Kinetic Parameters Estimation in a MTR Research and Production Reactor in Subcritical States

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Introduction

Objectives

Kinetic parameters estimation

- Inverse kinetics as a reactimeter in subcritical states (monitoring a refueling operation).
- Determination of the strength of the neutron source (point kinetic model).
- Characterization of the neutron source. Photoneutron effectiveness estimation ($\gamma^{ph}$).
- Neutron noise technique in presence of $^{135}$Xe and high gamma exposure rate ($10^6 R/h$).
- Reactivity and power estimations (30 $mW$ to 200 $mW$).
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Neutron source

Photoneutrons

- Produced in the reaction \( D(\gamma, n)H \) for \( E_{\gamma} > 2.23 \text{ MeV} \)
- Treated as nine extra groups of delayed neutrons in the point kinetic equations.
- Assumed to come from precursors originated during the normal operation of the reactor at full power.
- Measurements were made 36 h after the reactor shutdown. The photoneutron source was assumed to be constant during each measurement (∼ h).
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### Experimental procedure

#### RA-3 core configuration

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
<th>J</th>
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<tbody>
<tr>
<td>1</td>
<td>P</td>
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<tr>
<td>2</td>
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<td>FE</td>
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<tr>
<td>3</td>
<td>FC</td>
<td>FE</td>
<td>FE</td>
<td>CR1</td>
<td>FE</td>
<td>FE</td>
<td>FE</td>
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<tr>
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<td>CR4</td>
<td>FE</td>
<td>I</td>
<td>CR2</td>
<td>FE</td>
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<td></td>
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<tr>
<td>5</td>
<td>I</td>
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<td>FE</td>
<td>CR3</td>
<td>FE</td>
<td>FE</td>
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<td>I</td>
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<td>I</td>
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<td>8</td>
<td></td>
<td>T</td>
<td></td>
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<td></td>
<td></td>
<td>FC</td>
<td></td>
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</tr>
</tbody>
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- **A**-**J**: Rows and columns of the core configuration grid.
- **P**: Pressure sensor.
- **T**: Temperature sensor.
- **FC**: Reactor fission chamber.
- **I**: Irradiation position.
- **CR**: Control fuel element.
- **FE**: Standard fuel element.
- **FE**: Graphite reflector.
- **Empty position**

**Notes:**
- The core configuration includes standard fuel elements (FE) and control fuel elements (CR).
- Irradiation positions (I) are marked with CR symbols.
- The grid also includes locations for pressure and temperature sensors (P, T), reactor fission chambers (FC), and empty positions.
Results

Neutron noise technique

\[
Y(\tau) = \frac{\epsilon D}{\alpha^2 \Lambda^2} \left(1 - \frac{1 - e^{-\alpha \tau}}{\alpha \tau}\right)
\]

- \(\alpha\): Prompt neutron decay constant
- \(\Lambda\): Neutron generation time
- \(\epsilon\): Absolute efficiency (\(\sim\) Power)
- \(D\): Diven factor

\[
\begin{align*}
\text{Reactivities: } -6 < \$ < -0.5 \\
\text{Count rate: } 1 \times 10^5 \text{ cps} < R < 7 \times 10^5 \text{ cps}
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Power and reactivity are estimated in each stationary subcritical state.
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\(\alpha\)-Feynman method

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Estimation of $\alpha_c$

At each subcritical state:

$$\alpha = \alpha_c + \frac{\hat{S}}{R}$$

By measuring $\alpha$ and $R$ at different subcritical states a linear fit can be performed to obtain $\alpha_c$.

$$\alpha_c = (106 \pm 1) \text{s}^{-1}$$
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Parametric variation of $\gamma^{ph}$ in the point kinetics equations until the best fit of the simulation to the measured power is found.

$\gamma^{ph} = (1.15 \pm 0.06) \times 10^{-4}$

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Least square inverse kinetics method

Rod-drop between two subcritical states.

Transient evolution is fitted with a linearized model (LSIKM).

\[ R(t) = \frac{\Lambda^*}{\$_f - 1} \tilde{Q}(t) - \frac{\Lambda^* \tilde{S}}{\$_f - 1} \]

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- Detector at G8
  \[ \tilde{S} = (6.90 \pm 0.04) \times 10^6 \text{ cps/s} \]
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  \[ \tilde{S} = (2.6 \pm 0.1) \times 10^6 \text{ cps/s} \]

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With the estimation of $\tilde{S}$, the reactivity can be obtained measuring the count rate during a refueling operation.

Refueling operation
- Extraction CR from F5
- Extraction FE from F5
- Entering fresh FE at F5
- Entering CR at F5
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Subcritical reactimeter

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Core 212 to 213

Extraction of burned FE, rotation and entering fresh FE

At these highly subcritical levels, spatial effects become important in reactivity estimations.
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Approach to critical

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**Numerical model**

**Diffusive code PUMA**

Using a homogeneous neutron source in all the fuel channels
(First step)

- As the magnitude of the neutron source was not known in advance, all the comparisons were made relative to the first state.
- A refueling operation was calculated.
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### Results from core 212 to 213

In FIG. 3 (Top) the count rate evolution during the refueling operation and the reactivity estimated with the inverse kinetics equations (Bottom) are shown. In all the intermediate states the subcriticality is far below 15 doldars, assuring a safe operation. However, performing a more detailed analysis of the estimated reactivity values for the core configuration changes, some discrepancies were found with the available reference values. These discrepancies were attributed to spatial effects that appear when working with highly subcritical cores.

In order to analyze more thoroughly the spatial effects found during the reactivity monitoring, a model of the RA-3 core was made with the PUMA code. As the photoneutron source was not known at this stage of the modeling, a uniform neutron source was assumed in all the fuel channels of the core (and zero in the graphite reflector and elsewhere). The absolute value was arbitrary, in such a way that only a relative comparison was possible.

All the core configurations between the 212 and 213 core were simulated for the stationary subcritical states. TABLE I shows the comparison between the experimental values and the calculated ones, all of them normalized to the initial subcritical state. According to the PRM for a subcritical reactor with external neutron source, the relation \( R_i/R_0 \) holds for any two arbitrary subcritical states. A good agreement was found between the local parameters \( R_i/R_0 \) and \( \rho_0/\rho_i \) (which are assumed to be proportional). However, the global parameters such as the power \( P_i/P_0 \) and \( \rho_0/\rho_i \) show discrepancies with the measured values. This confirmed the presence of spatial effects which are disregarded in the PRM.

<table>
<thead>
<tr>
<th>Core configuration i</th>
<th>Experimental</th>
<th>PUMA</th>
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<tr>
<td>Core 212</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>( 1 )</td>
<td>( 1 )</td>
</tr>
<tr>
<td>1</td>
<td>0.78 (3)</td>
<td>0.8 (1)</td>
</tr>
<tr>
<td>2</td>
<td>0.74 (3)</td>
<td>0.7 (1)</td>
</tr>
<tr>
<td>3</td>
<td>0.98 (4)</td>
<td>1.00 (5)</td>
</tr>
<tr>
<td>4</td>
<td>0.82 (3)</td>
<td>0.8 (1)</td>
</tr>
<tr>
<td>5</td>
<td>0.81 (3)</td>
<td>0.8 (1)</td>
</tr>
<tr>
<td>6</td>
<td>0.88 (4)</td>
<td>0.9 (1)</td>
</tr>
<tr>
<td>Core 213</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>1.11 (4)</td>
<td>1.12 (5)</td>
</tr>
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Future improvements

- Calculate the photoneutron source.
- ORIGEN with the information of each FE.
- MCNPX to obtain the photoneutron source.
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Photoneutron source (MCNPX)

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- Measurements at subcritical states with high gamma background and $^{135}$Xe.
- With the neutron noise technique reactivities were estimated between $-6$ and $-0.5$ dollars. Power between 30 mW and 200 mW.
- First estimations of the photoneutron effectiveness $\gamma^{ph} = (1.12 \pm 0.06) \times 10^{-4}$
- Estimation of the source strength value ($\tilde{S}$) that appears in the point kinetics equation.
- Using the inverse kinetics as a subcritical reactimeter
- Monitoring a refueling operation and an approach to critical with a subcritical reactimeter.
- Future measurements with two or more detectors. Detailed studies of spatial effects (correction factors).
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Thank you for your attention