ACR Workshop
-Core Design & Reactor Physics-

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Outline

- Overview of ACR Characteristics
- Major differences between current CANDU and ACR
  - Coolant
  - Fuel
  - Lattice Pitch
- Core Physics of ACR
  - Negative Coolant Void Reactivity
  - Negative Power Feedback Reactivity Coefficients
  - Enhanced Control & Safety Characteristics
  - Stable Operation at All Power Levels
- Summary

Reactivity Effects in ACR-700

Parameter	Value
Moderator Temperature (including density) effect	-0.013 (mk/°F)
Coolant Temperature (including density) effect	-0.006 (mk/°F)
Fuel Temperature effect	-0.008 (mk/ °F)
Power Coefficient (95% -105% full power)	-0.07 mk/% power
Reactivity change from 0% to 100% full power	-8.0 mk
Boron effect in Moderator	-2.1 (mk/ppm)
Full-Core Coolant-Void Reactivity	-3.0 mk

ACR –700 Core Characteristics

Parameter	Value
Number of fuel channels	284
Reactor thermal power output	1982 MW
Gross Electrical Power output	731 MW
Lattice Pitch (square)	22 cm (8.7 inches)
Coolant	H_2O @ 300 ^oC (572 ^oF)
Moderator	D_2O @ 80 ^oC (176 ^oF)
Enrichment of CANFLEX SEU Fuel	2.0%SEU (42 pins)+ NU/Dy
Core-Average Fuel Burnup	20.5 MWd/kg(U)
Max. Fuel Element burnup	26 MWd/kg(U)
Fuel Bundles Required per FPD	5.8
Channel Visits per FPD (2-bundle-shift scheme)	2.9
Max. Time-Average Channel Power (power form factor 0.93)	7.5 MW(th)
Max. Time-Average Bundle Power	874 kW(th)
Max. Instantaneous Linear Element Rating	51 kW/m

ACR-700 Reactor Control & Safety Systems

Control System

- 9 Mechanical Control Assemblies with 2 segments per assembly
  - 9 mk worth for bulk- and spatial-control functions
  - 12 minutes of xenon override time
  - power cycling from 100% -75% -100%,
  - reactivity for about 7 full-power days without refueling.
- 4 Mechanical Control Absorbers for fast power reduction

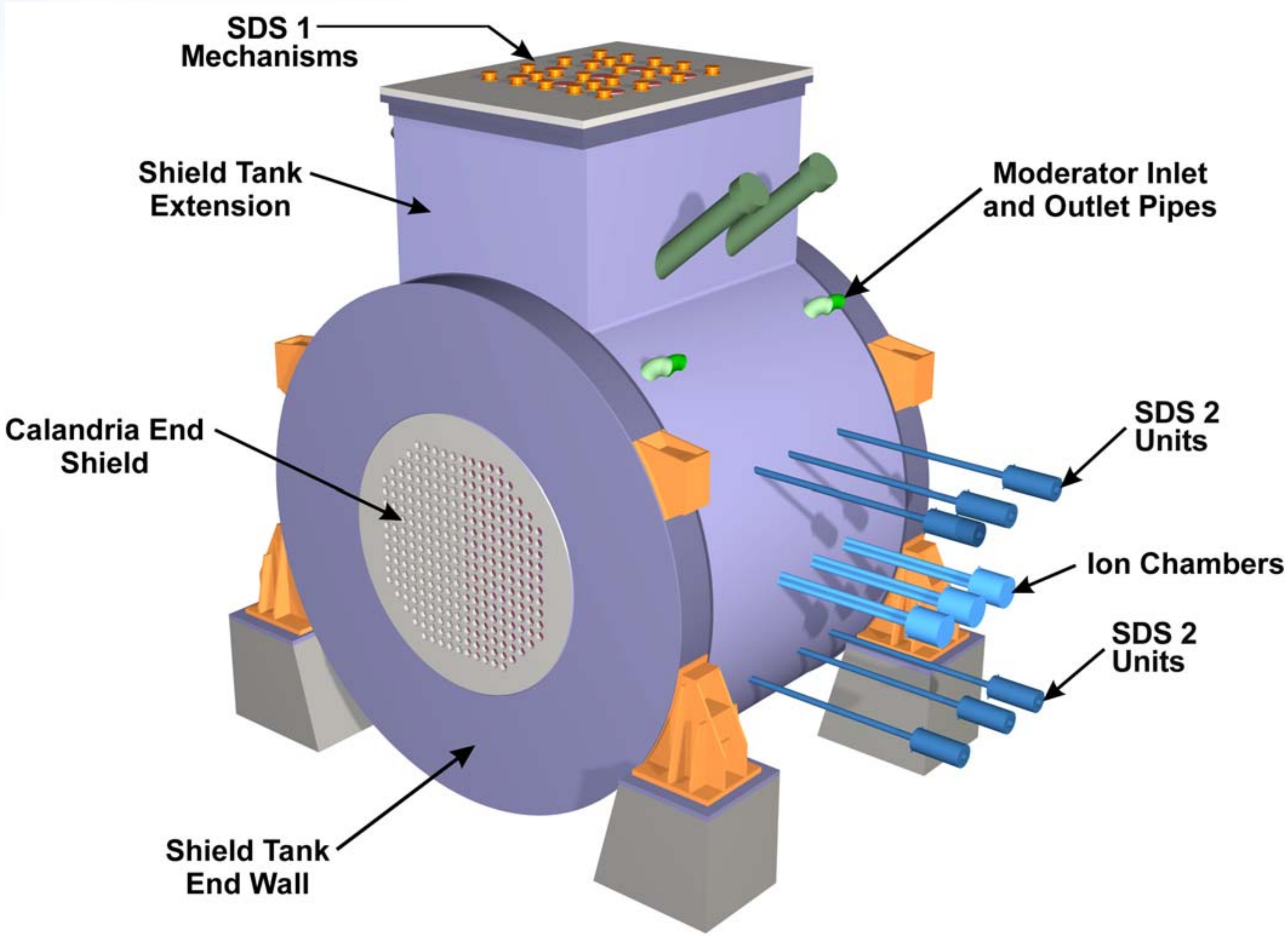
SDS1

- 20 Mechanical Absorbers

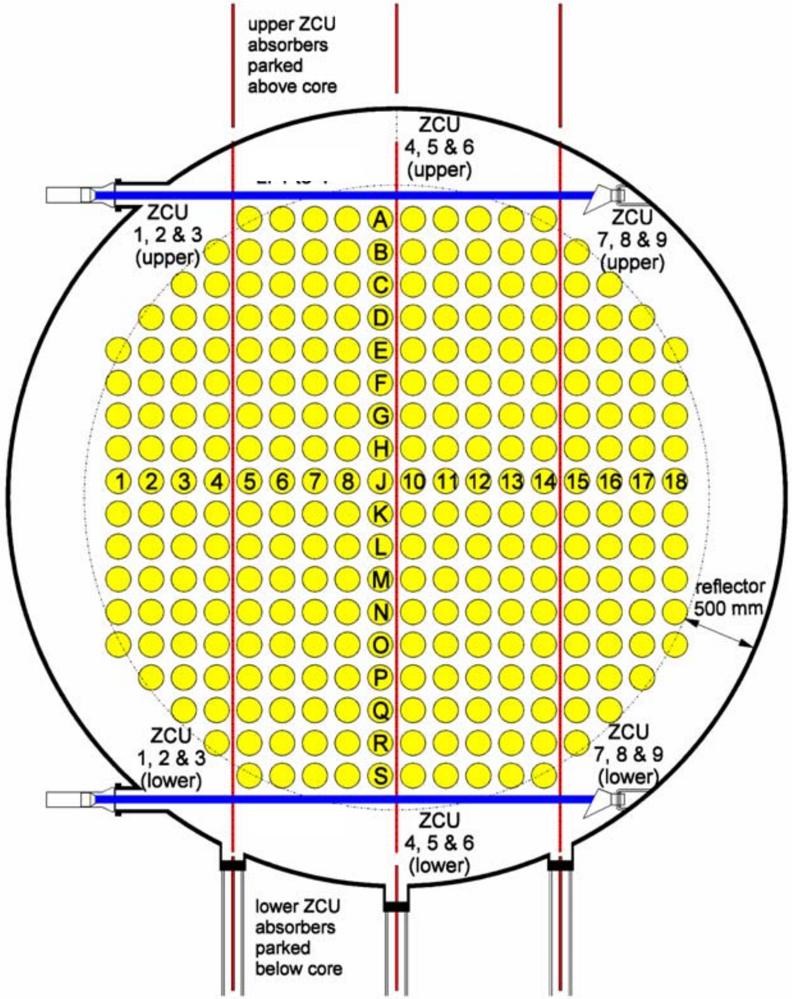
SDS2

- 6 liquid-poison injection nozzles in reflector region

ACR-700 Reactor Assembly

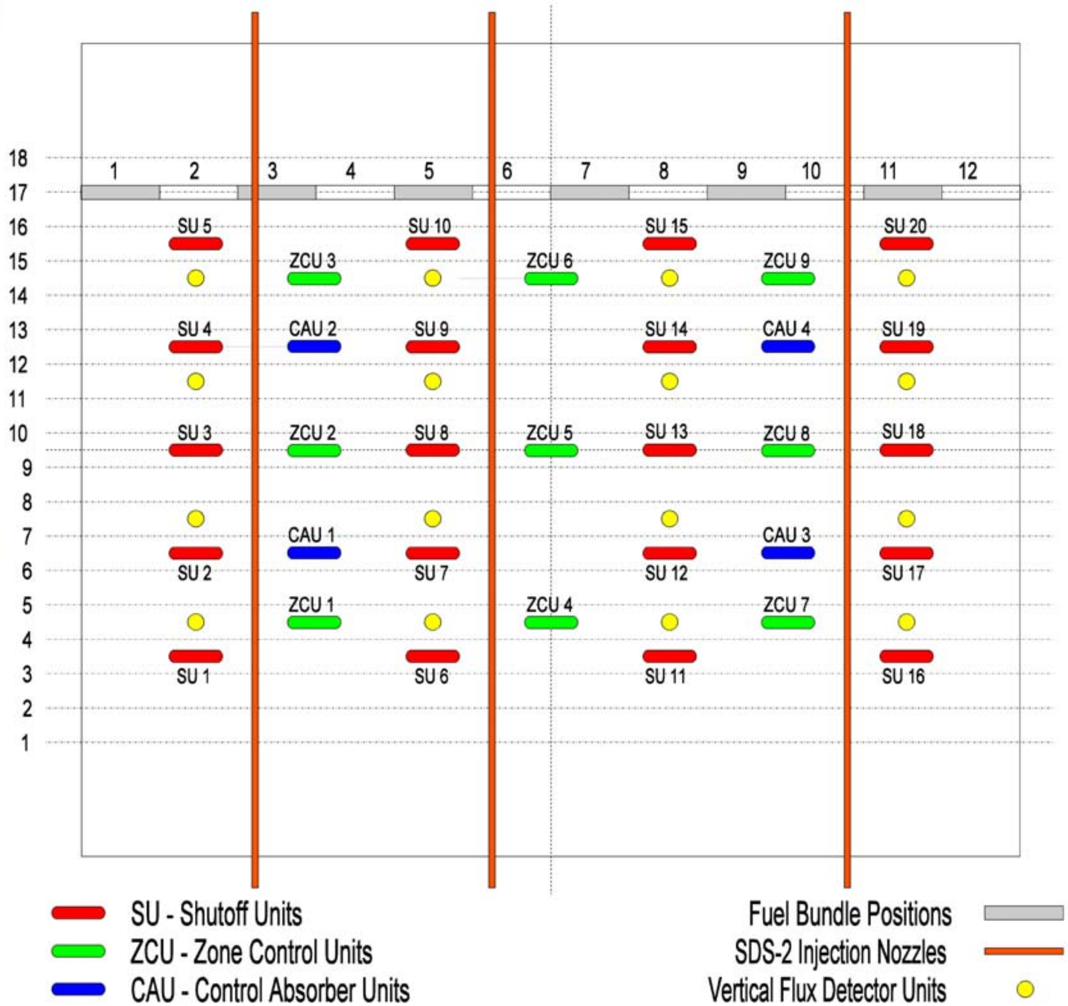


End-View of ACR-700



ACR-700 Reactor Core
284 Fuel Channels

ACR-700 Reactivity Mechanisms Plan View



Safety Parameters in ACR-700 and CANDU 6

	ACR-700	CANDU 6
Total Delayed Neutron Fraction (ß)	0.0056	0.0058
Prompt Neutron Lifetime (millisecond)	0.33	0.92
Full-Core Coolant Void Reactivity	- 3 mk	+ 15 mk (Approx.)
Power Coefficient	-0.07 (mk per % power)	~ 0
SDS1	20 Absorber Rods	28 Absorber Rods
SDS2	6 Poison Nozzles (reflector region)	6 Poison Nozzles (core region)

Characteristics of ACR-700 and CANDU 6

	ACR-700	CANDU 6
Fuel Channels	284	380
Reactor Thermal Power (MW)	1982	2064
Gross Electrical Power (MW)	731	728
Fuel Enrichment	2.0% in 42 pins Central NU/Dy pin	37 NU pins
Core-Averaged Burnup (MWd/kgU)	20.5	7.5
Fueling Rate (Bundles per Day)	5.8	16
Channel Visits/Day	3	2

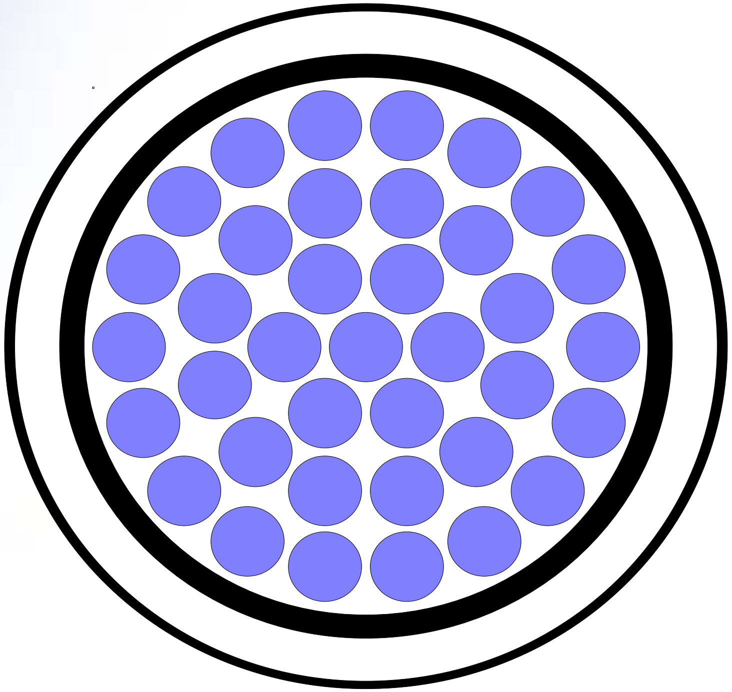
Major Differences between CANDU 6 and ACR

- Coolant
  - CANDU 6 (D_2O)
  - ACR (H_2O)

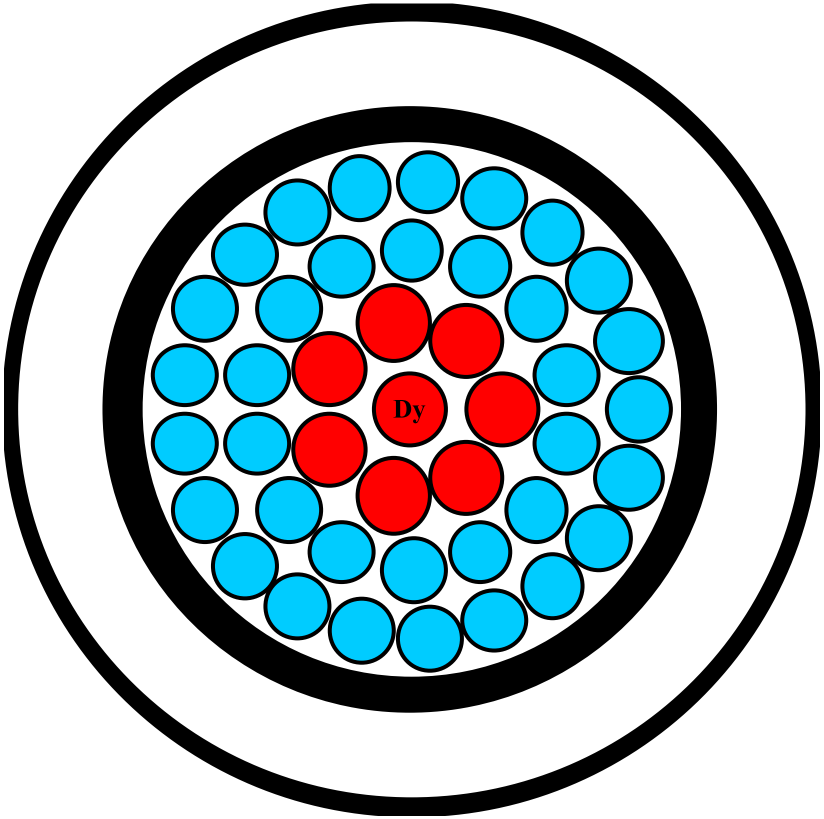
- Fuel
  - CANDU 6 (NU in 37-element bundle)
  - ACR (2.0 % SEU in 42 pins, Central Pin Dy/NU, CANFLEX bundle)

- Lattice Pitch
  - CANDU 6 (28.575 cm, 11.25 inches)
  - ACR (22.0 cm, 8.66 inches)

CANDU Fuel Bundle Designs



37-Element Bundle
C6 Fuel Channel

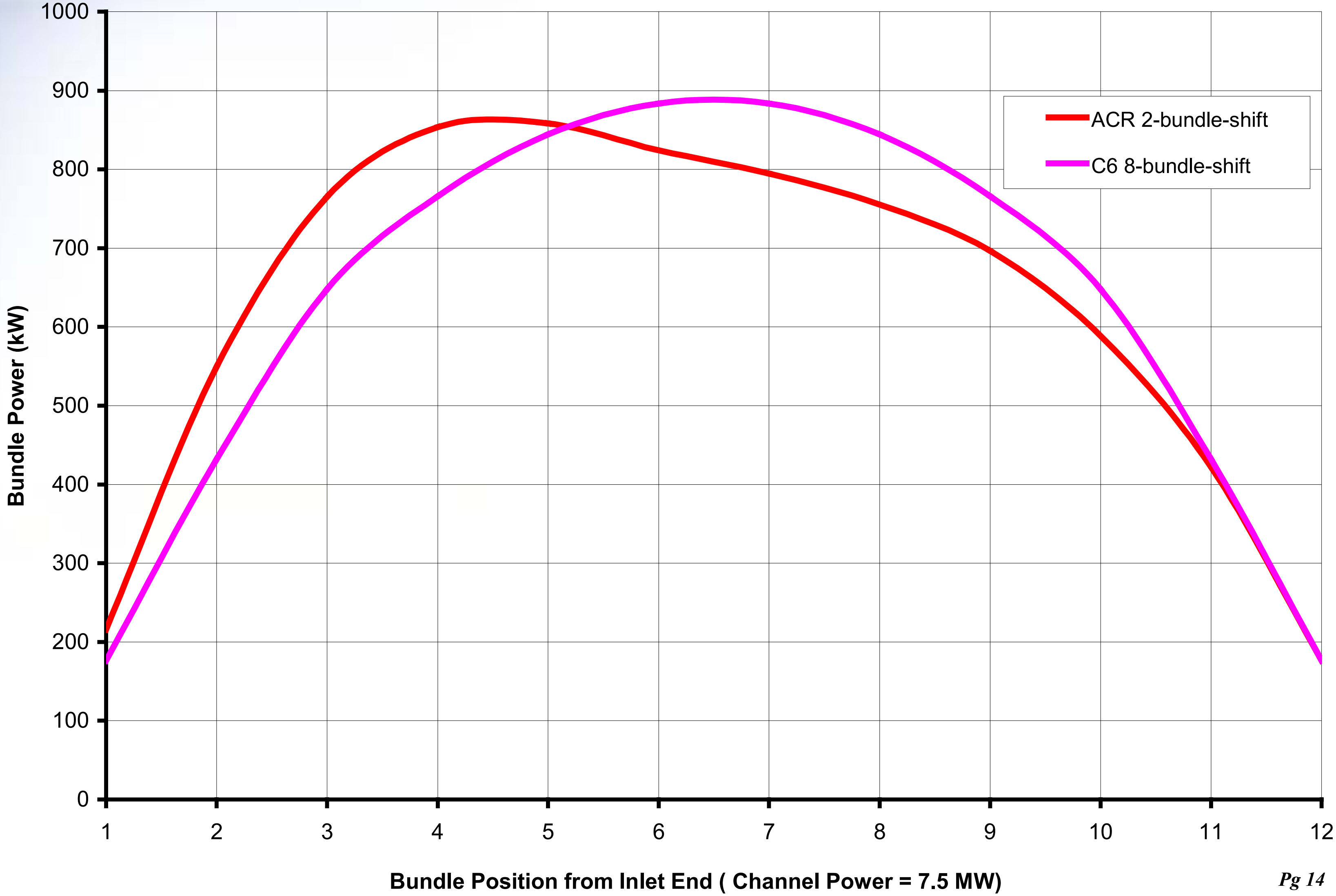


CANFLEX
Bundle (43 elements)
ACR Fuel Channel

Effects of CANFLEX SEU Fuel in ACR

- Enables the use of H_2O Coolant
- Allows the reduction of moderator to reduce Coolant Void Reactivity (CVR)
- Allows the use of neutron absorber in the central fuel pin to further reduce CVR to target of – 3 mk
- High fuel burnup
- Reduction in maximum fuel element rating
- Inlet skewed axial power profile improves thermalhydraulic margin

Axial Power Profiles in ACR and in C6



Effect of Coolant Void in ACR

- ACR lattice is under-moderated with normal H_2O coolant
- H_2O acts as both coolant and moderator
- LOCA further reduces moderation from the lattice
- Coolant Void Reactivity (CVR) is a combined effect due to loss of absorption (positive) and loss of moderation (negative) from H_2O
- Increase in fast flux and decrease in thermal flux upon LOCA
- U238 and Pu239 generate negative components in CVR
  - Increase in Resonance Absorption (1 eV to 100 keV) in U238
  - Decrease in Fission (0.3 eV resonance) in Pu239

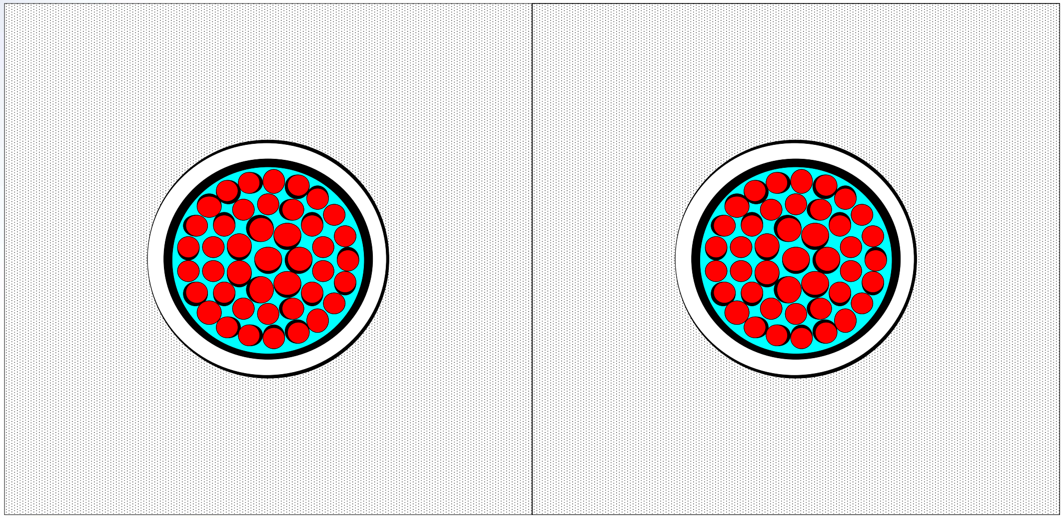
Physics Innovations to achieve slightly negative CVR (H_2O Coolant)

- Large Moderator/Fuel ratio (Vm/Vf) means high CVR
- Current Lattice Pitch (LP) 28.575 cm (11.25 inches)

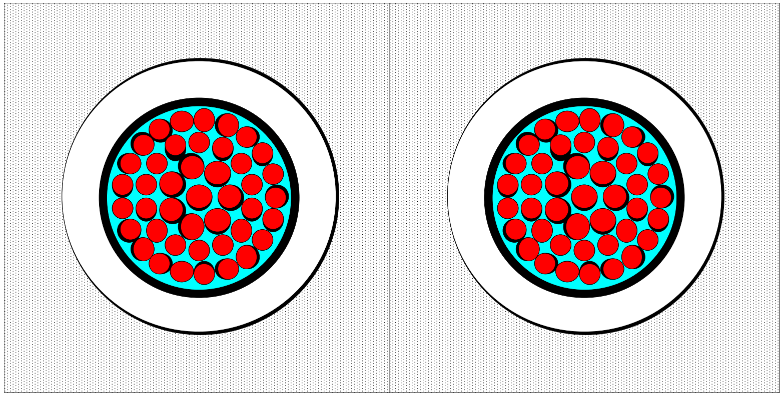
  Vm/Vf =16.4 CVR = + 60 mk
- Target CVR **=** -3 mk requires Vm/Vf < 6.0, 0 LP < 20 cm (7.87 inches)
- Minimum LP **=** 22 cm (8.66 inches) required to provide space for feeders between channels

  Vm/Vf = 8.4
- Use larger CT, OR =7.8 cm (3.07 inches) to displace more moderator
  - Vm/Vf = 7.1
  - Add Dy (4.6%) to central NU pin CVR = - 3 mk

Comparison of CANDU 6 and ACR Lattices

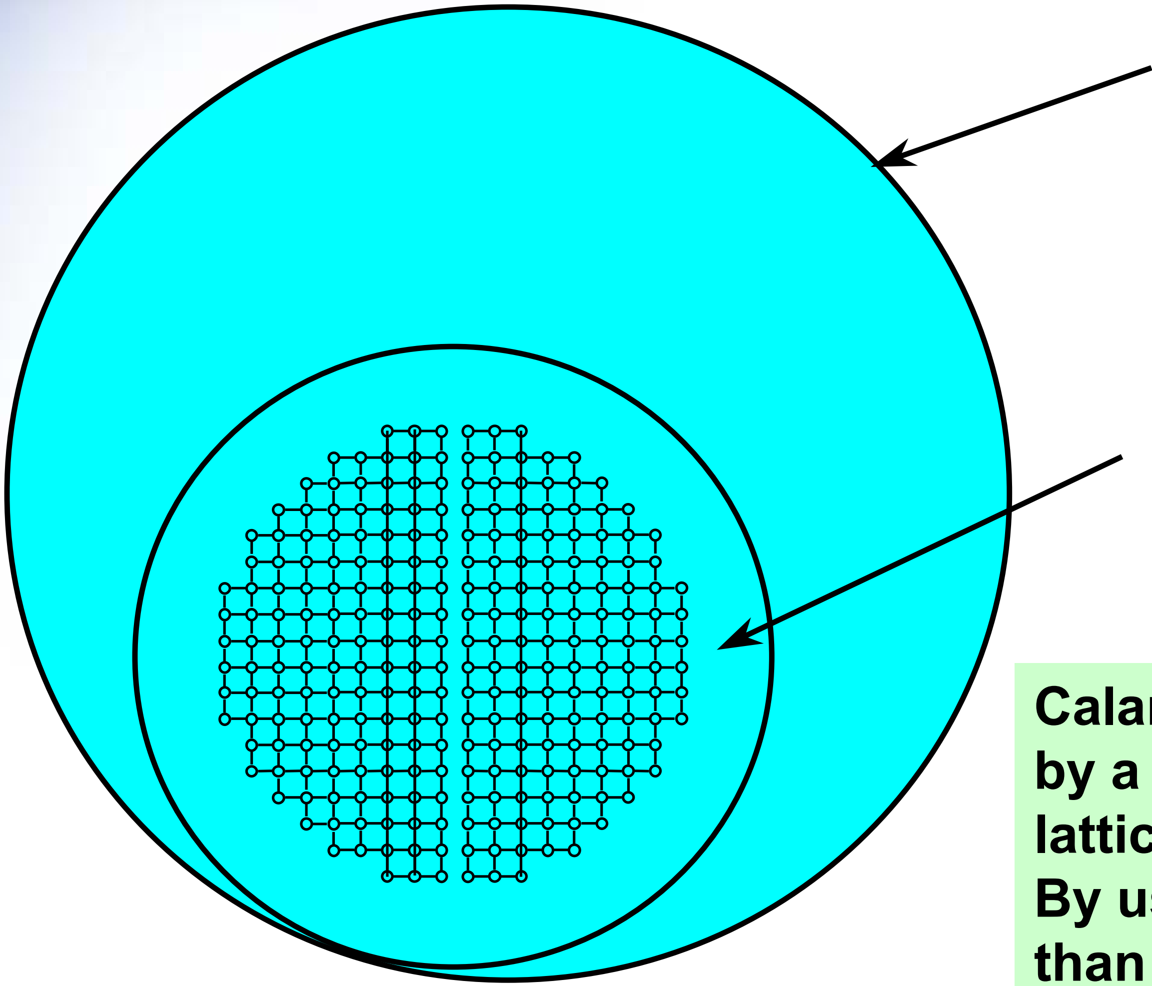


CANDU 6 Lattice



ACR Lattice

Core Size Comparison



CANDU 6
728 MWe
380 channels
Diameter = 760 cm
(299 inches)

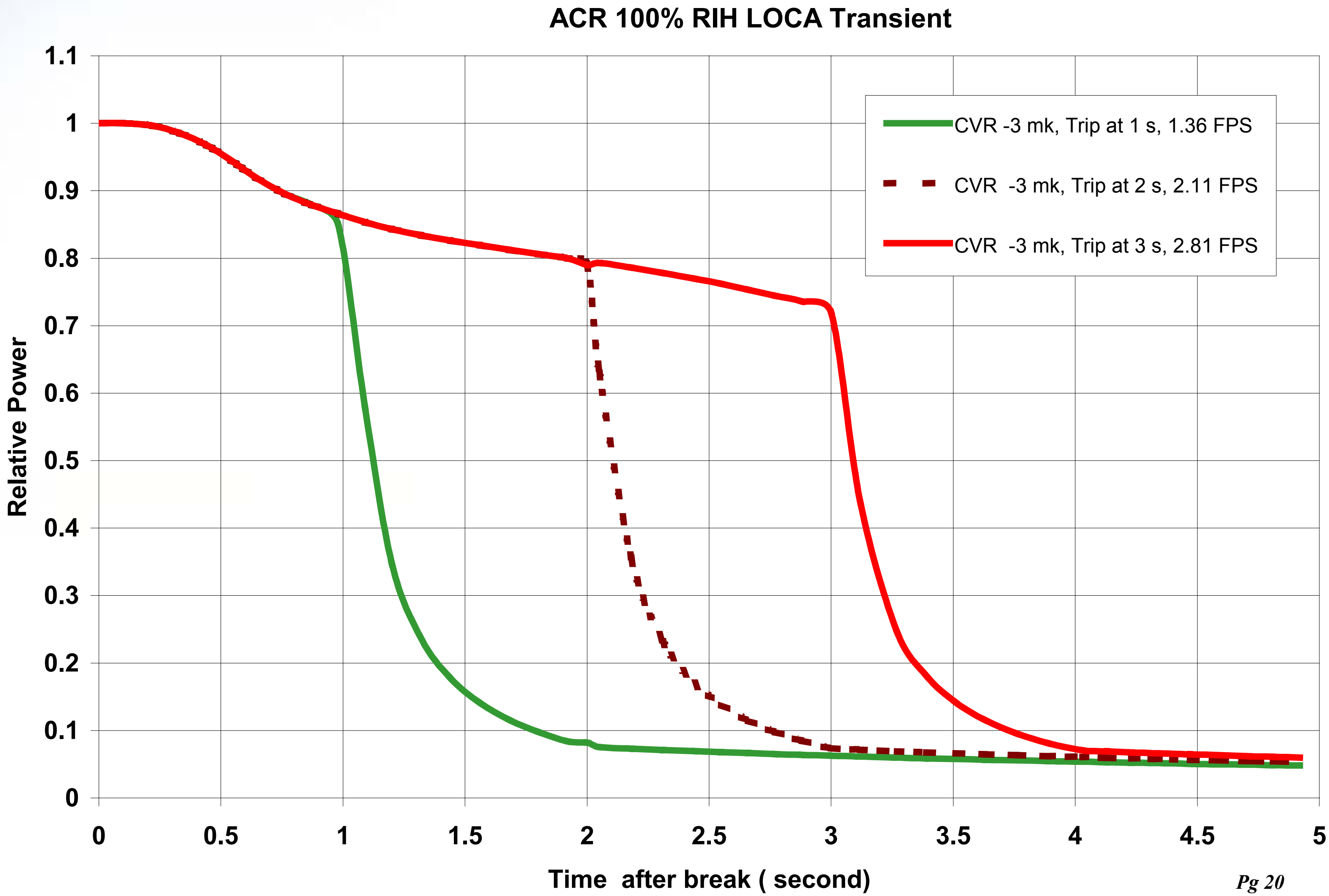
ACR
731 MWe
284 channels
Diameter = 520 cm
(205 inches)

Calandria volume reduced by a factor of 2.5 (smaller lattice pitch).
By using H_2O coolant, less than 25% of D_2O used in C6 is required.

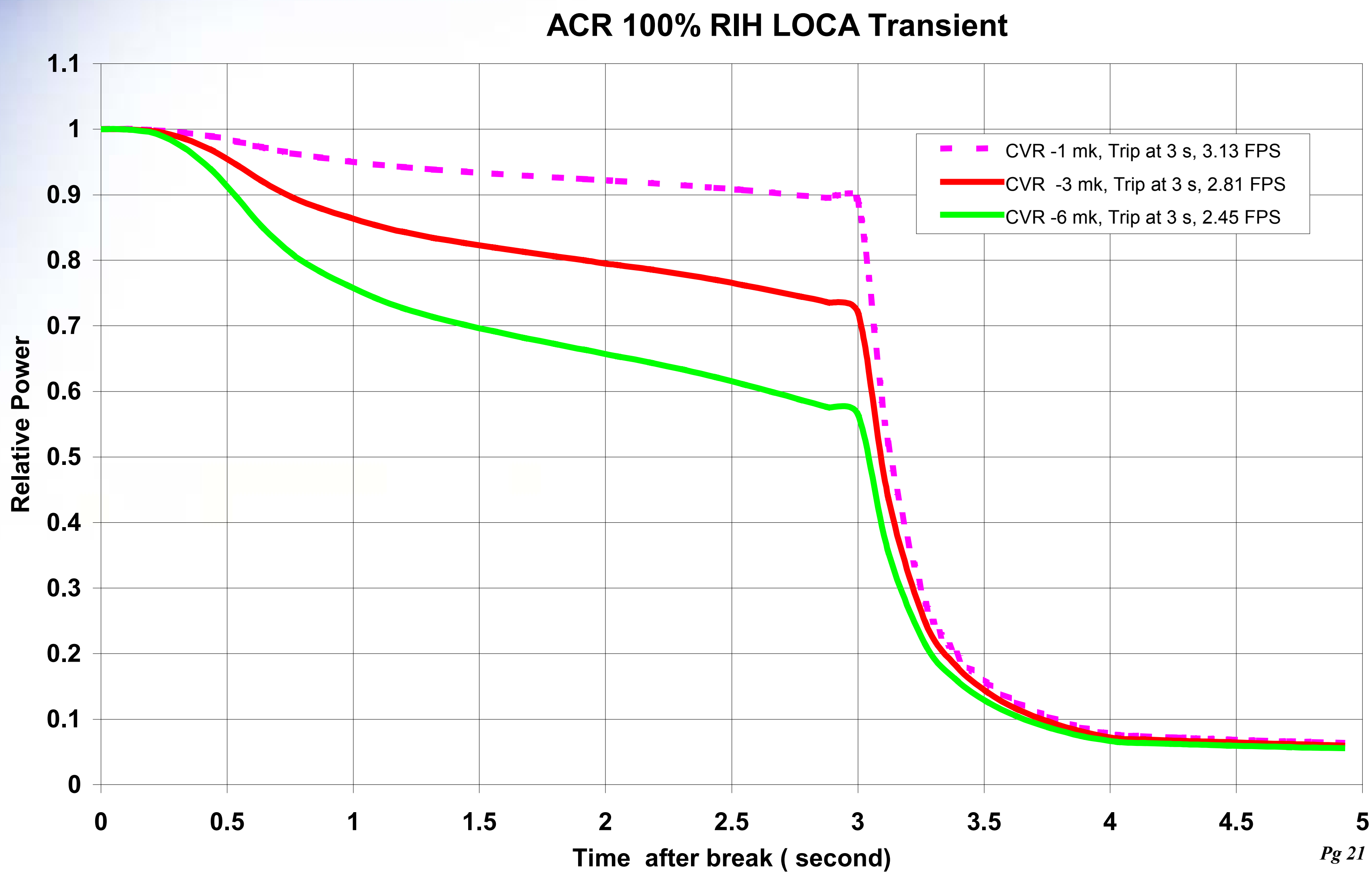
Effect of Trip Time & CVR on LOCA Transients in ACR

- LOCA power transients in ACR
  - Not sensitive to trip time (1 to 3 seconds)
  - Not sensitive to the magnitude of the negative CVR (-1 mk to –6 mk)

Effect of Trip Time on LOCA Transient

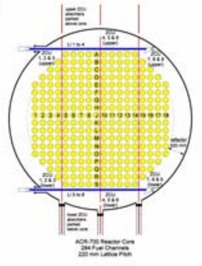


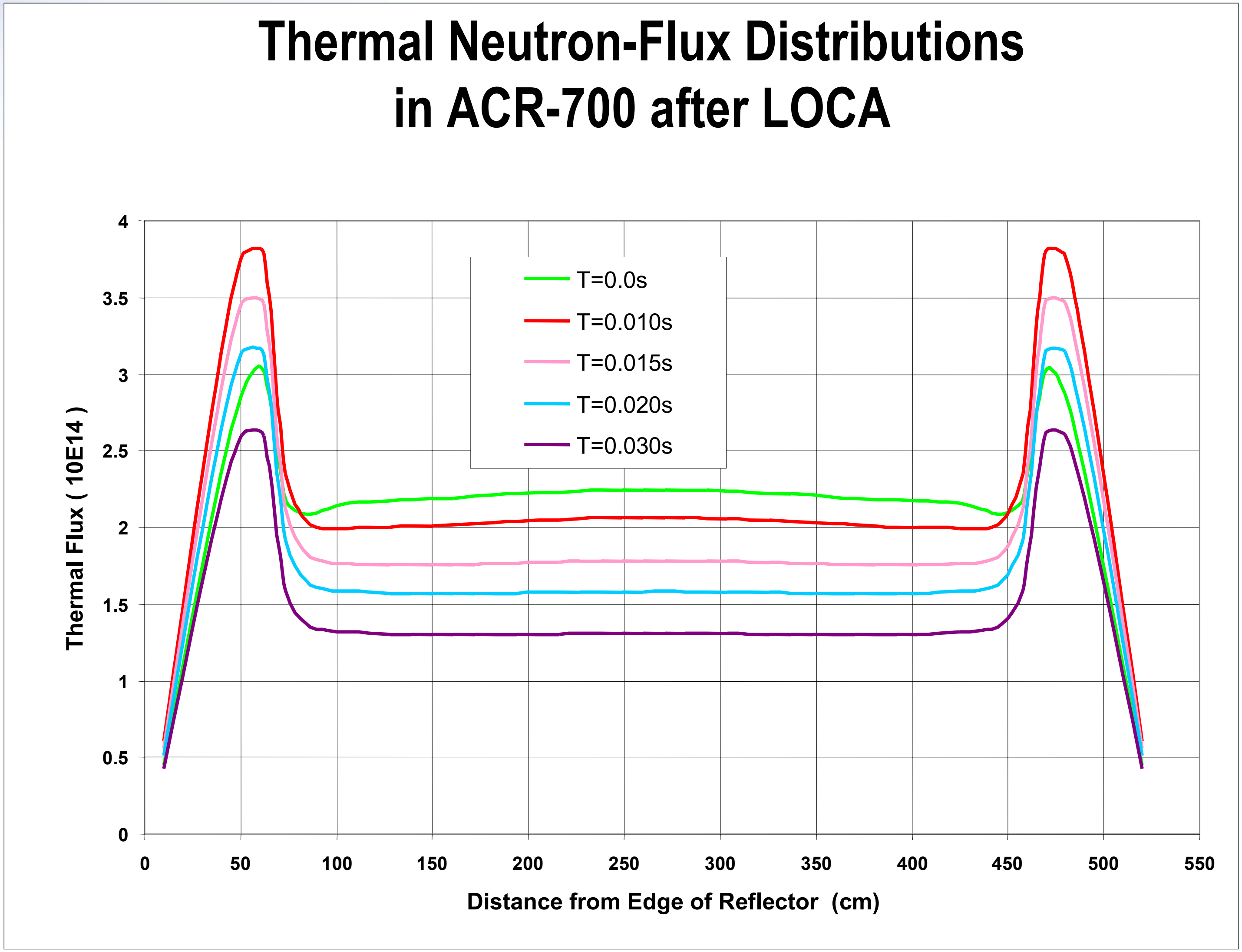
Effect of CVR on LOCA Transient



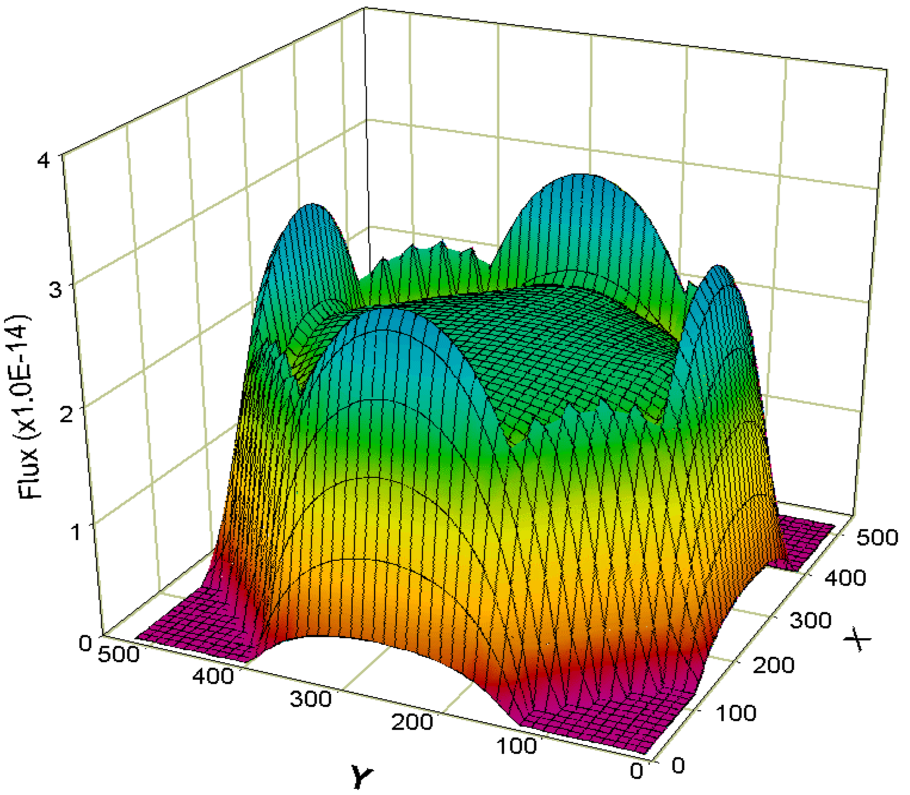
Unique LOCA Features in ACR

- **Power in reactor core region drops upon LOCA due to negative void reactivity**
- **Rapid rise in thermal neutron flux in the reflector region due to migration and subsequent thermalization of fast neutrons from the core region**
- **Fast neutronic trip is available from neutron detectors in the reflector region**

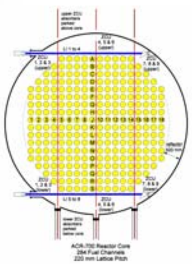


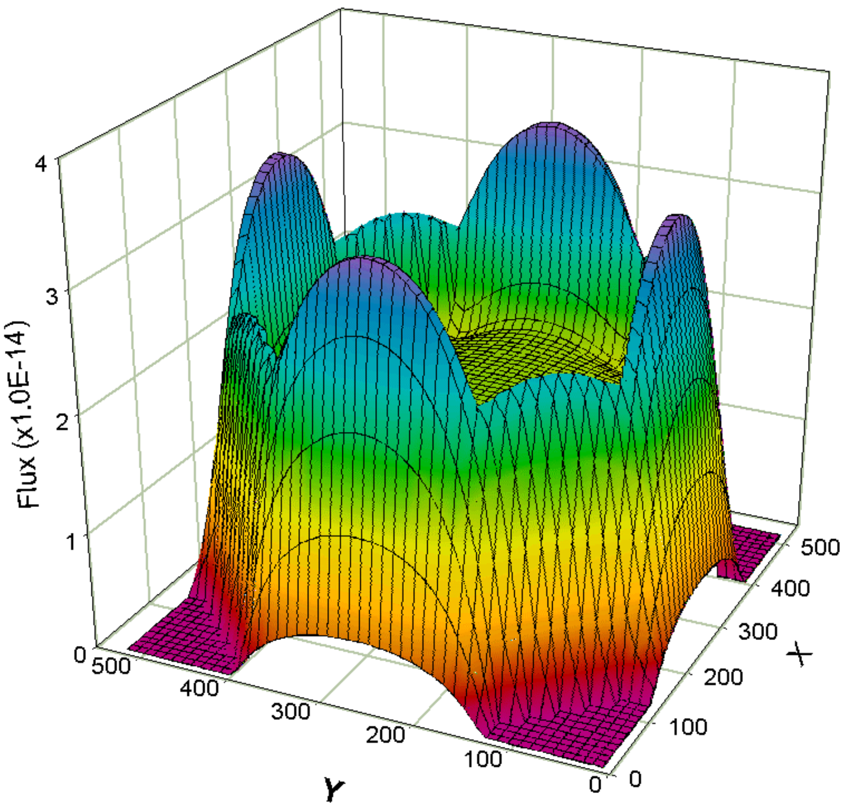

Thermal Neutron-Flux Distributions
in ACR-700 after LOCA
T=0.0s
T=0.010s
T=0.015s
T=0.020s
T=0.030s
Thermal Flux (10E14)
Distance from Edge of Reflector (cm)
0
0.5
1
1.5
2
2.5
3
3.5
4
0
50
100
150
200
250
300
350
400
450
500
550

Thermal Flux Profile upon LOCA at t=0 s

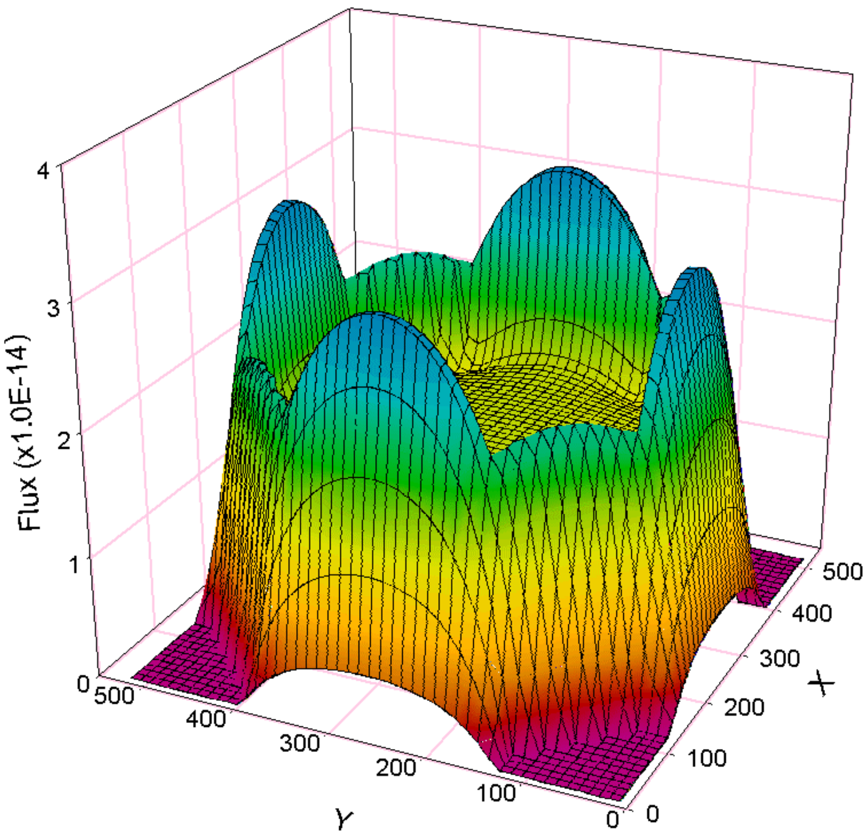


Thermal Flux Profile upon LOCA at t=0.015 s

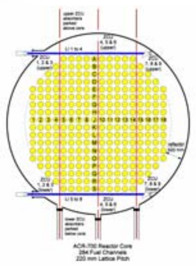


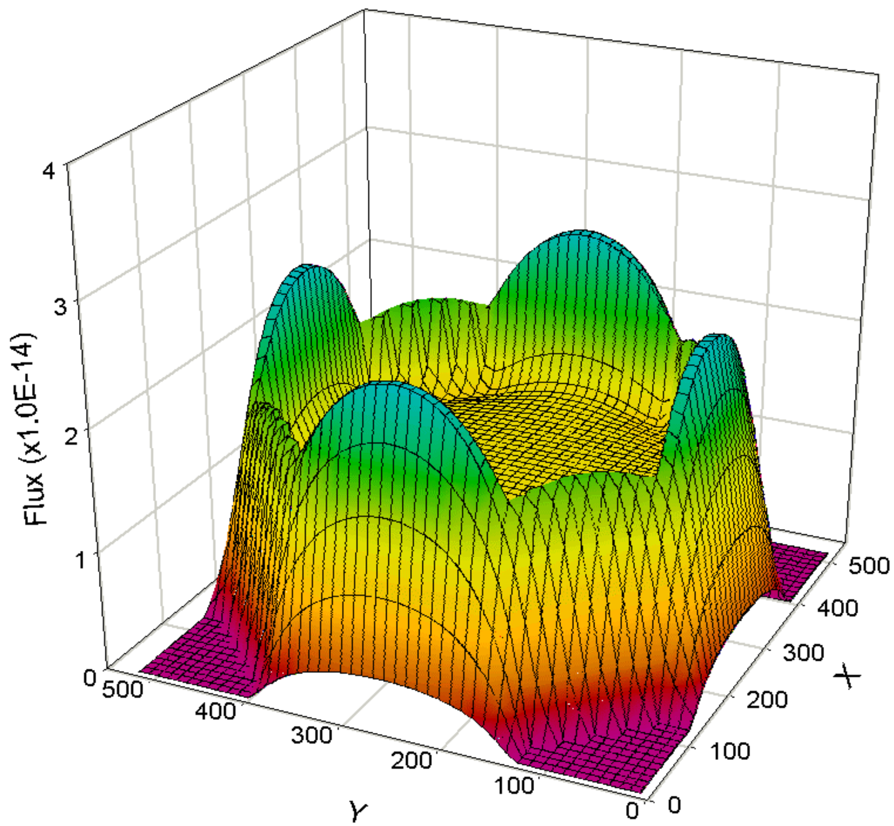


Thermal Flux Profile upon LOCA at t=0.02 s



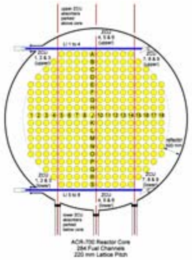
Thermal Flux Profile upon LOCA at t=0.03 s

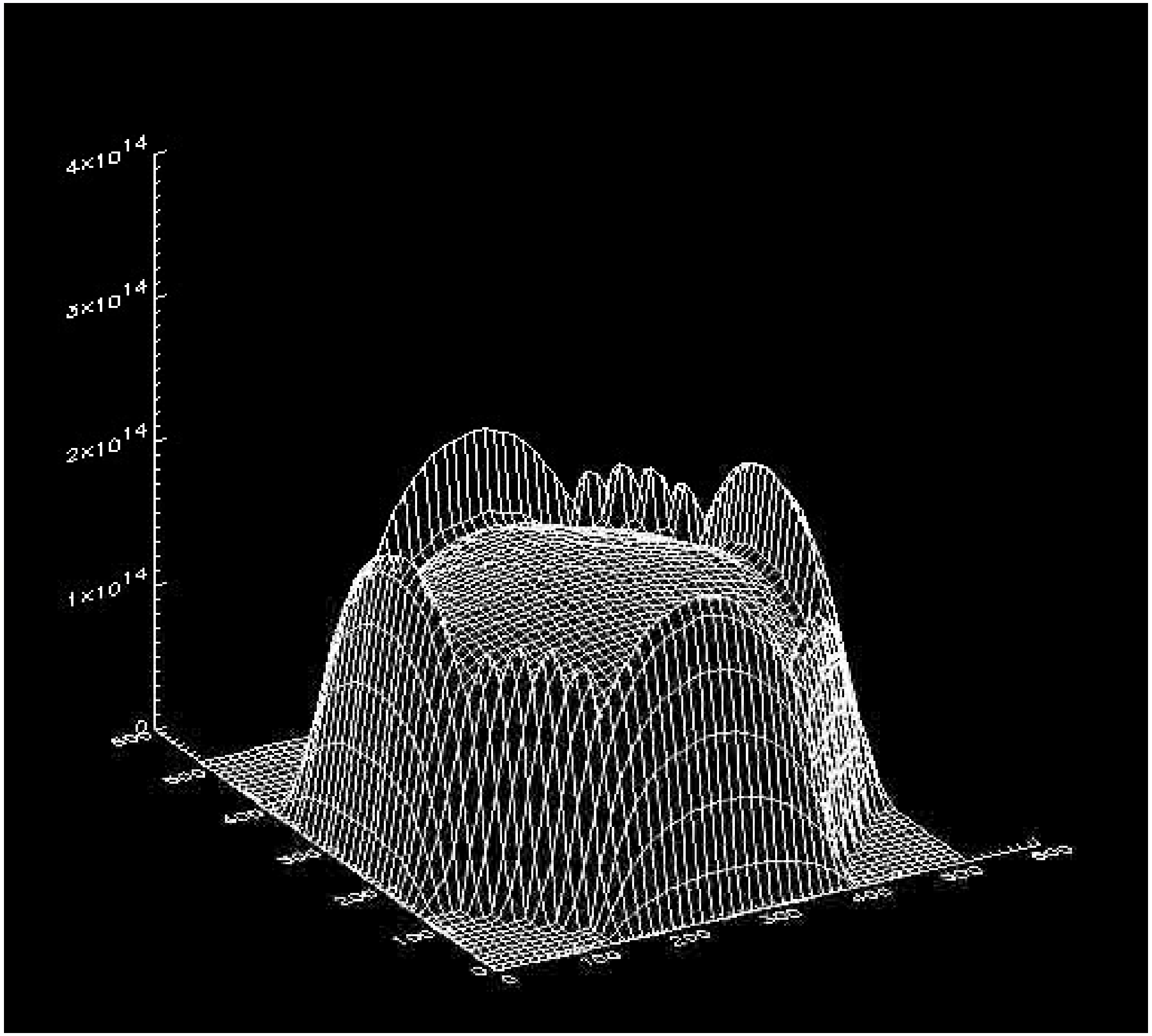




Thermal Flux Profiles in ACR-700 upon LOCA

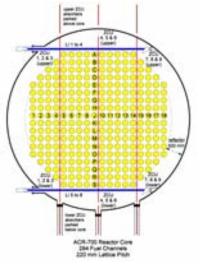
(click picture to start animation)

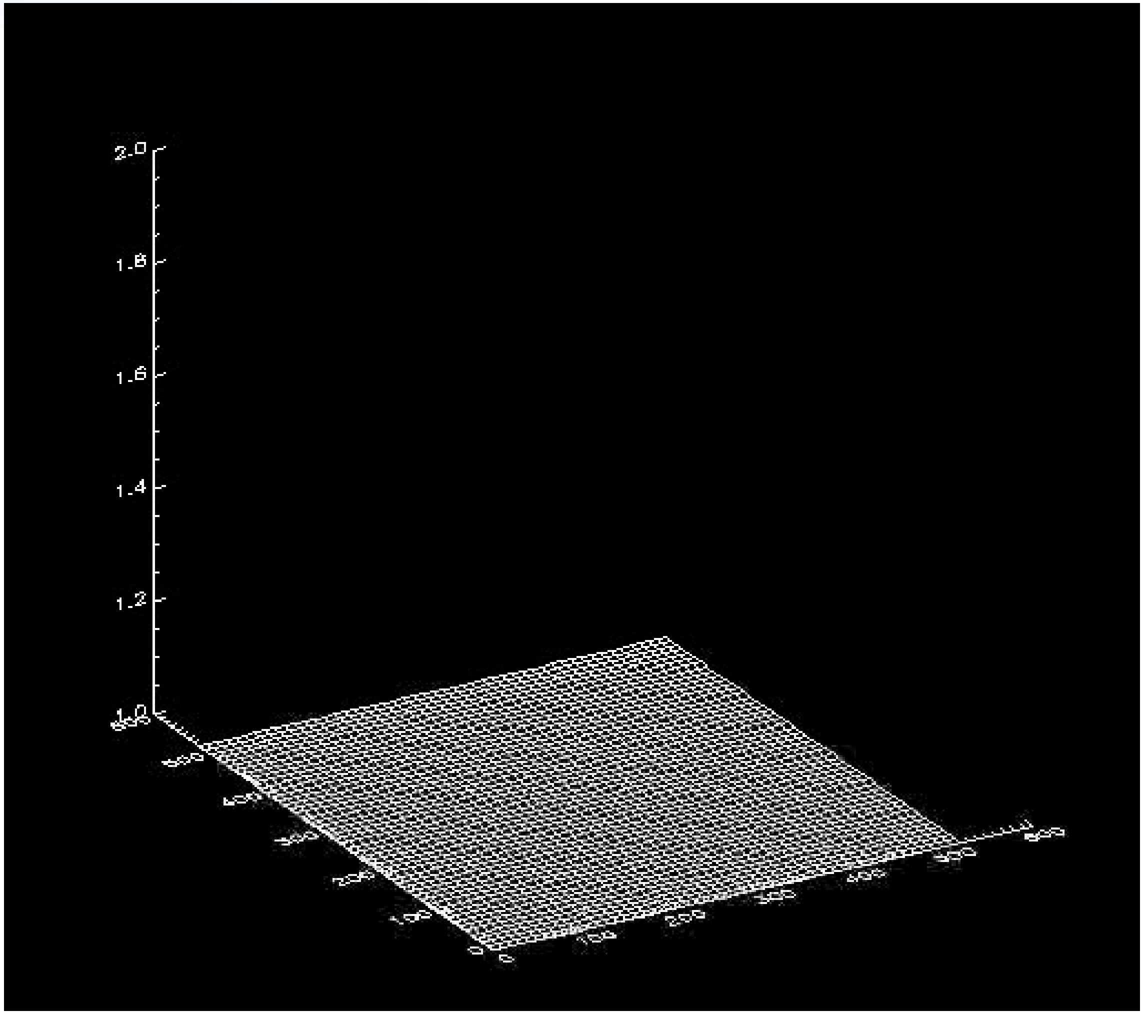




Thermal Flux Ratios in ACR-700 upon LOCA

(click picture to start animation)





Summary

- ACR is an evolutionary design of current CANDUs

- Common features between ACR and current CANDUs:
  - Horizontal fuel channels
  - D_2O moderator
  - On-power fueling
  - Simple fuel bundle design

- ACR specific features:
  - H_2O coolant
  - High burnup SEU fuel
  - Smaller lattice-pitch and compact reactor core
  - Negative coolant void reactivity enhances safety margins
  - Negative power feedback coefficients enhances reactor stability

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