RECENT EXPERIMENTS IN THE IPEN/MB-01 REACTOR

Adimir dos Santos

asantos@ipen.br
The IPEN/MB-01 Research Reactor Facility

The IPEN/MB-01 thermal research reactor is a zero power critical facility specially designed for measurement of a wide variety of reactor physics parameters to be used as benchmark experimental data. Several IPEN/MB-01 critical configurations have been benchmarked by ICSBEP (see September 2014 edition) and many of its experiments are available at IRPhE DVD (see March 2015 edition)

Location: São Paulo, Brazil

Core configuration: 28x26 rectangular array of UO$_2$ fuel rods inside a light water tank

$^{235}$U Enrichment: 4.3486 wt. %

Control banks: 12 Ag-In-Cd rods

Safety banks: 12 B$_4$C rods
Two activities going on right now at the IPEN/MB-01 reactor are shown here.

a) Validation of the Delayed Neutron Data of the recent nuclear data libraries; namely: ENDF/B-VII.0, ENDF/B-VII.1, JENDL-4.0, JENDL-3.3, and JEFF 3.1.1. The Nickel heavy reflector experiment is employed for this purpose.

b) Experimental determination of the reaction rates ($^{238}$U(n,γ) and $^{235}$U(n,f)) along the pellet radius.
Delayed Neutron Data Validation
Nickel Heavy Reflector Experiment Configuration
Axial View of the Positioning of the Ni Plate relative to the IPEN/MB-01 core
Quantity Measured is the reactivity inserted per Ni plate. Inverse kinetic model is employed for this purpose.

\[ \frac{dN(t)}{dt} = \frac{\rho(t) - \beta}{\Lambda} N(t) + \sum_{i=1}^{6} \lambda_i C_i(t) \]

\[ \frac{dC_i(t)}{dt} = \frac{\beta_i}{\Lambda} N(t) - \lambda_i C_i(t) \]

\[ \rho(t) = \frac{\Lambda}{N(t)} \frac{dN(t)}{dt} + \beta_{\text{eff}} - \frac{\Lambda}{N(t)} \sum_{i=1}^{6} \lambda_i C_i(0)e^{-\lambda_i t} \]

\[- \frac{1}{N(t)} \sum_{i=1}^{6} \lambda_i \beta_i e^{-\lambda_i t} \int_{0}^{t} N(t') e^{\lambda_i t'} dt' \]
Measured effective kinetic parameters for the IPEN/MB-01 core

<table>
<thead>
<tr>
<th>$\beta_i$</th>
<th>$\lambda_i ; (s^{-1})$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$(2.679 \pm 0.023)E-4$</td>
<td>$0.012456 \pm 0.000031$</td>
</tr>
<tr>
<td>$(1.463 \pm 0.069)E-3$</td>
<td>$0.0319 \pm 0.0032$</td>
</tr>
<tr>
<td>$(1.34 \pm 0.13)E-3$</td>
<td>$0.1085 \pm 0.0054$</td>
</tr>
<tr>
<td>$(3.10 \pm 0.10)E-3$</td>
<td>$0.3054 \pm 0.0055$</td>
</tr>
<tr>
<td>$(8.31 \pm 0.62)E-4$</td>
<td>$1.085 \pm 0.044$</td>
</tr>
<tr>
<td>$(4.99 \pm 0.27)E-4$</td>
<td>$3.14 \pm 0.11$</td>
</tr>
</tbody>
</table>

$\beta_{eff} = (7.50 \pm 0.19)E-3$, $\Lambda = 31.96 \pm 1.06 \; (\mu s)$
Reactivity (pcm)

Time (s)

$\Delta \rho = 49.37 \quad \sigma_{\Delta \rho} = 0.15$

$\rho = -173.49 \quad \sigma_{\rho} = 0.23$
Theory/Experiment Comparison

The Effective Delayed Neutron Parameter of the several nuclear data libraries of this work were calculated by Steven Van Der Mark, Netherlands employing MCNP5.

Comparison is shown as: 
(C-E)/E ± 1σ in units of %.
ENDF/B-VII.1

(C-E)/E (%) vs. Reactivity (pcm)
ENDF/B-VII.0

Reactivity (pcm)

(C-E)/E (%)
JENDL-3.3

Reactivity (pcm)

(C-E)/E (%)
<table>
<thead>
<tr>
<th>$(C-E)/E$ (%)</th>
<th>$\beta_{\text{eff}}$</th>
<th>$\lambda_1$ (s$^{-1}$)(a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENDF/B-VII.0</td>
<td>$0.00 \pm 0.82$</td>
<td>$0.01249$</td>
</tr>
<tr>
<td>ENDF/B-VII.1</td>
<td>$-0.53 \pm 0.94$</td>
<td><strong>0.01335</strong></td>
</tr>
<tr>
<td>JEFF-3.1.1</td>
<td>$2.13 \pm 0.95$</td>
<td>$0.01247$</td>
</tr>
<tr>
<td>JENDL-3.3</td>
<td>$-0.55 \pm 0.94$</td>
<td>$0.01244$</td>
</tr>
<tr>
<td>JENDL-4.0</td>
<td>$-0.67 \pm 0.94$</td>
<td>$0.01248$</td>
</tr>
</tbody>
</table>

(a) The experimental value is $0.012456 \pm 0.000031$. 
$^{238}$U capture and fission rates along the pellet radius.
Dismountable Fuel Rod and Positioning of the \( \text{UO}_2 \) disk

The \( \text{UO}_2 \) disk was obtained cutting of the IPEN/MB-01 \( \text{UO}_2 \) pellets by a sharp tool. The Uncertainty in the \( \text{UO}_2 \) disk thickness was less than 1\%.
Cadmium Sleeve Arrangement and Positioning

Support

Cadmium Sleeve

UO₂ DISK

7 cm

1.5 cm

0.5 mm
Irradiation Conditions

100W
One hour
20 °C
Critical Control Bank
Position: 58% Withdrawn
Gamma Detection System

LED HPGe Detector

-Small crystal with high efficiency for energies between 50 – 200 keV.
The selected gamma energies was chosen to improve the collimator effectiveness. The lower the better.

$^{238}$U Radiative Capture:

Inferred from the $^{239}$Np gamma decay.
$E_\gamma=106.12$ keV with 27.2 emission probability

Total Uranium Fissions
Inferred from Gamma of FP $^{99}$Mo.
$E_\gamma = 140.51$ keV
Lead Collimator Disk
- Correction Factors Applied to the Experimental Data

  a) Gamma Self-Absorption in the UO$_2$ Disk
  b) Solid Angle Correction (Collimator)
  c) Collimator Shielding Effectiveness.

- Reported Experimental Data are shown relative to the case without collimator (full disk).
- Quantities reported:

$^{238}$U neutron Capture
Uranium fission density
Theory/Experiment Comparisons. Calculated Values From MCNP5 (ENDF/B-VII.0) for all cases.

Total $^{238}$U(n,γ)
Epithermal $^{238}\text{U}(n,\gamma)$
Thermal $^{238}$U($n,\gamma$)
Total $U(n, f)$
Epithermal U(n,f)
Conclusions

-Effective Delayed Neutron Parameters

a) JENDL 4.0 shows excellent agreement. All calculated values are inside of $1\sigma$ of the experimental uncertainty.

b) JENDL3.3 and JEF 3.1.1 overestimated the reactivity by around 5%. A little bit over the $1\sigma$ value.

c) ENDF/B-VII.0 and –VII.1 underestimate the reactivity by around 11%.
Conclusions

- Reaction rates along the pellet radius
  a) Experiments so far successfully performed
  
b) Epithermal $^{238}\text{U}(n,\gamma)$ shows very good agreement.
  
c) Thermal reaction rates show a lot of discrepancies.
  
d) The experiments suggest that the thermal cross section shape of $^{235}\text{U}(n,\text{f})$ in ENDF/B-VII.0 is not well represented.
  
e) The same applies to the thermal $^{238}\text{U}(n,\gamma)$ cross sections.
Thanks for the Attention