# ACR Fuel

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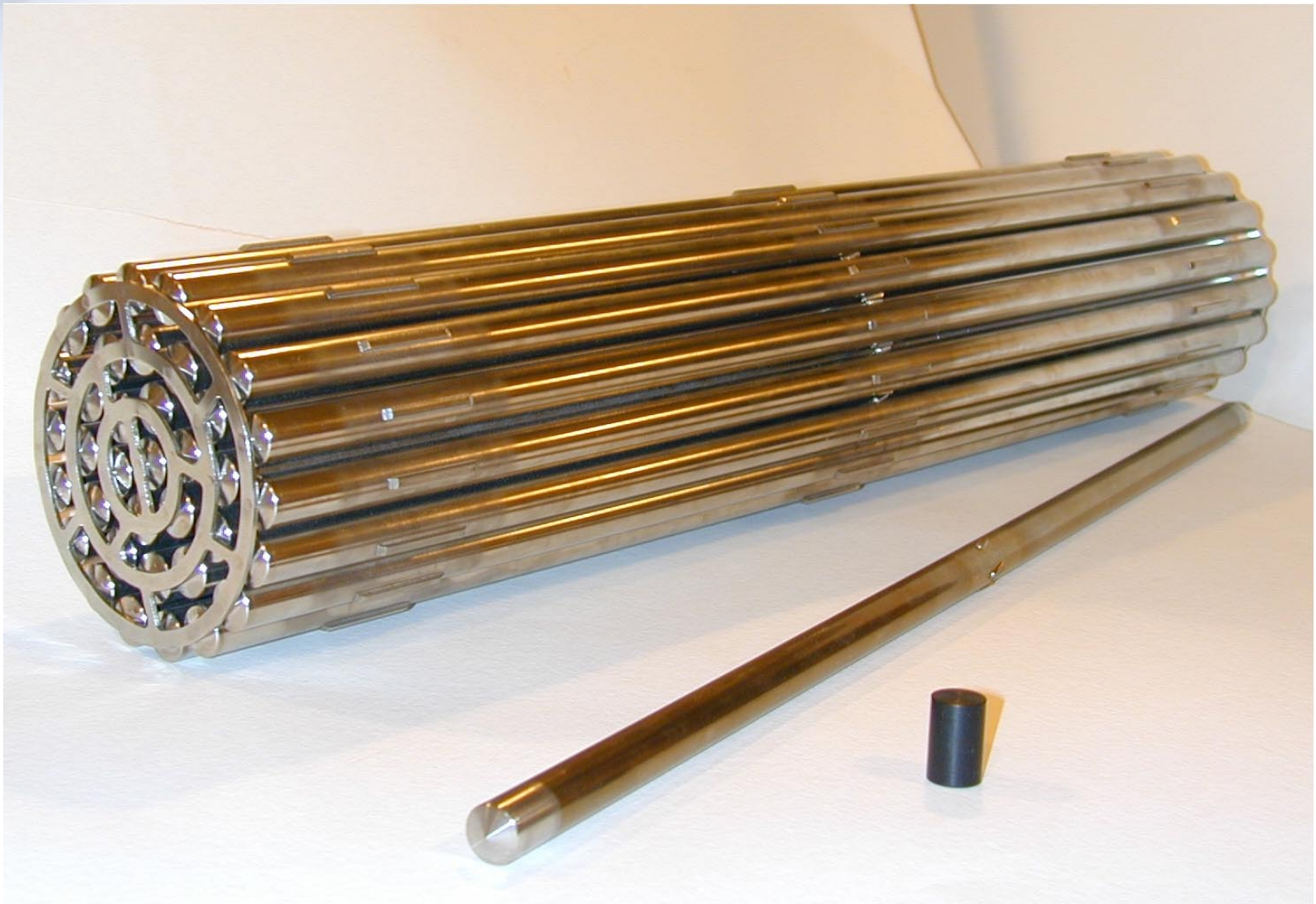
# Outline

- Introduction to CANDU fuel
- ACR fuel design
- Experience relevant to ACR fuel
  - CANFLEX
  - extended burnup experience
  - low void reactivity fuel
- ACR fuel qualification

# Characteristics of CANDU Fuel

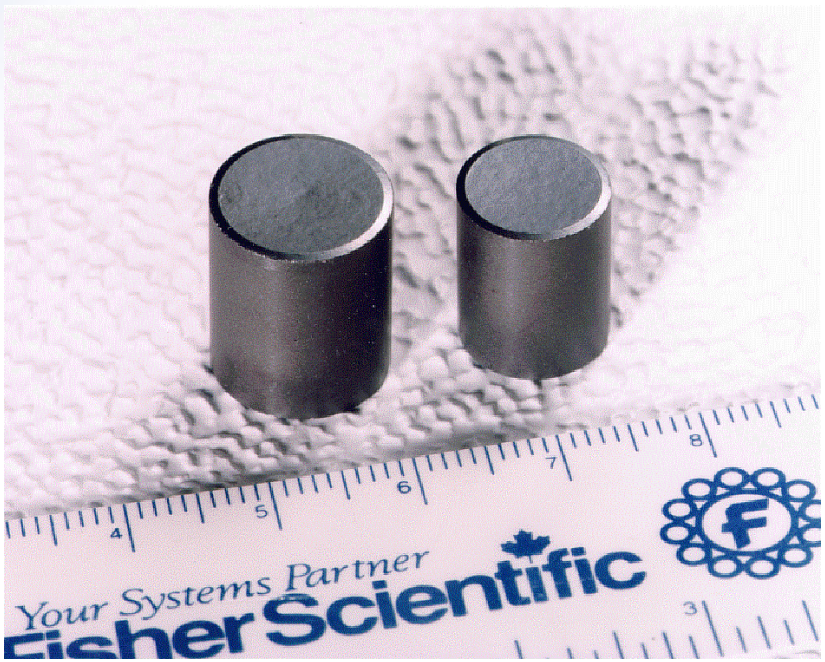
- Small, simple, light-weight
  - 20” length, 4” dia, 50 lb / bundle
  - CANFLEX has only 8 components
- Inexpensive
  - low fuel cycle costs (dollars/unit energy)
- Efficient
  - good use of uranium
- Excellent performance
  - ~ 2 million bundles fabricated; ~ 2 clad defects per million elements
  - on-power defect detection, location and removal
- Easy to manufacture and localize
  - CANDU fuel is manufactured domestically in 7 countries
  - CANDU (and its fuel) licensed in many different regulatory jurisdictions

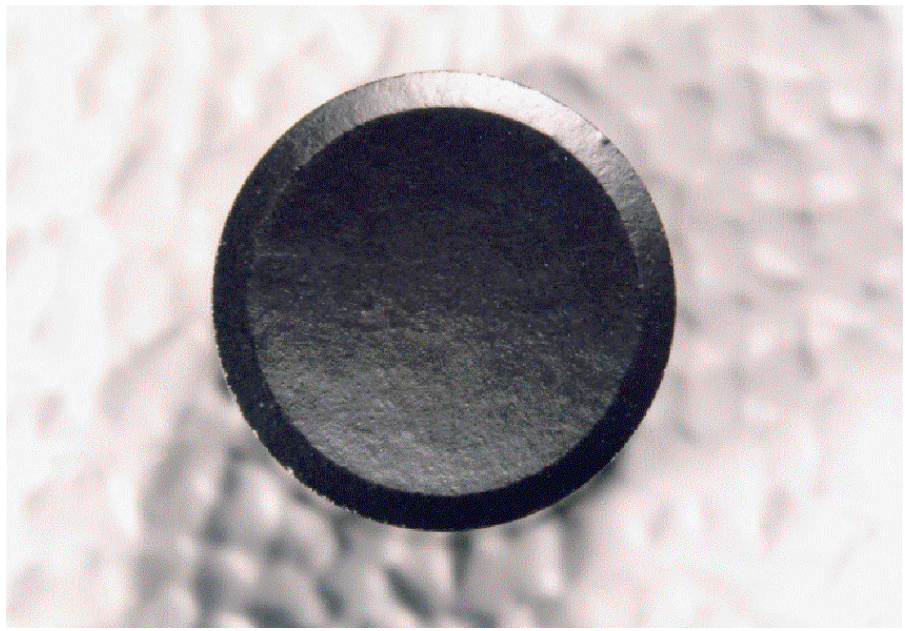
# CANDU 6  37-element Fuel



# $UO_2$ Pellets

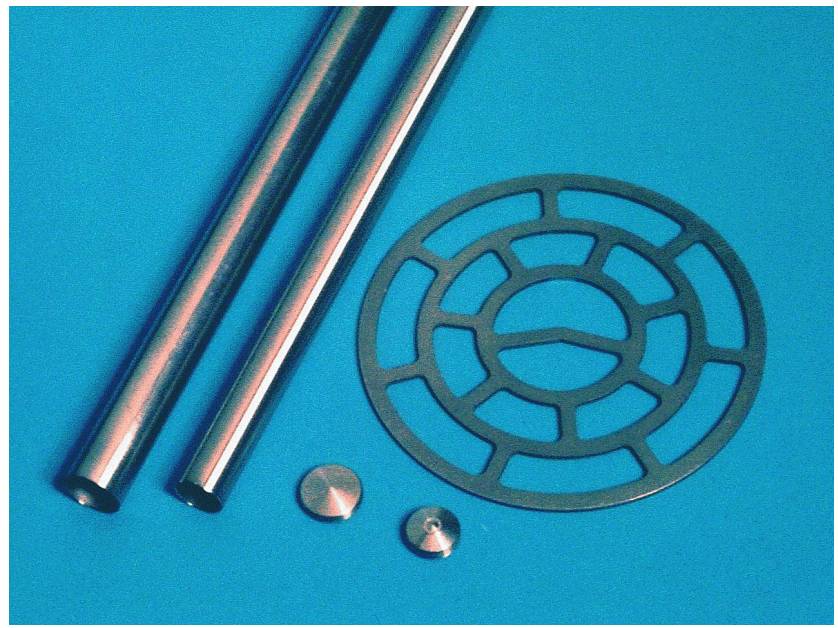
- $UO_2$, high density (for dimensional stability)
- Chamfers and end-dishes (reduce inter-pellet stresses on clad, volume for fission gas)



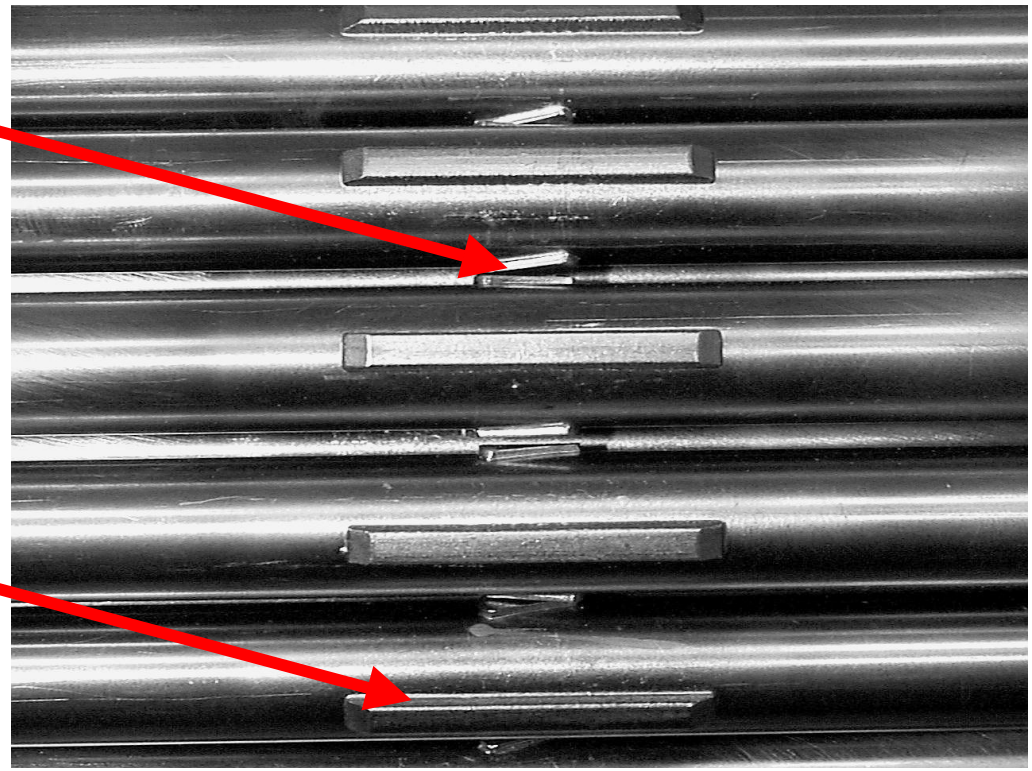
# Clad, CANLUB, Endcaps, Endplates

- Clad
  - thin, collapsible (~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 and ductile to provide structural support and element separation



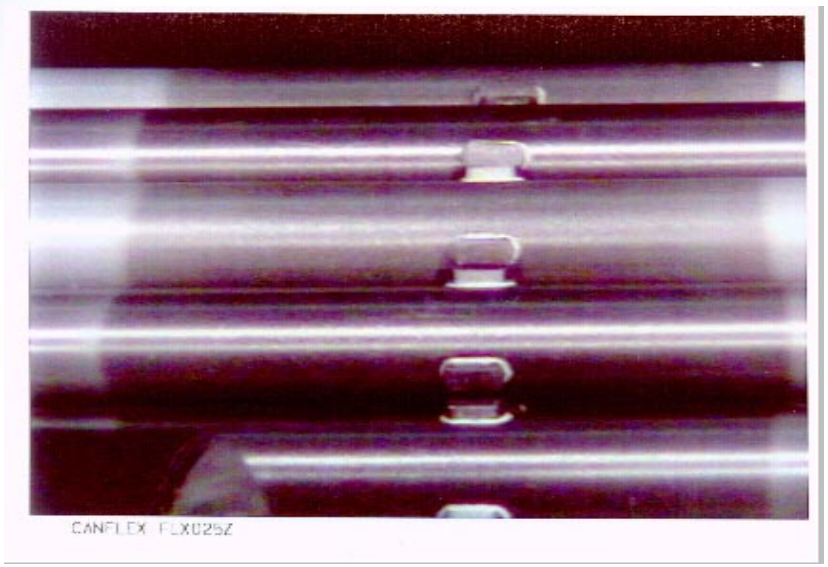
# Spacers, Bearing Pads

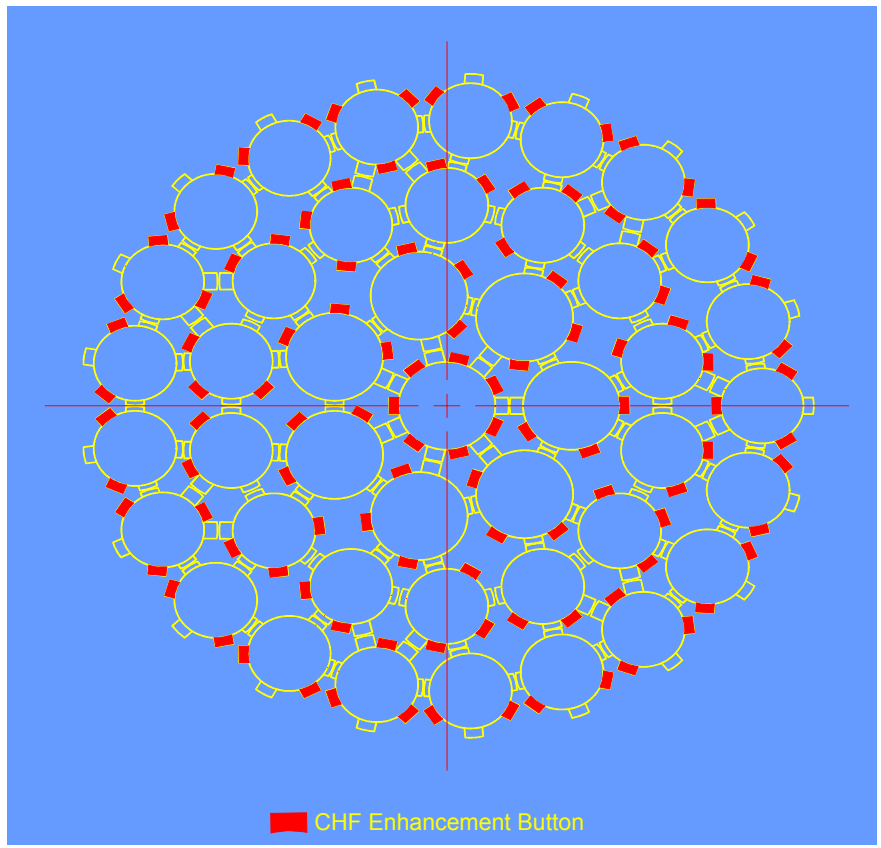
- Inter-element spacers
  - provide element separation at the bundle midplane
- Bearing pads
  - provide element-to-pressure tube separation



# CHF-Enhancing Buttons (CANFLEX)

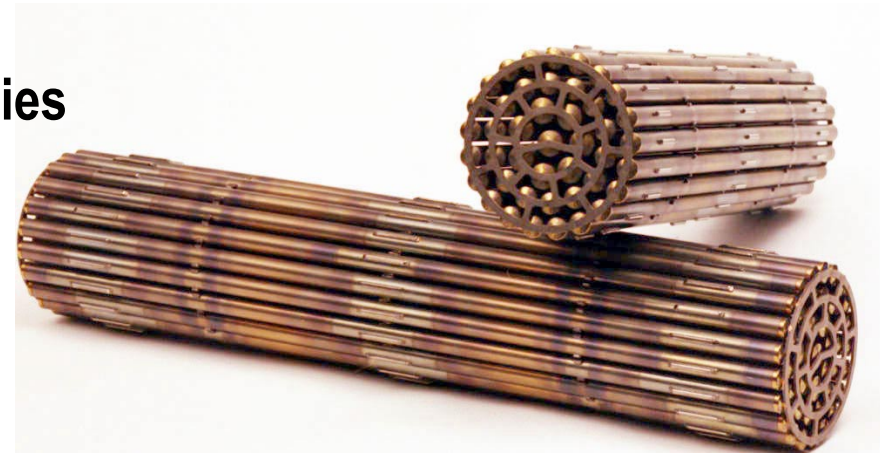
- Appendages are attached on the 1/4 and 3/4 bundle planes



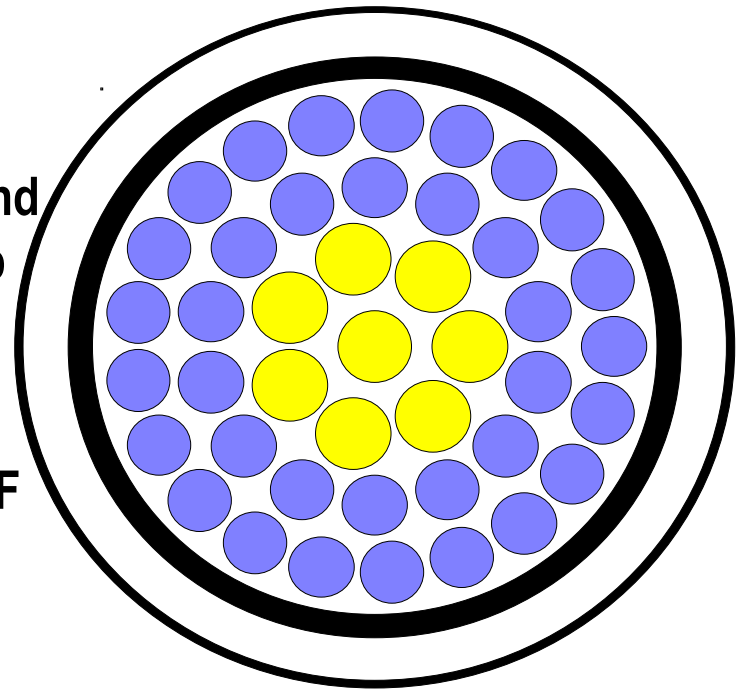
# ACR Fuel Design

- Evolutionary extension of current fuel
  - extensive experience base on underlying technologies
- Based on 3 underlying technologies
  - CANFLEX geometry
  - low void reactivity fuel
  - extended burnup
- Key design features
  - 2.1% $U^{235}$ in outer 42 elements
  - 7.5% Dy in nat. $UO_2$ in central element
  - 21 MWd/kg burnup

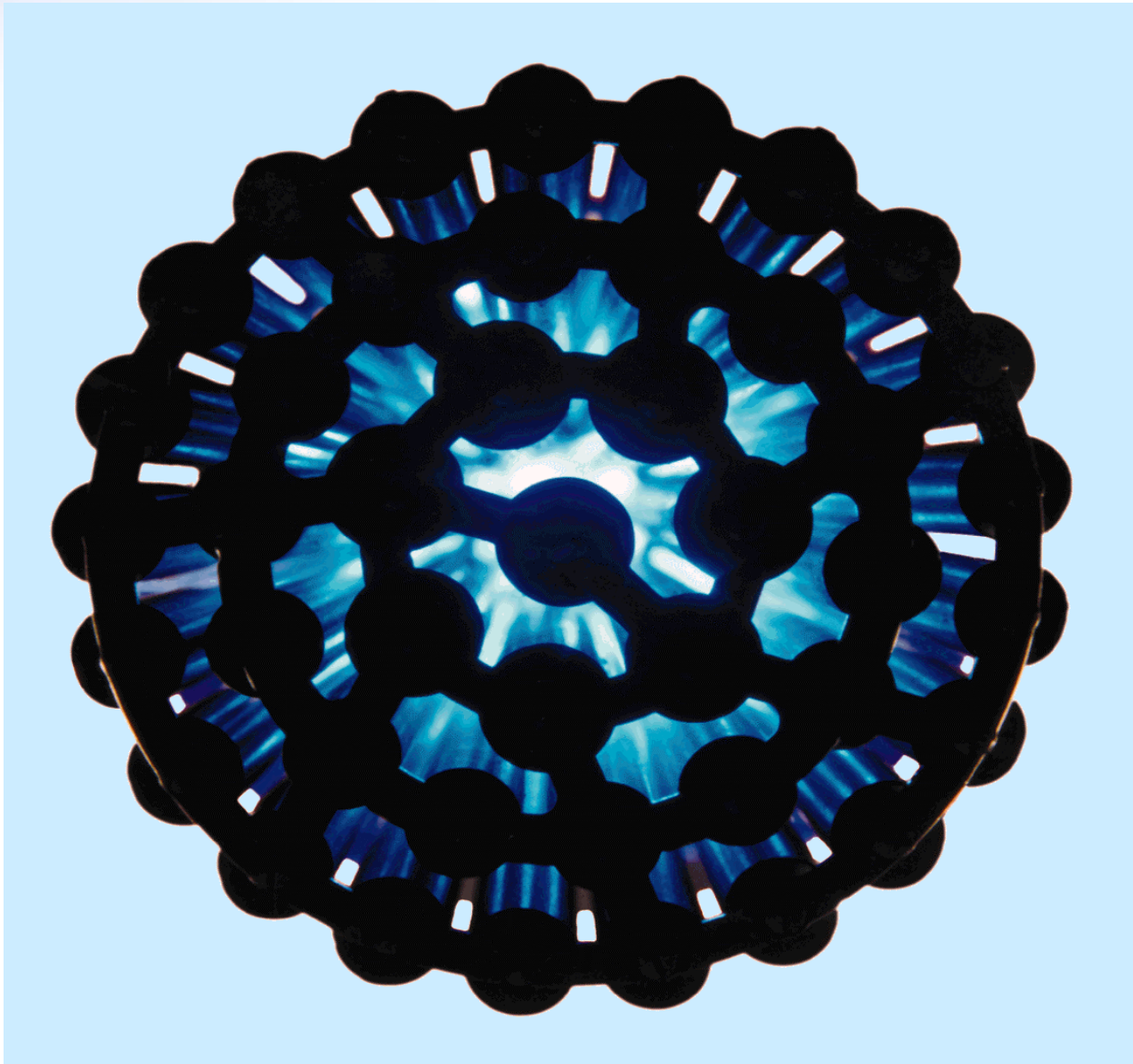


# CANFLEX Geometry

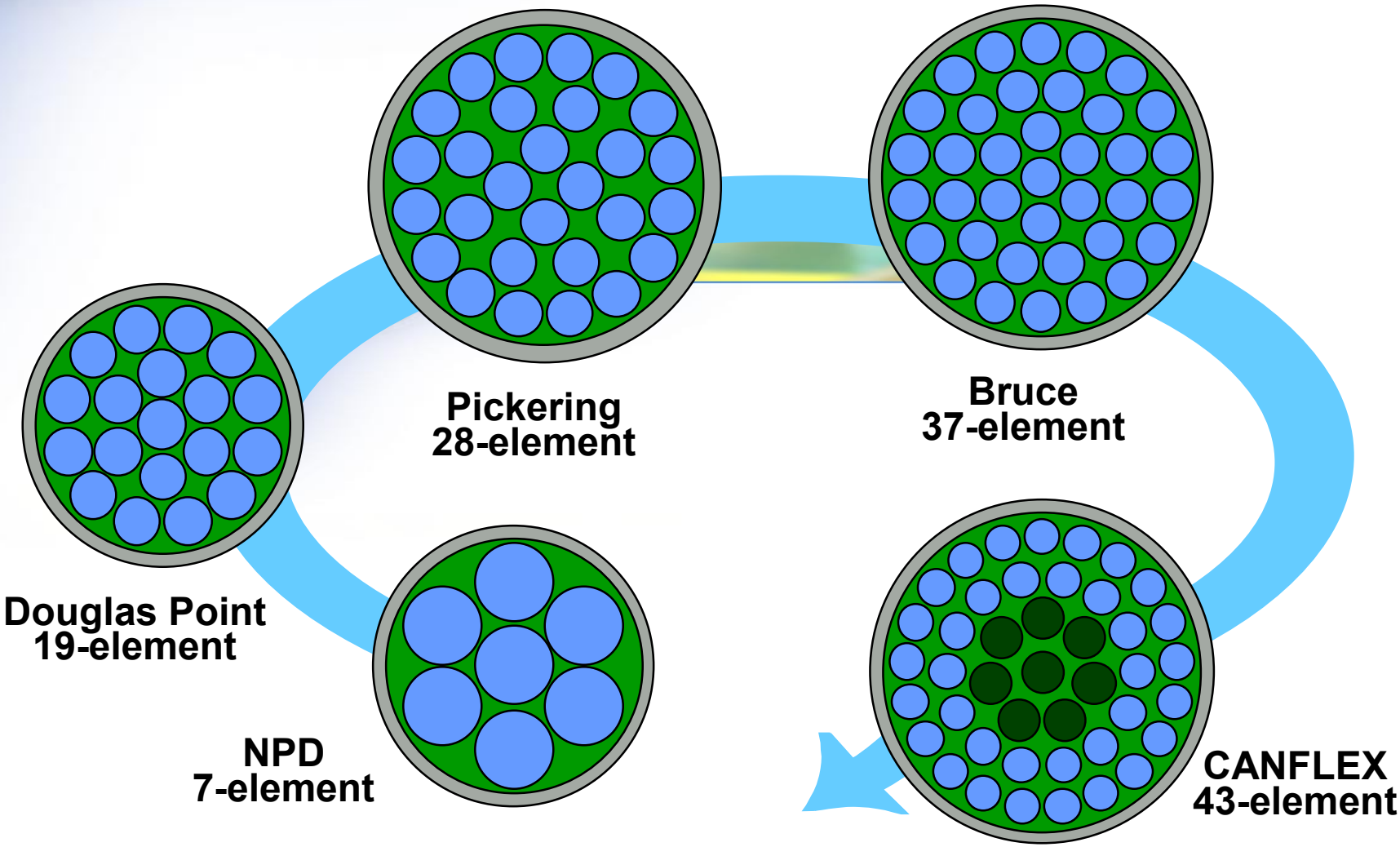
- ACR fuel based on CANFLEX Mk IV geometry
  - 43 elements, 2 element sizes
  - greater “subdivision” reduces ratings and facilitates achievement of higher burnup
  - “buttons” increase CHF
  - qualified for NU fuel
  - higher bearing pads further improve CHF compared to Mk IV



# CANFLEX Geometry



# Evolution of CANDU Fuel



# Other Design Features

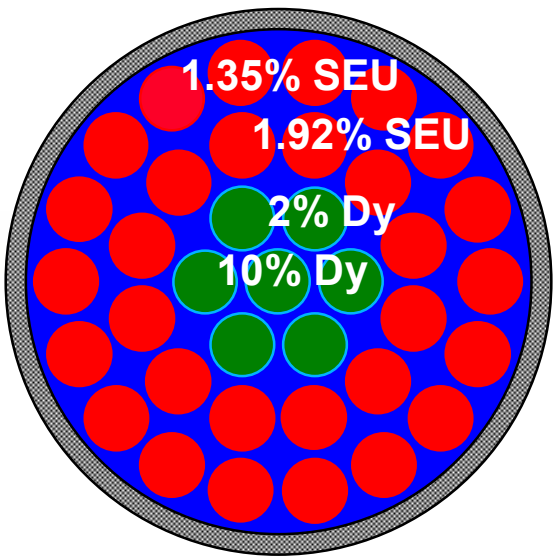
- Optimized pellet design
  - in smaller elements (highest ratings)
    - larger chamfers, deeper dishes, shorter pellets
    - more internal void for accommodating fission gas release
    - reduces inter-pellet clad strain
- Slightly thicker clad
  - to accommodate higher coolant pressures and temperatures

# Summary of CANFLEX NU Qualification

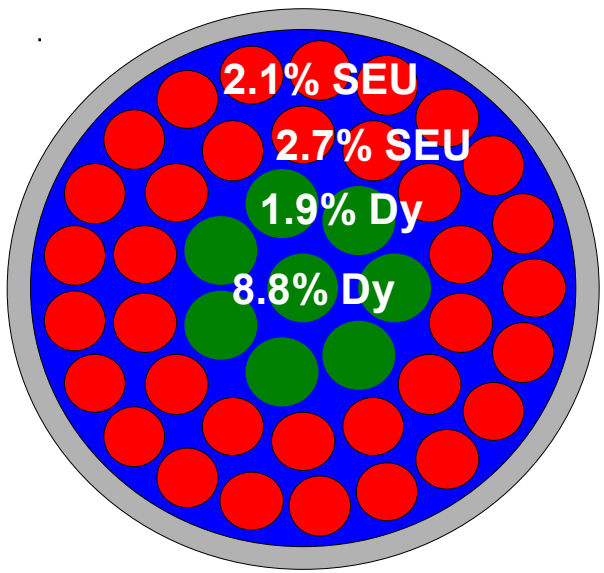
- Design requirements documented in Design Requirements, Design Verification Plan
- Tests and analysis confirmed that CANFLEX met all requirements
  - strength
  - impact and cross-flow
  - fueling machine compatibility, endurance
  - sliding wear
  - fuel performance (NRU irradiations)
  - CHF thermal hydraulic
- Demonstration Irradiation (DI) in Point Lepreau 1998 to 2000
  - 2 channels, 24 bundles
  - irradiation of 24 bundles currently taking place in Wolsong 1
- Design qualification program documented in Fuel Design Manual
- Ready for commercial implementation in CANDU 6 reactor

# Experience with Low Void Reactivity Fuel

- ACR fuel is variant of LVRF
- Generic testing done for
  - 37-element LVRF (NU burnup, with negative void reactivity in CANDU 6)
  - CANFLEX LVRF (3x NU burnup, with negative void reactivity in CANDU 6)




37-element LVRF




CANFLEX LVRF

# Overview of LVRF Testing

- $Dy_2O_3$ -$UO_2$ pellet fabrication
  - measurement of thermal properties
  - corrosion behavior of $UO_2$
- Bundle fabrication
- Irradiation testing in NRU & PIE
  - Dy-doped demountable elements with Dy levels of 1 to 15%
  - prototype bundles
- Reactor physics
  - ZED-2 measurements
    - void reactivity
    - fine structure
  - WIMS validation
- Thermalhydraulics
  - measurements
  - modeling
- Safety experiments
  - interactions with Zircaloy
  - grain-boundary inventory

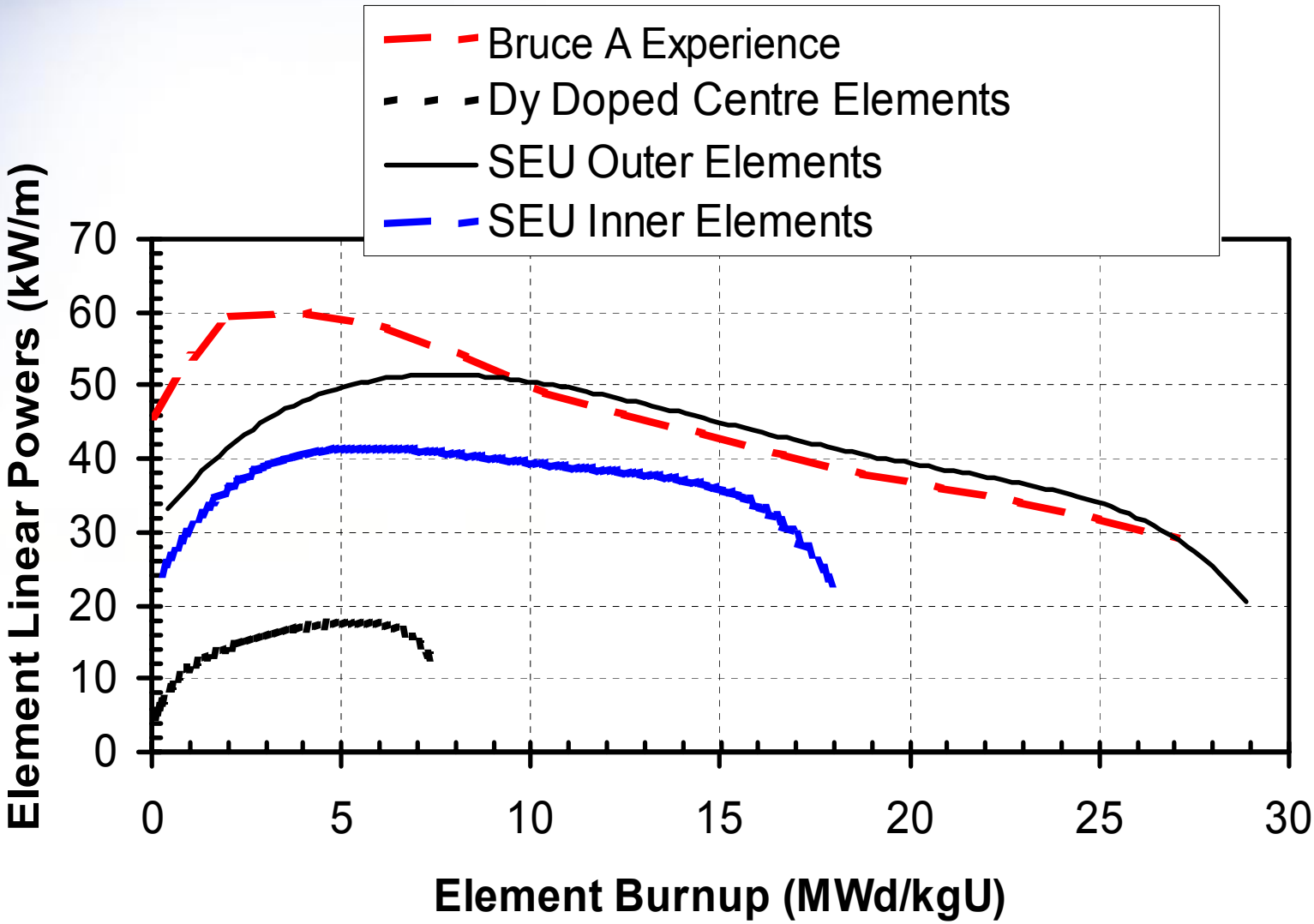
- CANFLEX LVRF currently being qualified for Bruce Power implementation
  - enrichment, Dy content tailored to meet station needs
  - synergistic with ACR fuel qualification

# 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
    - 15 irradiations with burnups greater than 21 MWd/kg
  - 10 of 24 irradiations also experienced power ramps
  - several irradiations ongoing
- Qualified irradiated fuel databases
  - 28-element, 37-element and CANFLEX
- Good confidence in ACR fuel performance based on our experience
  - ACR power envelope is below the high power envelope for which we have experience
  - ACR fuel pellet design is optimized for extended burnup, based on our experience base and assessments

# NRU Fuel String

# ACR Power Envelope vs. Bruce A Experience



# ACR Fuel Qualification

- Will ensure ACR has full thermal integrity, structural integrity, and compatibility with interfacing systems
- Comprehensive, integrated set of in-reactor tests, out-reactor tests, and analyses
- Qualified computer facilities, codes, and staff
- US fuel consultants providing guidance

# 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

# Summary

- ACR fuel builds on an extensive experience base
  - CANFLEX geometry
  - low void reactivity fuel
  - enriched fuel (extended burnup performance)
- ACR fuel qualification will be facilitated through recent AECL experience in fuel qualification
  - CANFLEX Mk IV fuel with natural uranium
  - current qualification of CANFLEX-LVRF for Bruce Power
- ACR fuel qualification will entail out-reactor tests, in-reactor tests, and analyses
- Numerous background papers on CANDU fuel have been sent to US NRC
- ACR fuel report, summarizing ACR fuel design, experience base, fuel design requirements, and qualification plan will be sent to US NRC shortly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