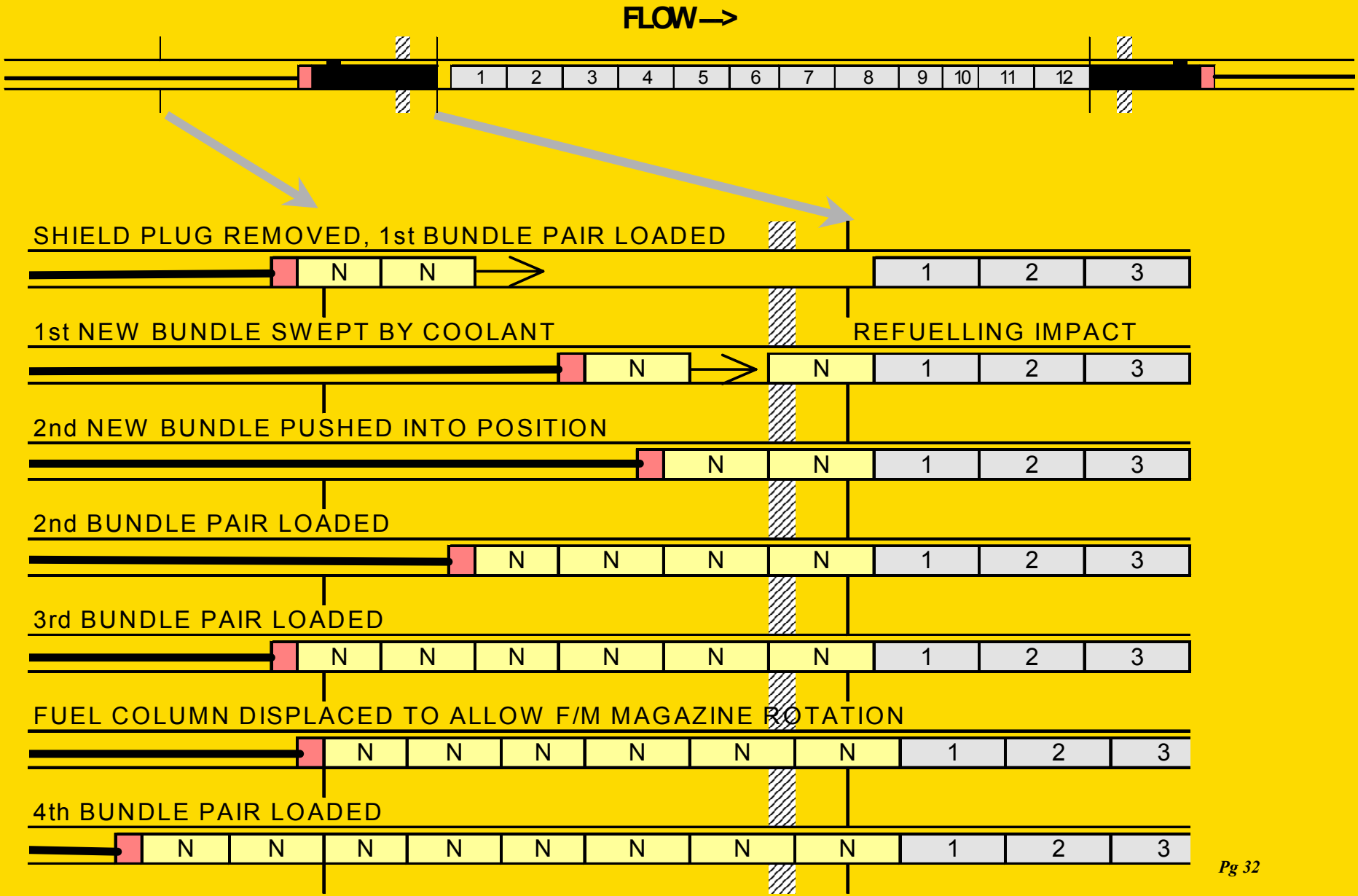
Fuel Channel Requirements on Fuel

- Reduction in pressure–tube wall thickness due to sliding wear and fretting within specified limits
- No jamming of bundle in channel
  - under all conditions of irradiation, pressure–tube sag, radial and axial creep, and misalignments between the pressure tube and end–fitting liners
- Sufficient fuel element strength and flexibility to maintain structural integrity
  - no contact of clad with the channel surfaces under steady and fluctuating loads applied thermally, mechanically, hydraulically, and by refueling operations
  - bearing pads are only points of contact between bundle and pressure-tube under NOC

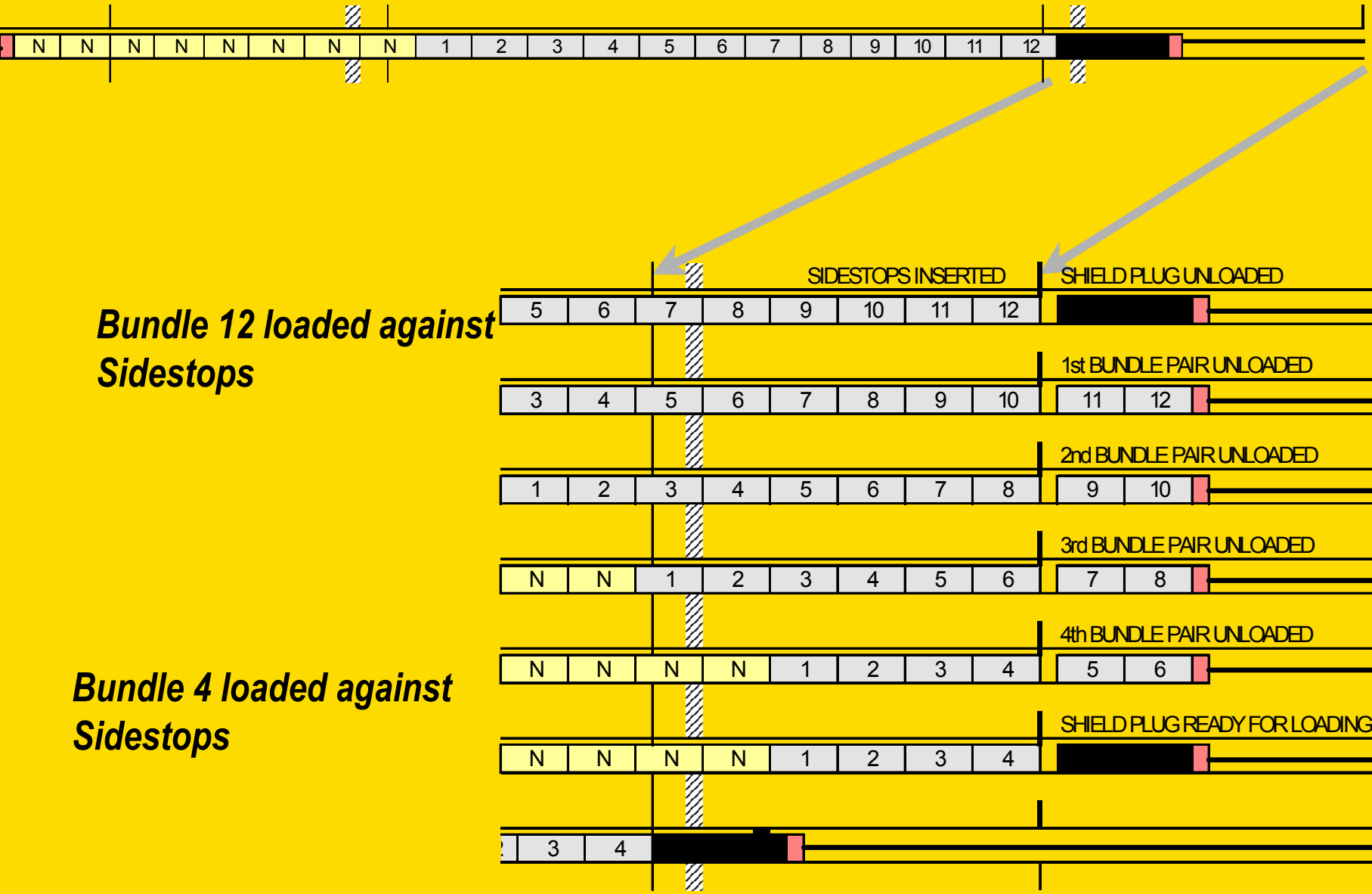
CANDU 6 Fueling Scheme



Fuel Loading Sequence (Upstream End)



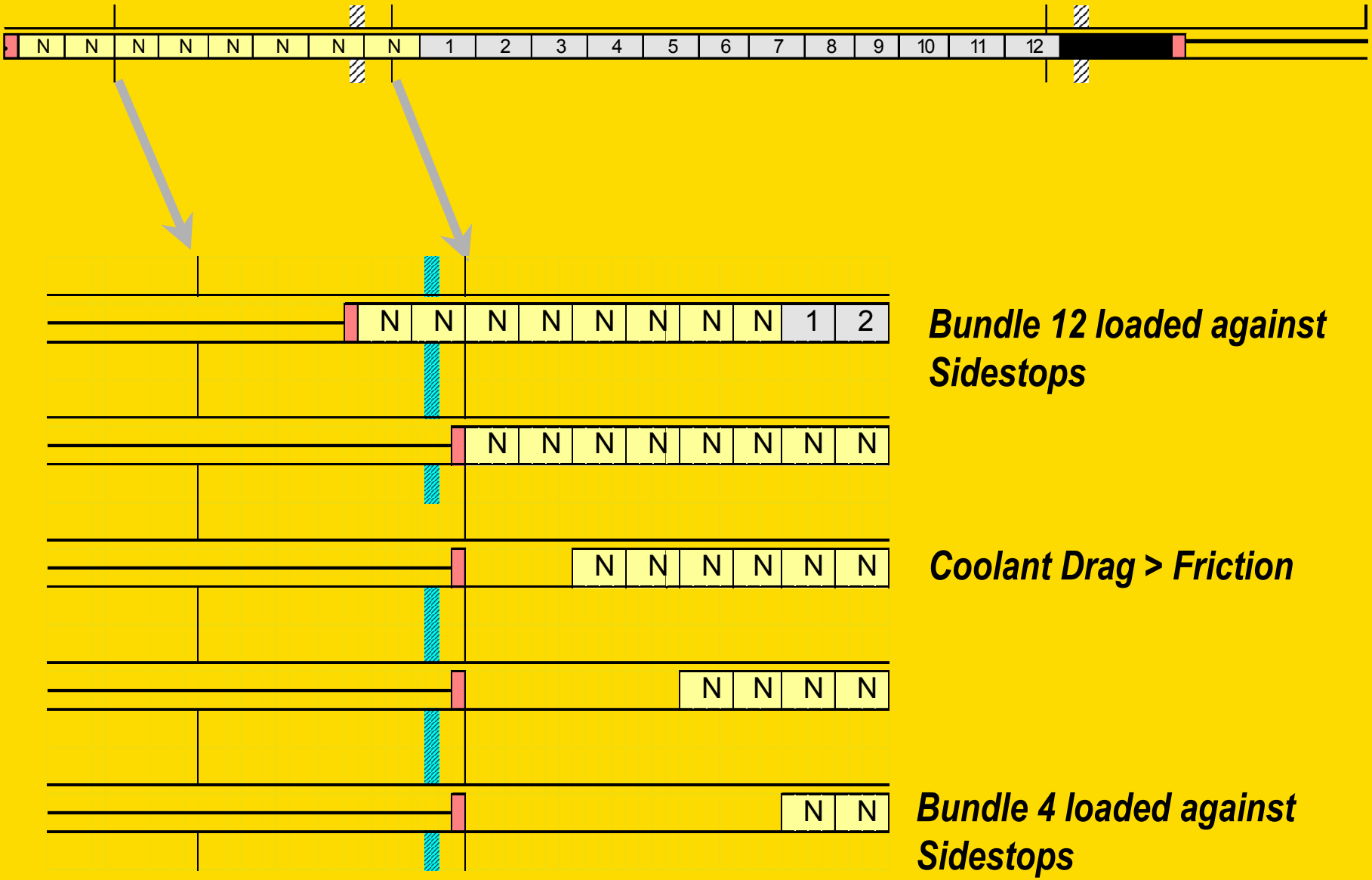
Fuel Unloading Sequence (Downstream End)



Bundle 12 loaded against Sidestops

Bundle 4 loaded against Sidestops

Fuel Unloading Sequence (Upstream End)



FH System Requirements on Fuel

- Bundle compatible with fueling–machine separator sensors and side–stops
- Bundle withstands all normal fuel–handling loads during on–power and off–power operations applied by side–stops, ram and shield plug
  - no significant bundle deformation or degradation of performance
- Bundle shall not become interlocked during NOC
- Bundle withstands normal refueling impacts
- Bundle withstands loads caused by cross–flows in the liner hole region of the end fittings
- Bundle operates successfully under bundle power changes associated with normal refueling movement
- Bundle withstands consequences of increased flow resulting from normal refueling

Fuel Management Requirements on Fuel

- Bundle able to operate continuously at high power
- Bundle withstands power changes caused by refueling, movement of reactivity control devices, and normal reactor power manoeuvres
- Bundle withstands bundle–end flux peaking

Failed Fuel Location System Requirements on Fuel

- Contamination on surface of new bundles limited to maintain the sensitivity of the Failed Fuel Location System
  - the failed fuel location system provides on-line capability for detecting and locating failed fuel

Seismic Requirements on Fuel

- Bundle retains coolable geometry and no loss in integrity of pressure tube or fuel elements in case of a seismic event or design–basis earthquake

Fuel Requirements on Other Systems

- No systematic fuel failures due to interfacing systems
  - translates to at least 22 specific requirements
- Sufficient allowance in fuel channel and fuel handling components to protect against damage due to interaction with fuel
  - translates to at least 4 specific requirements

Summary

- CANDU fuel is simple in its design and manufacture
  - CANFLEX fuel has only 8 components
- CANDU fuel has experienced a similar evolution towards greater sub-division as LWR fuel
  - CANFLEX fuel is the latest step in this evolution and features 2 element sizes as well as greater sub-division
- CANDU fuel must meet the requirements imposed by the reactor interfacing systems
  - reactor coolant system
  - fuel channels
  - fuel handling systems
  - fuel management (nuclear design or reactor physics)
- Qualification of CANFLEX fuel will be summarized in Presentation 4

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