INL/CON-23-75080-Revision-0

Local Power Impact Experiment Design for a New Fuel Type for use in the Advanced Test Reactor

November 2023

Changing the World's Energy Future

Erin Dubas

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Local Power Impact Experiment Design for Low Enriched Uranium Fuel for use in the Advanced Test Reactor

Erin Dubas, MPR Associates Inc.

ANS Winter Meeting

November 14, 2023

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Introduction

The Department of Energy (DOE) National Nuclear Security Administration's (NNSA) Office of Material Management and Minimization (M3) mission is to convert, remove, and dispose of vulnerable nuclear material located at civilian sites worldwide.

- Research reactors and isotope production facilities are being converted to non-weapon usable nuclear material
- Need to develop and qualify new low enriched uranium (LEU) fuels for use in the research reactors currently using highly enriched uranium (HEU)
- Selected a monolithic U-Mo fuel plate design consisting of uranium-10 wt% molybdenum alloy (U-10Mo) foils clad in aluminum alloy 6061.
- Analysis, testing, and demonstration of the new fuel is required to ensure that it meets the operational safety, dimensional stability, thermal stability, performance, and other requirements for the reactors

References [2] and [3]

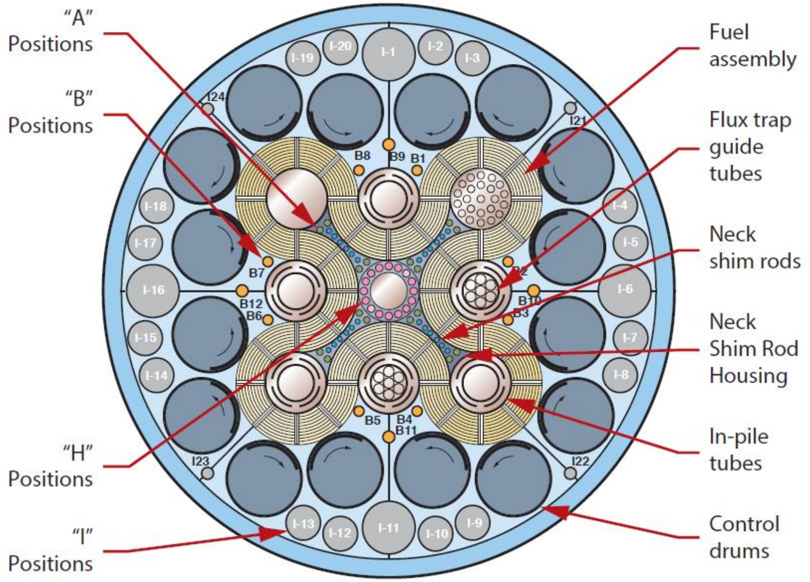
Introduction

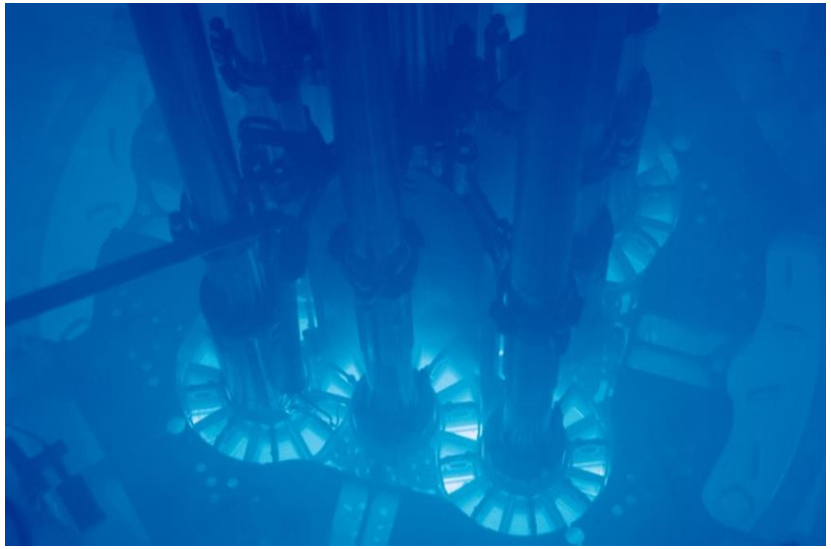
- Reactor physics safety evaluations for the ATR and ATRC currently use Monte Carlo for the 21st Century (MC21)
  - MC21 models of the ATR and ATRC are validated for use in neutronics analyses with HEU fuel
  - The new design for the LEU fuel element for the ATR, LOWE, is not covered by the current validation basis and requires validation

- Validation Objectives:
  - Provide rigorous basis for use of the ATR and ATRC models, approximations, and nuclear cross sections safety analyses for use with LOWE
  - Quantify uncertainties to inform margin

This work evaluates inputs to and proposes the Power Impact Validation Experiment to validate the MC21 models for predicting power and few-group neutron spectrum in the ATR with LOWE fuel elements.

References [2] and [3]





Background

- Power Measurements
  - HEU fission wires are placed on a polyethylene flux wand
  - 17 wands are inserted into different channels between fuel element plates in an element (half the core is instrumented)
  - The fission wires are irradiated during a flux run, during which the reactor is brough to a critical state for 20 minutes
  - Once the cycle is done, the fission wires are taken to the INL Radiological Measurements Laboratory (RML) where the saturation fission rate for each wire is determined using beta counting
  - The beta counts are correlated to powers using HELIOS and MC21, in parallel. Lobe power is calculated from multiple fission wire power measurements.
    - Correlations were developed specifically for HEU fission wires being irradiated in an HEU environment

$$P_E = \frac{\sum\left(FR_{wire,i} \times Energy/Fission \times W_{n,i}\right) \times m_{U235E}}{N \times F}$$

$P_E = Fuel\ element\ power$, where:

$FR_{wire,i}$ = Fission rate in wire i

$\frac{Energy}{Fission}$ = Assumed energy per fission

$W_{n,i}$ = Weighting factor for wire i

m_{U235E} = Fuel element U235 mass

N = Normalization factor

F = Peaking factor at midplane

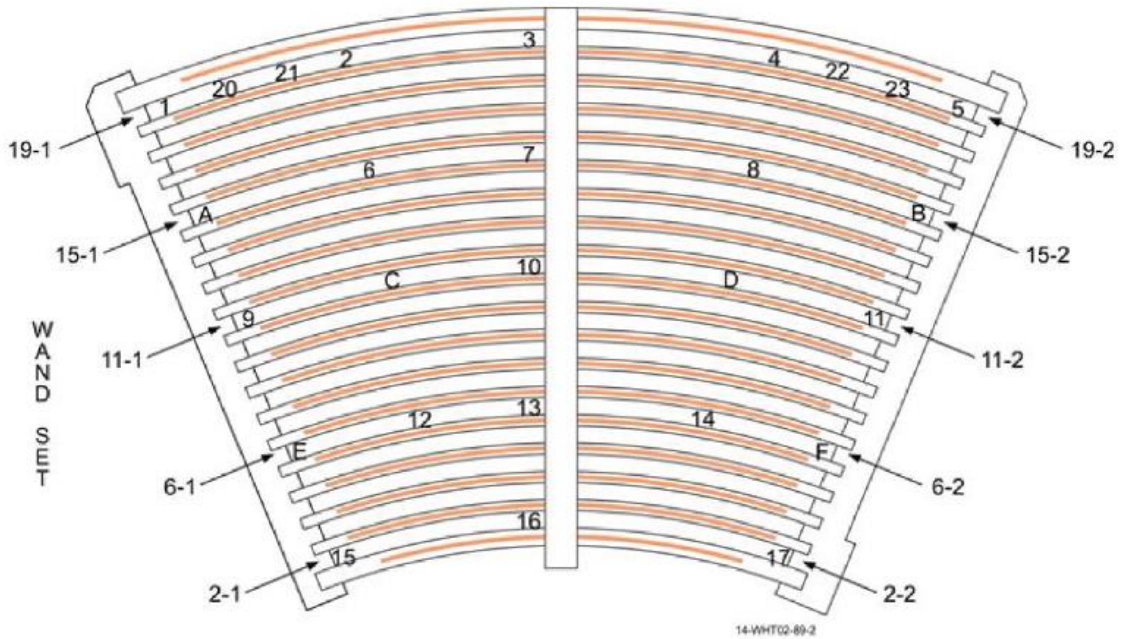


Figure 1. Flux Wand Set Locations [3]

Reference [4]

Approach

- Objective

  1. **Evaluate modeling accuracy for relative changes in power from the LOWE fuel element using experimental data**
  2. Correlate LEU-impacted fission rates to absolute power

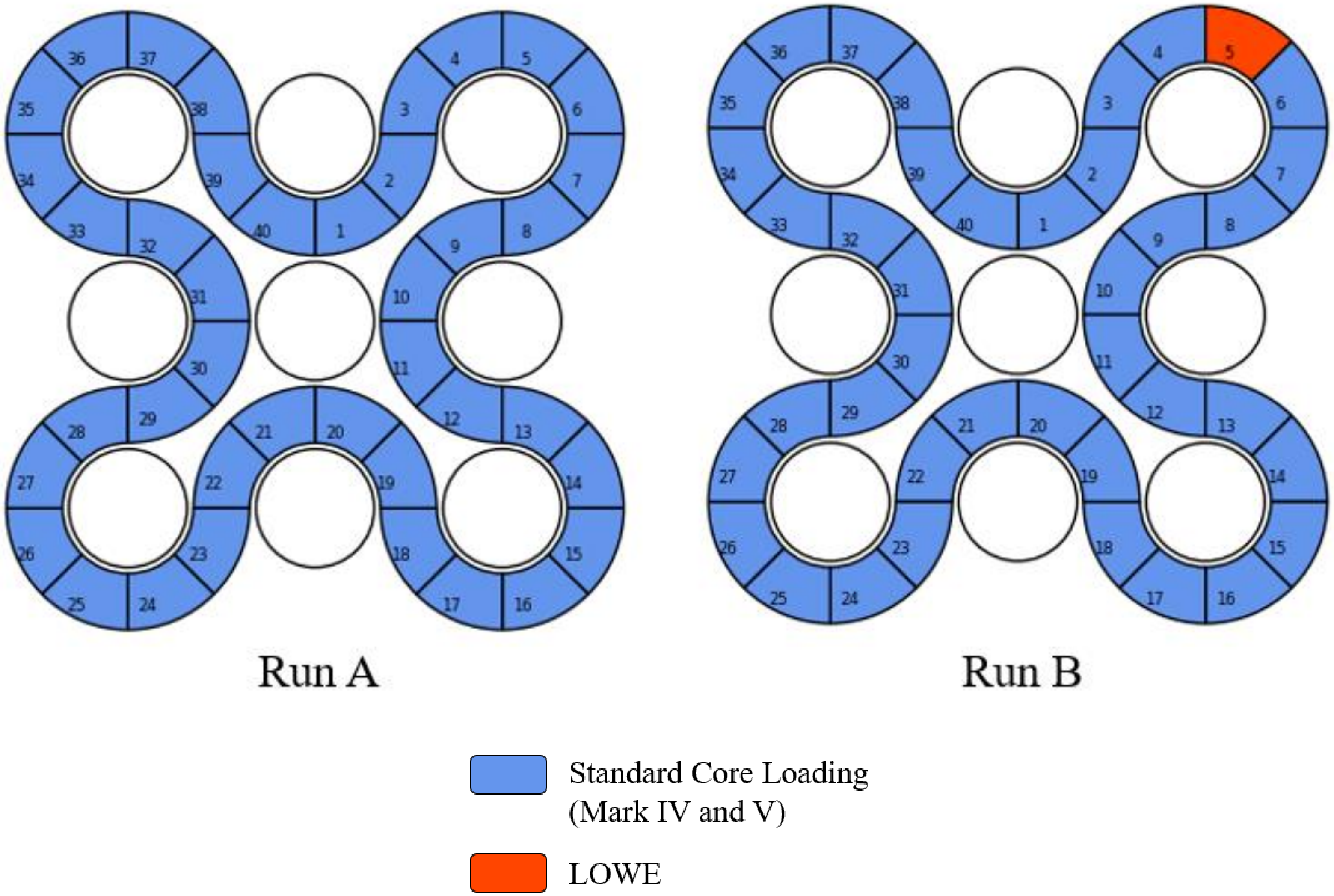
Relative changes:

1. Validate the MC21 predicted fission rate values against experimental data from a flux run in the ATRC
2. Evaluate the relative impact of the LOWE element on the adjacent HEU elements

Meeting these Objectives Gives Confidence that MC21 Captures the Flux Perturbations from the LOWE Element

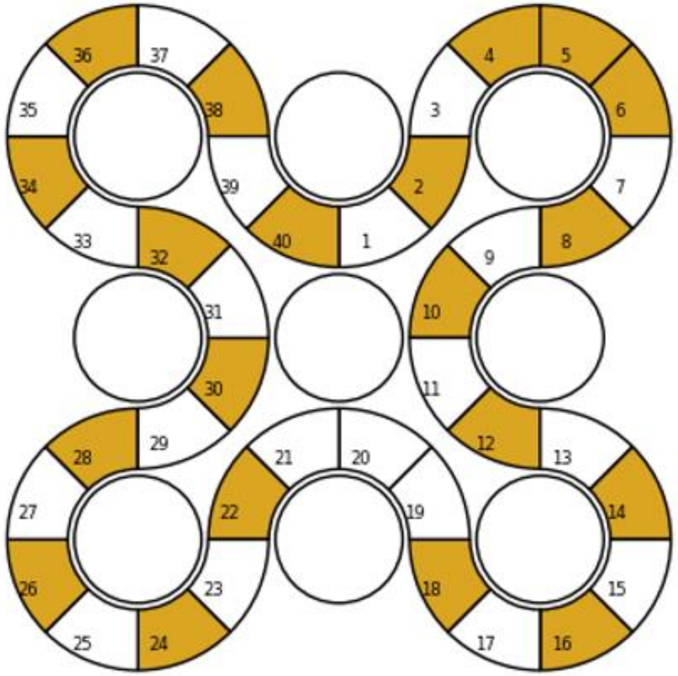
Experiment Design

- Experiment control
- Core loading



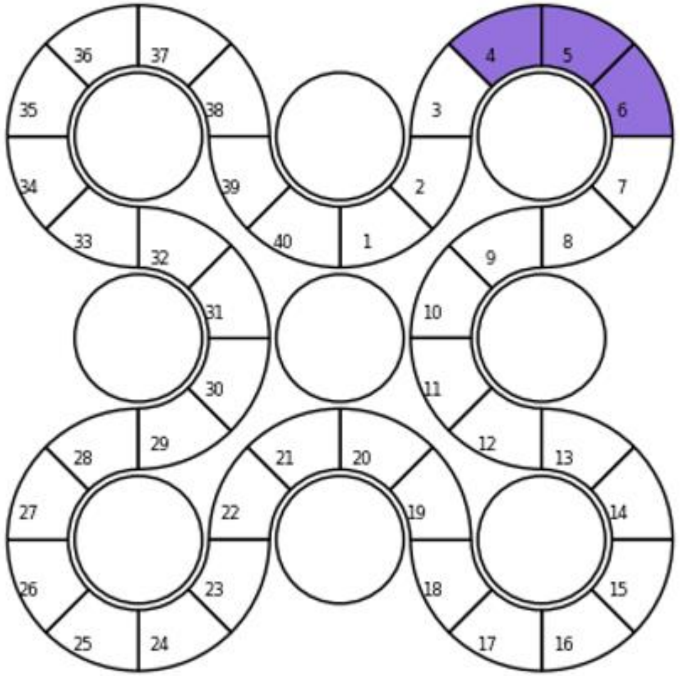
Experiment Design

- Experiment control
- Core loading
- Amount of instrumentation



Azimuthal Instrumentation

Un-Instrumented
Instrumented



Axial Instrumentation

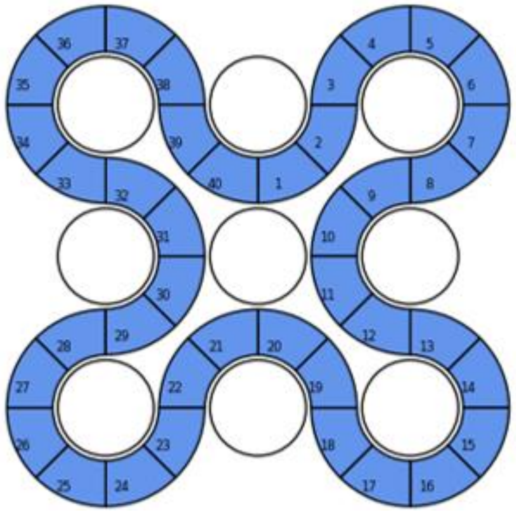
Un-Instrumented
Instrumented

Agenda

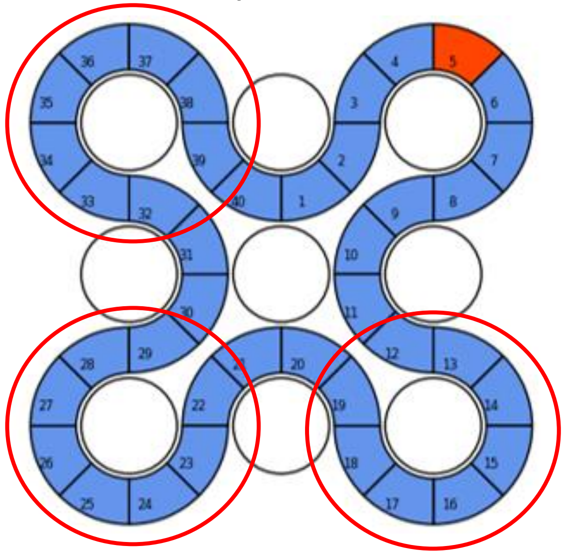
- **Experiment Design**
  - **Define the experiment control**
    - Flux runs are expensive and take time to prepare for and run
  - **Define the core loading**
    - The ATR and ATRC use different fuel. Procuring ATR fuel for use in the ATRC would be expensive. Switching out the core loading would add multiple days to the experiment
  - **Define the level of instrumentation required**
    - How much instrumentation is needed for the experiment, and what impact will the instrumentation have on our results?

Design Considerations

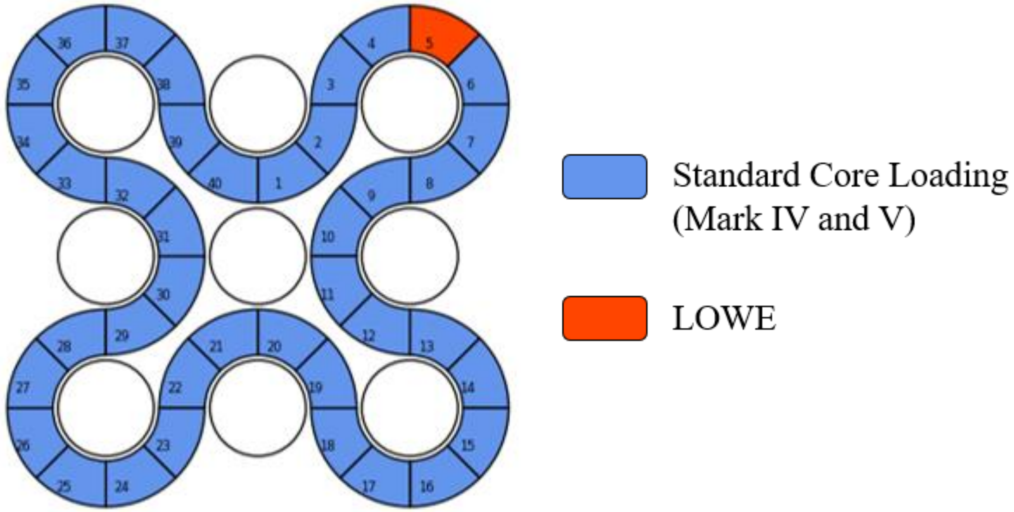
- Two flux runs may be necessary for evaluating relative differences in fission rates
  - Option 1: Lobe in the same flux run as the experiment flux run [Red Circles in middle Core Loading]
  - Option 2: Separate flux run with only HEU elements [Left Core Loading]



Option 1



Option 2

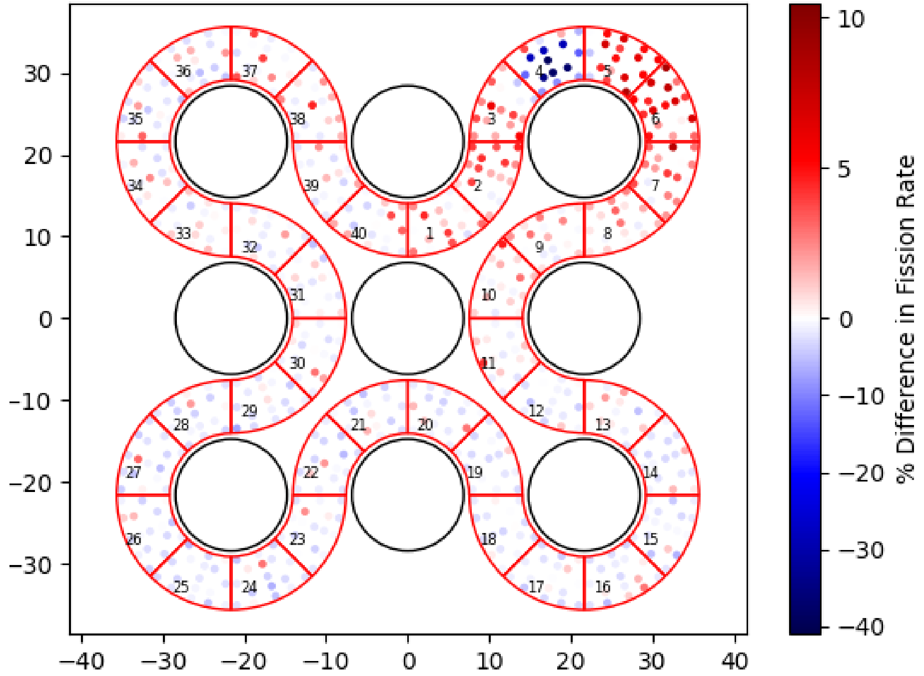


Experiment Flux Run

Design Considerations

- Two flux runs are necessary to evaluate the impact of the LOWE element on power
  - Minimize outside effects
  - Minimize time and cost

Absolute Value of % Difference in Fission Wire Fission Rate		
Lobe	Average (%) ± 0.4 % Uncertainty	Maximum (%) ± 4.0 % Uncertainty
Northwest	2.2	8.8
Northeast	4.8	38.6
Center	1.6	5.6
Southwest	1.8	6.9
Southeast	2.2	5.8



% Difference between Flux Run A and Flux Run B

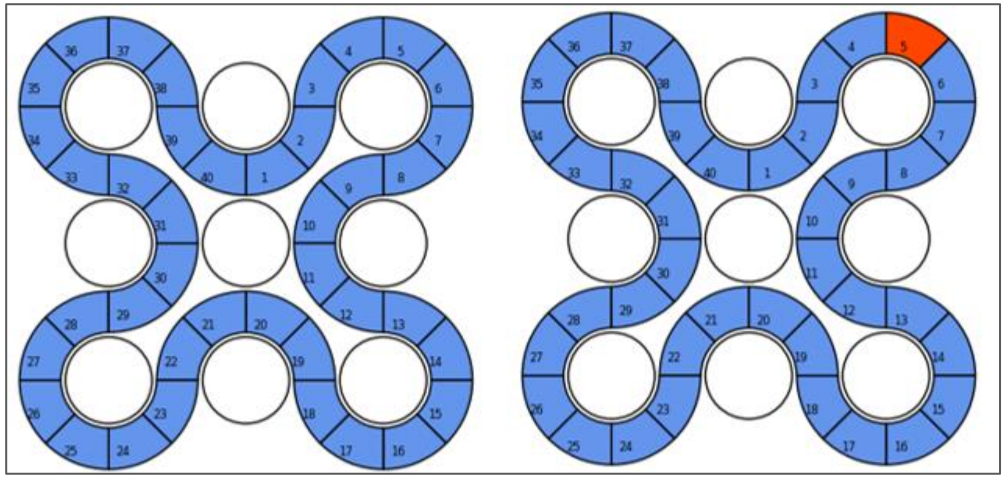
Design Considerations

Standard Core Loading (Mark IV and V)

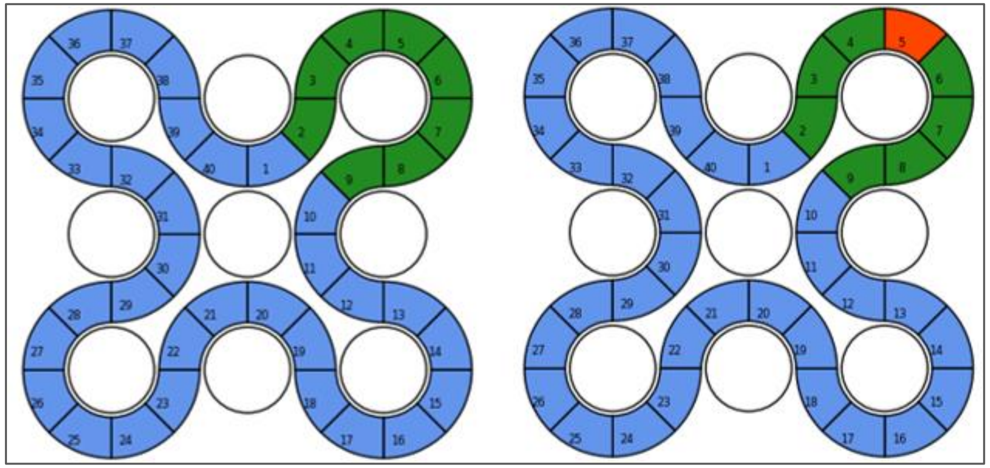
Mark VII

LOWE

- Standard ATRC core loading would significantly reduce cost and schedule
  - ATRC standard loading consists of Mark IV and V elements
  - ATR standard loading consists of all Mark VII elements



Run A: Standard ATRC Loading
(Mark IV and V Elements)



Run B: Standard ATR Loading in LOWE Lobe
(Mark VII, IV and V Elements)

Design Considerations

- Standard core loading should be used
  - Difference of approximately 0.003 Δ$ / Δ°
  - Standard loading is advised

Total worth is calculated as shown in Equation 8.

$$\rho_{feedback} = \frac{\left(\frac{k_2 - k_1}{k_1 * k_2}\right)}{\beta_{eff}} \qquad \text{Equation 8}$$

Where:

$\rho_{feedback}$	=	Reactivity worth ($)
k_1, k_2	=	Final k-effective for Run 1 and Run 2, respectively
β_{eff}	=	The delayed neutron fraction (assumed to be 0.007 per Reference 2)

Table D-5. Sensitivity to Driver Element Loading

Core Loading	Worth per Degree Change in OSCC Position, $W/\Delta P$ in ($/º)
IV_V	0.132 ± 0.001
IV_V_LOWE	0.133 ± 0.001
VII	0.130 ± 0.001
VII_LOWE	0.131 ± 0.001

Design Considerations

- Standard core loading should be used
  - Difference of approximately 0.003 \$/° at most
  - LOWE element worth is appx. \$0.13 (position dependent)

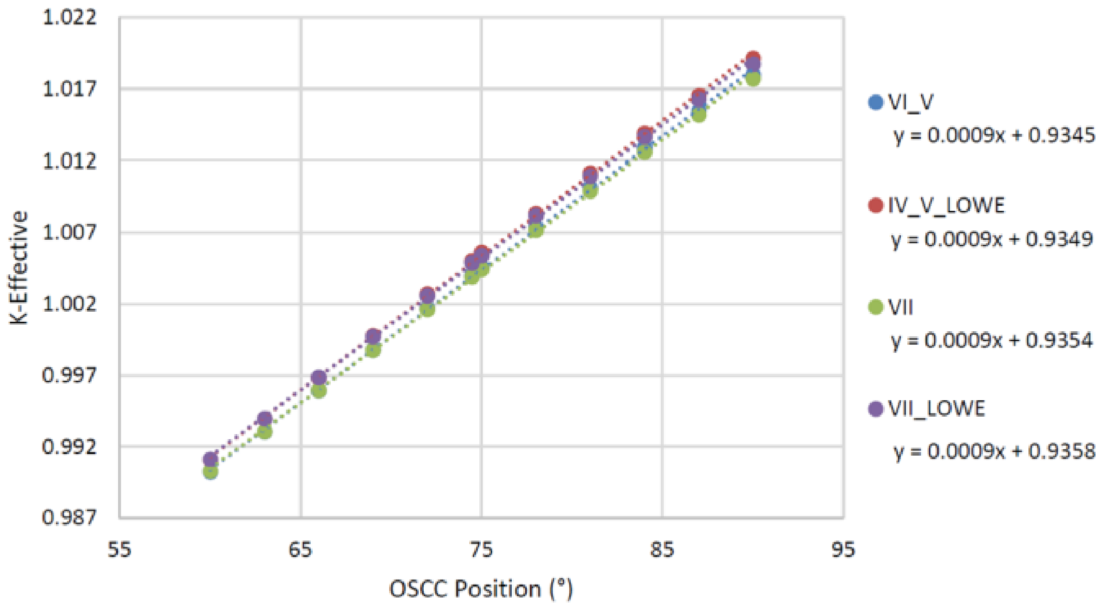


Figure D-5. K-Effective vs. OSCC Position as a Function of Driver Element Loading

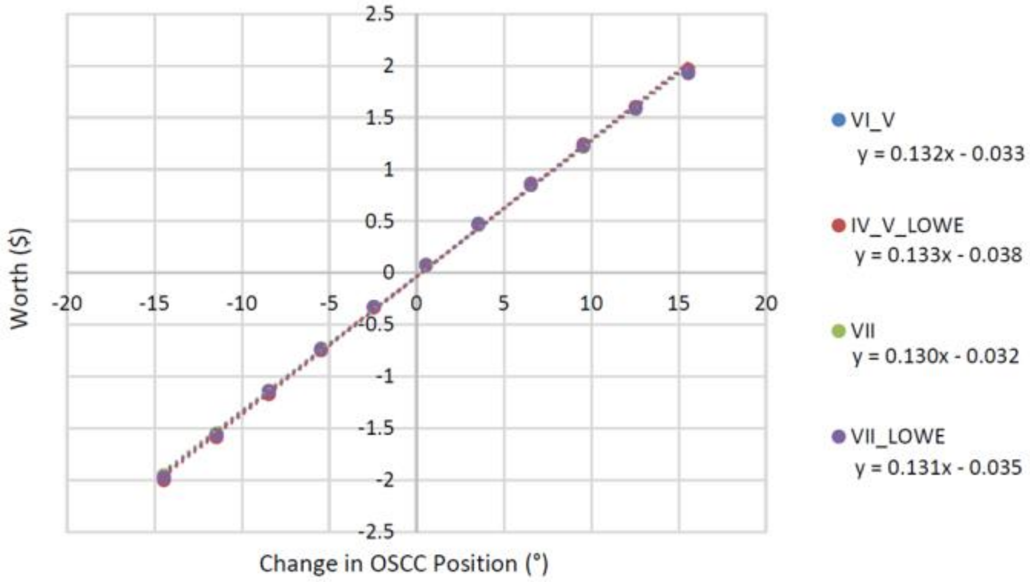
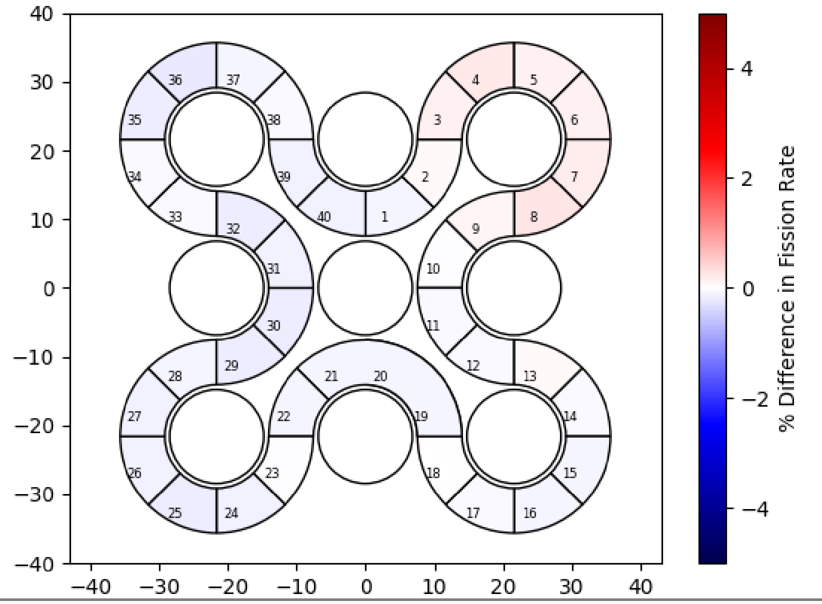


Figure D-6. Worth vs. Change in OSCC Position as a Function of Driver Element Loading

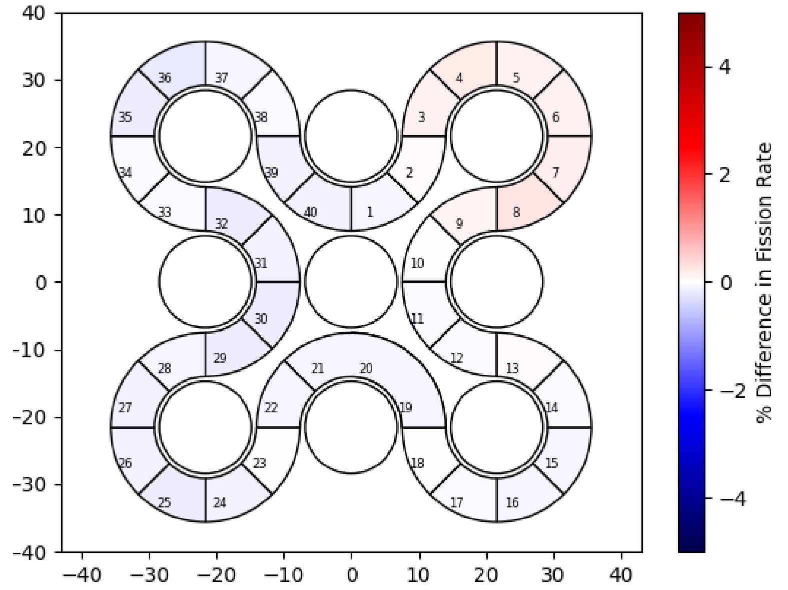
Design Considerations

- Evaluating the impact of fission wires on fission rate
- Quantify the effects of observation
- Negligible differences were observed

Fission Wire Bias Evaluation	
Core Loading	**Max % Difference**
All HEU	< 0.3%
39 HEU, 1 LOWE	< 0.3%



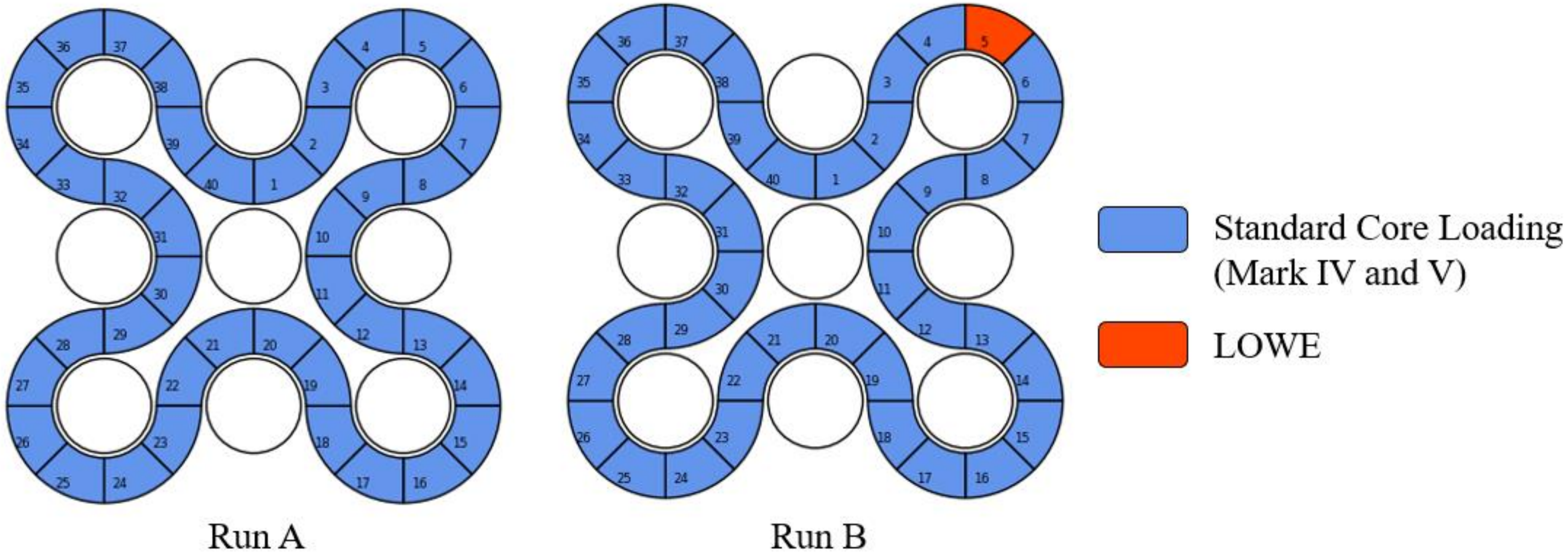
Difference between instrumented/un-instrumented cores with all HEU elements

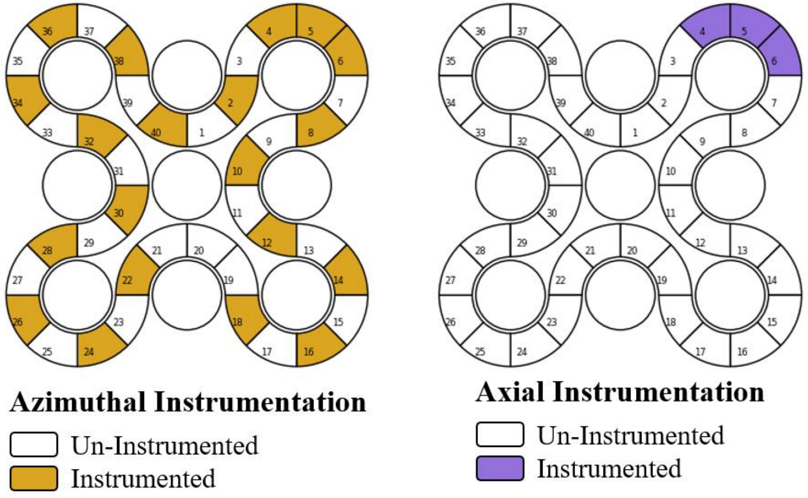


Difference between instrumented/un-instrumented cores with 39 HEU and 1 LOWE element

Summary

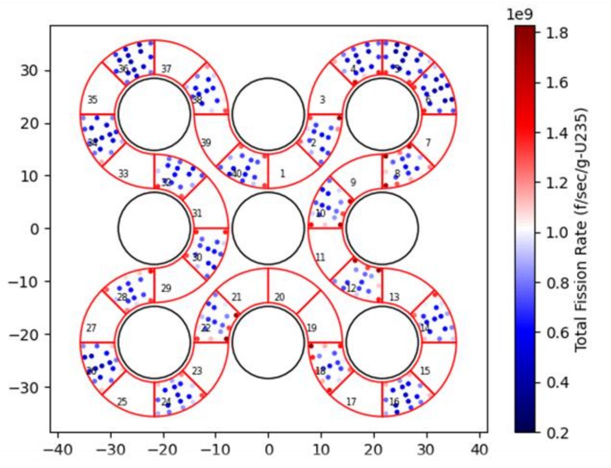
- Experiment Design
  - Two flux runs are necessary for evaluating relative differences in fission rates
  - Standard core loading should be used
  - There is negligible impact from the fission wires on fission rate



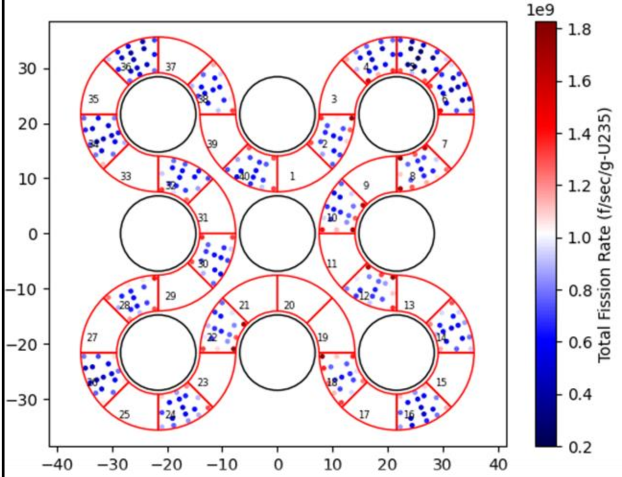


Preliminary Findings

Azimuthal Output



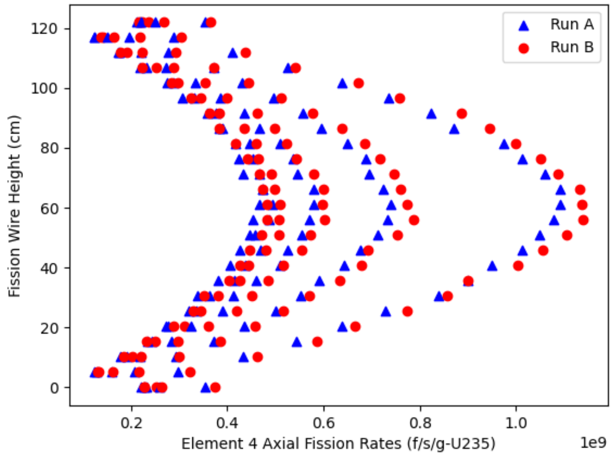
Run A: Standard Loading



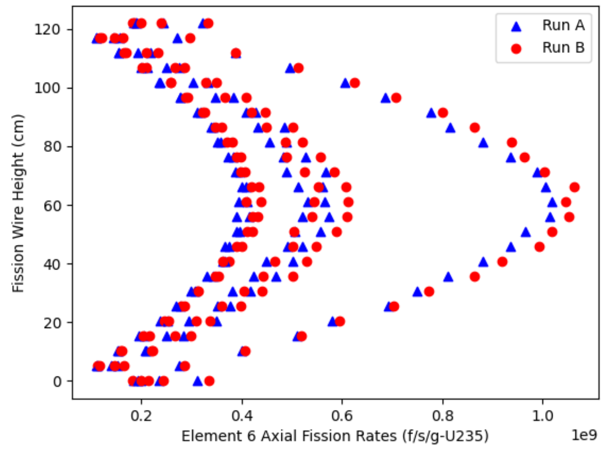
Run B: LOWE in Position 5

Axial Output

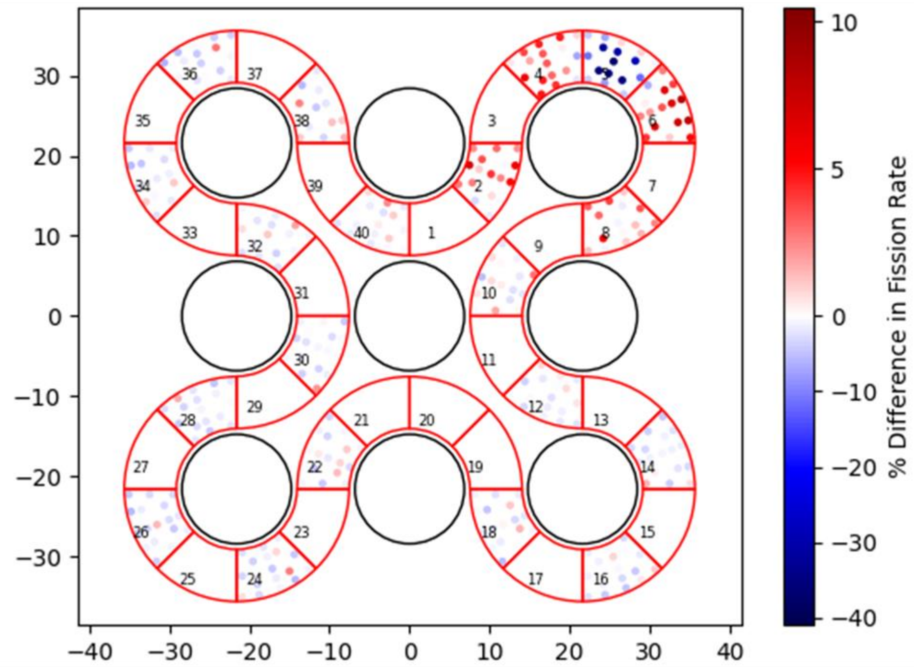
Element 4



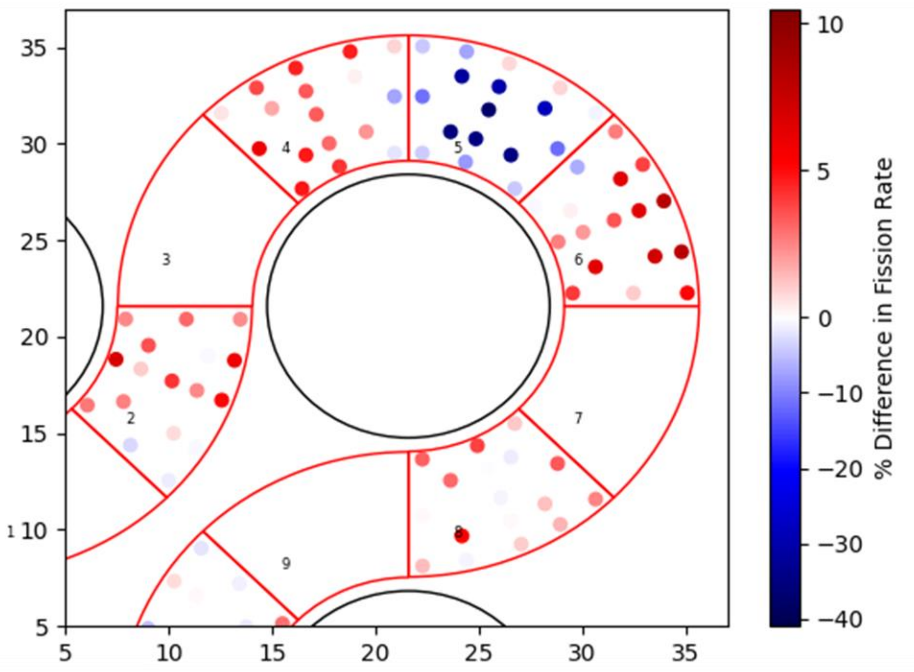
Element 6



Preliminary Findings



% Difference



% Difference

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5. Hardtmayer, D., “Monte-Carlo Based Evaluation of HEU and LEU Fuel Neutron and Photon Spectra”, MPR Calculation 1129-0226-CALC-007, Revision 0.