

NEUTRON PERTURBATION DEVICE REACTIVITY WORTH MEASUREMENTS IN THE ZED-2 REACTOR

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Canadian Nuclear
Laboratories

Laboratoires Nucléaires
Canadiens

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Presentation Overview

- ZED-2 Background
- ZED-2 Experiments
- Flux Perturber Background
- Measuring the Flux Perturber Reactivity Worth
- Flux Perturber Experiments
- Questions



ZED-2 Background

Canadian Nuclear Laboratories (CNL) Location



ZED-2 Background

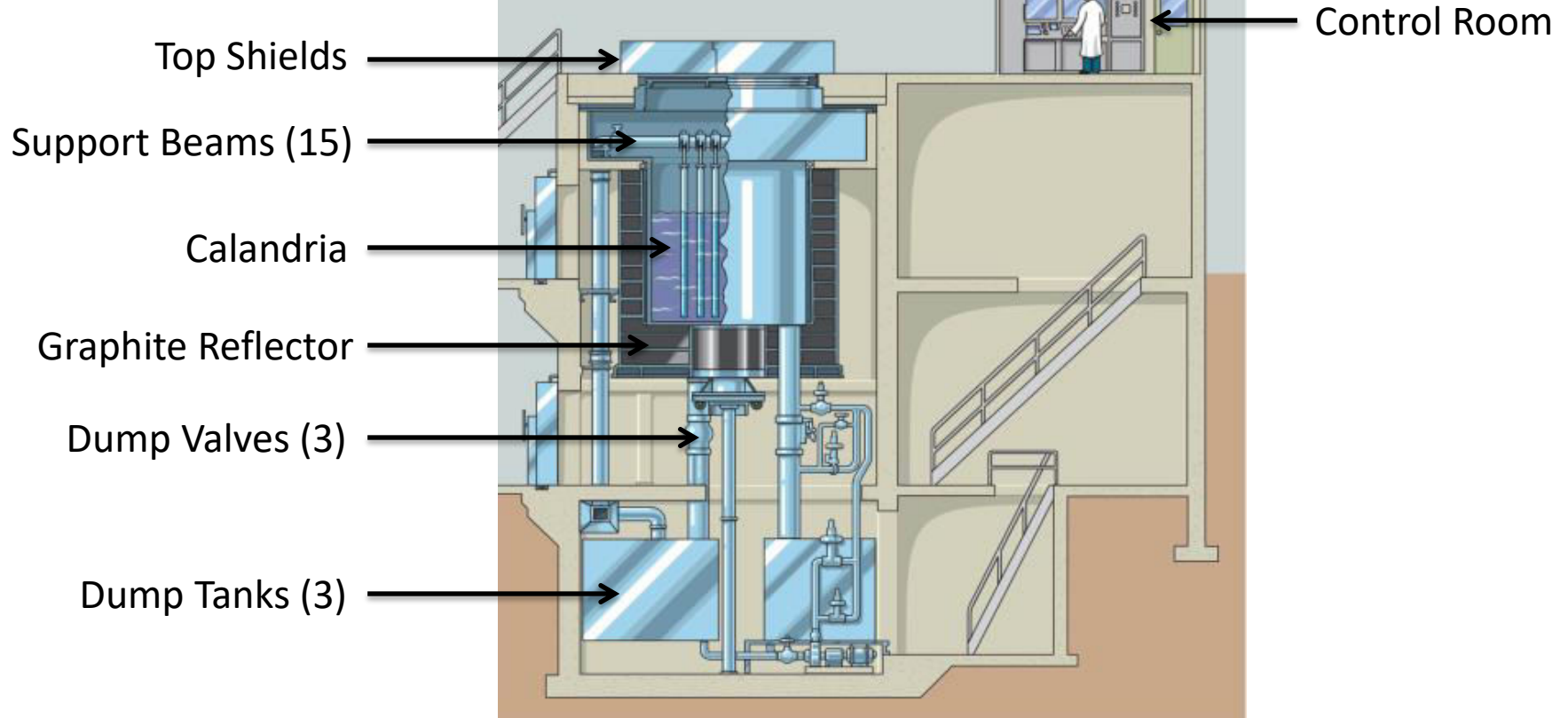
ZED-2 Overview

- First Criticality: September 7, 1960
- Maximum Power: 200 W (indicated), 700 W (thermal)
- Maximum Neutron Flux: 1×10^9 n/cm²/s
- Moderator: Heavy Water
- Coolant: Air, Heavy Water, Light Water
- Fuel: NU, LEU, Other Mixed Oxides



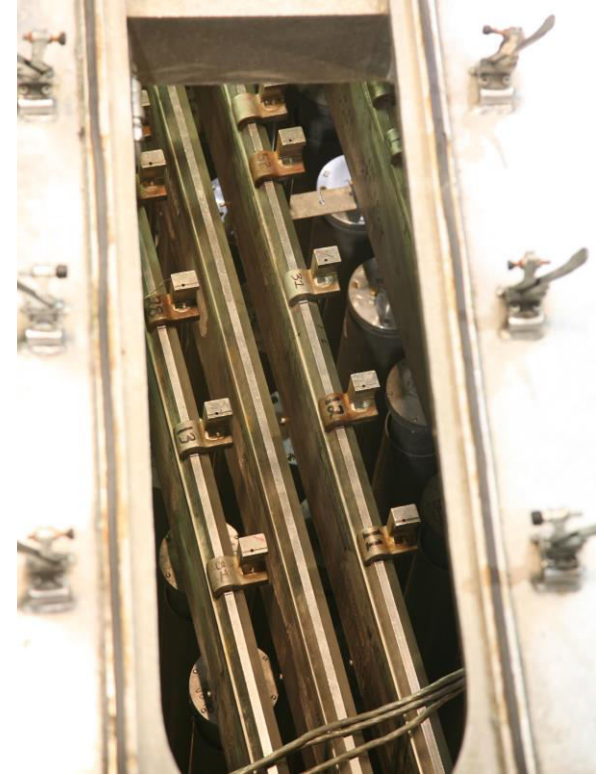
ZED-2 Background

ZED-2 Facility Layout



ZED-2 Background

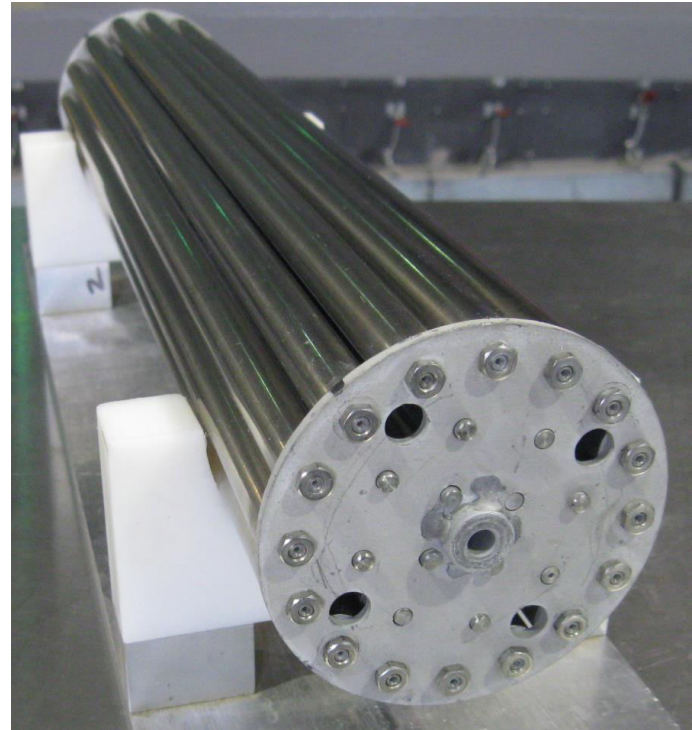
ZED-2 Calandria



ZED-2 Fuel

Fuel Bundles

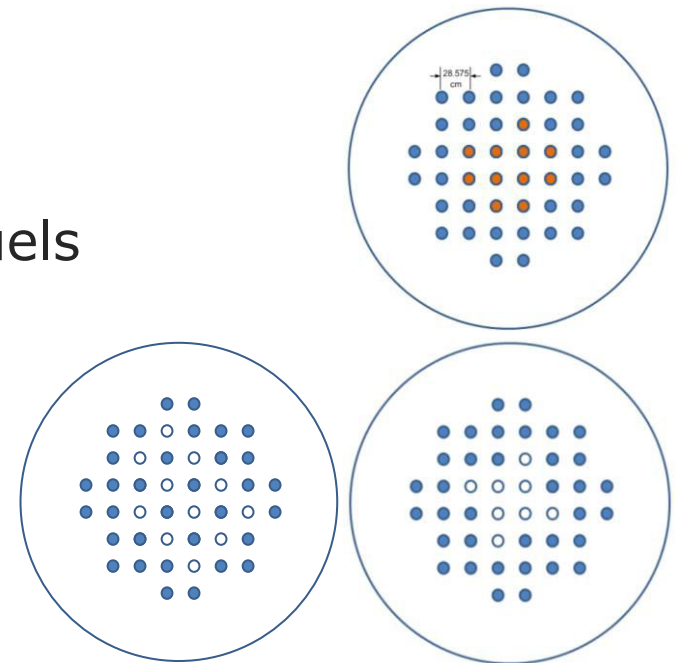
- Natural UO_2 Bundles
 - 7, 19, 28, 37, 43 element
- Uranium Carbide
- Uranium Silicide
- Uranium Metal
- Mixed Oxides
 - Pu-U (Depleted)
 - U^{233} -Th
 - Pu-Th
- Bundles with absorber elements
- Enriched or reprocessed UO_2 bundles (LEU, RU)



ZED-2 Experiments

Ongoing and Recent Experiments

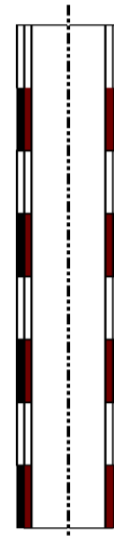
- Critical Height Measurements
 - Reactor Physics Code Validations
- 3-D Kinetics Measurements
- Reactivity Transient Measurements
 - Transients utilizing Thoria-Based Fuels
 - Flux Perturber Experiments



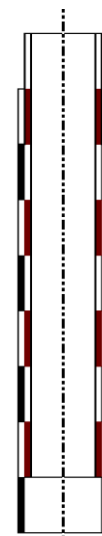
Flux Perturber Background

Physical Description

- Periodic binary reactivity changing device
- Constant time averaged reactivity worth



Less Neutron
Absorption



More Neutron
Absorption



Flux Perturber Background

Reactor Point Kinetics Analysis



Flux Perturber Background

Reactor Point Kinetics Analysis



$$H(s) = \frac{\delta N(s)/N_0}{\delta \rho(s)} = \frac{1}{\Lambda} \frac{1}{s \left(1 + \sum_{i=1}^M \frac{\beta_i}{\Lambda(s + \lambda_i)} \right)}$$



Reactivity Worth

Previous Method for Determining Flux Perturber Reactivity Worth

- ZED-2 Accurate Height Probe Measurement
 - Relative Height Accuracy of ± 0.020 cm
- Level Coefficient of Reactivity
 - Varies between 0.15 mk/cm to 2.2 mk/cm
- Reactivity Accuracy at Critical
 - 3 μ k to 44 μ k
- Flux Perturber Reactivity Worth
 - ~ 100 μ k



Reactivity Worth

New Method for Determining Flux Perturber Reactivity Worth

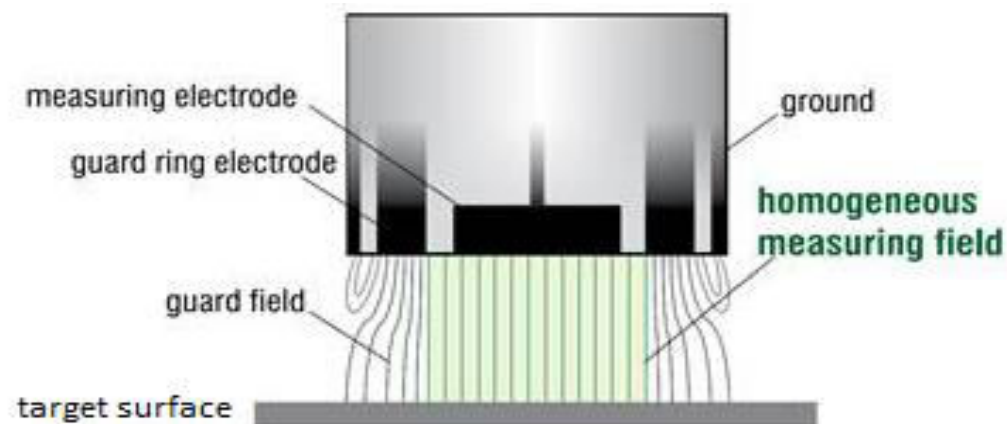
- Design Requirements
 - Accuracy: 1.0 μm
 - Set Range: 0.7 cm
 - Maneuverable Range: 1.0 m
 - Handle High Radiation Levels



ΔH_c System

Principle of Operation

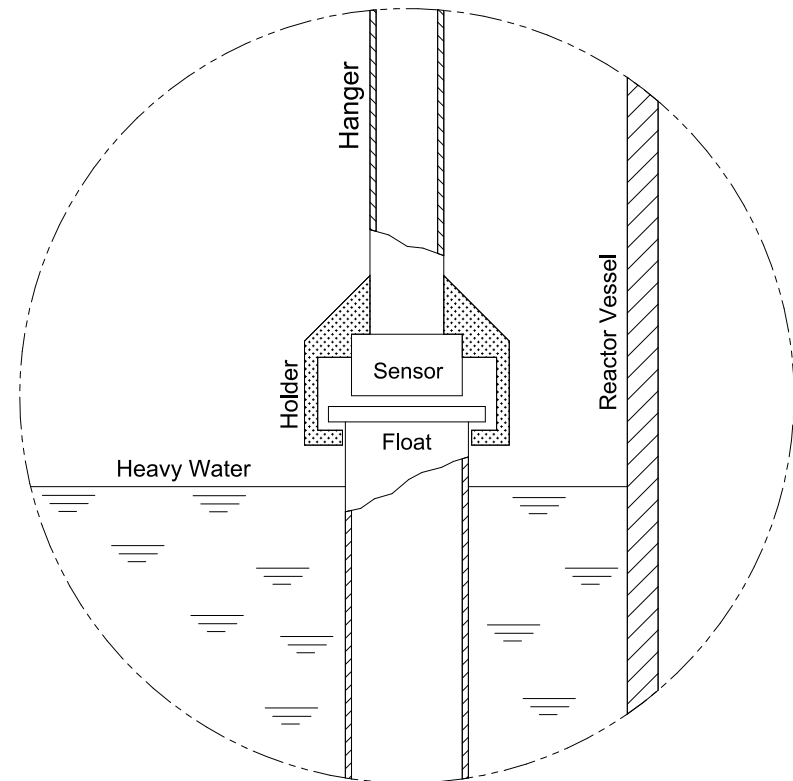
- Displacement Sensor
- No active electronics in radiation areas
- Resolution of 2.25 nm



ΔH_c System

Principle of Operation

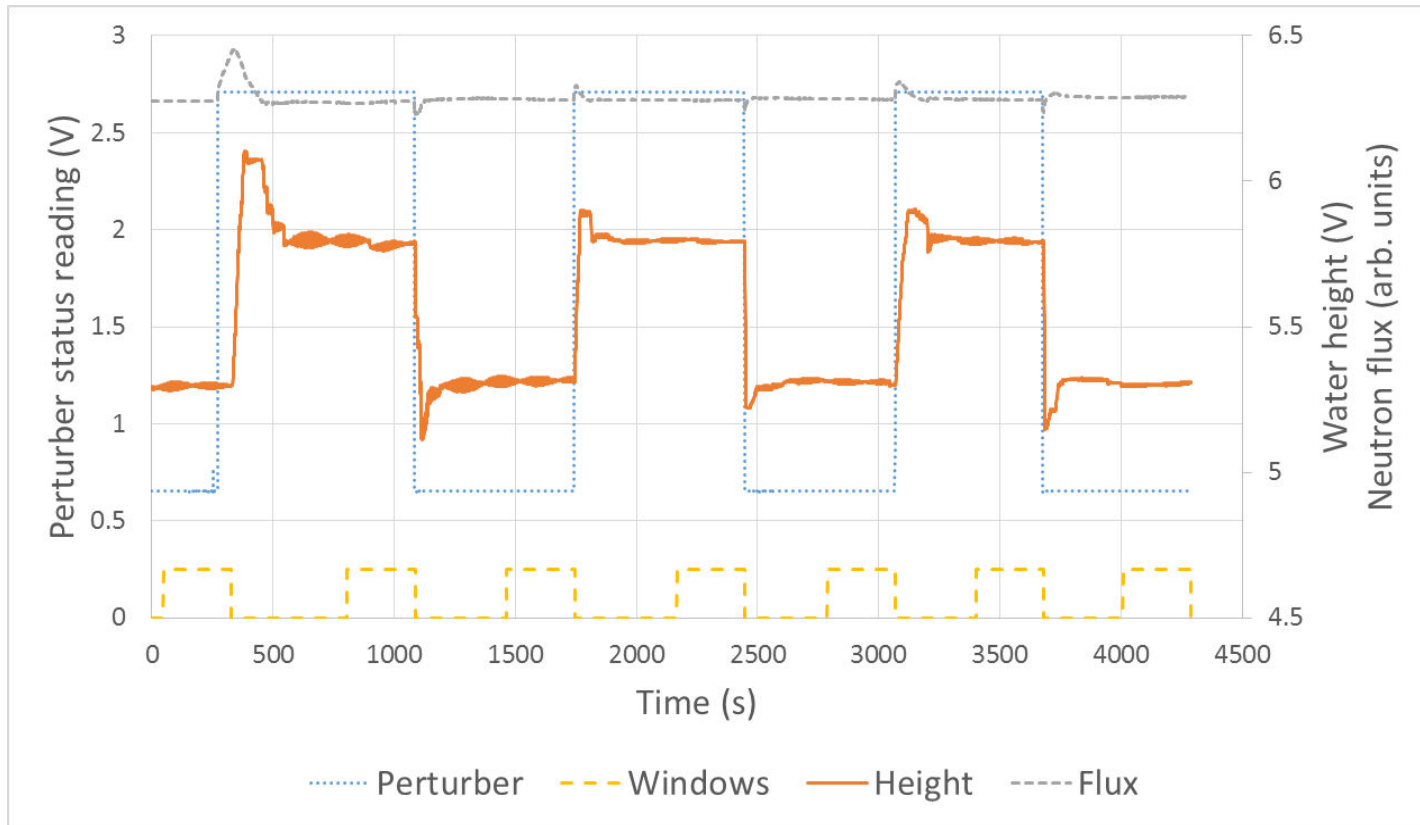
- Maneuverable float with displacement sensor



Experiment

Flux Perturber ΔH_c Readings

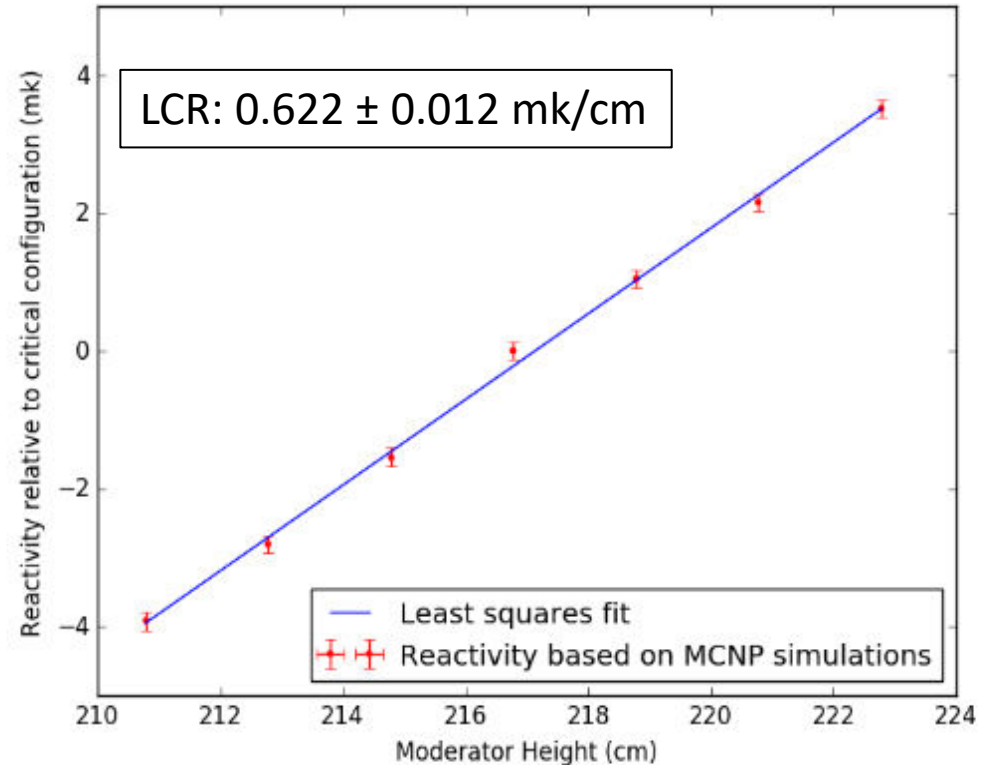
$$\Delta H_c = 0.384 \pm 0.017 \text{ mm}$$



New Reactivity Worth

Analysis - Level Coefficient of Reactivity

- Using the calculated LCR and moderator height difference between the two perturber states the reactivity worth is found to be $23.9 \pm 1.2 \mu\text{k}$.



ZED-2 Flux Perturber Experiments

Reactor Point Kinetics Analysis



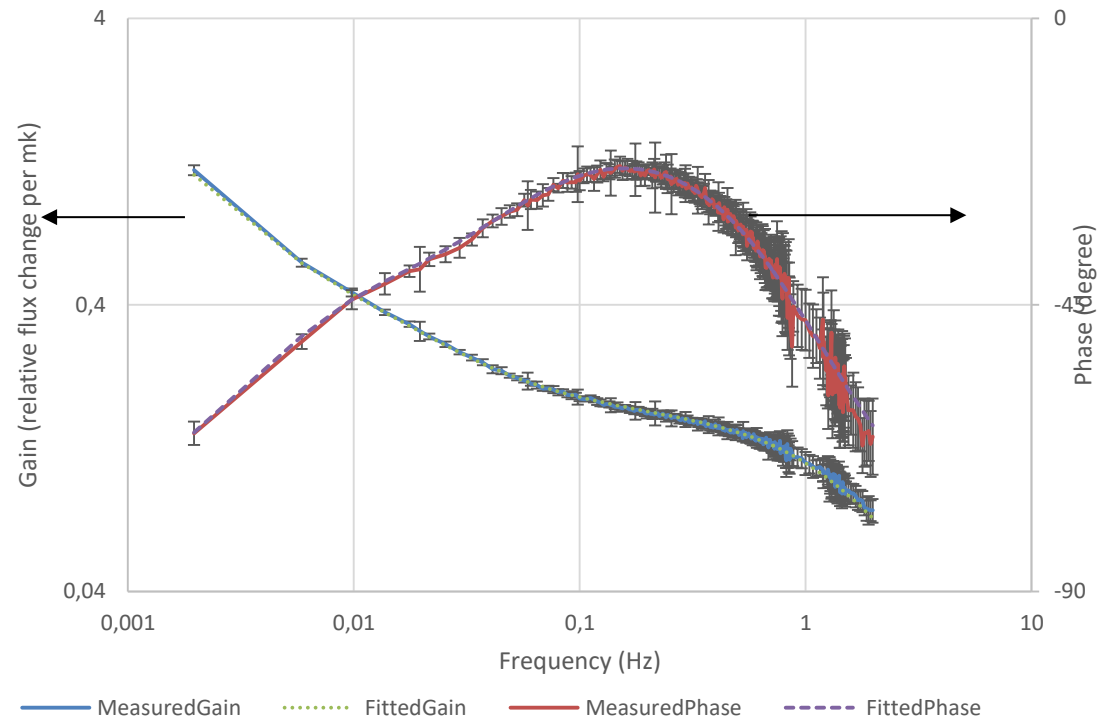
$$H(s) = \frac{\delta N(s)/N_0}{\delta \rho(s)} = \frac{1}{\Lambda} \frac{1}{s \left(1 + \sum_{i=1}^M \frac{\beta_i}{\Lambda(s + \lambda_i)} \right)}$$



Analysis

Fitting The Measured Transfer Function

- Prompt Neutron Generation Time Λ
 - 0.981 ± 0.029 ms
- Delayed Neutron Fraction β
 - 6.11 ± 0.18 mk

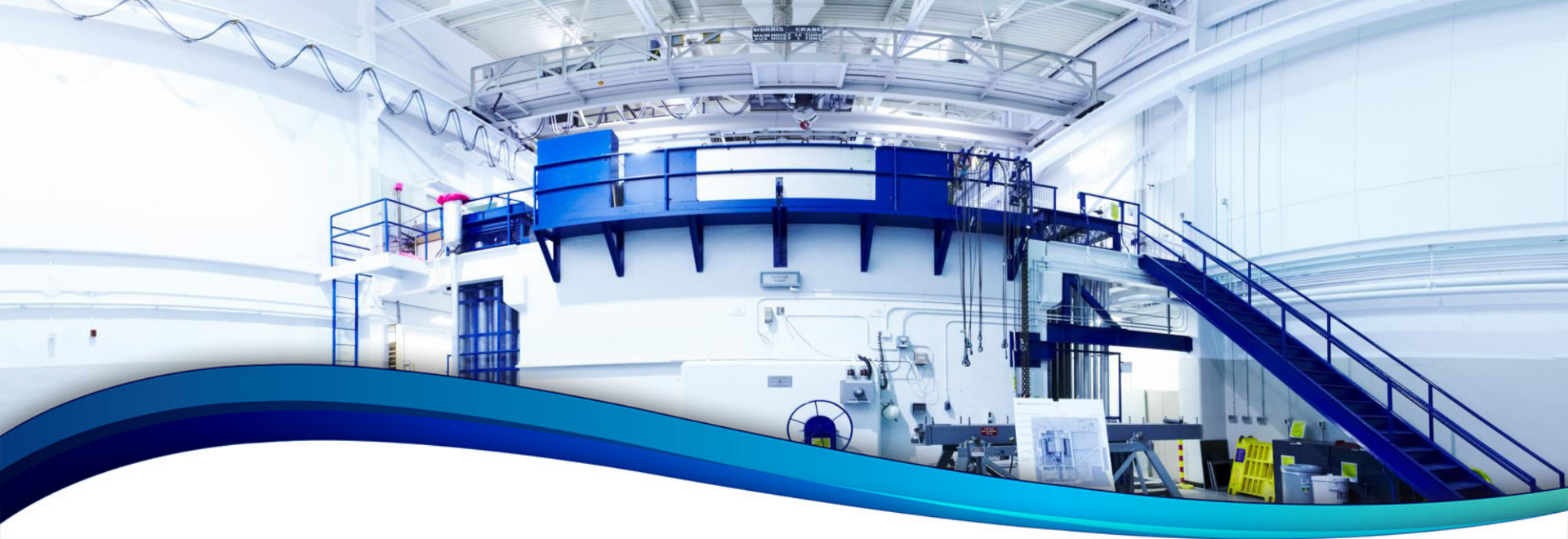


ΔH_c System and the Flux Perturber

Summary

- The flux perturber, a two state reactivity oscillator, had such a small reactivity worth that existing methods couldn't accurately measure it.
 - Small worth ideal for studying kinetics at critical
- Delta height system developed to determine the reactivity worth of the flux perturber through relative moderator level measurements
- Accurate reactivity worth allowed for improved fit of reactor transfer function, yielding kinetics parameters
- Can now apply methodology to other cores





Thank you. Questions?

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ZED-2 Reactor
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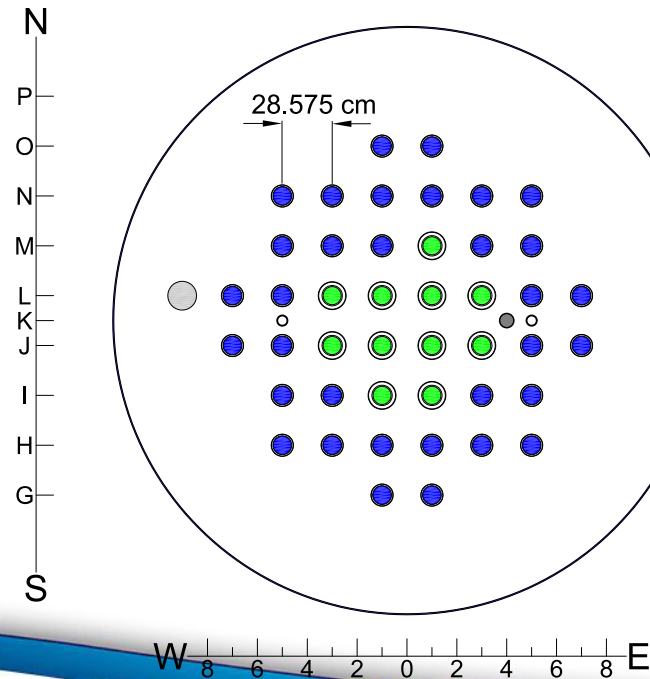
Additional Information



ZED-2 Flux Perturber Experiments

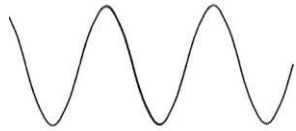
Experimental Setup

- A. 5 CANFLEX-LEU Bundles in CANDU-AI Channel
- B. 3 36-Element ^{233}U -Th bundles below 2 CANFLEX-LEU Bundles in ACR-AI Channel
- C. Reflector Ion Chamber in Dry Well
- D. Core Ion Chamber in Dry Well
- E. Flux Perturber



ZED-2 Reactor Additional Information

Flux Perturber Input Signals



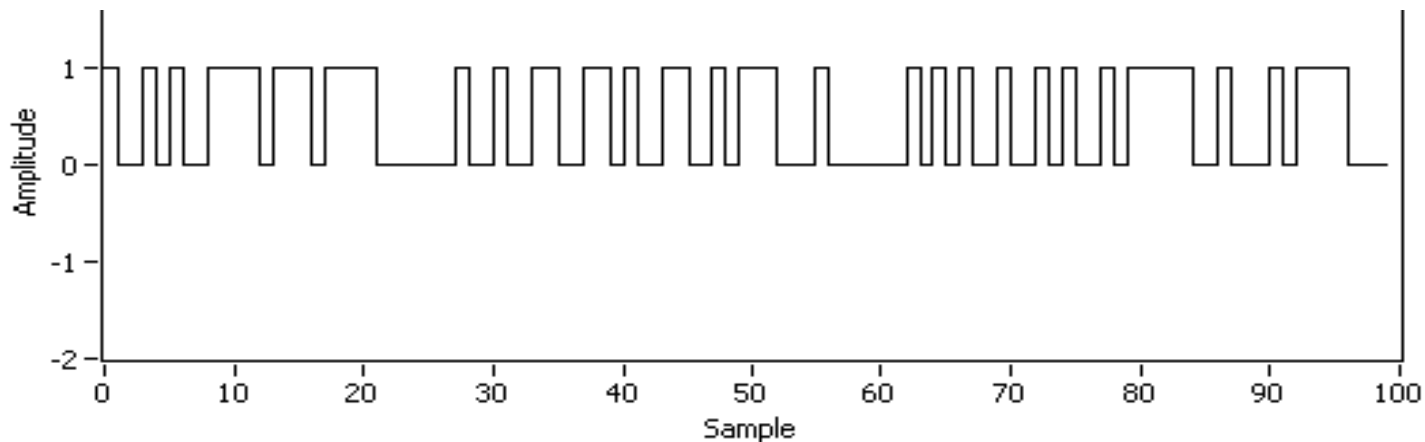
Single Frequency



~Single Frequency



Step Change



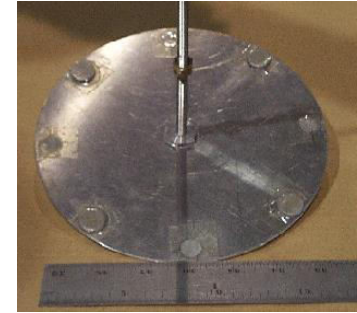
Pseudo Random Binary Sequence (PRBS)



ZED-2 Reactor Additional Information

ZED-2 Counting Laboratory

- Detectors are germanium- and sodium-based (scintillation detector with photomultiplier tubes)



Reference Wheel



Foil Hangers



Foil Counting Station



Copper Foils



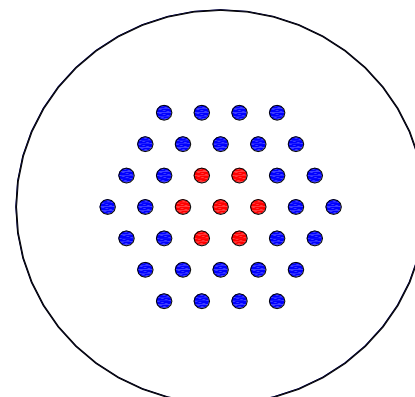
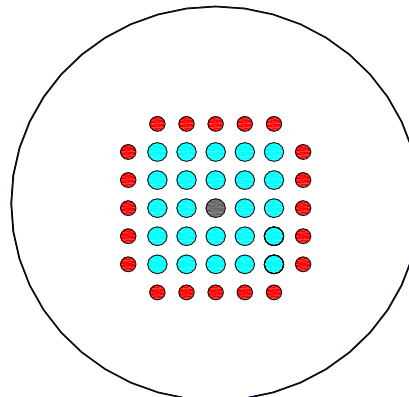
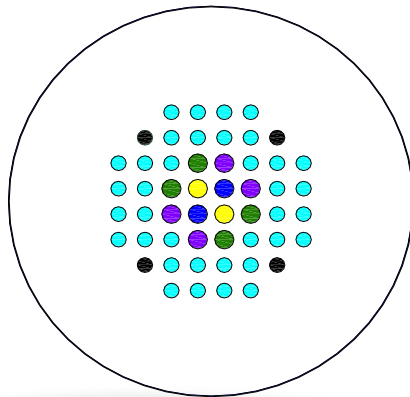
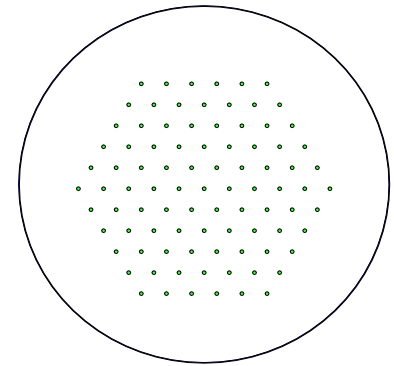
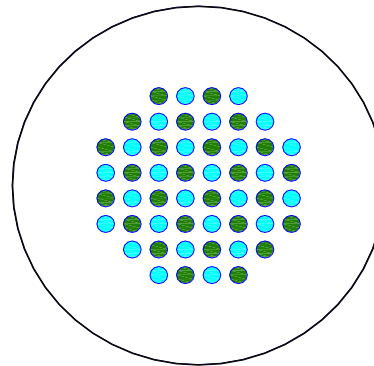
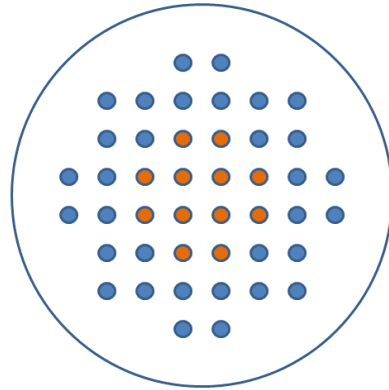
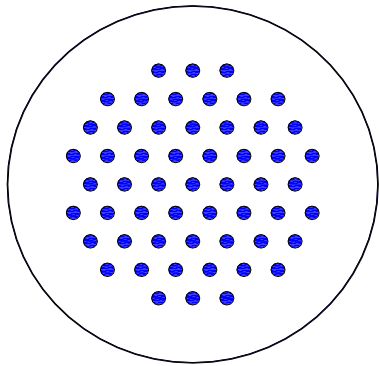
ZED-2 Background

ZED-2 Control Room



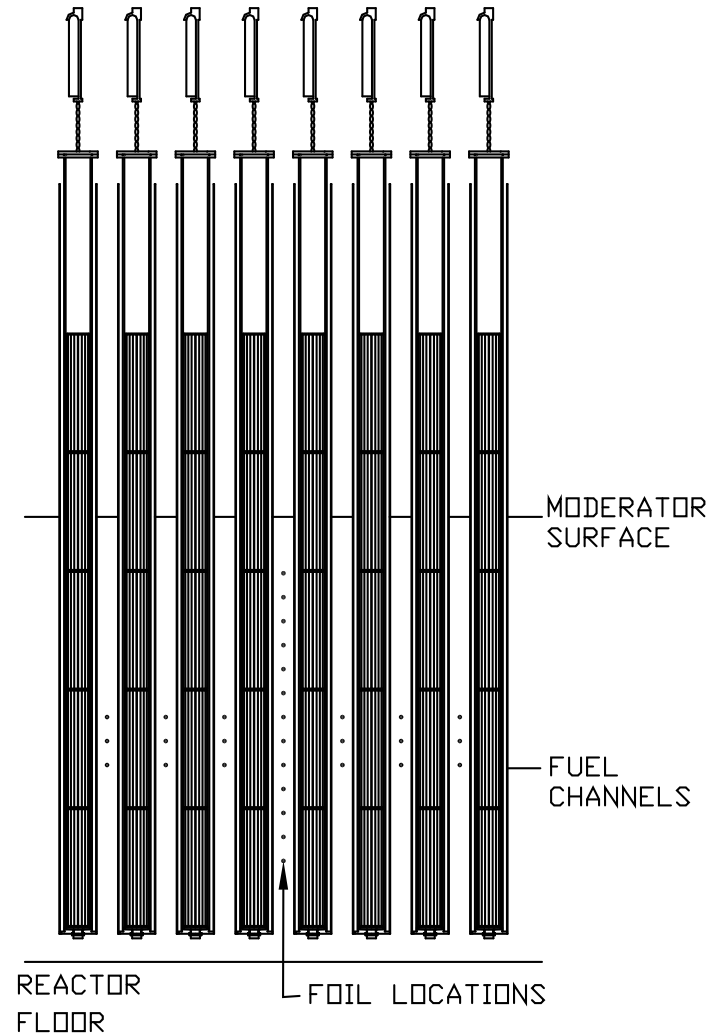
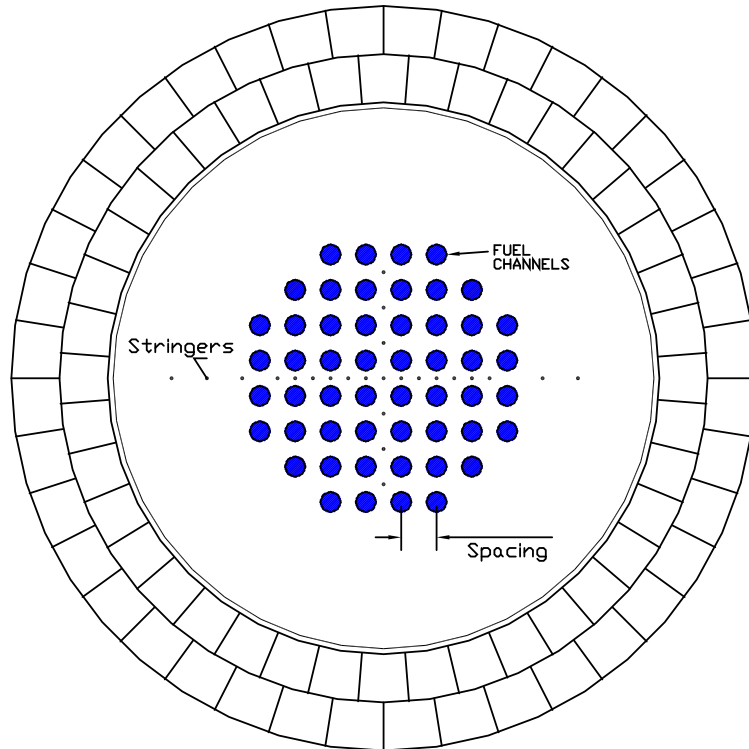
ZED-2 Experiments

Core Configurations



ZED-2 Experiments

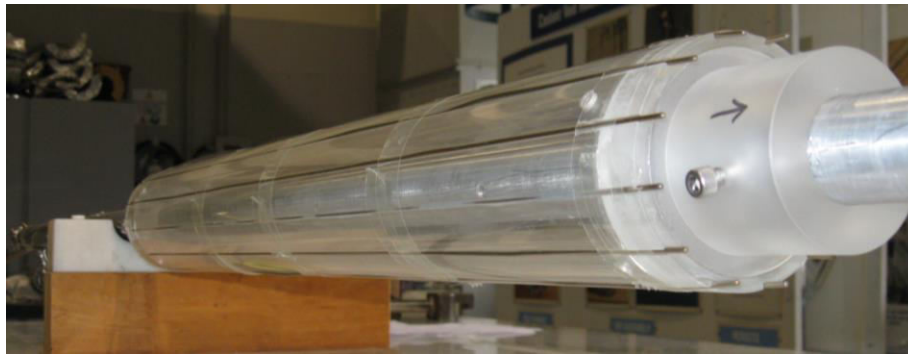
Flux Maps



ZED-2 Experiments

Self Powered Flux Detector Calibrations

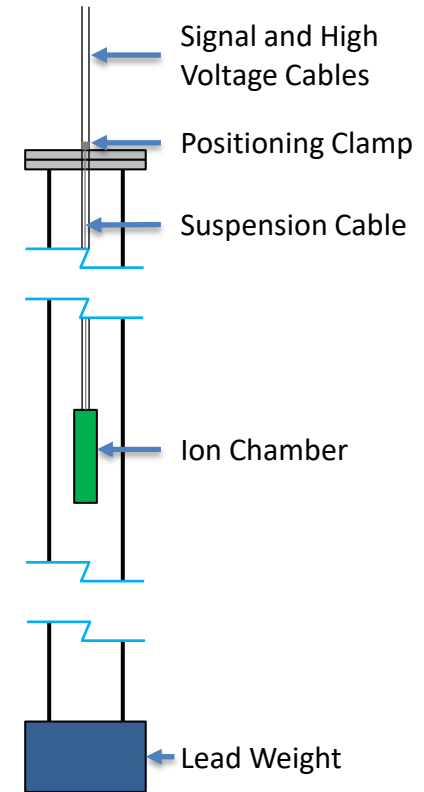
- Calibrate 30 Vanadium Detectors per reactor operation
- Calibrate an entire CANDU 6 Reactor fleet in less than 1 week
- ZED-2 Counting Laboratory aids in calibrating detectors



ZED-2 Experiments

Ion Chamber Calibrations

- Low Flux (Maximum 10^9 nHcm⁻²Hs⁻¹)
- Same Day Handling
- ZED-2 Counting Laboratory Support



ZED-2 Reactor Additional Information

Demountable Bundle

