Confirmation of Negative Coolant Void Reactivity (ACR Physics Design)

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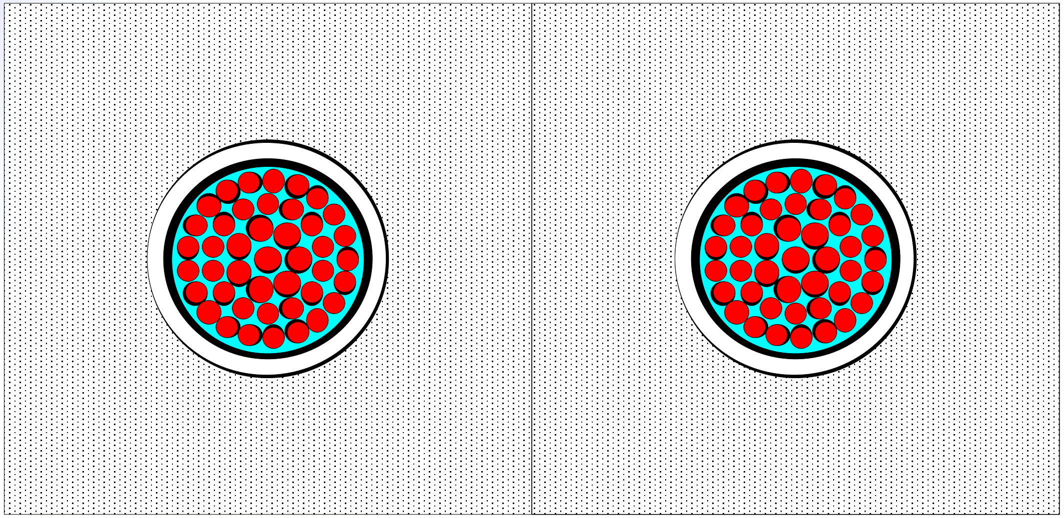
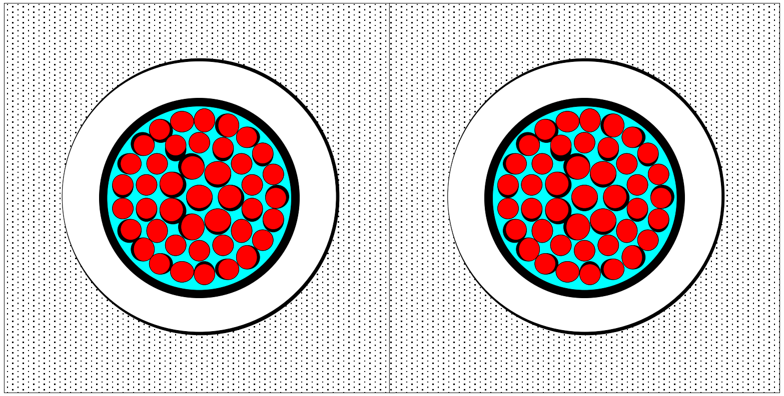
Outline

- **ACR achieves a slightly negative Coolant Void Reactivity (CVR) by manipulating upon voiding**
  - **Changes in Spatial Flux Shape**
  - **Changes in Neutron Spectrum**
- **Confirmation of Negative Coolant Void Reactivity in ACR by:**
  - **Comparisons of CVR calculated by AECL's computer codes (WIMS, RFSP, DRAGON) with other international codes such as MCNP, HELIOS, DONJON, NESTLE**
  - **Experimental verification of negative CVR in AECL's ZED-2 Reactor at Chalk River Laboratories (CRL)**

Comparison of NU CANDU and ACR Lattices



NU CANDU
Lattice Pitch 28.6 cm
Moderator/Fuel Ratio
= 16.4



ACR
Lattice Pitch 22 cm
Moderator/Fuel Ratio
= 7.1

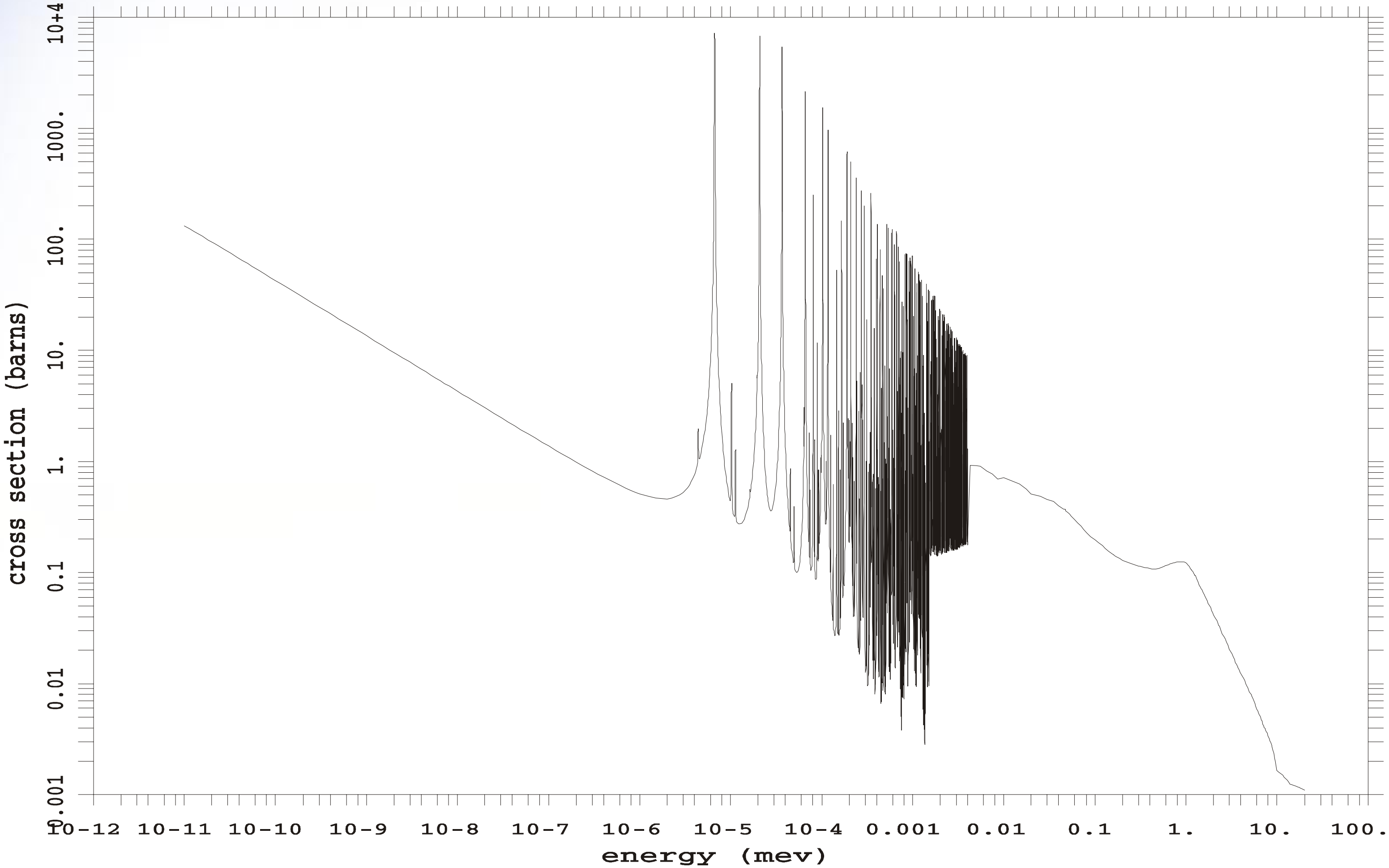
Physics Innovations to Achieve Slightly Negative CVR in ACR

- **WIMS lattice simulations indicate CVR can be reduced by reducing the Moderator / Fuel ratio in the lattice cell**
- **Design Target of Slightly Negative CVR requires reduction of lattice pitch (LP) from current value of 28.6 cm to 20 cm**
- **Minimum LP = 22 cm required to provide space for feeders between channels**
  - **Use larger calandria tube (CT) to displace more moderator**
  - **Add Dy (7.5%) to central NU pin**
  - **Use 2.1% SEU fuel in remaining 42 fuel pins to achieve average fuel burnup of about 21 MWd/kgU**
- **Full core LOCA reactivity effect = - 7 mk**

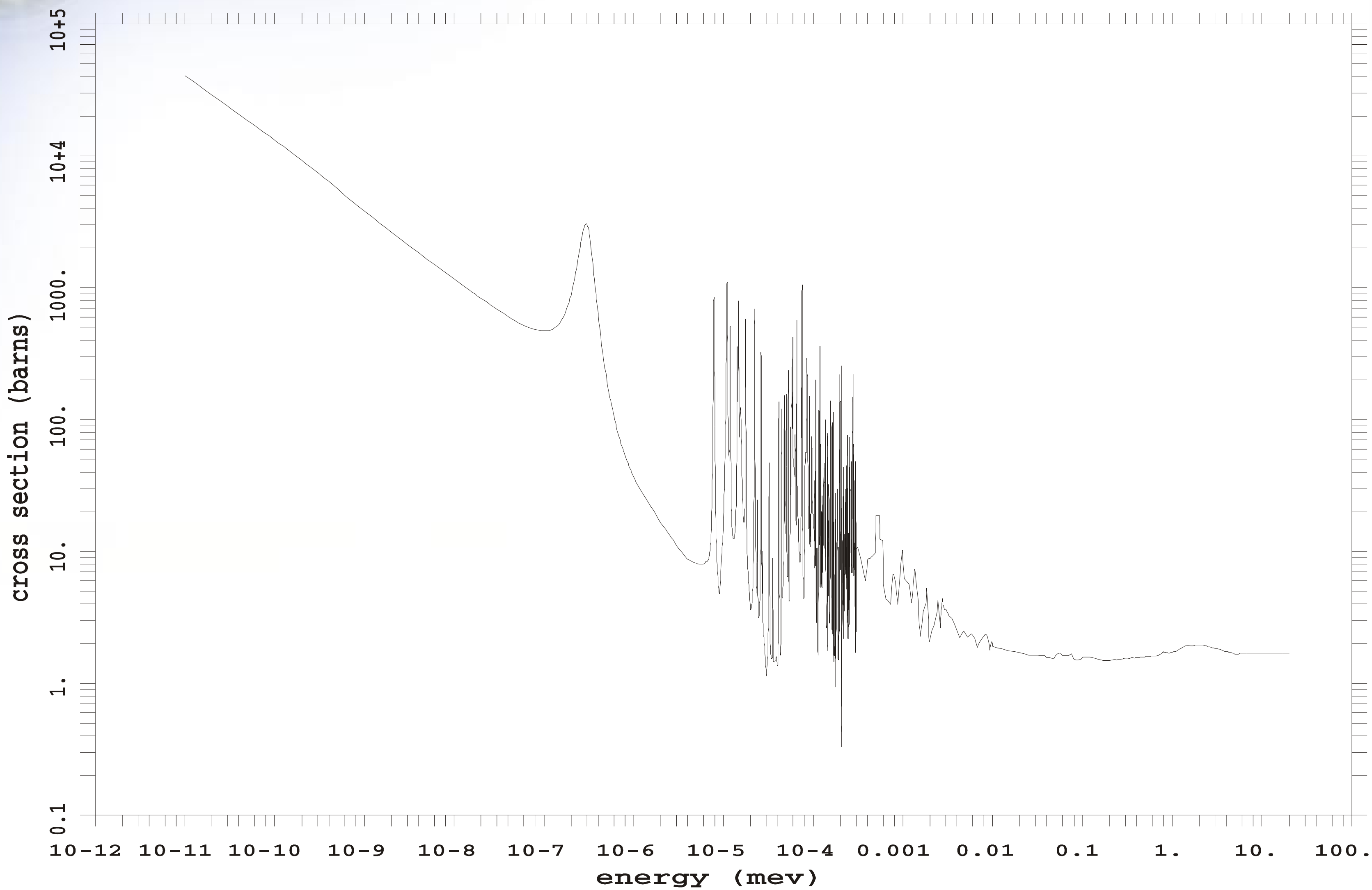
Effect of Coolant Void in ACR

- 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
- Major contributors to the negative CVR
  - Lattice Cell
    - Increase in Resonance Absorption (1 eV to 100 keV) in U238
    - Decrease in Fission (0.3 eV resonance) in Pu239
    - Increase in neutron absorption by Dy in the central pin upon voiding
  - Increase in Reactor Leakage

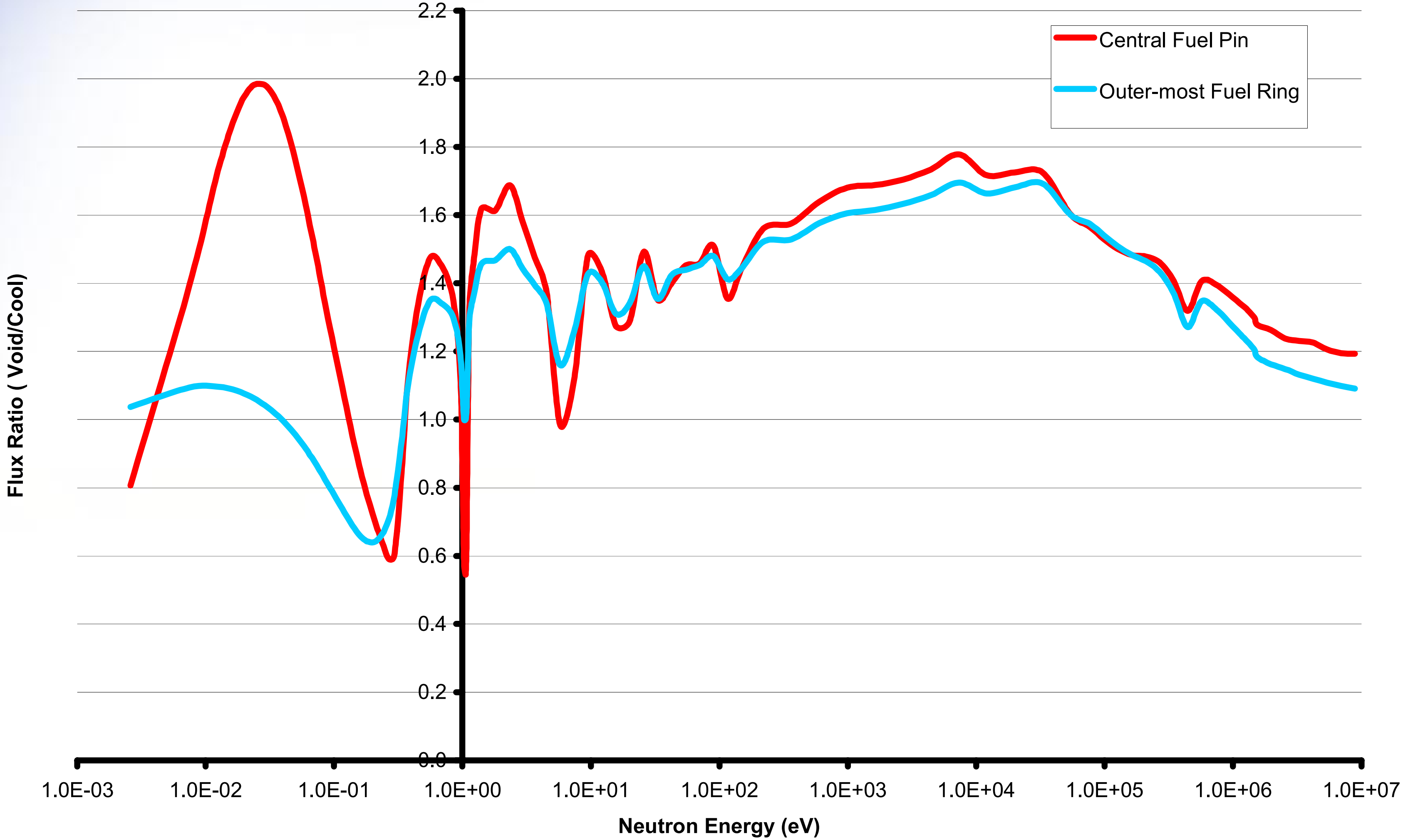
Absorption Cross Section of ^{238}U



Fission Cross Section of ^{239}Pu



Spatial and Spectral Changes in Neutron Flux due to Coolant Voiding in ACR



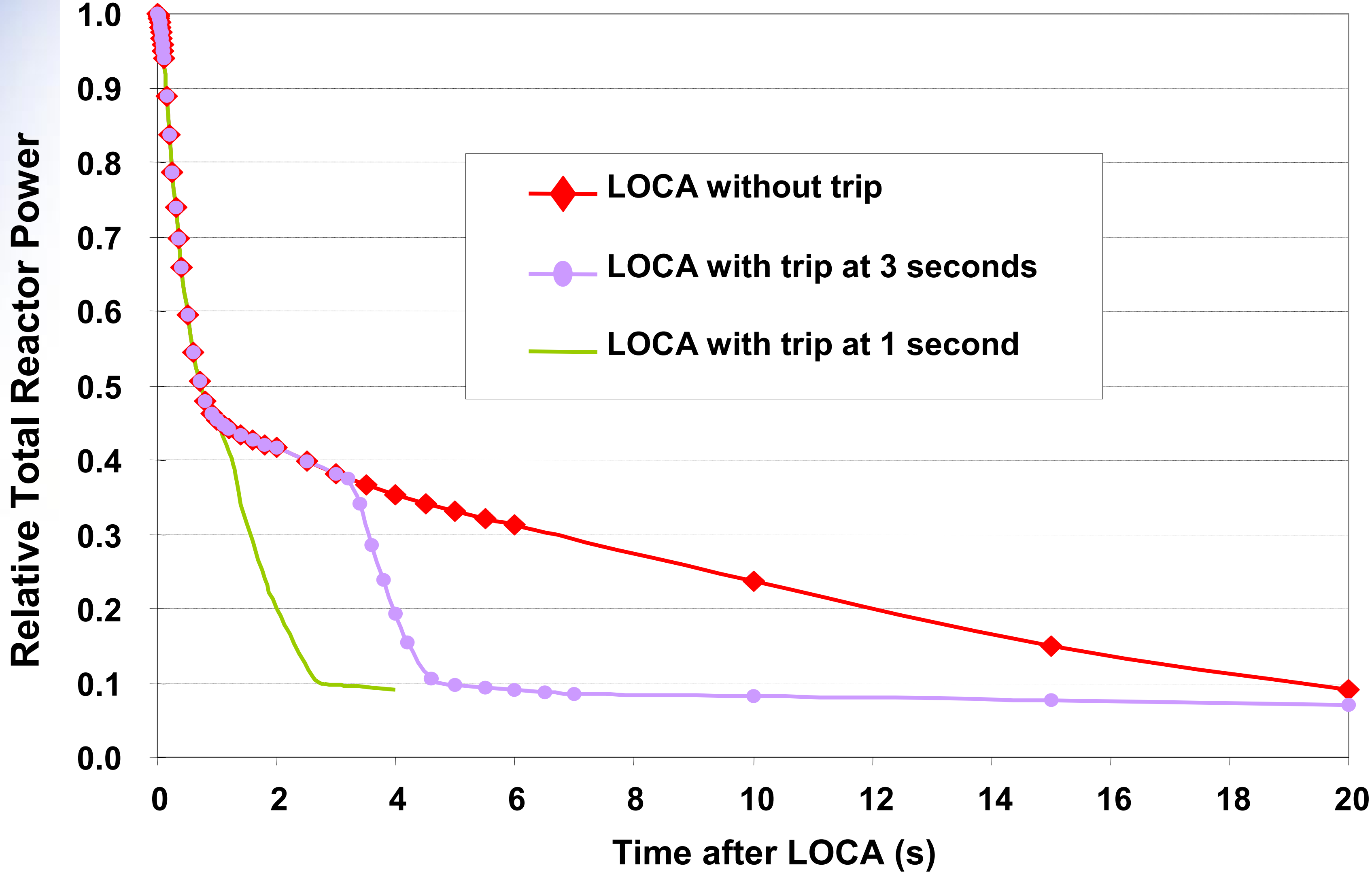
Major Contributors to CVR (mk) in ACR

U235	10.1
U238	-15.1
Pu239	-11.5
Pu240	-0.4
Pu241	-1.6
Pu242	-0.1
H1(Coolant)	31.5
Dy	-10.7
Other Nuclides in Lattice	-4.7
Net Lattice Reactivity	**-2.8**
Reactor Leakage	-4.2
Full-Core CVR	**-7.0**

Unique LOCA Features in ACR

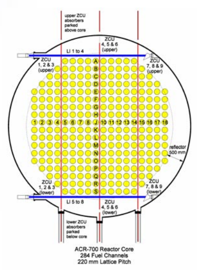
- Power in reactor core region drops upon LOCA due to negative void reactivity
- Process trip is sufficiently fast to terminate LOCA
- Rapid rise in thermal neutron flux in the reflector region relative to the core region due to migration and subsequent thermalization of fast neutrons from the core region
- This increase in neutron leakage results in a more negative LOCA reactivity than that predicted by the lattice code

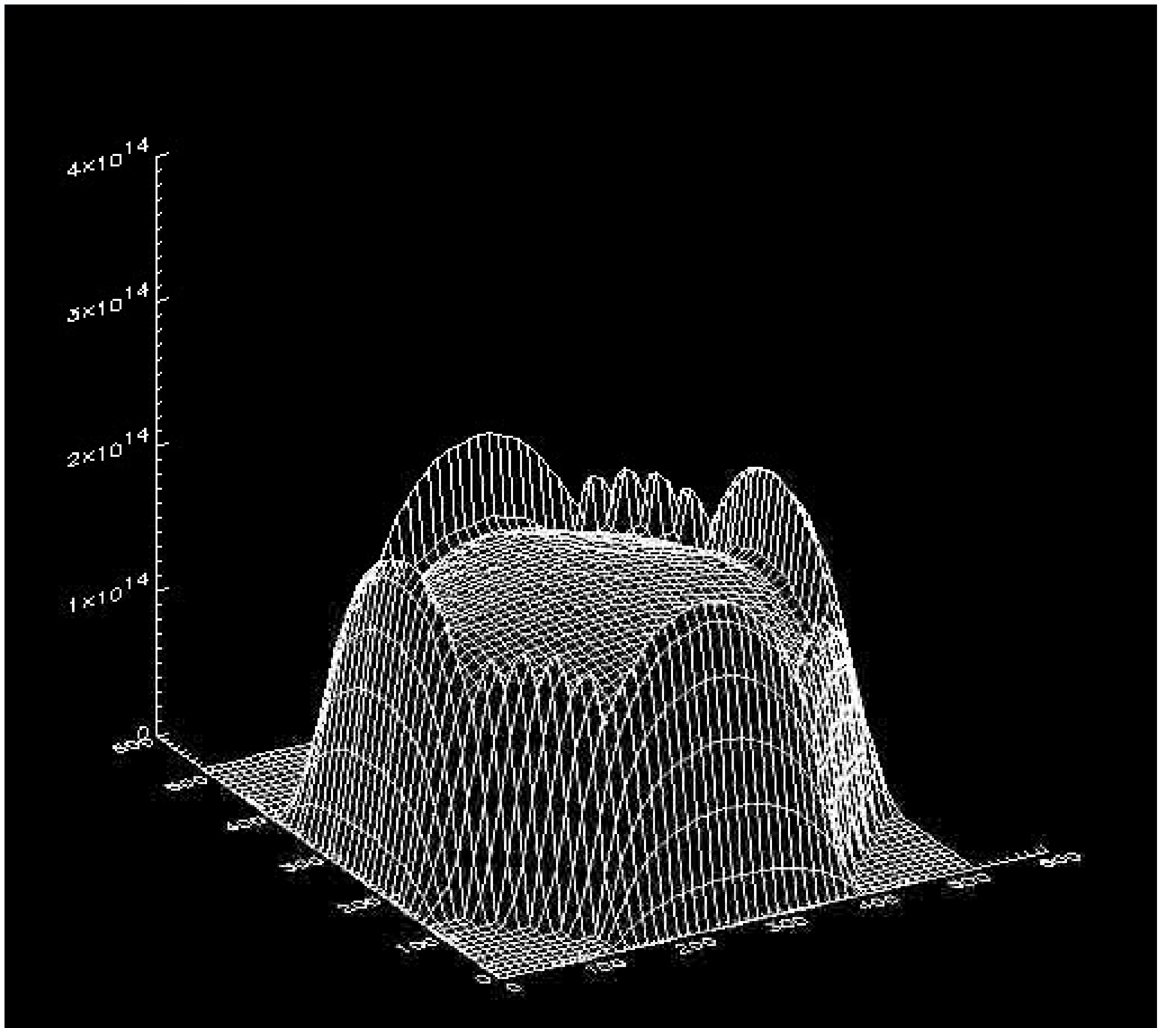
LOCA Power Transient in ACR-700
(Nominal Voiding Rate)



Thermal Flux Profiles in ACR-700 upon Instantaneous LOCA

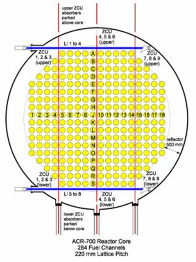
(click picture to start animation)

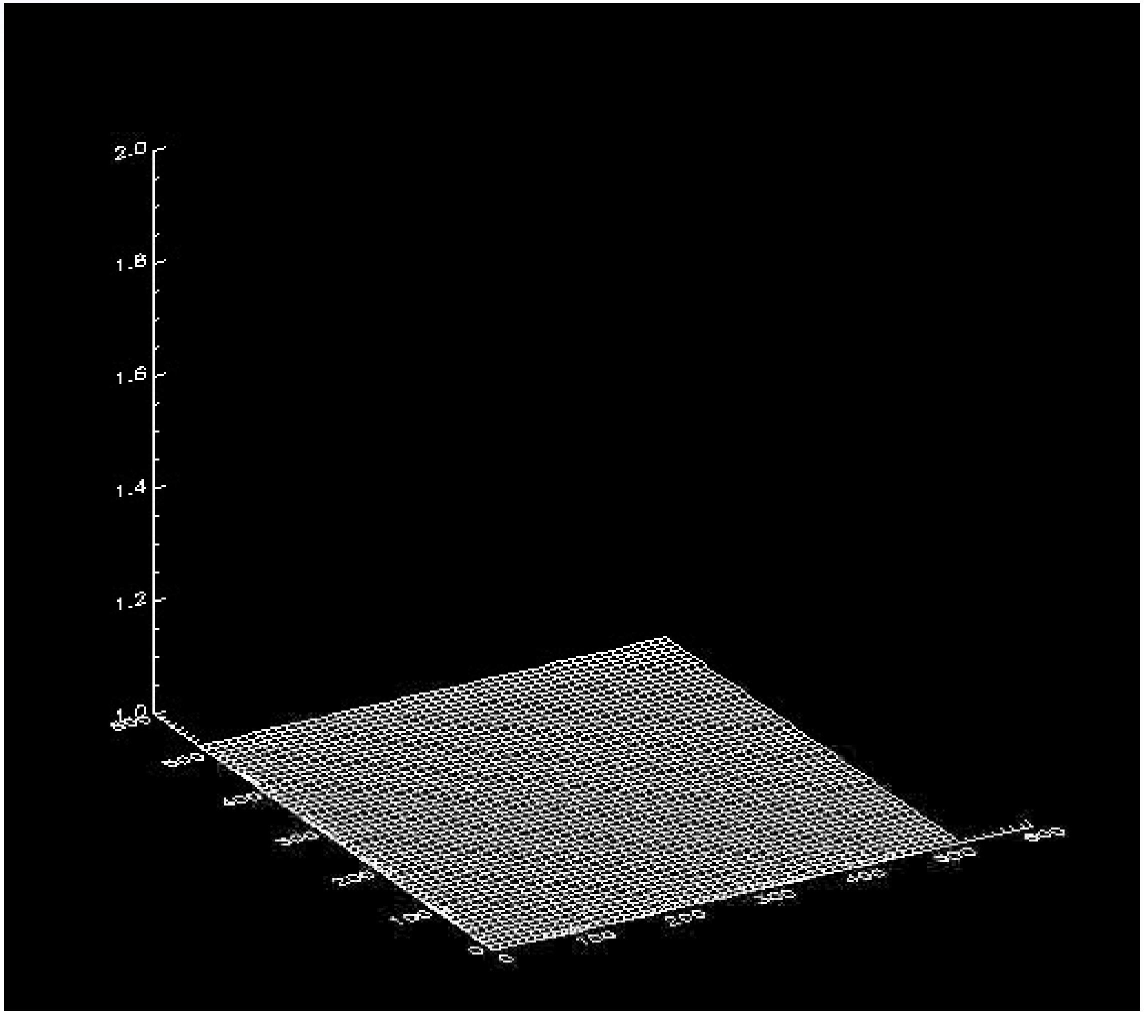




Thermal Flux Ratios in ACR-700 upon Instantaneous LOCA

(click picture to start animation)





ACR Physics Codes

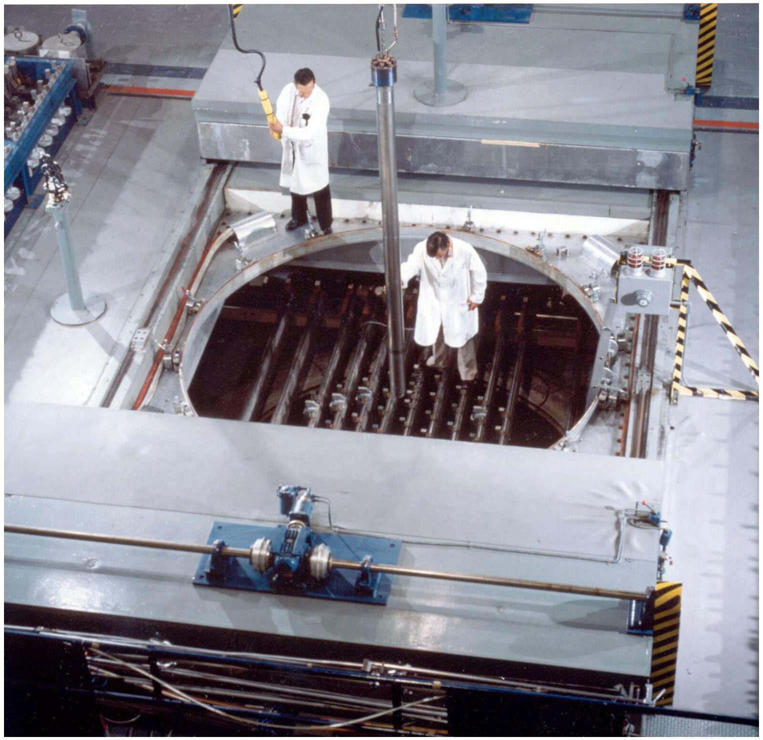
- **WIMS**
  - lattice-code produces 2-group cell-averaged cross sections for use in RFSP
- **RFSP**
  - 2-group diffusion method
  - wide range of calculational models: Reactor core design, fuel management, kinetics, xenon-transients
- **DRAGON**
  - from Ecole Polytechnique, for supercell calculations
    - device "incremental x-sections", added to cell-averaged cross sections in RFSP at device locations
- **MCNP**
  - extensively used for benchmarking the major physics codes
- **DONJON**
  - multi-group diffusion code from Ecole Polytechnique for comparison with RFSP

Confirmation of Negative CVR

- WIMS CVR of ACR fuel lattice has been confirmed by comparisons with
  - MCNP
- Negative reactivity due to Full-Core LOCA in ACR calculated by RFSP has been confirmed by comparisons with
  - DONJON
- Full-core MCNP model will be used to simulate LOCA in ACR and to confirm results from WIMS/RFSP simulations

Experimental Confirmation of Negative CVR in ZED-2 Reactor

- Tank-type critical facility, 3.3 m in diameter and depth
  - runs at a few watts
- Flexible facility
  - allows testing of a variety of fuels, different pitches, different coolants: D_2O, H_2O, air (voided)
- D_2O moderated
- Typical lattice arrangement is hexagonal, with 55 channels, each containing 5 bundles
  - can also have square lattice
- 7 “hot sites” can be located in center
  - 10 MPa up to 300 ^oC



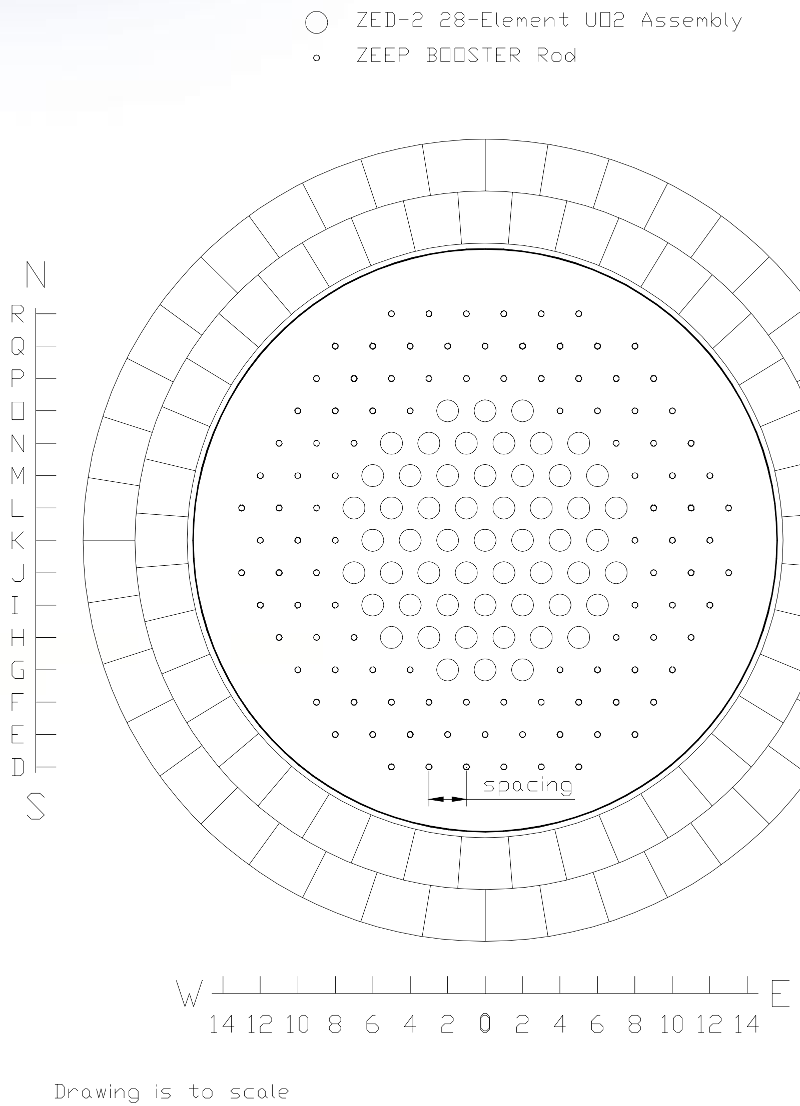
ZED-2 Measurements: General

- Material buckling (reactivity)
  - full core flux maps and substitution experiments
    - substitution method extensively validated
  - reactivity coefficients
    - void reactivity; fuel temperature; coolant temperature and purity; moderator temperature, purity, and poison
- Worth of reactivity devices (shutoff rod, adjuster rod)
- Reactor period measurements (for neutron kinetics)
- Reaction rates in foils
  - U-235, Pu-239, Dy-164, Cu-63, Mn-55, Au-197, In-115, Lu-176
  - reaction-rate ratios are sensitive indicators of the energy spectrum
- Fine lattice cell flux distribution (Cu-63)

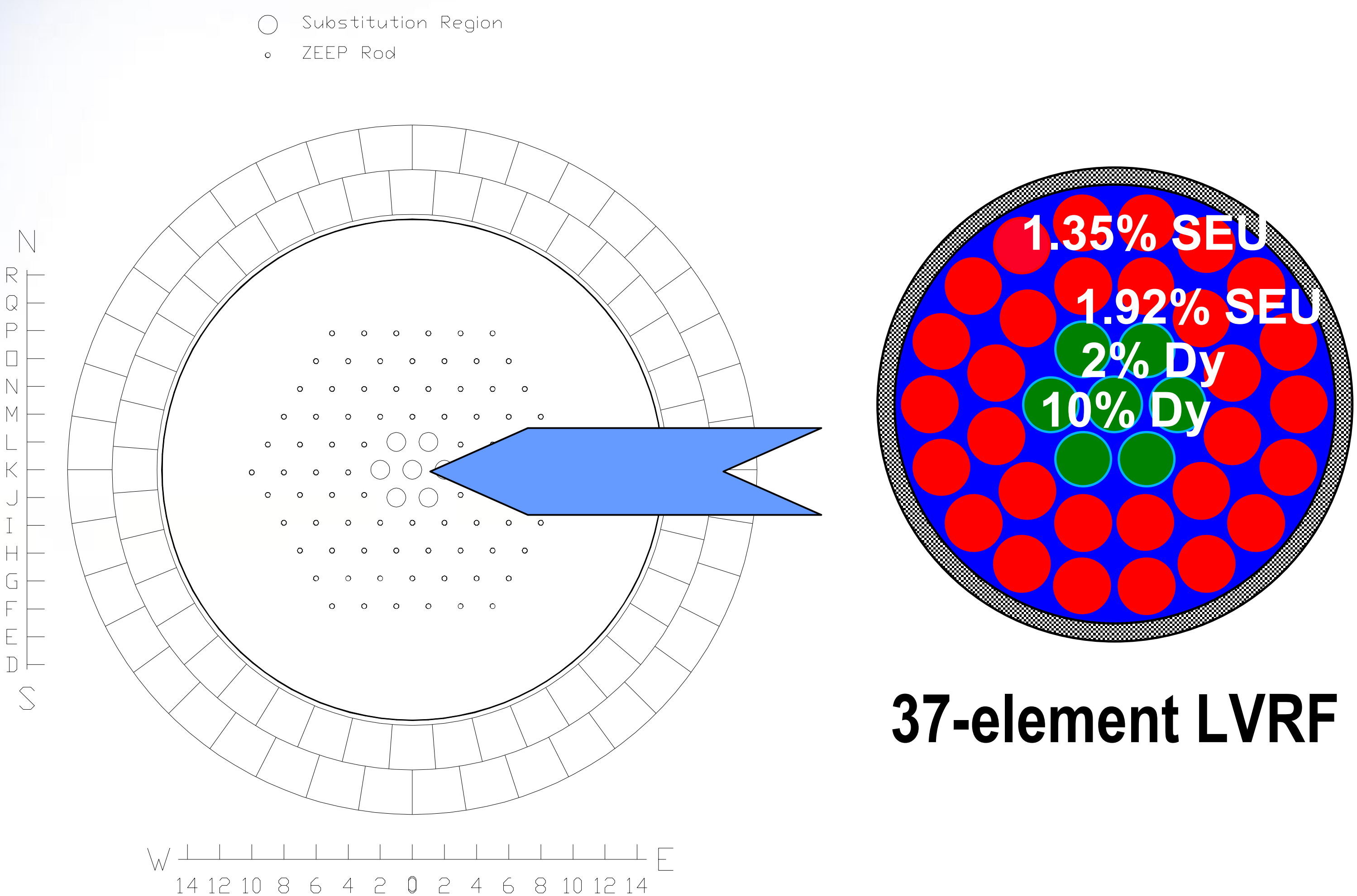
Preliminary ZED-2 Measurements Completed using Existing Fuel

- Buckling measurements using 28-element NU fuel
  - flux-maps, H_2O and air-cooled, hex lattices 20, 21.59, 22.86 cm pitch
  - 21.59 cm hex lattice pitch gives ACR moderator to fuel ratio of 7.1
  - measurements confirmed that CVR decreases when lattice pitch is reduced
- Substitution experiments using 37-element LVRF (Low Void Reactivity Fuel)
  - 7 channels into ZEEP (Zero Energy Experimental Pile) lattice at 21.59-cm hexagonal pitch, with H_2O, D_2O and air
  - Measurements confirmed negative CVR
- Fine-structure experiments using 37-element LVRF
  - a special demountable bundle with removable elements loaded with thin activation foils positioned between fuel pellets
  - activation data will be compared to WIMS predictions

Lattice Used for the 28-element Flux Maps



Physics Measurements of SEU and Dy Fuel in ZED 2

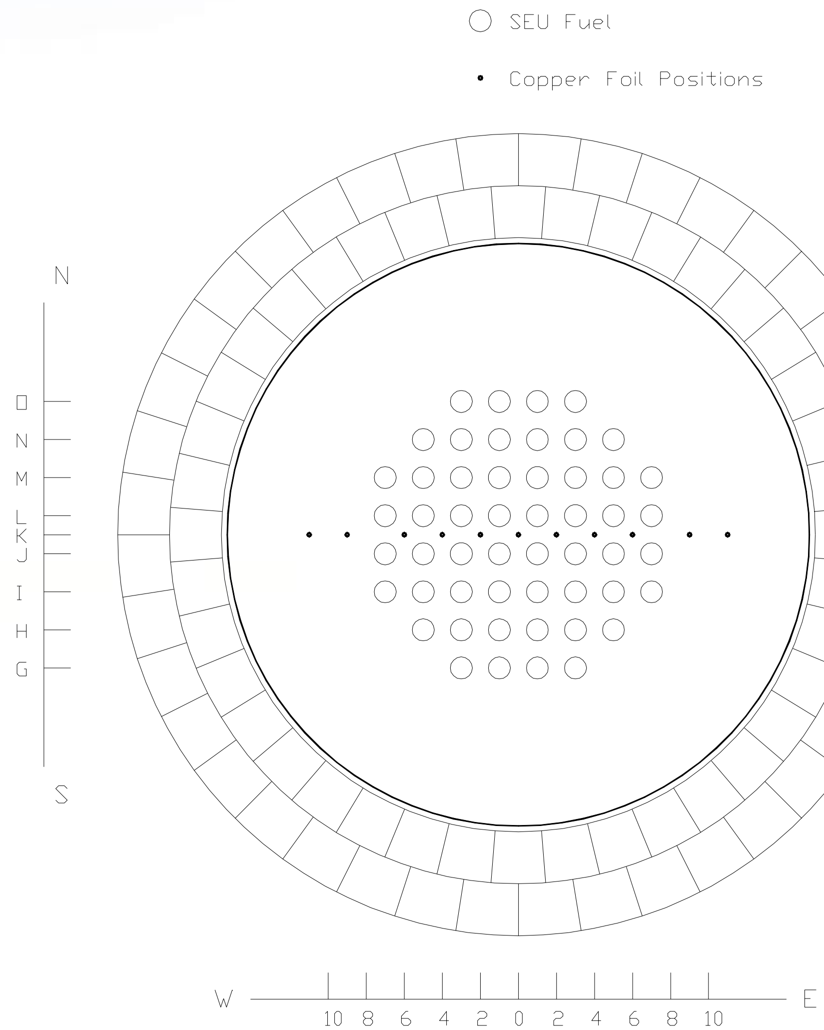


37-element LVRF

ZED-2 Measurements using Full-Core CANFLEX 0.95% SEU (Scheduled in 2004)

- **Flux-maps and buckling measurements in hexagonal lattice**
  - existing ZED-2 aluminum PT/CT assemblies with 3 coolants - H_2O, D_2O and air coolant, at 3 or more lattice spacings
- **Flux-maps and buckling measurements in square-lattice**
  - repeat of above using square lattice
  - copper activation foils will be positioned across the lattice and into the heavy water-reflector to measure the thermal flux peak in reflector on voiding
- **Substitution measurements**
  - 0.95% SEU into various ref. lattices (validation of substitution method)
  - 7-rod substitutions in ACR-type PT/CT assemblies with H_2O, D_2O and air coolant into ref lattice of 0.95% SEU (in existing ZED-2 aluminum PT/CT)
    - CANFLEX LVRF (1% SEU, Dy with NU in central element)
    - MOX (simulating irradiated ACR fuel)
- **Temperature Reactivity Effects of Fuel, Coolant, and Moderator for various configurations**

Flux-Map Set Up For Square Lattice



Summary

- **Coolant Void Reactivity in CANDU lattice is caused by spatial and spectral changes of neutron flux upon voiding**
- **The physics design of ACR manipulates these changes to achieve a slightly negative coolant void reactivity with H_2O coolant, by:**
  - **Using a tighter lattice pitch and a larger gap between pressure tube and calandria tube than the existing designs**
  - **Adding burnable poison (Dy) in the central fuel pin**
  - **Using SEU fuel**
- **Confirmation of Negative CVR by:**
  - **Comparisons of AECL's physics codes with international physics codes**
  - **Verification of negative CVR in ZED-2 reactor experiments at CRL**

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