ACR TECHNOLOGY BASE: FUEL

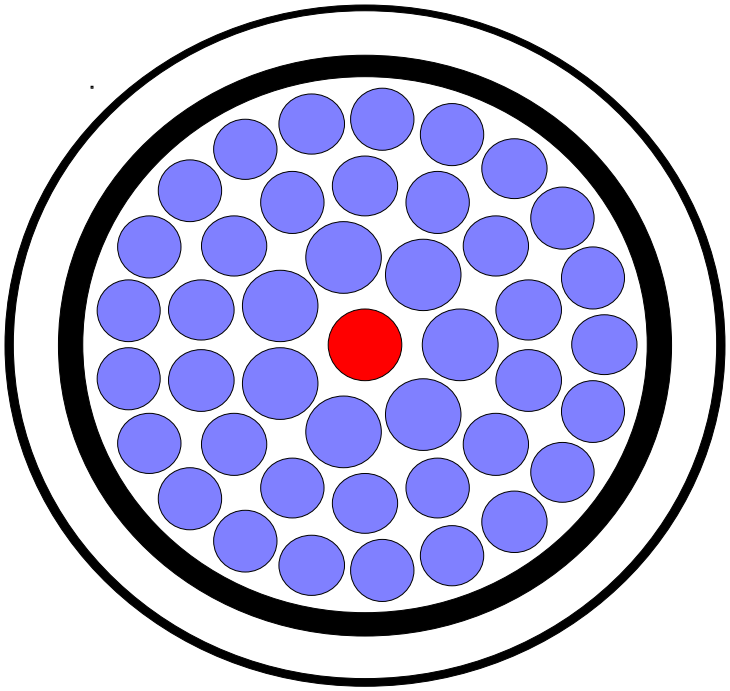
By Peter G. Boczar, Director
Reactor Core Technology Division

Presented to US Nuclear Regulatory Commission
Office of Nuclear Reactor Regulation
September 26, 2002

AECL
TECHNOLOGIES INC.

ACR Fuel

- CANFLEX geometry
- 2% SEU (20.5 MWd/kg bundle burnup)
- 4.6% Dy in nat UO_2 in central element

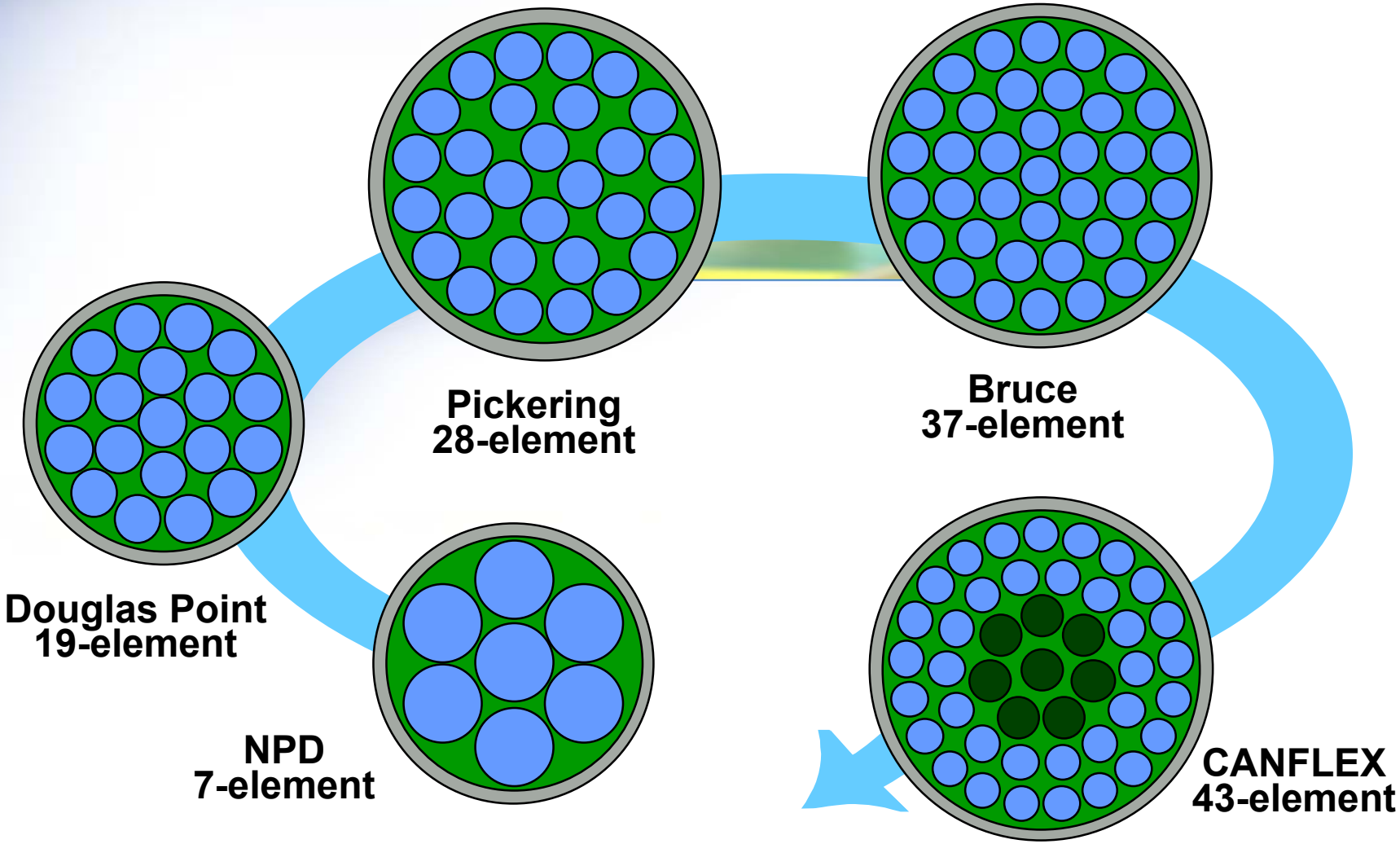


Outline

- CANDU fuel
- CANFLEX
- Extended burnup experience
- Dy-doped fuel experience
- ACR fuel qualification

Foundation for ACR fuel

Evolution of CANDU Fuel

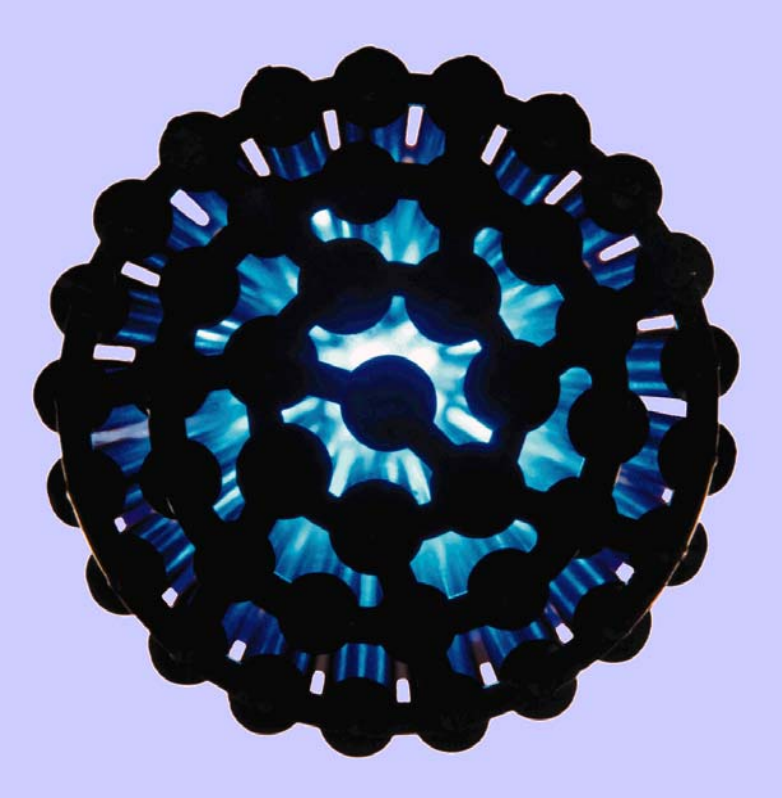


Features of CANDU Fuel

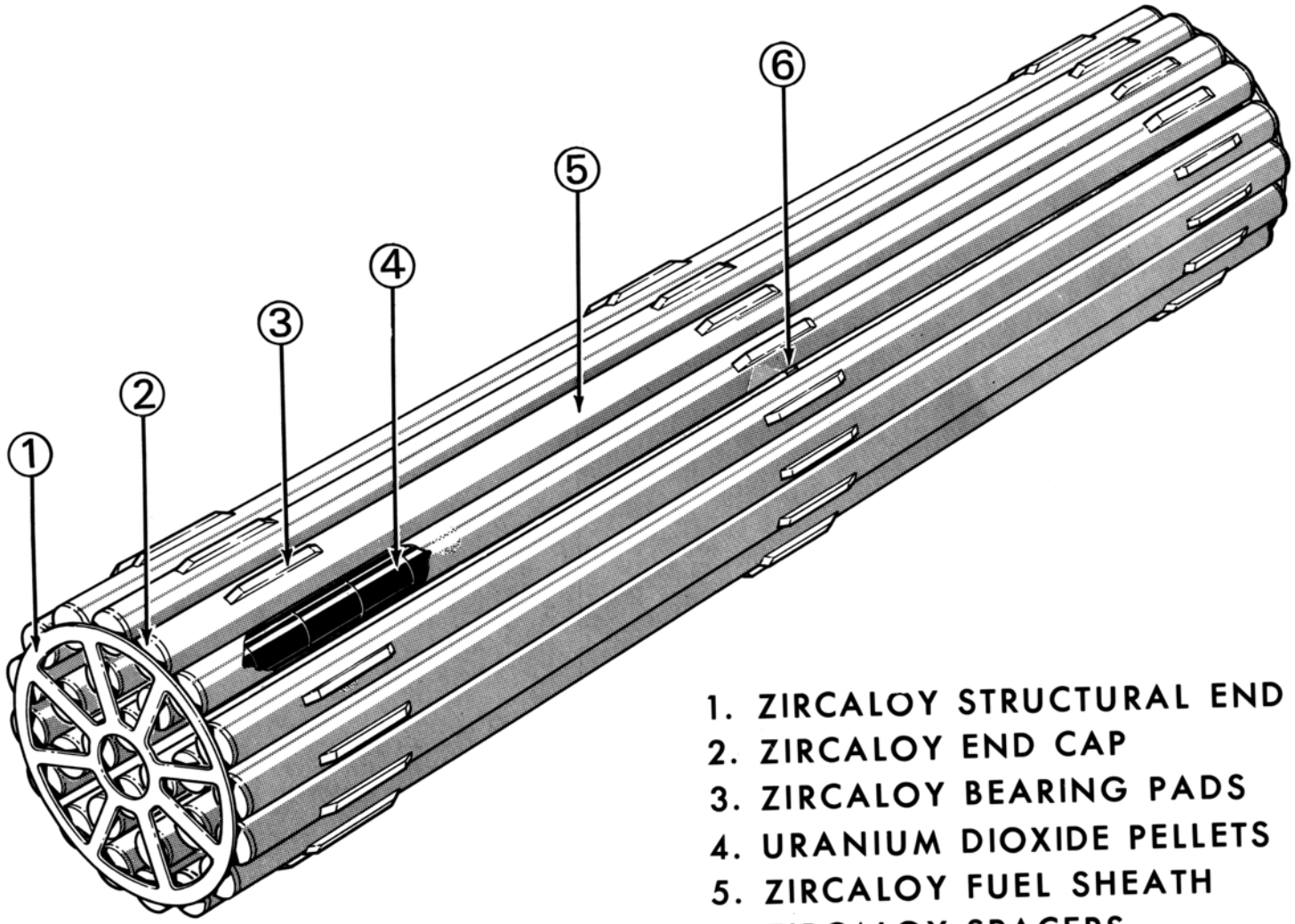
- Small
  - 50 cm (20”) length, 10 cm (4”) dia
- Lightweight
  - ~24 kg (50 lb) / bundle
- Simple in design
  - CANFLEX has 8 separate components
- Easy to manufacture
  - all countries having CANDU reactors manufacture their fuel
- Excellent performance
  - defect rate ~ 2 defects per million elements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

CANFLEX Fuel

- 43 elements, 2 pin sizes
  - 8 central elements 13.5 mm (0.53”) in diameter
  - 35 outer elements 11.5 mm (0.45”) in diameter
- ~20% lower peak rating than for 37-element fuel
  - facilitates achievement of higher burnup
- CHF-enhancing buttons
  - increase coolant turbulence
  - higher operating margins

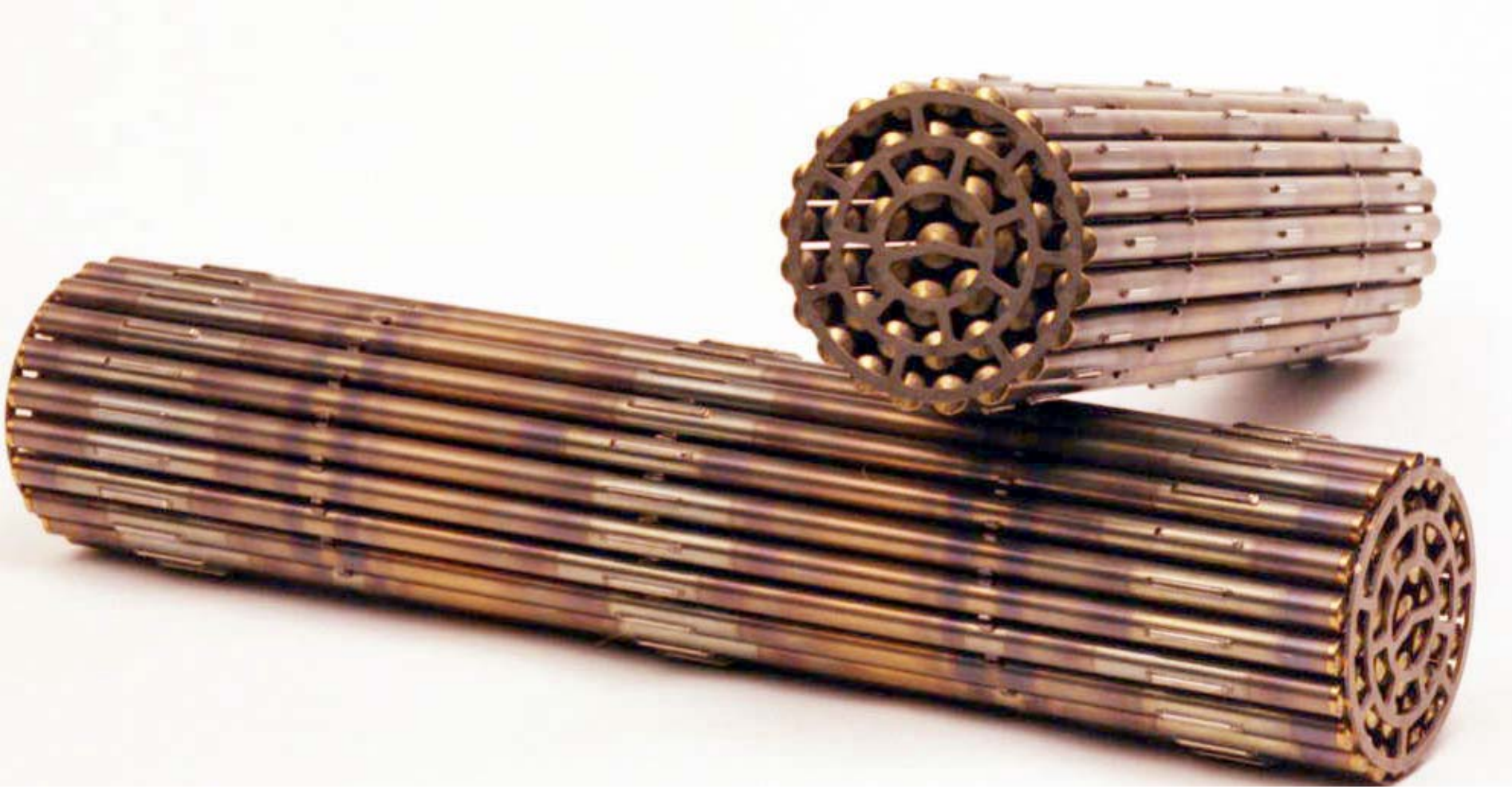


CANDU Fuel Components



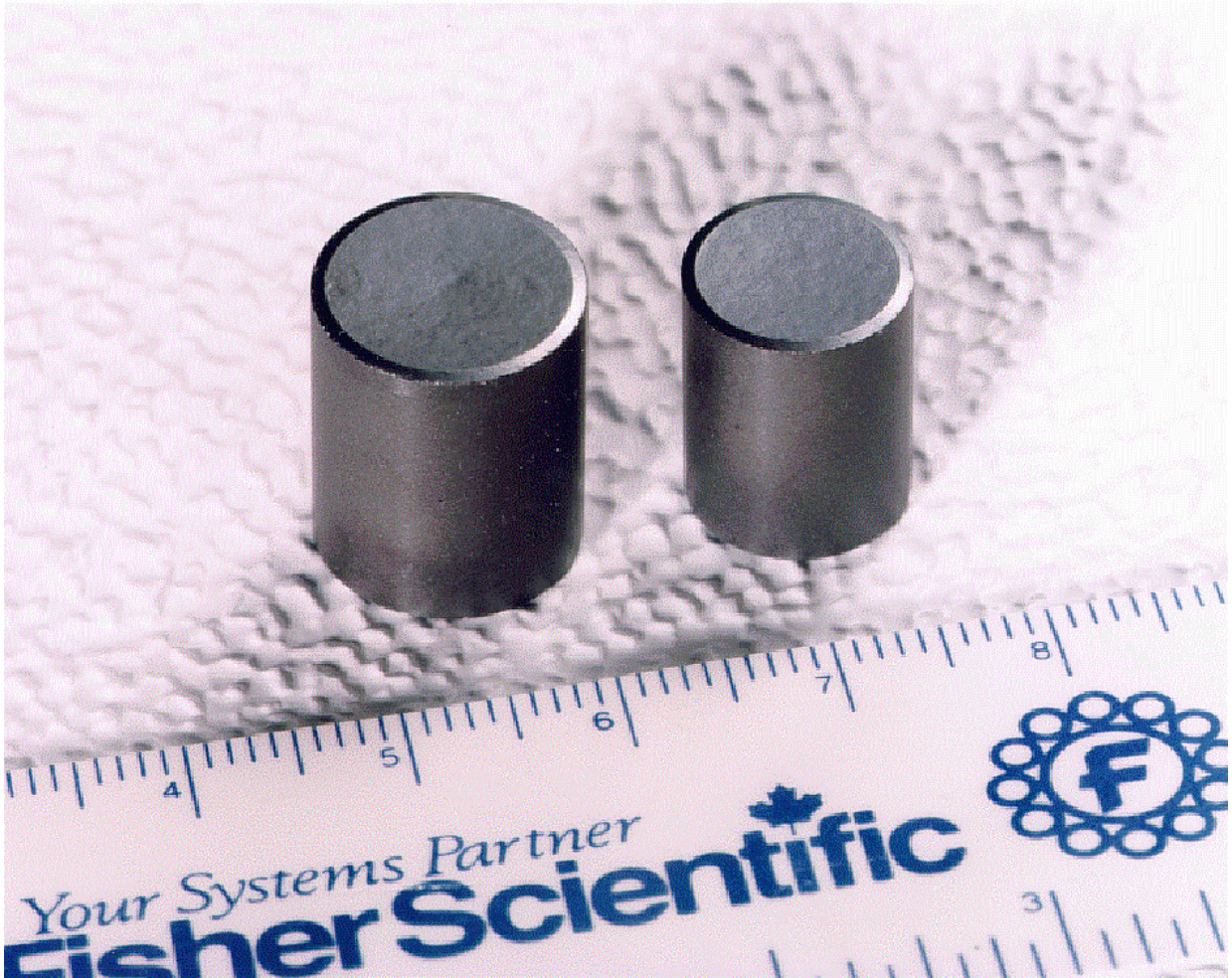
1. ZIRCALOY STRUCTURAL END PLATE
2. ZIRCALOY END CAP
3. ZIRCALOY BEARING PADS
4. URANIUM DIOXIDE PELLETS
5. ZIRCALOY FUEL SHEATH
6. ZIRCALOY SPACERS

CANFLEX Bundle



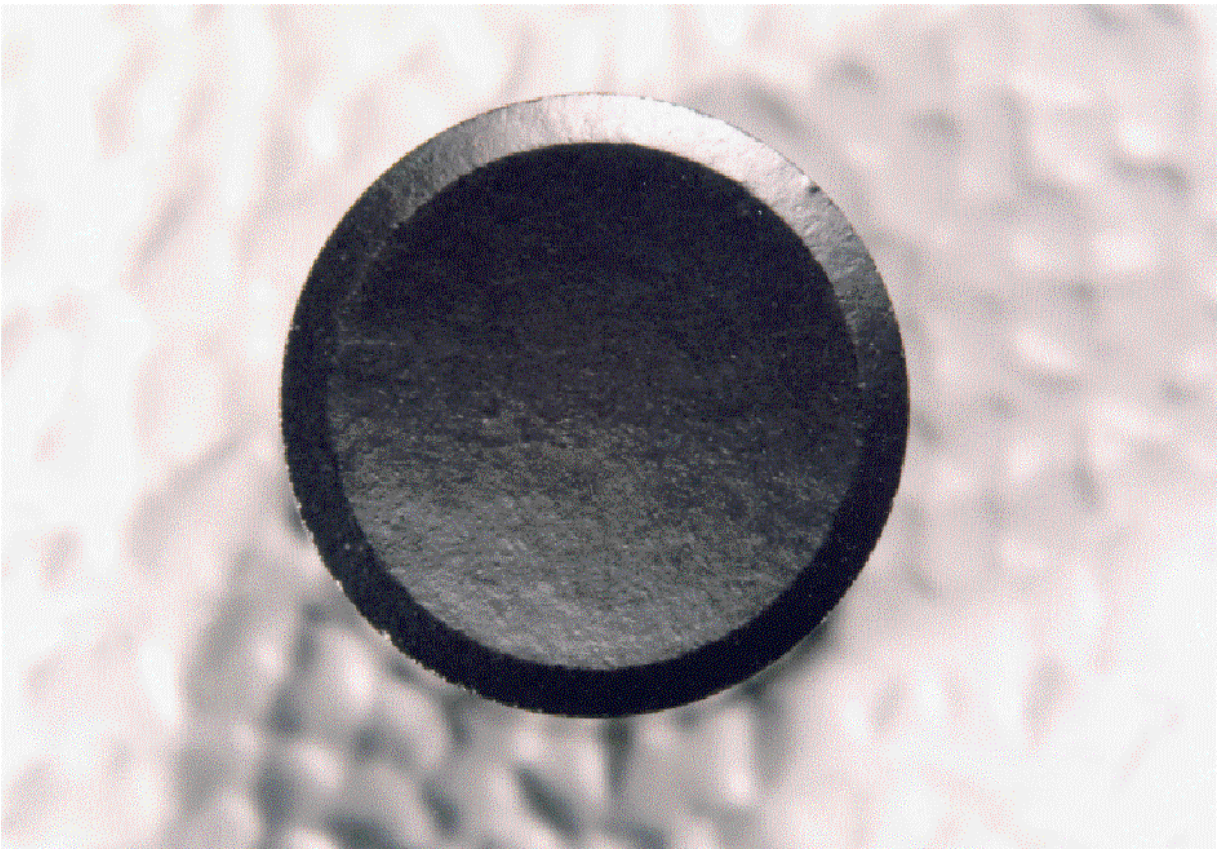
Pellets

- UO_2, high density (for dimensional stability)



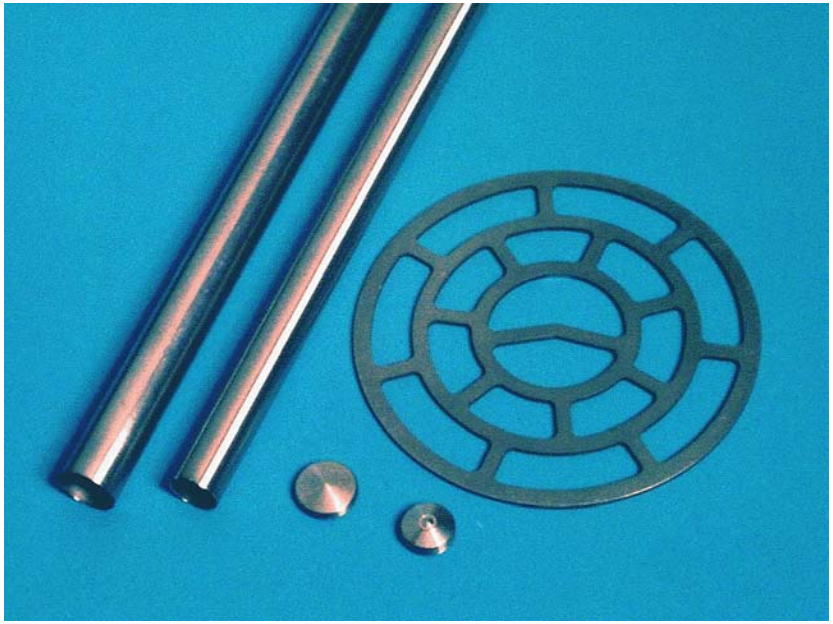
Pellets

- 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”)
  - low neutron absorption, Zr-4
- CANLUB
  - graphite coating applied to inside of clad
  - provides protection against power ramp failures
- Endcaps
  - profiled to interact with fuel channel and fuel handling components



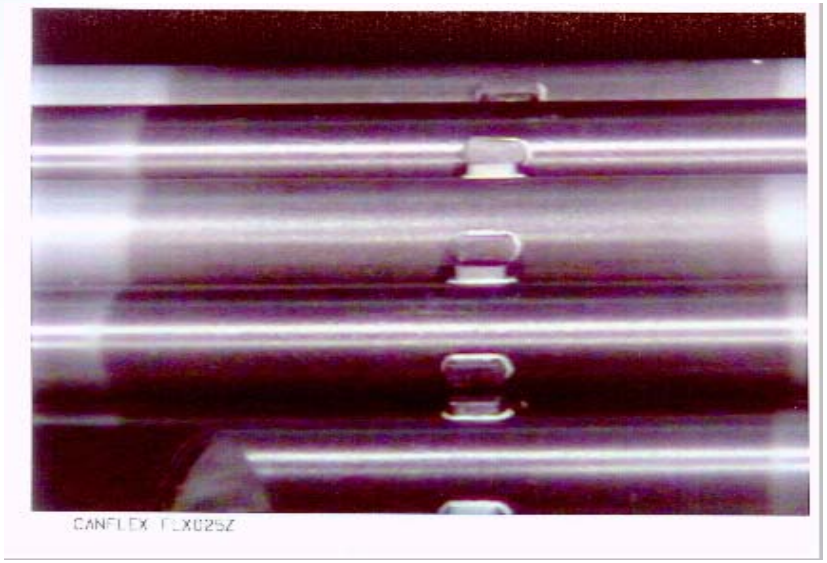
- Endplates
  - thin to minimize neutron absorption
  - flexible to accommodate fuel element differential expansion
  - strong to provide structural support and element separation

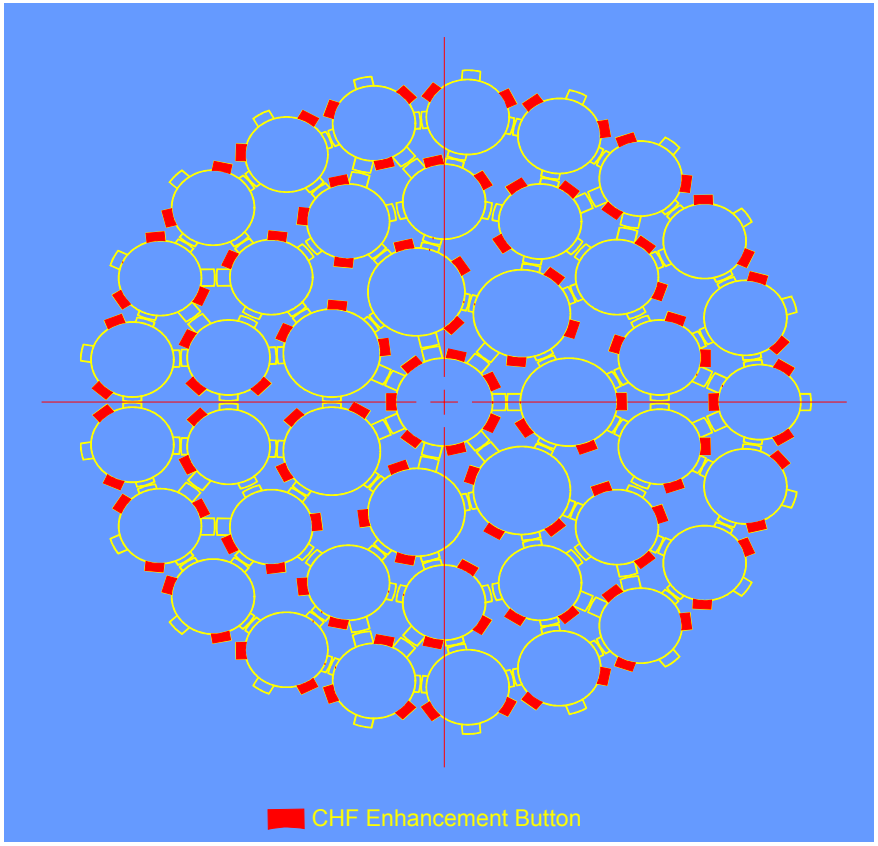
Spacers, Bearing Pads

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

CHF-enhancing Buttons

- On CANFLEX, CHF-enhancing appendages are attached to the clad on the 1/4 and 3/4 bundle planes

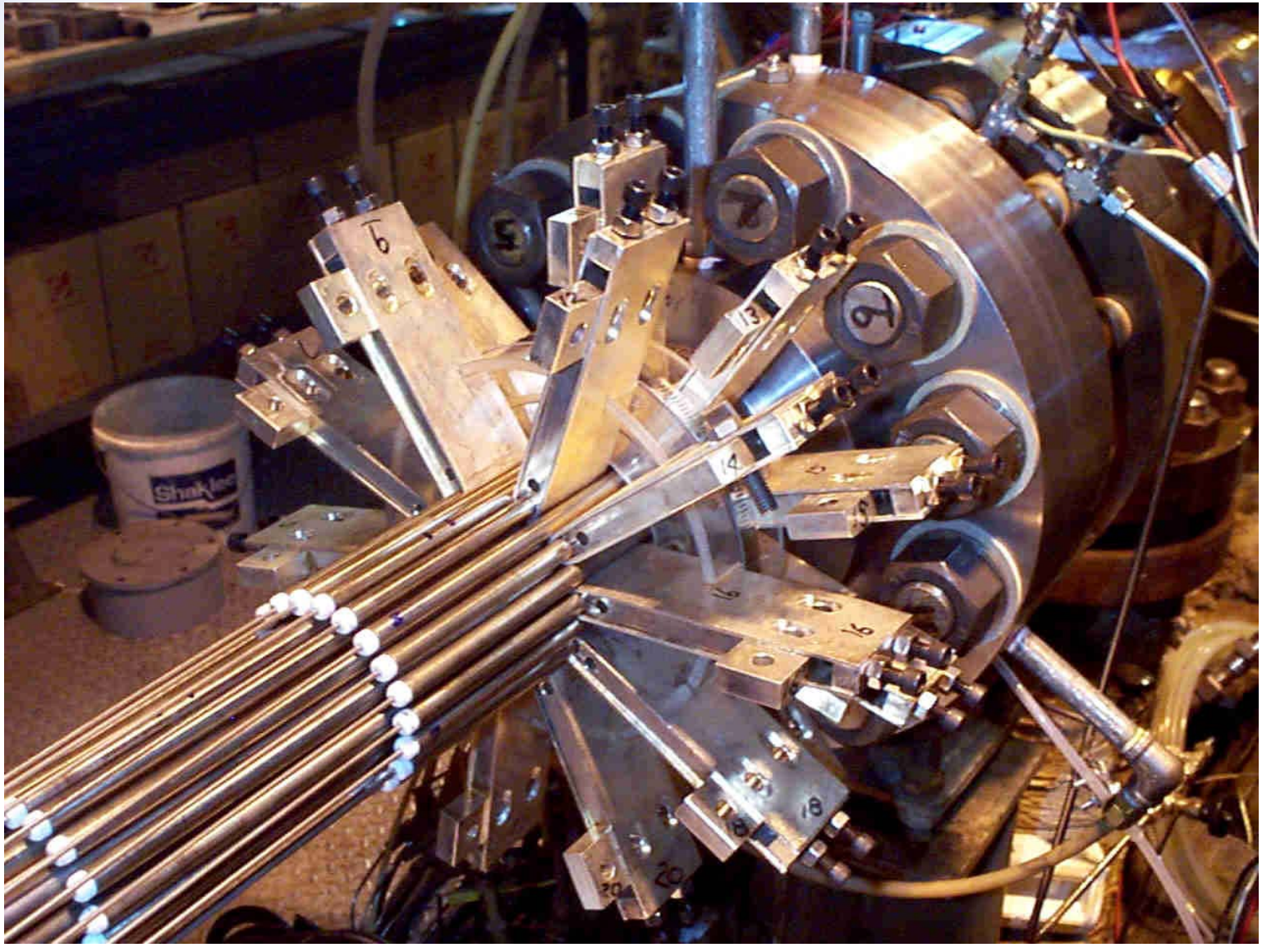




CANFLEX Mk-IV, NU Fuel Qualification

- Design requirements were documented in Design Verification Plan
- Analysis and tests confirmed that CANFLEX met all requirements
  - strength
  - impact and cross-flow tests
  - fueling machine compatibility, endurance
  - fuel performance (NRU tests)
  - CHF thermalhydraulic tests
- Demonstration irradiation (DI) in Point Lepreau 1998 to 2000
- Design qualification program documented in Fuel Design Manual
- Formal industry-wide Design Reviews conducted for demonstration irradiation and full core implementation

Power Connection for Water CHF Test

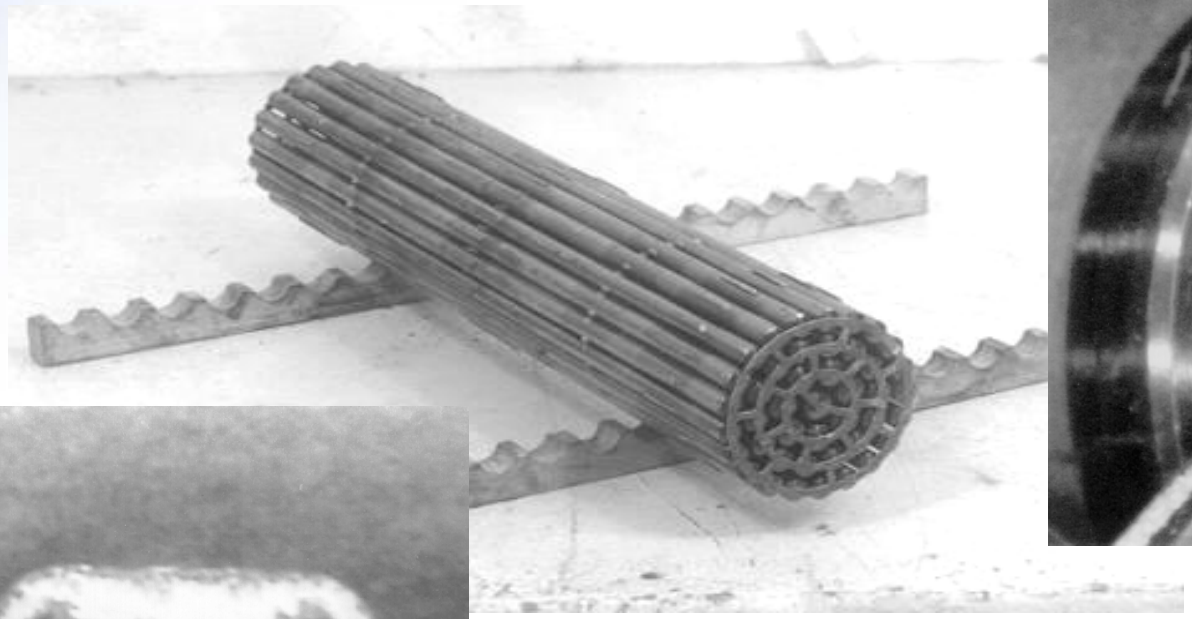


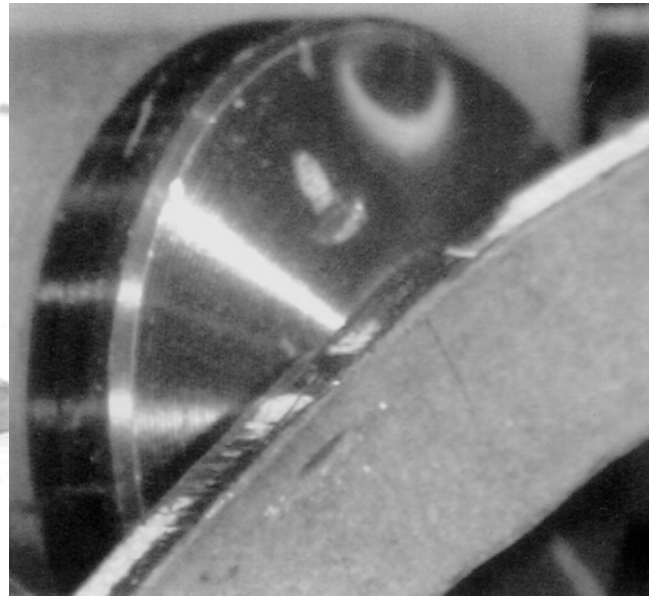
CANFLEX Demonstration Irradiation (DI)

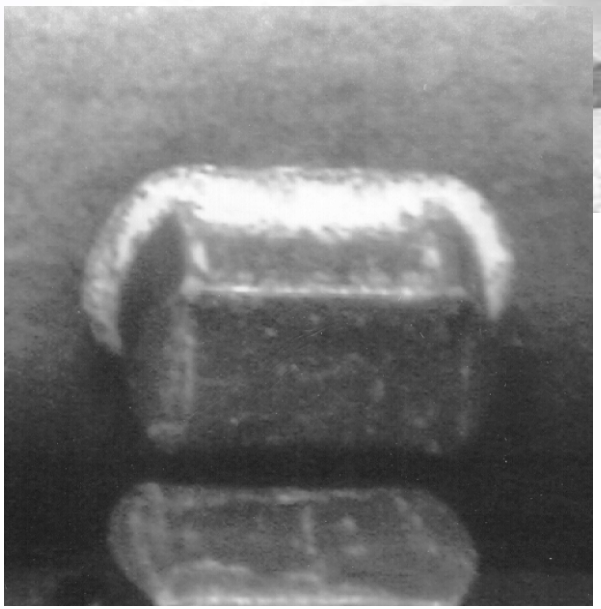
- In 2 channels in the Point Lepreau Generating Station (PLGS)
  - a high-power and low-power, instrumented channel
- All on-power refueling with CANFLEX was normal
- 24 discharged bundles were inspected visually and in normal condition for irradiated fuel
- Two bundles were examined in the hot cells at Chalk River and no abnormalities found
- All evidence showed excellent fuel performance
- As a result of DI minor changes were made to the CANFLEX design

Loading CANFLEX at PLGS Fuel Room

PIE of CANFLEX Bundle from PLGS





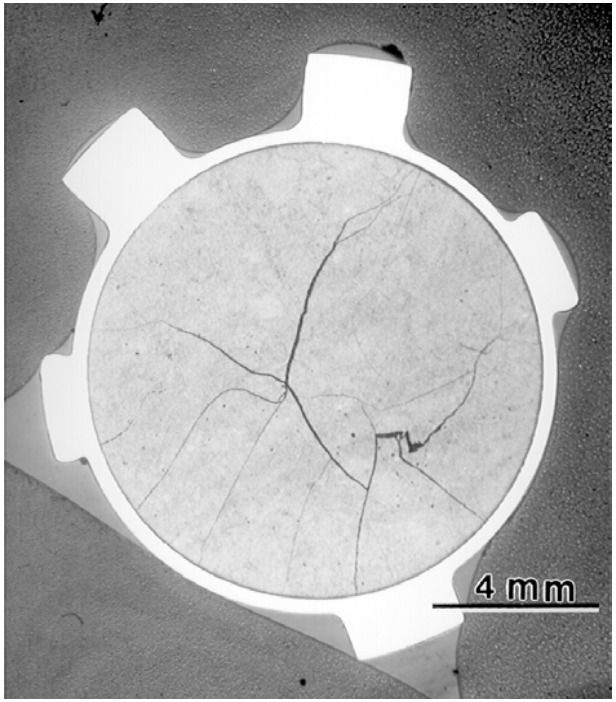


Summary for CANFLEX Mk-IV NU

- The Design Qualification process has been completed in accordance with CAN/CSA-N286.2 to meet the interface requirements of existing CANDU 6 stations

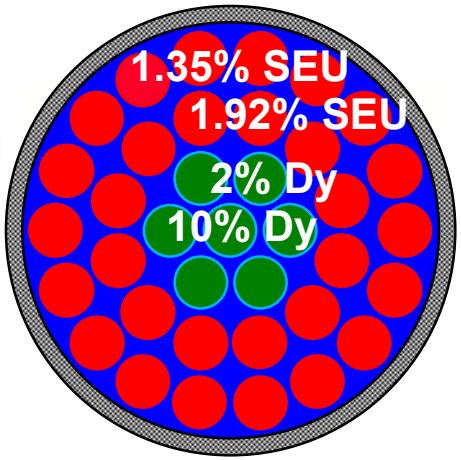
- Business case for full core implementation of CANFLEX into Gentilly 2 and Wolsong 1 being assessed

- CANFLEX is ready for full commercial implementation

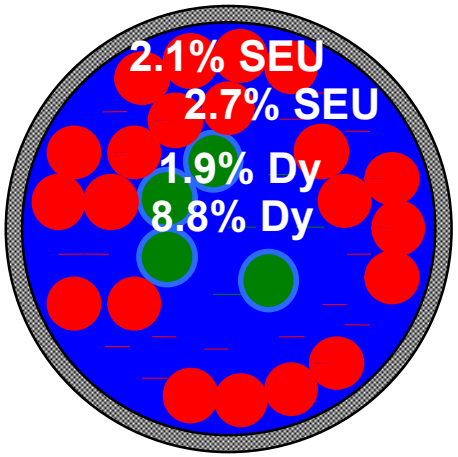


Generic Qualification of CANFLEX LVRF

- ACR fuel is variant of low void reactivity fuel (LVRF)
- Generic qualification completed for both 37-element, and CANFLEX LVRF bundles having negative void reactivity
  - ZED-2 tests, fuel fabrication, irradiation and PIE, thermalhydraulic testing



37-element LVRF



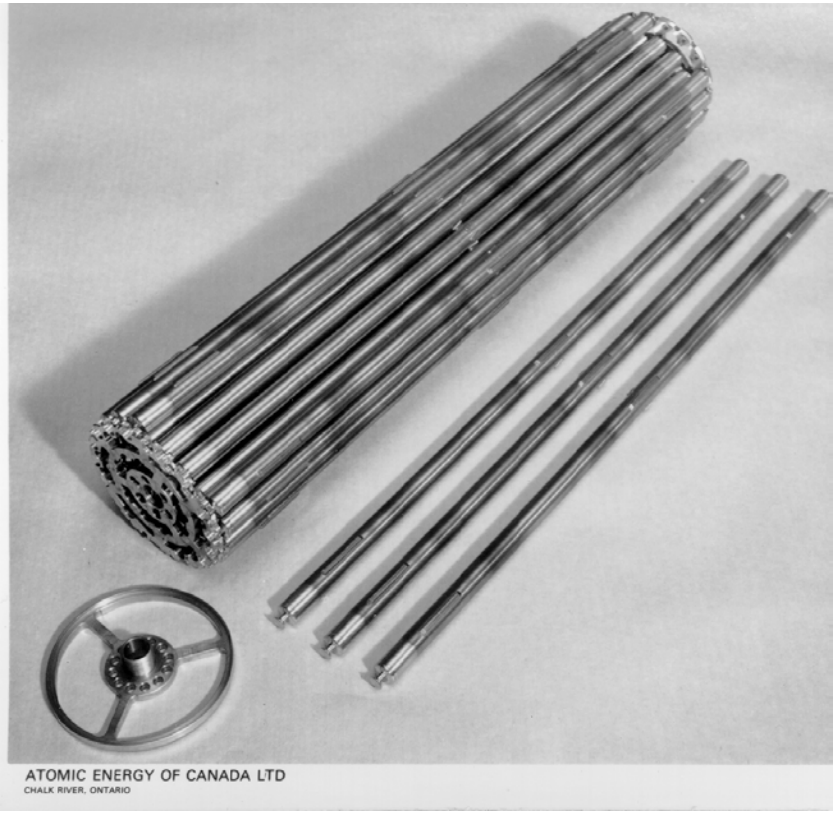
CANFLEX LVRF

Extended Burnup Irradiation Experience

- Power reactor experience:
  - >230 37-element bundles achieved burnups > 17 MWd/kg in Bruce A
- Research reactor experience:
  - >24 bundle and element irradiations in NRU > 17 MWd/kg
- Good fuel performance in ACR assured
  - the ACR power envelope is well below the high power envelope for which we have experience
  - ACR fuel design is optimized for extended burnup, based on our experience base

AECL Experience with Dy-Doped Fuel

- Demountable elements irradiated in NRU with Dy levels of 1 to 15%
- No changes in microstructure
- Low fission gas release, typical of that in UO_2 under similar power histories
- 2 37-element and 2 43-element LVRF bundles also irradiated in NRU



ACR Fuel Design Features

- Some ACR fuel requirements
  - operate at higher coolant temperatures and pressures
  - perform well at required burnups and ratings
  - be dimensionally compatible with the fuel channel and fuel handling systems
  - achieve higher critical heat flux margins
- Design differences in ACR fuel from CANFLEX Mk IV
  - thicker clad
  - higher fissile content
  - lower length-to-diameter (L/D) pellets with larger chamfers
  - improved clad/endcap weld geometry
  - longer & taller bearing pads

ACR Fuel Qualification

- Design Verification Plan: specifies
  - the qualification, development & design verification activities required
  - the process of confirming that the requirements are complete and that the design satisfies these requirements
- Qualification will be done under N286.2 QA program

ACR Fuel Qualification Activities

- NRU irradiations
- Thermalhydraulic tests
  - pressure drop, CHF, PDO measurements; in water and Freon-134
- Out-reactor mechanical tests
  - flow endurance, sliding wear, “bent-tube” gauge, fueling machine compatibility, fuel handling, strength, refueling impact, inlet and outlet cross flow, autoclave
- Analytical assessments (fuel performance, bundle mechanical performance)

Summary

- CANDU fuel has performed extremely well
- ACR fuel builds on an extensive experience base
- Key design aspects of ACR fuel have been demonstrated
  - CANFLEX geometry
  - enriched fuel (extended burnup performance)
  - Dy-doped fuel performance
- ACR fuel qualification will be facilitated through recent AECL experience in fuel qualification
  - CANFLEX Mk IV fuel with natural uranium
  - generic qualification of CANFLEX-LVRF

AECL

TECHNOLOGIES INC.