Evolution of ACR Physics from CANDU 6

By Peter Chan, ACR Fuel & Physics Section Head

Presented to US Nuclear Regulatory Commission

Office of Nuclear Reactor Regulation

December 4, 5, 2002 at CRL

AECL

TECHNOLOGIES INC.

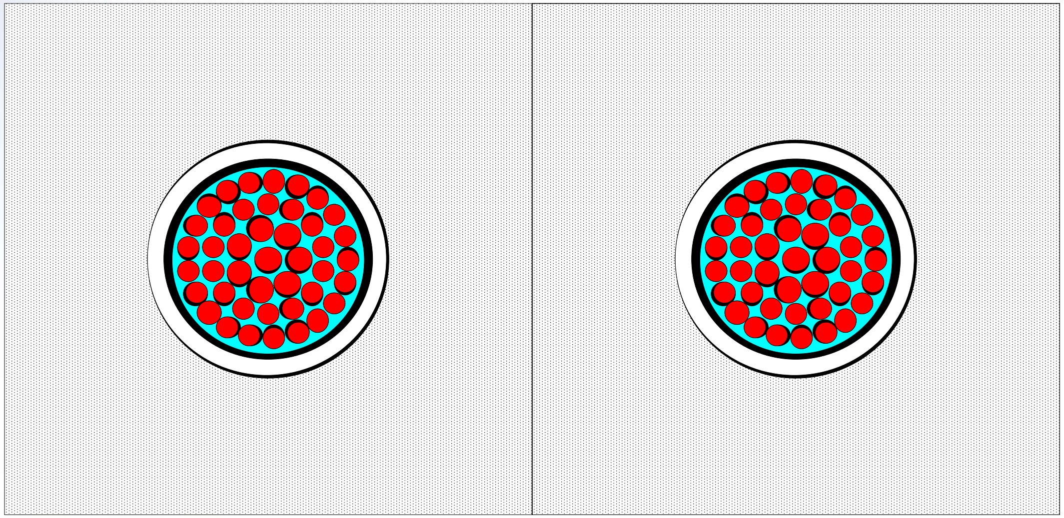
Outline

- Major differences between ACR and CANDU 6 Core Designs
  - Coolant
  - Fuel
  - Lattice Pitch
- Core Physics of ACR
  - High Power Output in a Compact Core
  - Negative Power Feedback Reactivity Coefficients
  - Negative Coolant Void Reactivity
  - Unique LOCA features
- Summary

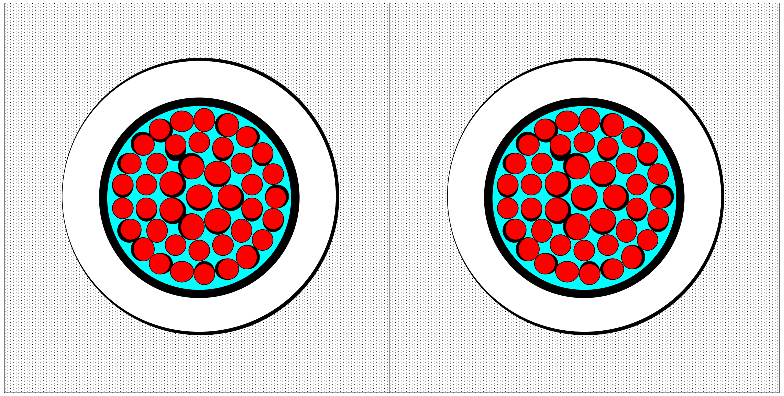
Major Differences between CANDU 6 and ACR

- 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)

Comparison of CANDU 6 and ACR Lattices

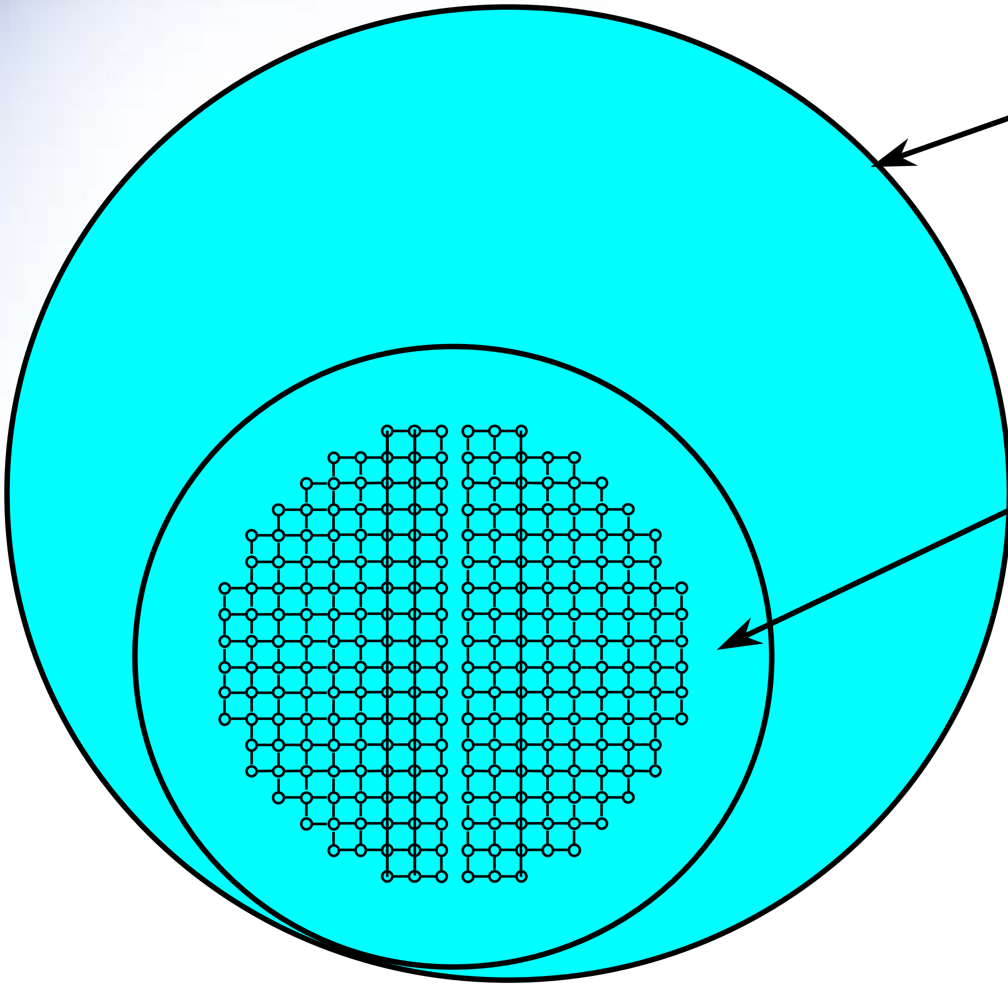


CANDU 6 Lattice



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.

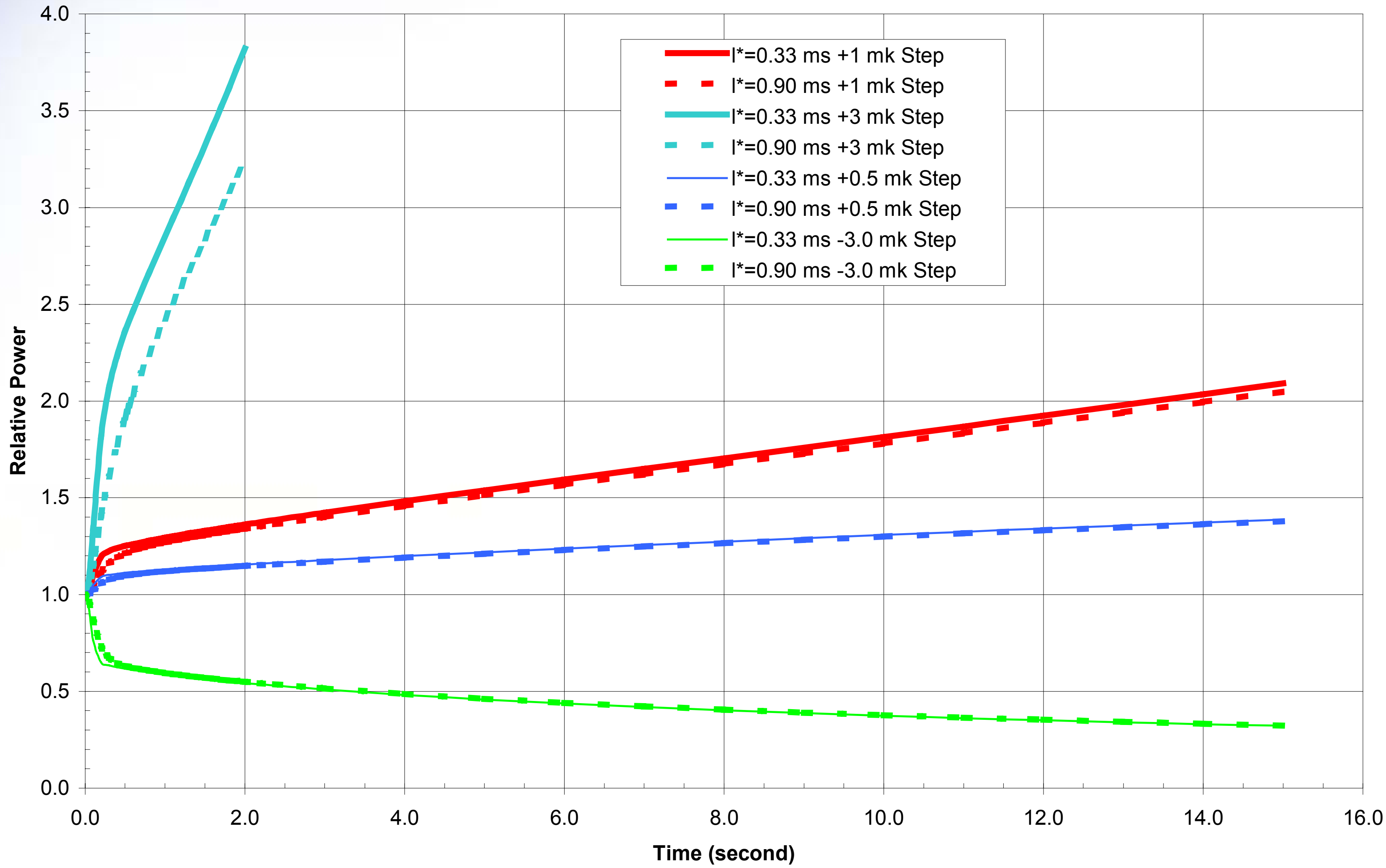
Reactivity Effects in ACR-700 and CANDU 6
(Equilibrium Core)

	ACR-700	CANDU-6
Moderator Temperature (including density) effect	-0.013 (mk/°F)	slightly positive
Coolant Temperature (including density) effect	-0.006 (mk/°F)	positive
Fuel Temperature effect	-0.008 (mk/ °F)	small negative
Power Coefficient (95% - 105% full power)	-0.07 mk/% power	~ 0
Full-Core Coolant-Void Reactivity	-3.0 mk	+10 to +15 mk

Safety & Control 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
Bulk & Spatial Control	18 Controllers in 9 Assemblies	14 Controllers in 7 Assemblies
Fast Power Reduction	4 Mechanical Absorber Rods	4 Mechanical Absorber rods
Shutdown System (SDS1)	20 Absorber Rods	28 Absorber Rods
Shutdown System (SDS2)	6 Poison Nozzles (reflector region)	6 Poison Nozzles (core region)

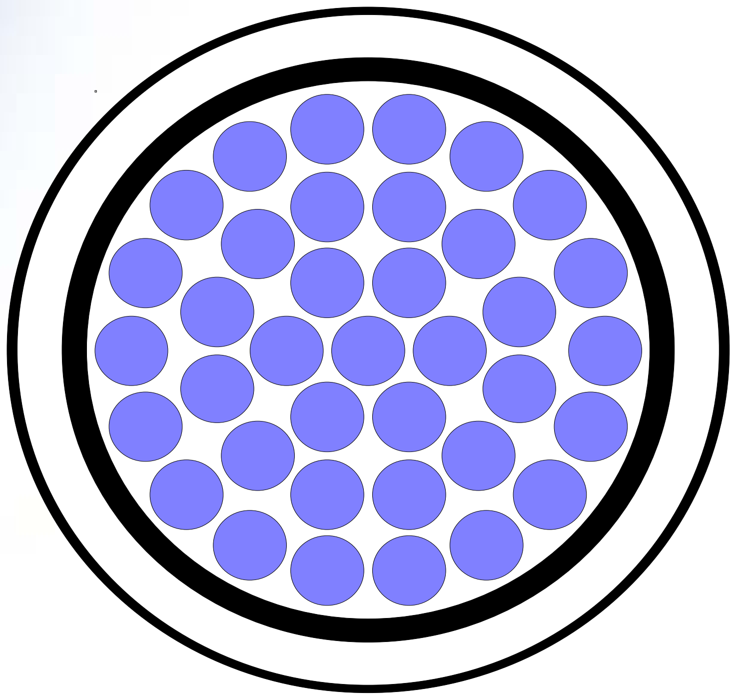
Effect of Prompt Neutron Lifetime on Power Transients



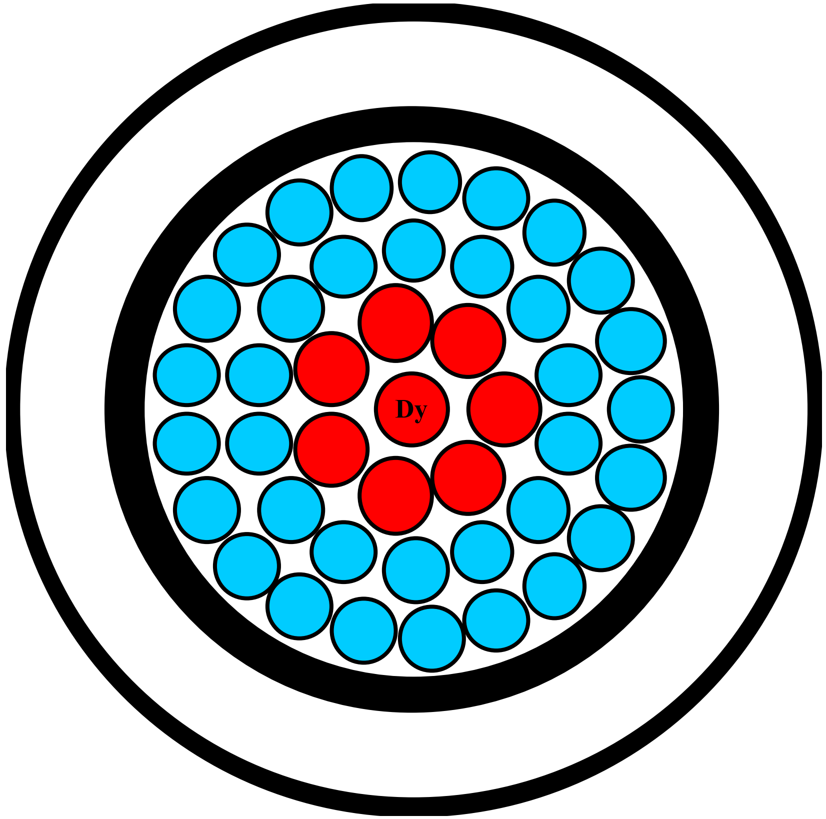
Characteristics of ACR-700 and CANDU 6

	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

CANDU Fuel Bundle Designs



37-Element Bundle
C6 Fuel Channel



CANFLEX
Bundle (43 elements)
ACR Fuel Channel

Effects of CANFLEX SEU Fuel in ACR

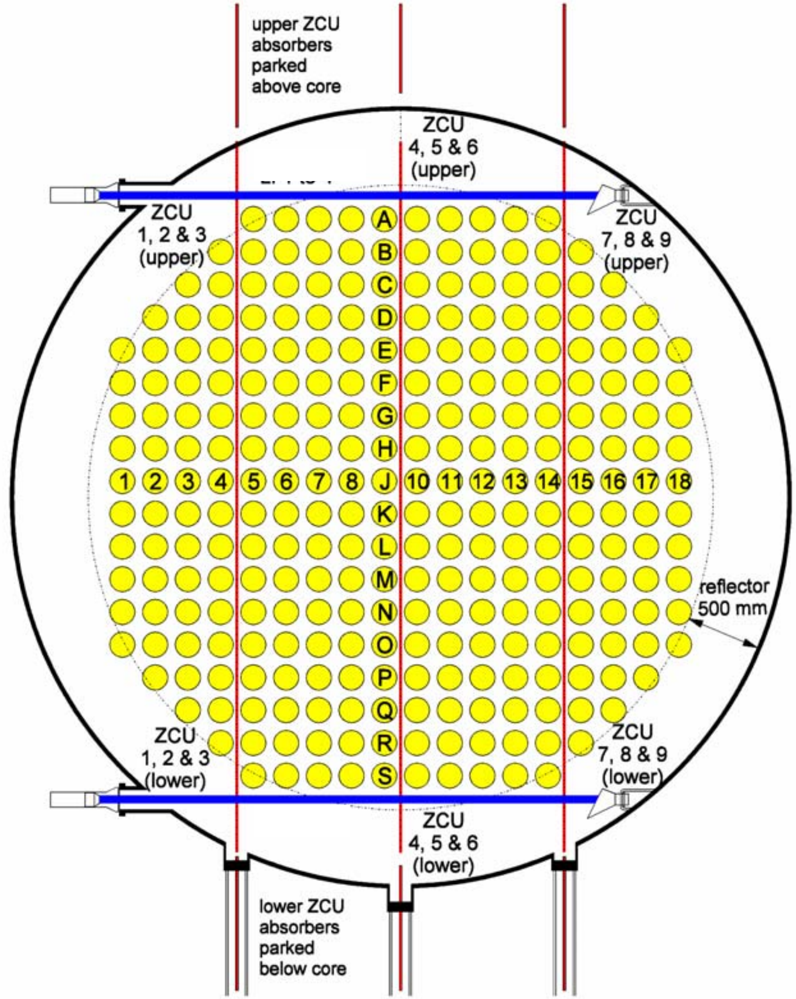
- Enables the use of H_2O Coolant
- Allows the reduction of moderator to reduce Coolant Void Reactivity (CVR)
- Allows the use of neutron absorber in the central fuel pin to further reduce CVR to target of – 3 mk
- High fuel burnup and high power output
- Flat radial channel power profile (0.93 form factor)
- Reduction in maximum fuel element rating
- Inlet skewed axial power profile improves thermalhydraulic margin

Element Ratings (ACR vs CANDU-6)
for 900 kW bundle power at mid-burnup

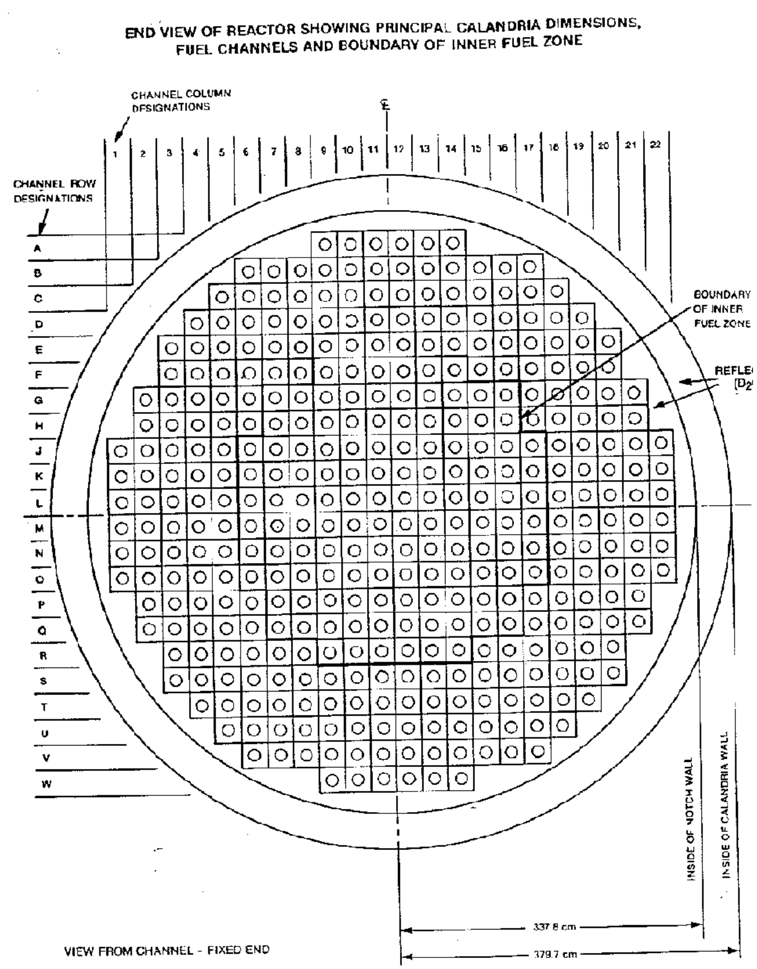
	ACR (Canflex SEU) (kW/m)	C-6 (37-el NU) (kW/m)	% Change ACR vs C-6
Ring 1 (Central)	19.0	39.7	- 52.1
Ring 2	43.8	41.3	+ 6.1
Ring 3	37.9	46.5	-18.5
Ring 4	48.5	57.2	-15.2 **

** lower element rating allows higher power and higher burnup

End-View of ACR-700

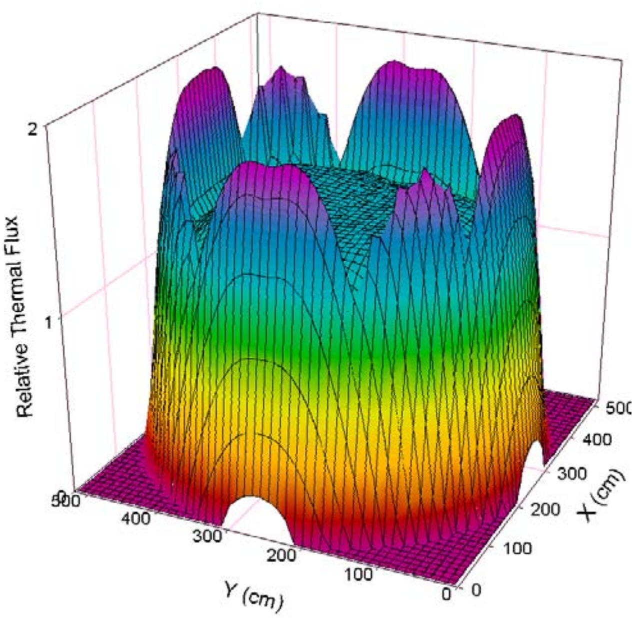


ACR-700 Reactor Core
284 Fuel Channels

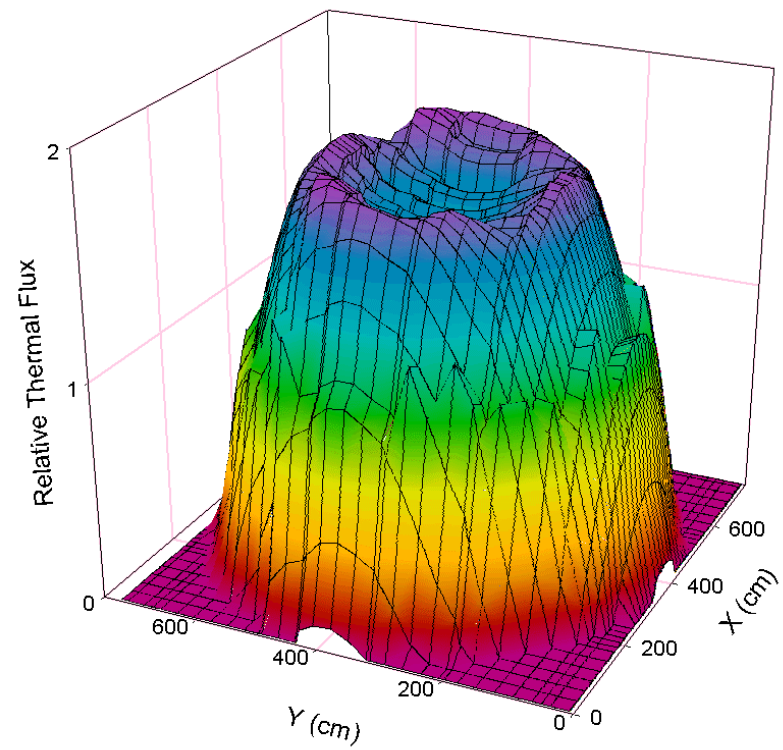


Schematic Face View of CANDU 6 Reactor

Radial Thermal Flux Profiles

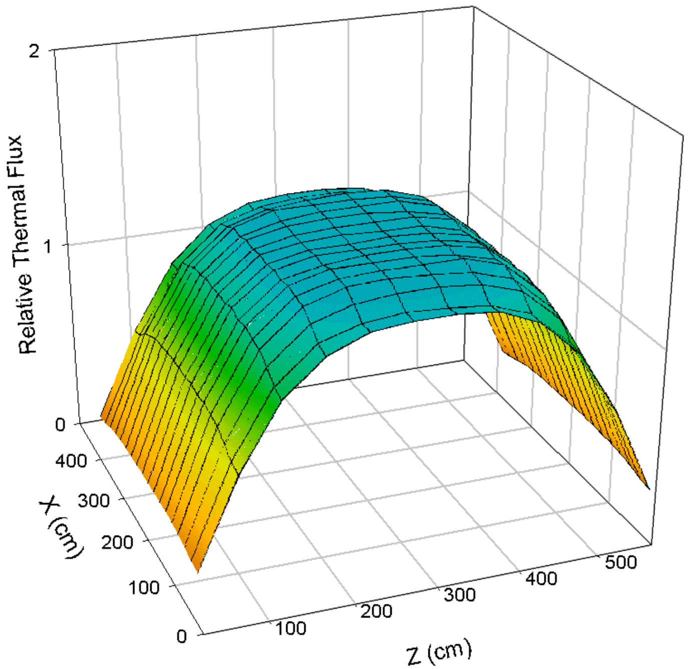


ACR-700

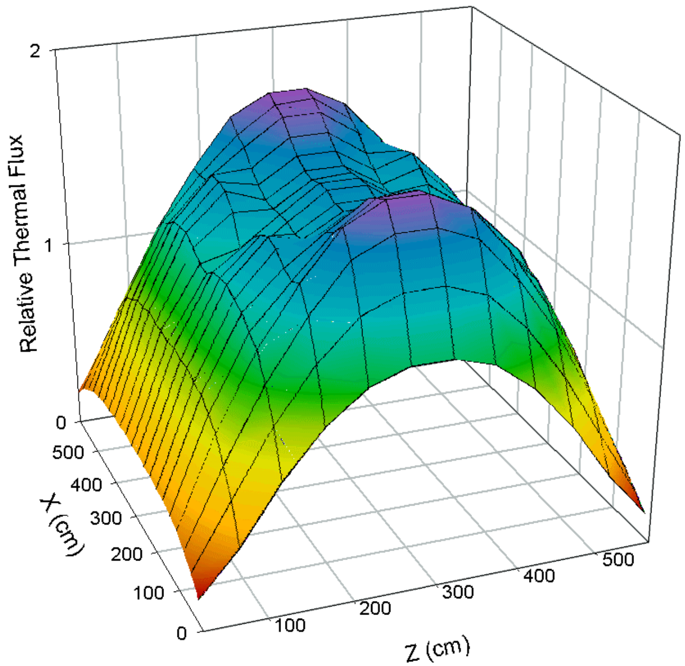


CANDU-6

Axial Thermal Flux Profiles

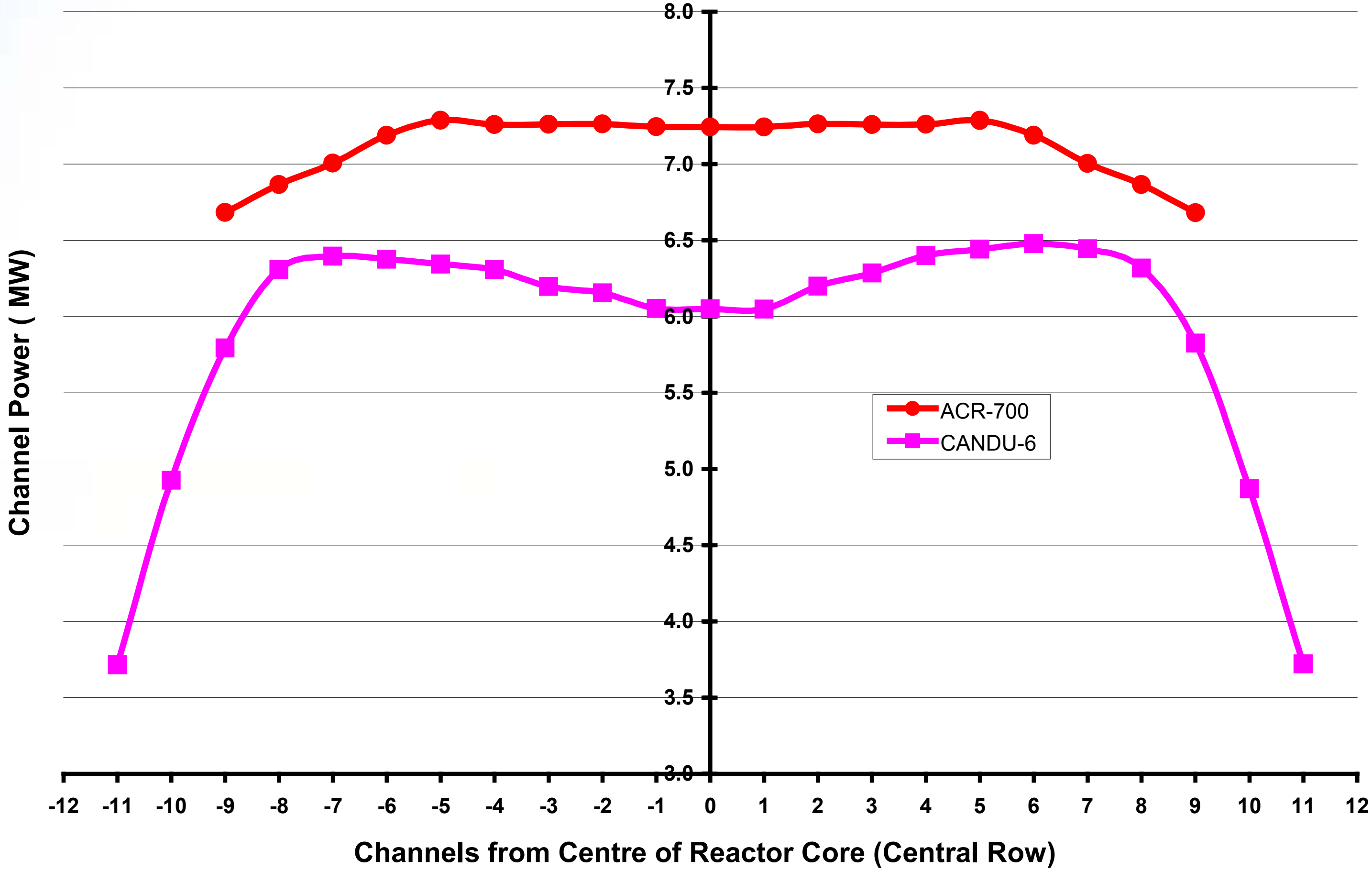


ACR-700

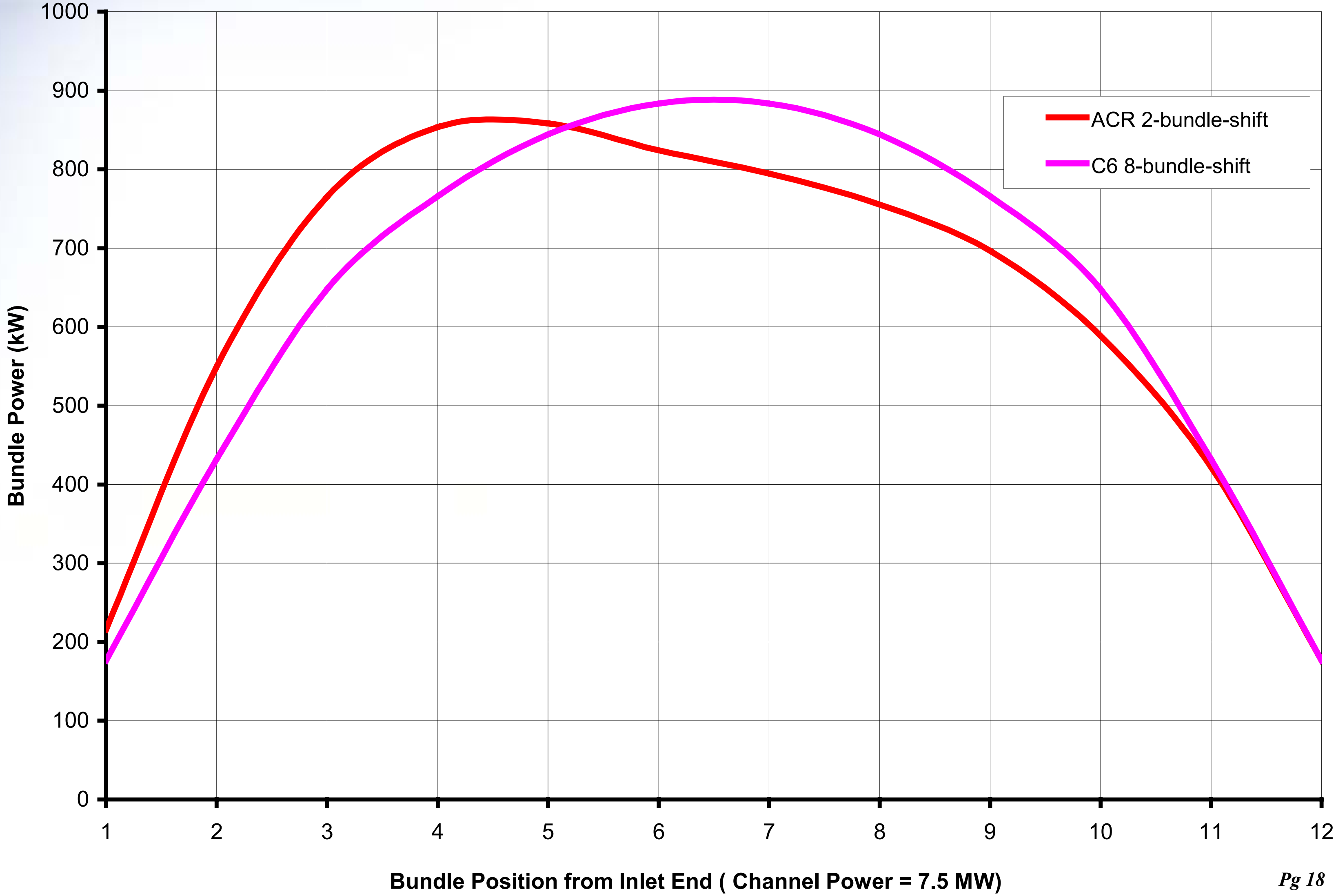


CANDU 6

Channel Power Profiles in ACR-700 and CANDU 6



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

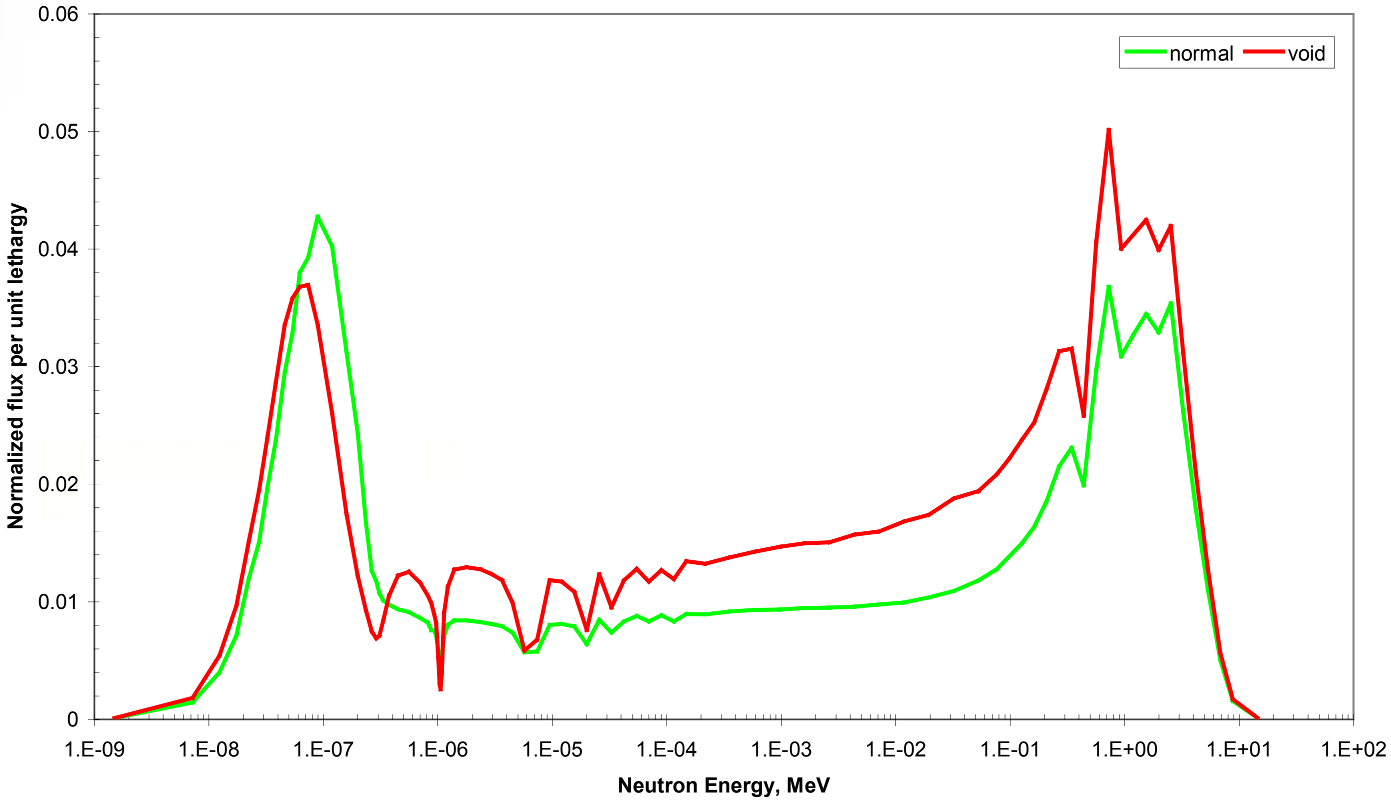
Physics Innovations to achieve slightly negative CVR (H_2O Coolant)

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

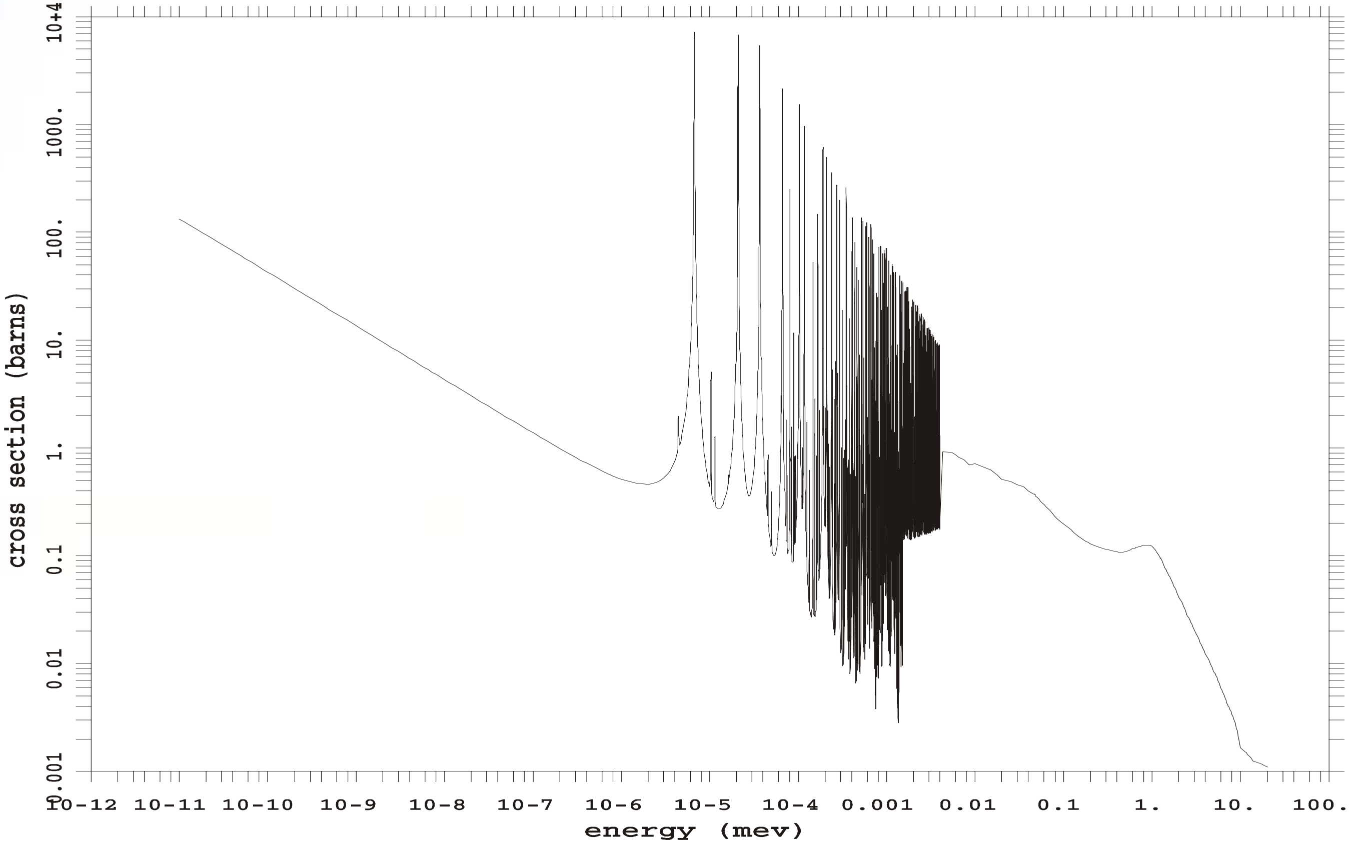
  Vm/Vf =16.4 CVR = + 60 mk
- Target CVR **=** -3 mk requires Vm/Vf < 6.0, 0 LP < 20 cm (7.87 inches)
- Minimum LP **=** 22 cm (8.66 inches) required to provide space for feeders between channels

  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

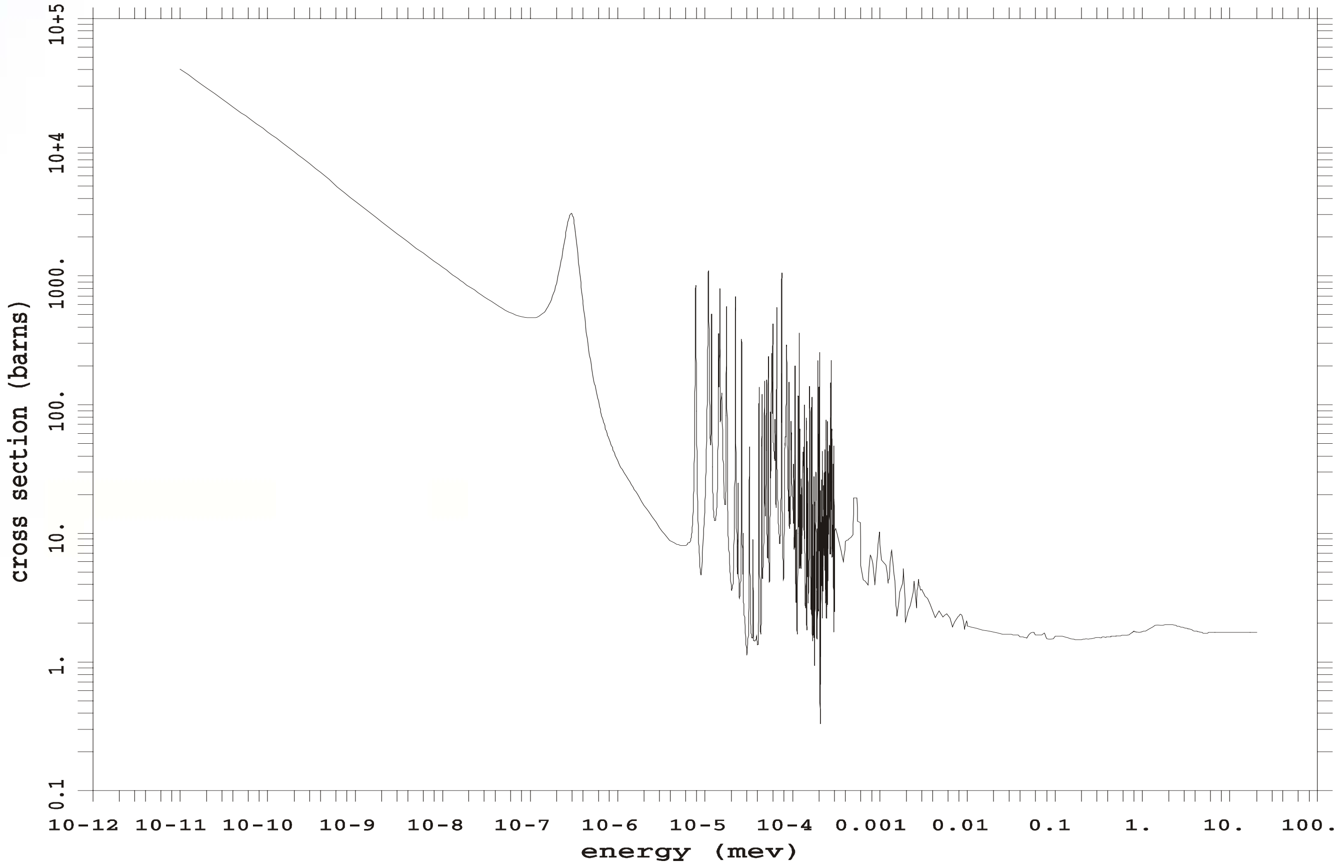
Neutron Flux Averaged over Fuel and Coolant within the Pressure Tube (MCNP Model)



Absorption Cross Section of ^{238}U



Fission Cross Section of ^{239}Pu



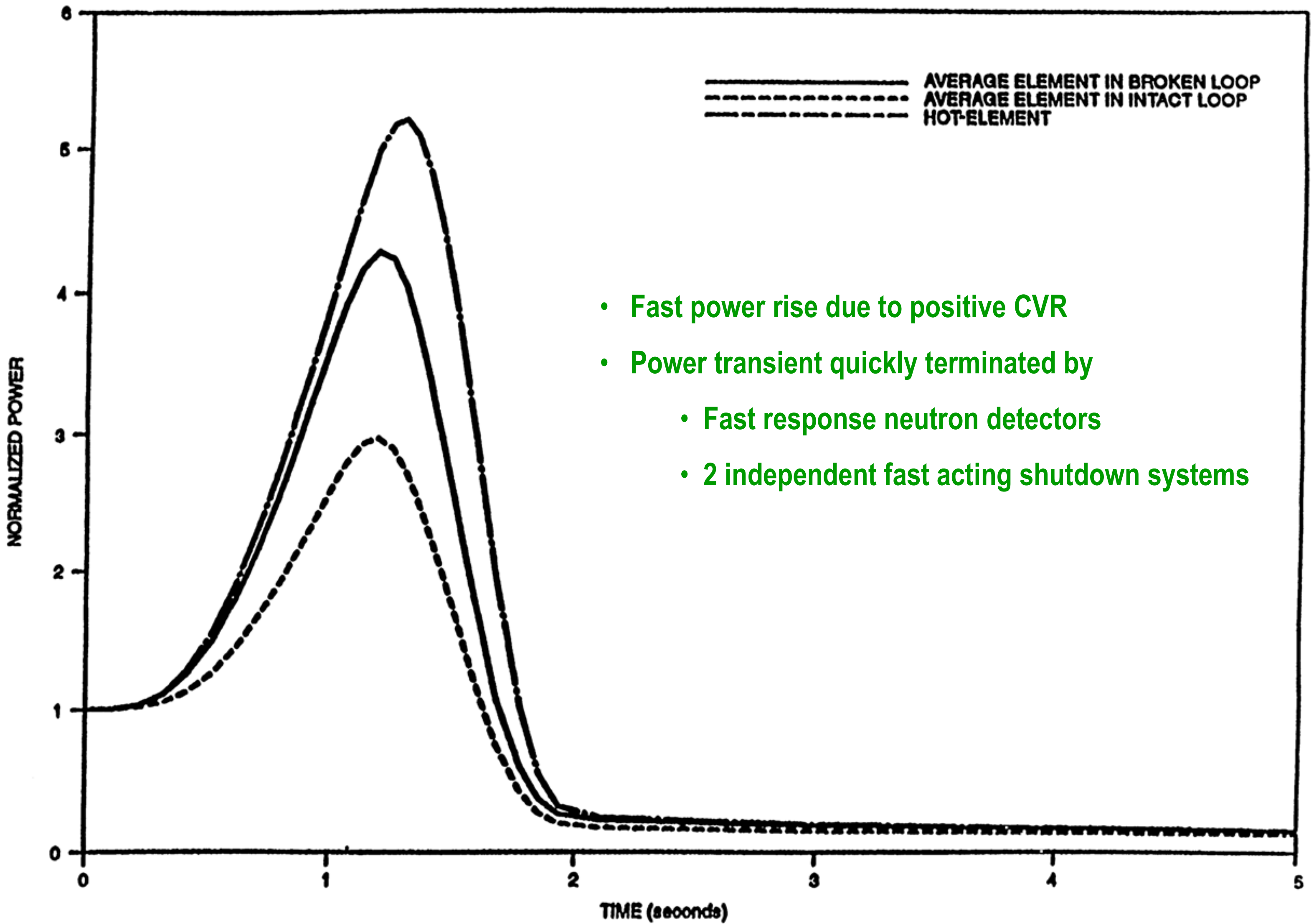
Change in Power/Flux Profile due to LOCA

for 900 kW bundle power at mid-burnup of ACR CANFLEX Fuel

	ACR Cooled (kW/m)	ACR Voided (kW/m)	% Change due to LOCA
Ring 1 (Central Pin) NU + 4.6 wt% Dy	19.0	23.0	+ 21.1 **
Ring 2 2 % SEU	43.8	50.2	+ 17.2
Ring 3 2 % SEU	37.9	39.4	+ 4.0
Ring 4 2 % SEU	48.5	45.2	- 6.8

** current CVR design target is – 3 mk
-10 mk CVR can be achieved by using less than 10 wt% Dy in the central pin

Typical Power Pulses in CANDU 6 for Individual Bundle and for Broken- & Intact-Loop Core Halves

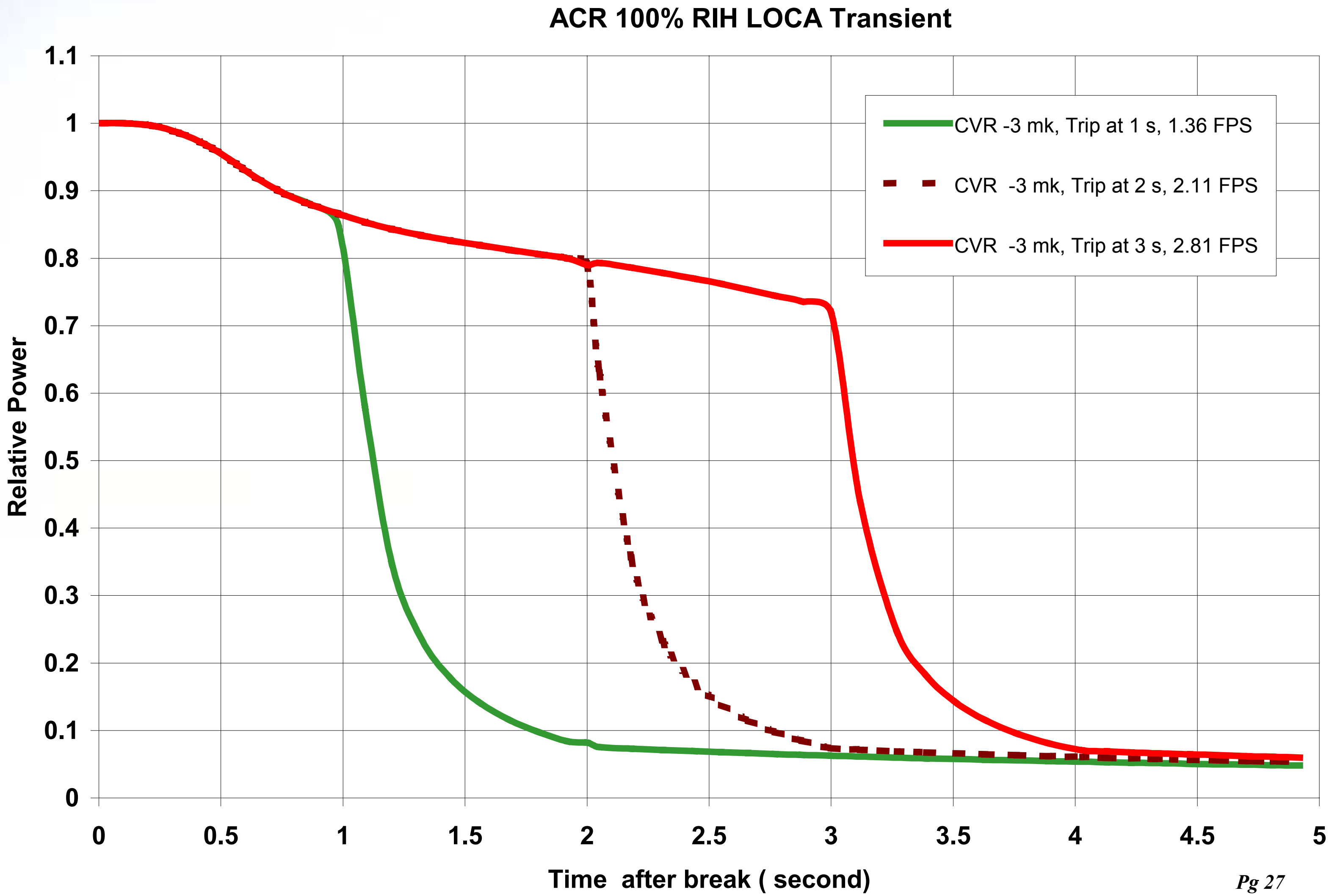


- Fast power rise due to positive CVR
- Power transient quickly terminated by
  - Fast response neutron detectors
  - 2 independent fast acting shutdown systems

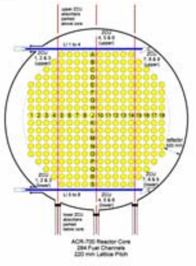
Unique LOCA Features in ACR

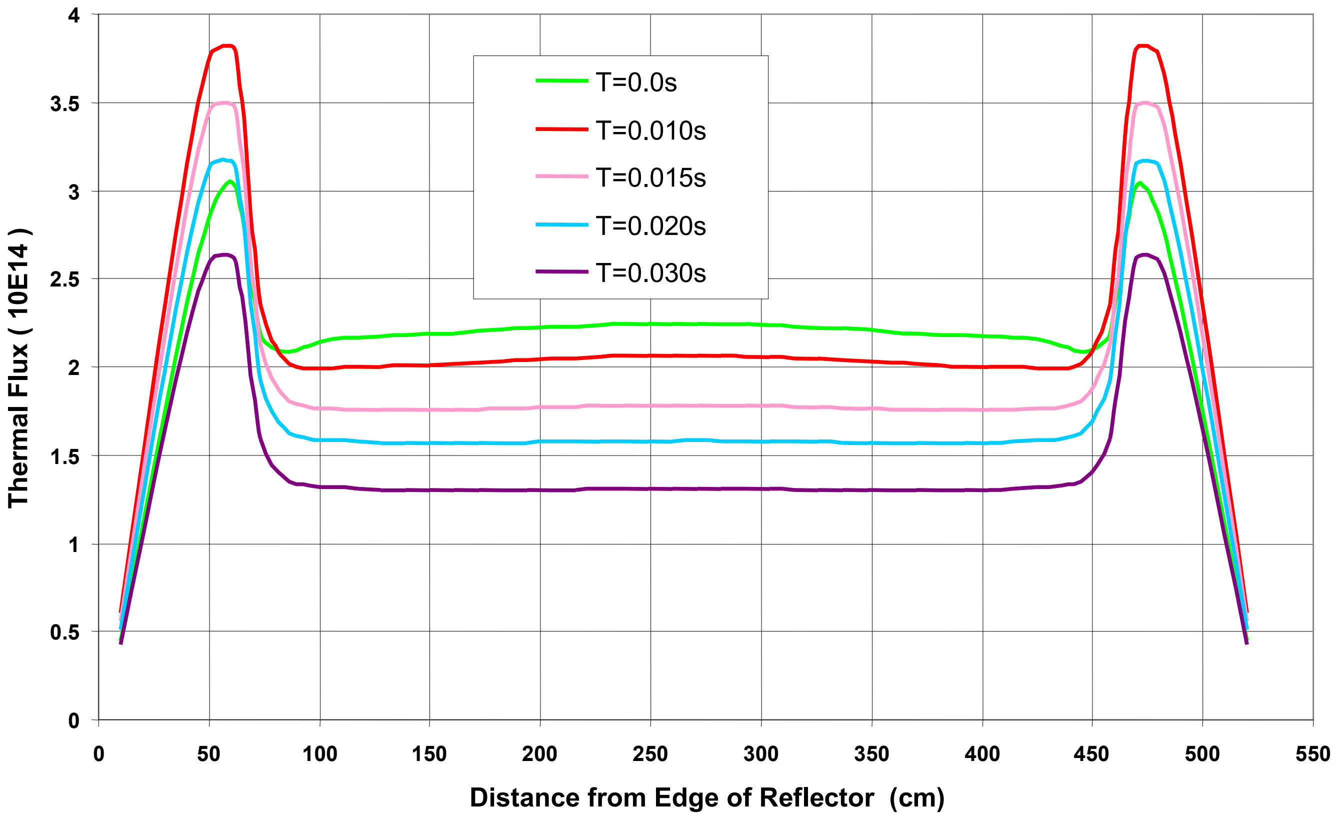
- Power in reactor core region drops upon LOCA due to negative void reactivity
- LOCA power transients not sensitive to trip time (relative to CANDU 6)
- Rapid rise in thermal neutron flux in the reflector region due to migration and subsequent thermalization of fast neutrons from the core region
- Fast neutronic trip is available from neutron detectors in the reflector region
- Slower process trip is sufficient to terminate LOCA

Effect of Trip Time on LOCA Transient

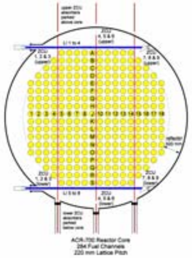


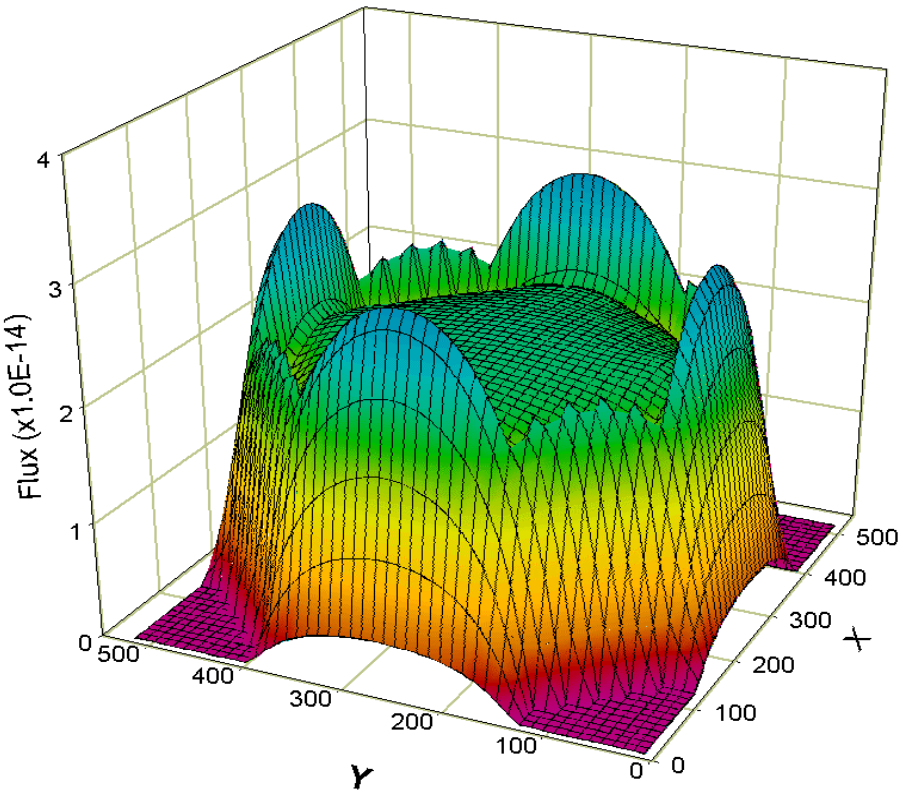
Thermal Neutron-Flux Distributions in ACR-700 after LOCA



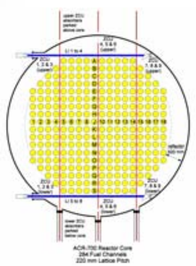


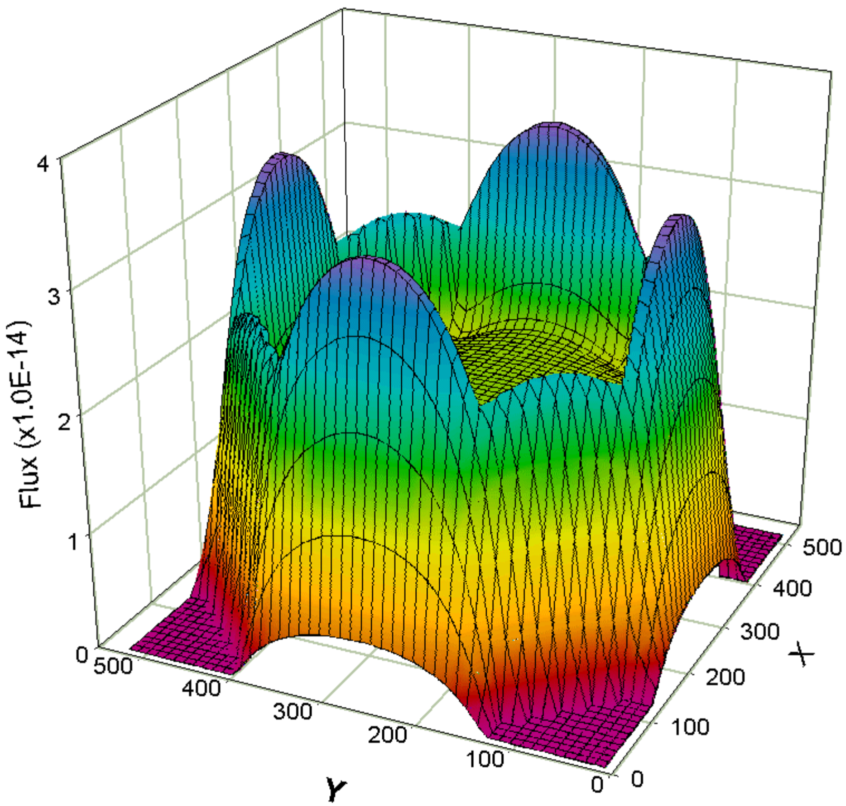
Thermal Flux Profile upon LOCA at t=0 s



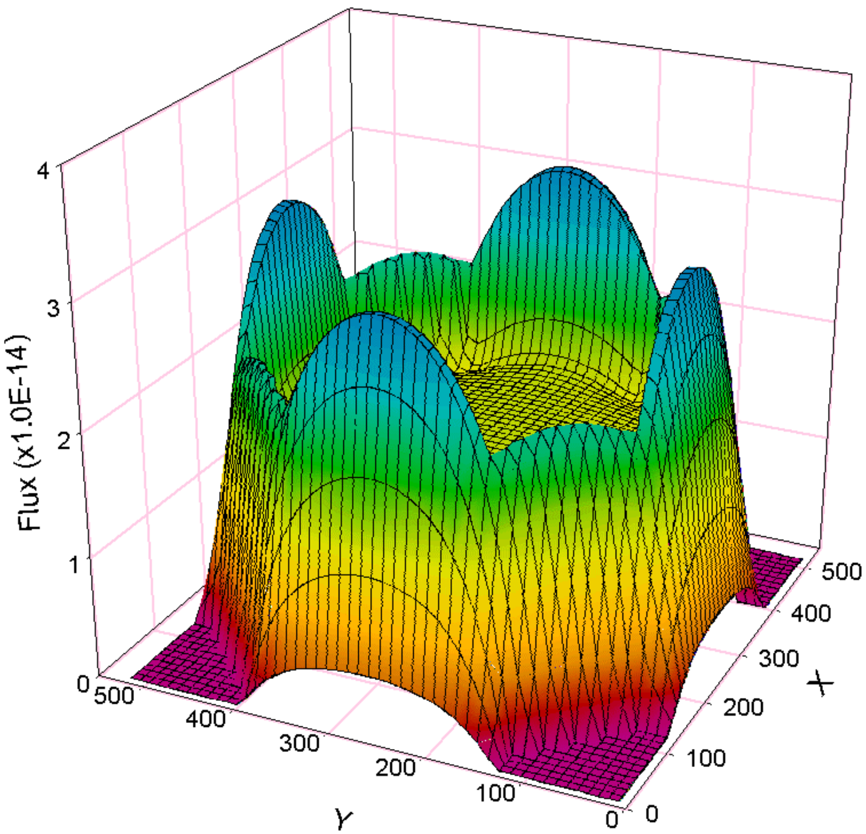


Thermal Flux Profile upon LOCA at t=0.015 s

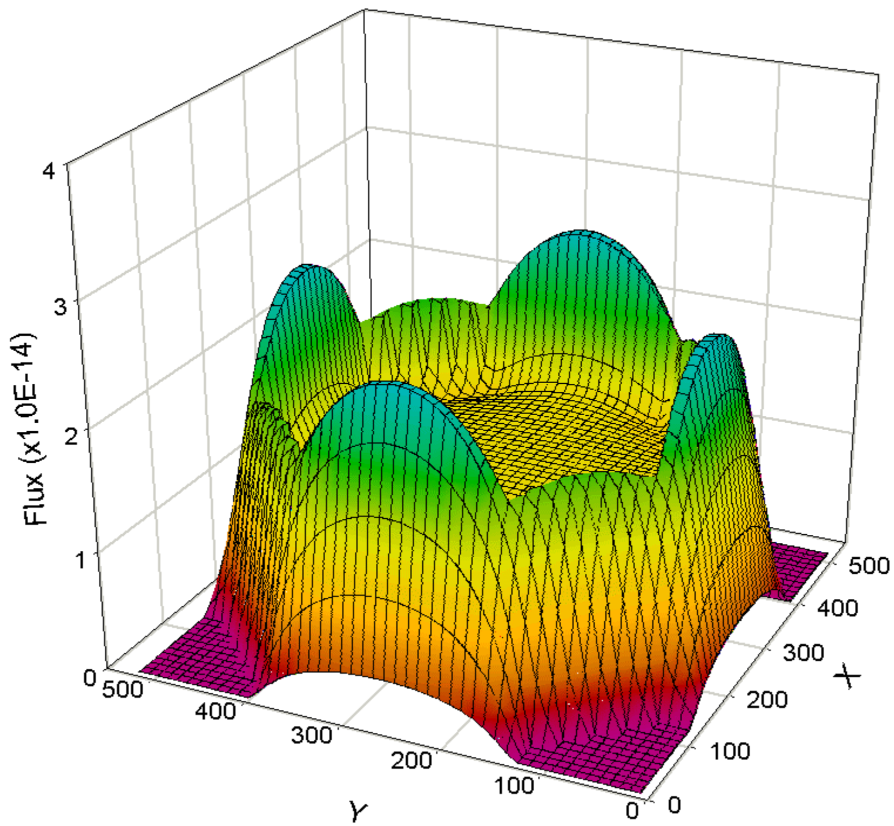




Thermal Flux Profile upon LOCA at t=0.02 s

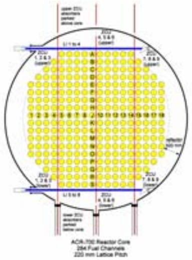


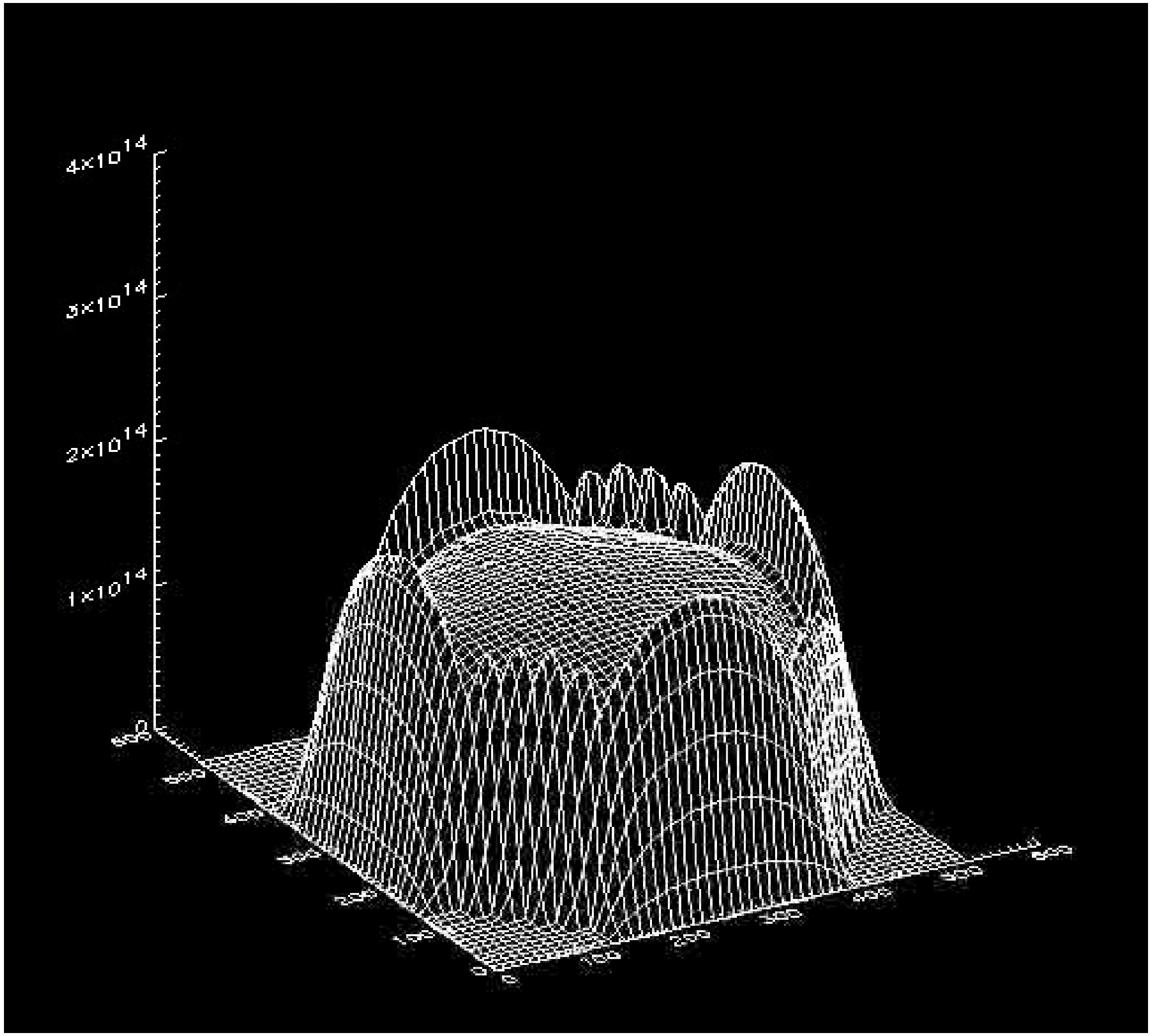
Thermal Flux Profile upon LOCA at t=0.03 s



Thermal Flux Profiles in ACR-700 upon LOCA

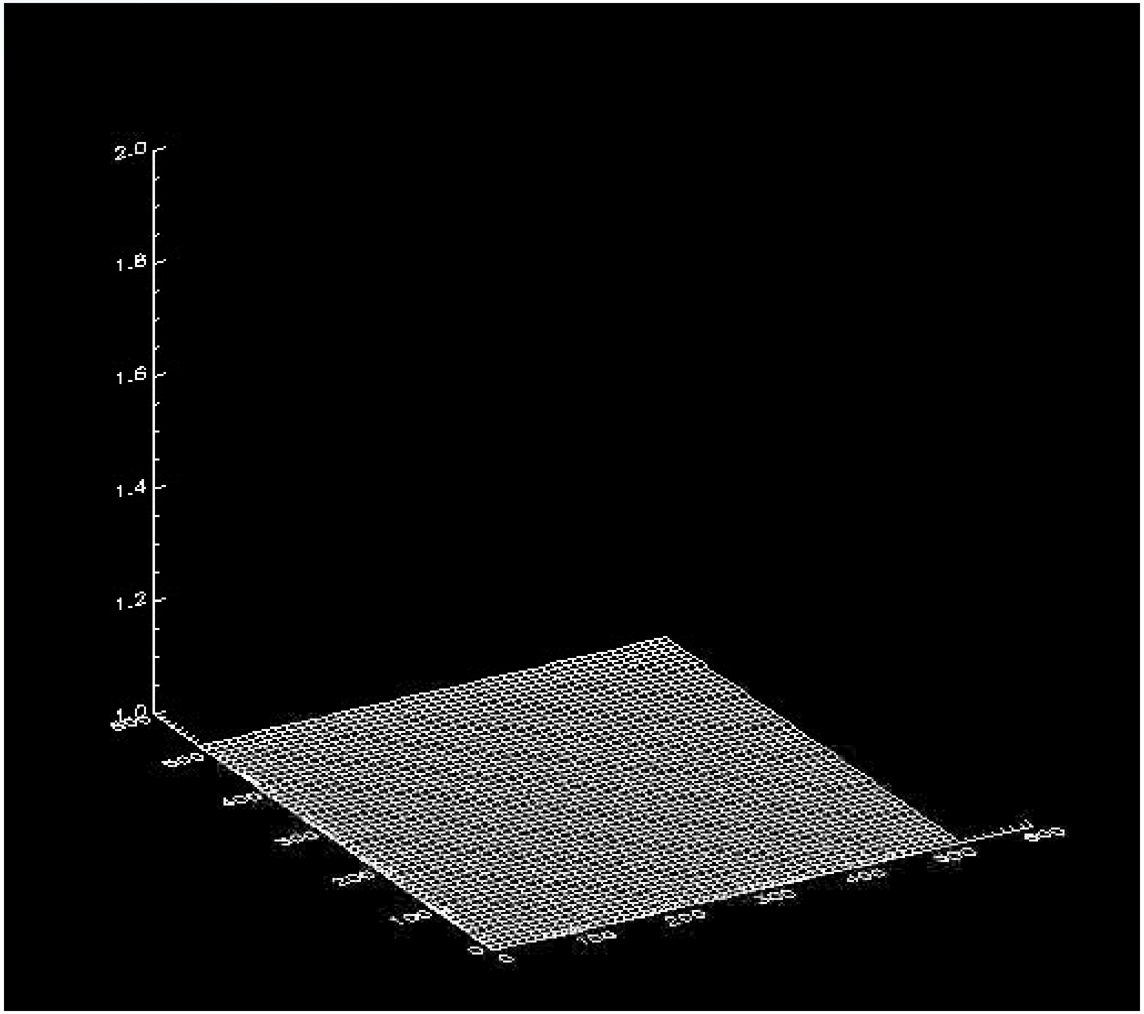
(click picture to start animation)





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
  - Smaller lattice-pitch and compact reactor core
  - High burnup SEU fuel
  - High power output
  - Negative coolant void reactivity
  - Negative power feedback coefficients

AECL