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Title: Critical Unresolved Region Integral Experiment Execution

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Critical Unresolved Region Integral Experiment Execution

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November 2020
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Outline

- What is the URR?
- Motivation
- CURIE Final Design
- Experiment Execution
- Future Work

Introduction

Where is the Neutron Cross Section Unresolved Resonance Region (URR)?

- The URR is generally located in the neutron cross section intermediate energy region
 - The intermediate energy region is generally considered to be between 0.7 eV and 100 keV
- The URR is specifically located after the resolved resonance region (RRR) ends, but before the fast (smooth) region begins
 - There are distinct physical resonances at these energies, but they cannot be fully determined empirically.
 - URR is different for different isotopes and different data evaluations

How is the URR currently being treated in Monte Carlo transport codes?

- In the URR, average resonance parameters extracted from experimental data are used to produce probability distribution functions (pdf) representing the total neutron cross section.
 - Mean value is the infinitely dilute smooth average of the cross section
- These distribution functions are represented in tabular form for application in MC transport codes and are referred to as “probability tables”.
 - “ladders” of sampled resonances based on average parameters and statistical laws
 - generated as a pre-processing step before the start of a simulation and are sampled at each instance that a URR cross section is needed.
 - more accurately represent the data to properly capture self-shielding effects

Motivation

Why is the Unresolved Resonance Region for ^{235}U important to re-visit?

#1: Differential Nuclear Data Validation

- **New US differential measurements**
 - New high resolution ^{235}U capture measurements from RPI (Danon et al.) and LANL (Jandel et al.) were significantly below ENDF/B-VII.1 below 2 keV and above it for energies up to 50 keV
- **Recently updated ENDF/B-VIII.0 ^{235}U evaluated file incorporated changes in the capture cross section based on these measurements.**
- **There still remains disagreements between international evaluations**
 - URR bounds and average parameters
 - Additional evaluation work and new high-resolution capture data will be needed to improve the evaluated fission and capture cross sections in the energy region up to about 50 keV.

^{235}U URR Bounds for Several Data Libraries

ENDF/B-VIII.0	2.25 keV - 25 keV
JEFF 3.2	2.25 keV - 25 keV
JENDL 4.0	500 eV - 30 keV

Why is the Unresolved Resonance Region for ^{235}U important to re-visit?

#2 Computational Methods Validation

1. As previously noted, production Monte Carlo codes have typically used the probability table method to account for self shielding in the URR
2. Recent work by Walsh et al. (MIT/LLNL) provides an alternative method by which a single resonance structure is realized and used throughout a single neutron transport simulation.
 - Used same sampling techniques as probability tables, but does not rely on a pre-processing step.
3. All URR methods implemented in Monte Carlo codes will benefit from additional benchmark experiments, such as CURIE

OpenMC

Why is the Unresolved Resonance Region for ^{235}U important to re-visit?

#3: Integral Benchmarks for URR Data and Methods Validation are Sparse

- **Only a handful of intermediate benchmarks available/used for the ^{235}U evaluation in this region.**
 - ZEUS is used in all of them.
- **This is the first benchmark designed to focus specifically on URR as opposed to intermediate (in general).**
 - RPI is also exploring quasi-integral experiment designs for a dedicated complimentary set of ^{235}U URR validation measurements of the URR.
- **Intermediate benchmark may help with other ^{235}U nuclear data validation needs**
 - Intermediate energy benchmarks found to be sensitive nuclear changes (See CSEWG presentation by A. Pavlou, J Thompson).

Naval Nuclear Laboratory Analysis of the
ENDF/B-VIII.0 $\beta 5$ Library

CSEWG 2017
November 6-9, 2017

Final Design

Basis: Zeus

- **Why Zeus?**

- Designed to address need for intermediate energy integral experiments
 - Established by criticality safety community
- Considerations that factored into Zeus design
 - Requires large amount of SNM
 - Similarly, requires large overall size
 - Mid Z number reflector would reduce size and SNM quantity to within the LACEF inventory
 - Mid Z number reflector would return neutrons to core with some energy loss, but not overly thermalized

- **National Criticality Experiments Research Center located at the Nevada National Security Site**

- Four critical assembly devices: Comet, Planet, Flat-Top, Godiva-IV
 - Zeus experiments have been reproduced here on Comet

Zeus- General Description

- **HEU plates**

- 0.299 cm thick, 53.34 cm OD
- ~93 wt% U-235

- **Copper Reflector**

- 16.205 cm thick on all sides (including top and bottom)
- Log form to reduce leakage gaps
- All pieces are well characterized with known impurity content
- All at least 95 wt% Cu

- **Moderator (CURIE specific)**

- Polytetrafluoroethylene [Teflon, C_2F_4]
- Balance of scatter and energy reduction

Final Design: Critical Unresolved Region Integral Experiment (CURIE)

- **Zeus setup (same HEU plates, same copper reflector)**
- **Moderators considered**
 - Lucite, Teflon, BeO, Be, Graphite, Alumina
 - Optimized thickness for fission sensitivity in the URR
- **Utilized ENDF-B/VII.1 and MCNP®6.2**
- **Additional Parameters of Interest**
 - URR Capture Sensitivity
 - Total Fission Integral Sensitivity
 - Fission to Capture Ratio Integral Sensitivity
 - URR Fission to Capture Ratio Integral Sensitivity
 - Financial Feasibility

Final Design: Critical Unresolved Region Integral Experiment (CURIE)

- **Configurations**

- Teflon moderator plates
- Thicknesses ranging from 5/8" to 9/8"

One Unit Cell

Final Configurations

• Details

- Teflon moderator plates thickness
- Spans above and below the URR
- Setup for feasible and reproducible experiment design while maximizing use of components
- All expected to go critical with 9-10 units

Teflon Thickness (inch)	Unit Cell Pieces	k_{eff}
5/8	$2*(1/16'' + 1/4'')$	1.01463
6/8	$2*(1/8'' + 1/2'')$	1.00965
7/8	$2*(1/16'' + 1/8'' + 1/4'')$	1.00418
8/8	$2*(1/2'')$	1.02260
9/8	$2*(1/2'' + 1/8'')$	1.01399

Experiment Execution

Experiment Execution

- Conducted at NCERC
- January to February and June to July 2020
- Challenges
 - Building a URR targeted experiment has LOTS of sensitivities to material changes
 - URR unknowns made predictive simulations inconclusive
 - Adjusting system without changing energy and lifetime of system
 - COVID
- Solutions
 - New spacers varying from 0.05" to 0.5"
 - Replacement plates for portions of the HEU

5-8 Final Configuration

- **Final Selection**
 - 9 units (PTFE, HEU, PTFE)
- **Key**
 - Red: HEU
 - Blue: Teflon
 - Orange: Copper
 - Green: aluminum
 - Grey: steel

6-8 Final Configuration

- **Final Selection**
 - 9 units (PTFE, HEU, PTFE)
- **Key**
 - Red: HEU
 - Blue: Teflon
 - Orange: Copper
 - Green: aluminum
 - Grey: steel

7-8 Final Configuration

- **Final Selection**
 - 10 units (PTFE, HEU, PTFE)
- **Key**
 - Red: HEU
 - Blue: Teflon
 - Orange: Copper
 - Green: aluminum
 - Grey: steel

8-8 Final Configuration

- **Final Selection**
 - 10 units (PTFE, HEU, PTFE)
- **Key**
 - Red: HEU
 - Blue: Teflon
 - Orange: Copper
 - Green: aluminum
 - Grey: steel

9-8 Final Configuration

- **Final Selection**
 - 10 units (PTFE, HEU, PTFE)
- **Key**
 - Red: HEU
 - Blue: Teflon
 - Orange: Copper
 - Green: aluminum
 - Grey: steel

Reactivity of the Measured Configurations

Configuration	Measured Reactor Period (seconds)	Calculated Reactivity (cents)	Date
5-8	14.74	32.31	7/7/2020
6-8	44.36	17.14	6/15/2020
7-8	12.54	34.95	6/30/2020
8-8	27.30	23.17	7/8/2020
9-8	53.46	15.11	6/23/2020

Conclusions and Future Work

Future Work

- Detailed Simulations
 - Varying cross section sets
 - Adjusting ACE files to better understand URR
 - Adjusting ACE files to understand copper angular scatter
 - Sensitivities to URR and angular scatter
- ICSBEP Benchmark, planned submission to WG 2021
- Comparison of C-E for different codes and methods
- Analyze Rossi-alpha data

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