



# **Annular Core Research Reactor Improved Pulse Repeatability/Prediction**

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# Outline

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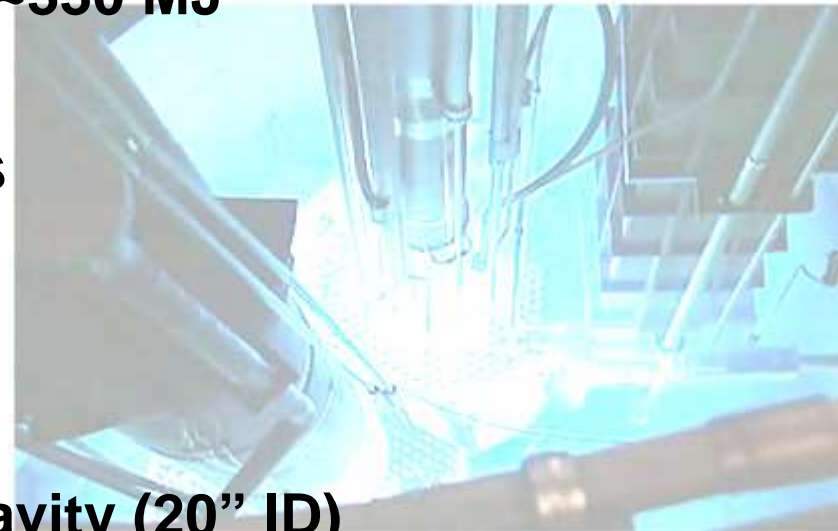
- **Background**
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- **Motivation**
  - ❖ **Improved Pulse Repeatability**
  - ❖ **Improved Pulse Prediction**
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  - ❖ **Current and Recommended Worth Curve**
- **Test Results and Conclusions**
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## Background

### Annular Core Research Reactor (ACRR)

- TRIGA-type reactor with special  $\text{UO}_2\text{-BeO}$  fuel
- Pulse Operations
  - ❖ Reactivity Insertion - ~\$3
  - ❖ Pulse Max Power ~ 40 GW
  - ❖ Max energy deposition ~330 MJ
  - ❖ Pulse width – 6.5 ms
- Steady State Operations
  - ❖ 2.4 MWt
- Features
  - ❖ Central Cavity (9" ID)
  - ❖ Fuel Ringed External Cavity (20" ID)
  - ❖ Spectrum Modifying Inserts





# Background

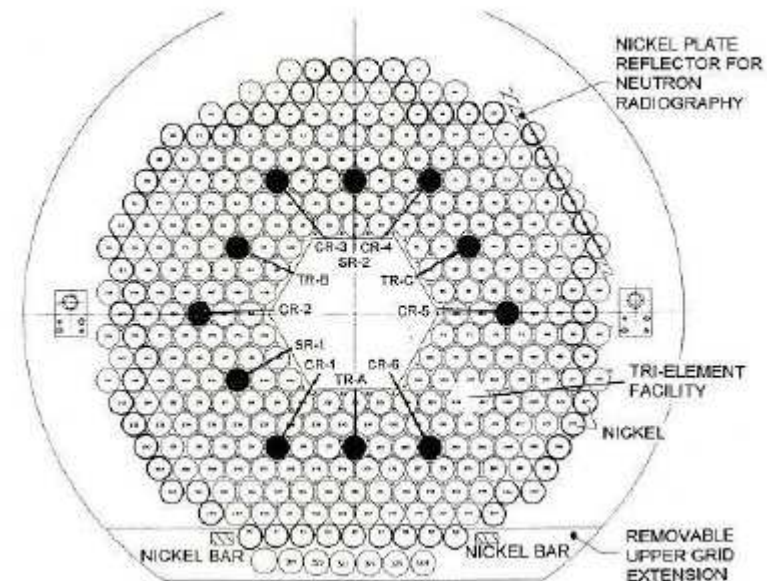
## Annular Core Research Reactor

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### Standard Configuration

236 fuel elements (FEs) in hexagonal lattice including 6 control rods, 2 safety rods

- ❖ Control Rods (CRs)
  - ❖ Motor driven
  - ❖ B4C poison, fuel followed
  - ❖ Controlling reactor power
- ❖ Safety Rods (SRs)
  - ❖ B4C poison, fuel followed
  - ❖ Additional shutdown reactivity
- ❖ Transient Rods (TRs)
  - ❖ B4C poison, void followed
  - ❖ Control reactor
  - ❖ Pulse





# Background

## ACRR Primary Mission

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- **Provide appropriate neutron radiation environments for radiation testing and qualification of electronic components and other devices, such as:**
  - ❖ **Passive neutron and/or gamma dosimetry devices (e.g., activation foils, TLDs)**
  - ❖ **Active neutron and/or gamma dosimetry devices (e.g., SNL developed diamond PCDs, calorimeters)**
  - ❖ **Explosive components (including neutron generators)**
- **Other Applications**
  - ❖ **Reactor fuel materials testing (GNEP, GEN IV)**
  - ❖ **Reactor accident phenomenology testing (Severe core damage in LWRs, LMFBRs)**



# Motivation

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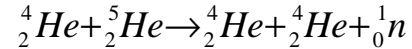
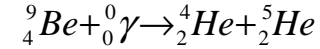
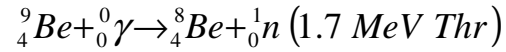
- **Facility has already developed and approved operating procedures and documented data**
- **ACRR pulse procedure modified to:**
  - ❖ **Reduce variability in reactivity insertions**
    - **Overcome photoneutron effects**
    - **Fix transient rod (TR) removal time**
  - ❖ **Improve ACRR pulse performance prediction**
    - **Higher fidelity control rod (CR) bank integral worth curve**



# ACRR Problems

## UO<sub>2</sub>-BeO Fuel and Photoneutrons

- Beryllium produces background neutrons problematic to ACRR operations



- ❖ Keepin has experimentally separated photoneutron precursors into 9 groups
- ❖ Small fraction of delayed neutron fraction (~2%), long-lived decay groups ( $\beta_{\text{U235,th}}=0.0065$ ,  $\beta_{\text{photo}}=0.00015$ )
- ❖ Photoneutron precursors have long half-life compared to delayed neutron precursors

### Problems

- ❖ Delayed critical established when reaching self-sustaining fission chain reaction
- ❖ Photoneutron population acts as source and skews true DC conditions (DC is subcritical)
- ❖ Changes control rod (CR) DC positions and intended reactivity insertions

Group Constants for Delayed Photoneutrons from U235 Fission Products on Beryllium (Keepin 1965)

Group Index, j	Group half-life	Group Fraction $\beta_j$ ( $10^{-5}$ )
1	12.8 d	0.057
2	77.7 h	0.038
3	12.1 h	0.260
4	3.11 h	3.20
5	43.2 m	0.36
6	15.5 m	3.68
7	3.2 m	1.85
8	1.3 m	3.66
9	0.51 m	2.07
Total	-	15.175

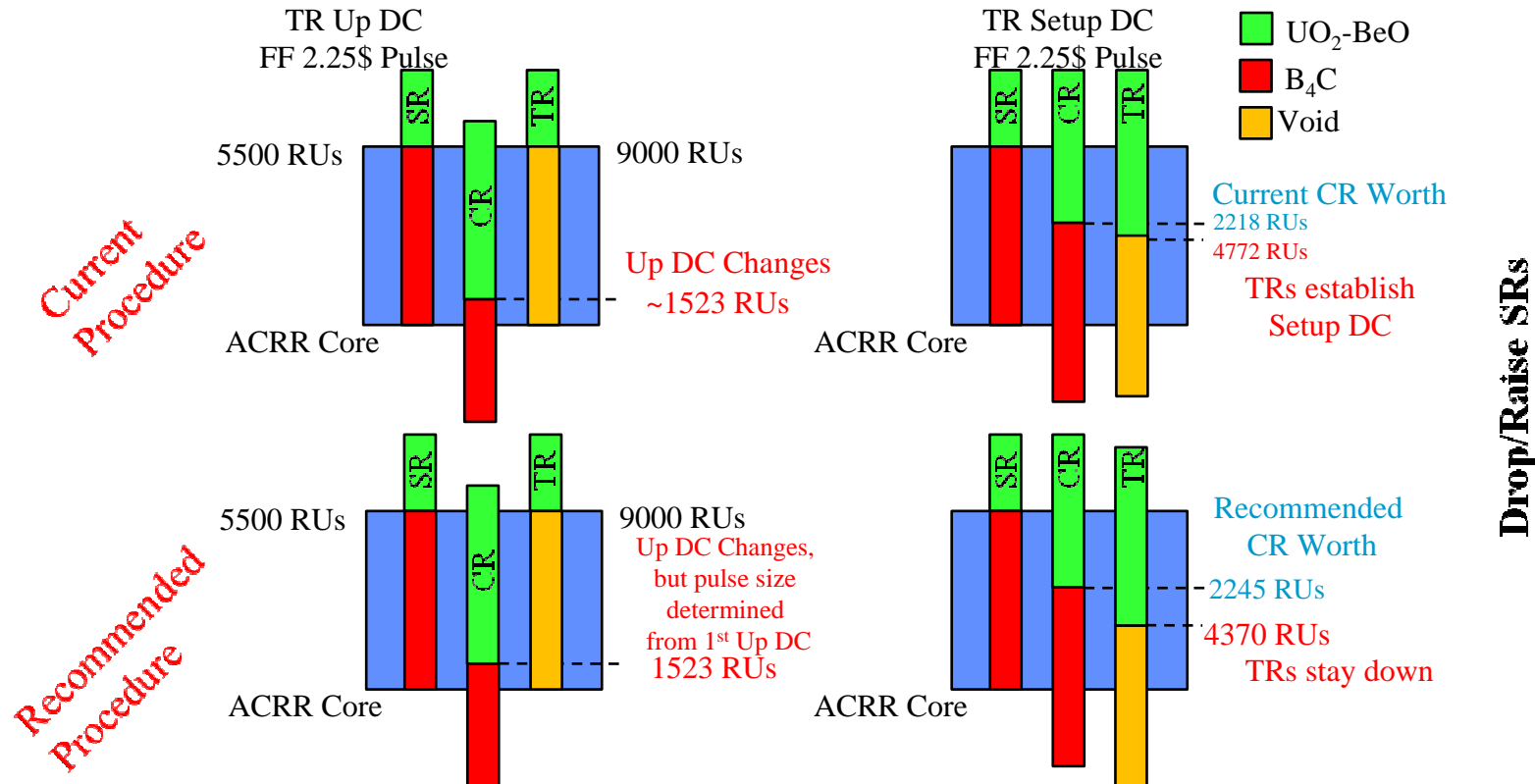
Group Constants for Delayed Neutrons from U235 Thermal Fission

Group Index, i	Group half-life	Group Fraction $\beta_i$ ( $10^{-5}$ )
1	55.0 s	21
2	23.0 s	142
3	6.2 s	127
4	2.3 s	257
5	0.61 s	75
6	0.23 s	27
Total	-	650



# Modifications Pulse Repeatability

- Current ACRR pulse procedure:
  - ❖ Uses current CR DC position to determine pulse size
  - ❖ Establishes DC at CR setup position
- Modified ACRR pulse procedure modified for testing:
  - ❖ Fixed TR Up DC CR position for reactivity insertion determination (photoneutrons)
  - ❖ Setup DC Modification, Pulse from Pedestals (reduce variability)







# ACRR Problems

## Pulse Predictability

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- Due to photoneutron effects, reactor operators (ROs) experience a decrease in the control rod DC positions and measured reactivity insertion ( $\sim 3 \text{ } \phi$ ) over the course of the day
- For “clean” core conditions (no photoneutrons), reactivity insertion is typically overpredicted (5 – 20  $\phi$ )
- Overprediction stems from “Bootstrap” method used to develop the CR Integral Worth curve

### “Bootstrap” Method for CR Integral Worth Determination

#### Core Condition

- ❖ 183 fuel elements (FEs)
- ❖ CR bank fully withdrawn
- ❖ DC condition

#### Procedure

- ❖ Add fuel element and measure positive period
- ❖ Insert CR bank to re-establish DC and determine differential worth
- ❖ Repeat until reaching ACRR full core configuration (236 FEs)



# ACRR Modifications

## Pulse Predictability

- With difference in starting (183) and final core sizes (236), measured CR bank integral worth may be overestimated (CR bank is larger fraction of total core fuel for small cores,  $dp/dz \uparrow$ )
- CR bank integral worth determination with full ACRR core configuration (236 FEs) performed to increase fidelity of CR bank integral worth curve

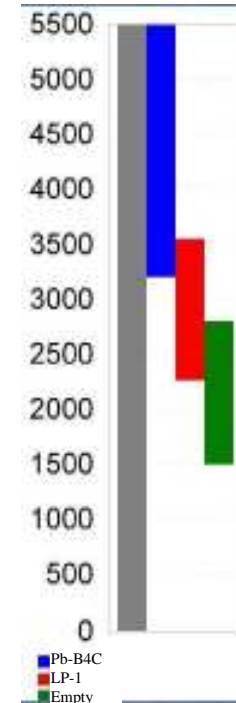
### Procedure to determine CR Bank Integral Worth with Full Core

#### Core Condition

- ❖ 236 FEs
- ❖ CR bank raised
- ❖ TR bank raised to DC condition

#### Procedure

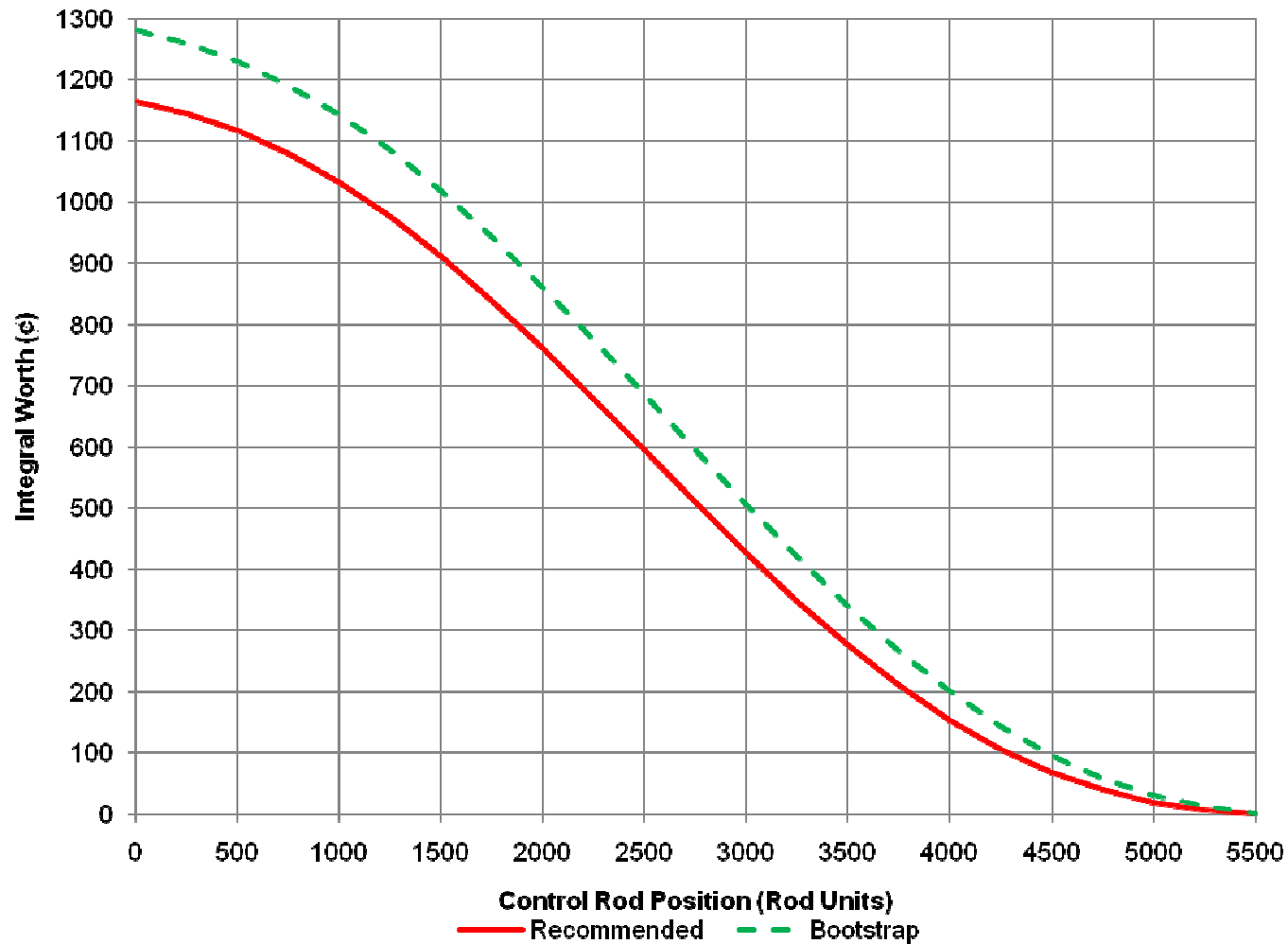
- ❖ Raise TRs and measure positive period
- ❖ Lower CRs, re-establish DC, and determine differential worth
- ❖ Use spectrum inserts of different worths to generate CR bank integral worth



Representation of CR positions that can be used to produce delayed critical configurations in the ACRR with various spectrum modifying inserts (Depriest, 2006)



# Modifications Pulse Predictability

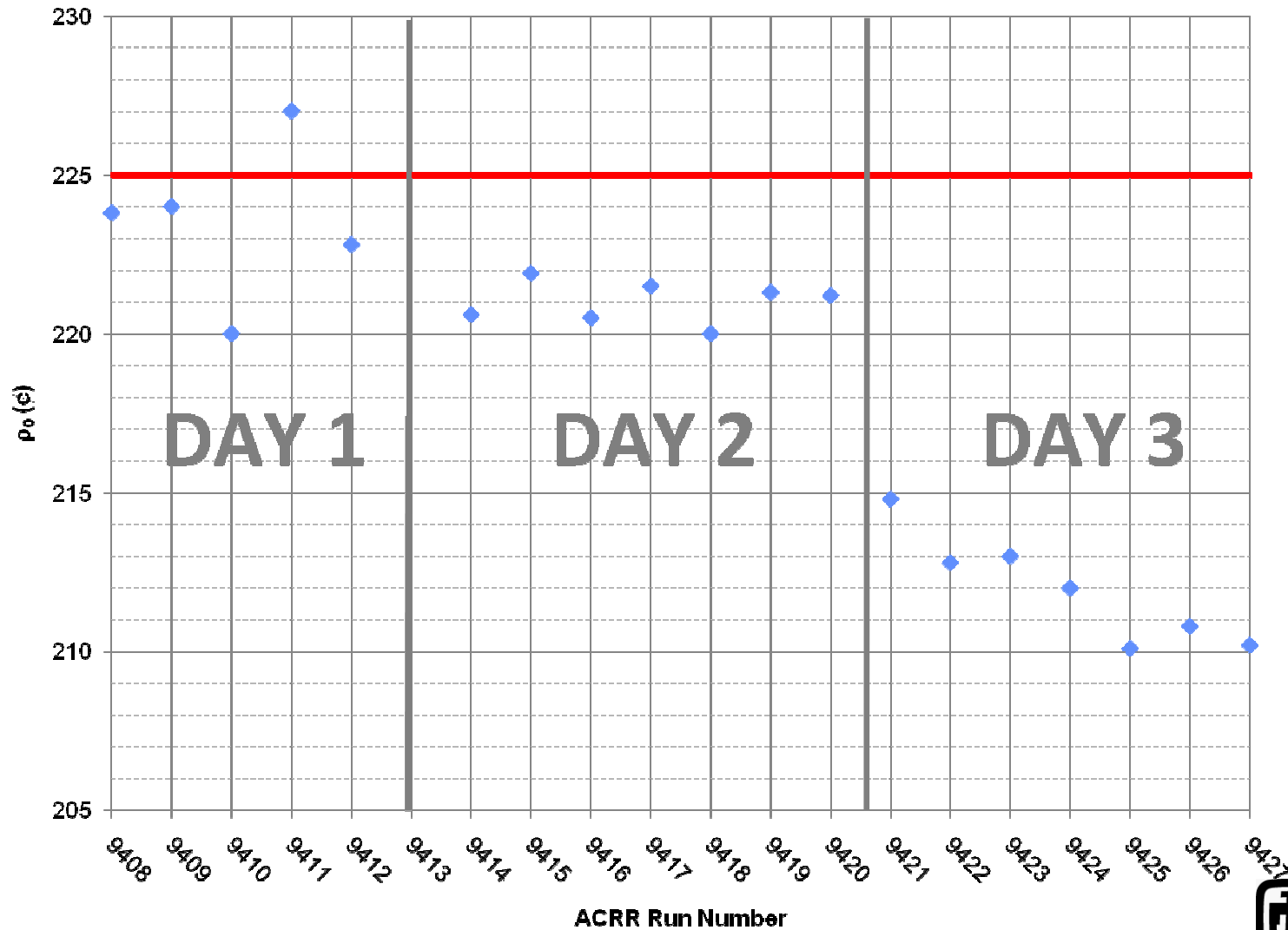


Integral Reactivity Curves Obtained from High-order Polynomial/Perturbation Theory Fits to Positive Period Measurements of "Bootstrap" and ACRR Full Core Experiments (DePriest 2006)



# Results and Conclusions

## Recommended Pulse Procedure + Curve





## Results and Conclusions

CR Integral Worth Curve and Procedure Used for Experiments

Day	Curve	Procedure
1	Recommended	Recommended
2	Recommended	Recommended
3	Current	Current

- Results obtained from ACRR pulse diagnostics (SPND/LabVIEW)
- Large deviation in measured reactivity insertion on Day 1 from operator adjustment to new procedure
- Day 2 shows expected results from modified procedure/curve
- Day 3 results are typical ACRR operations (photoneutron)

Bias in Predicted Reactivity Insertion for Modified and Current CR Worth Curves

	Day 2 (Recommended)	Day 2 (Current)	Day 3 (Recommended)	Day 3 (Current)
Avg Bias ( $\phi$ )	4.0	14.0	3.7	13.1
Std. Dev. ( $\phi$ )	0.7	0.7	1.6	1.6



## Future Work

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- **Preliminary results suggest improvement in pulse prediction/repeatability**
- **Test pulse repeatability for small reactivity insertions (<1.5\$)**
- **Field active dosimetry inside central cavity for further testing and analysis of reactor time varying behavior**
  - ❖ **Boron Calorimeter**
  - ❖ **Fission Chamber**



## References

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# Comments/Questions?

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