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Integral Experiment Request 206
CED-1 Summary Report

Critical and Subcritical Experiment Design Team (C_EdT)

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Allison D. Miller (SNL), C_EdT Experiment Member
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Thomas M. Miller (ORNL), C_EdT Methods Member
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August 21, 2013

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Summary

This integral experiment request proposes resuming the use of the Burnup Credit Critical Experiment (BUCCX) hardware which was last used in 2002. No hardware modifications are proposed though measurements of the outside diameter of the BUCCX fuel rods will likely reduce the k_{eff} uncertainties of some of the BUCCX configurations. The 2002 operating procedures will be updated and a readiness activity will likely be performed. Some or all of the LEU-COMP-THERM-079 benchmark experiment configurations [1] will be repeated to obtain data on the reproducibility of the experiments. Once the proposed activities are completed, the BUCCX hardware will be available for other NCSP experiments.

Introduction

This integral experiment request is for the return to operation of the Burnup Credit Critical Experiment (BUCCX), which was used in a set of benchmark critical experiments executed in 2002. These experiments were used to investigate the effects of small amounts of rhodium on the critical array size of the experiments. The BUCCX-specific hardware has been in storage since the completion of those experiments. The experiments were evaluated in LEU-COMP-THERM-079 (LCT079) "Water-Moderated U(4.31)O_2 Fuel Rod Lattices Containing Rhodium Foils." [1] The critical assembly used for the BUCCX was modified for use in the Seven Percent Critical Experiment (7uPCX). The 7uPCX hardware was used in the experiments done under IER-135 and IER-159 and for experiments under investigation in IER-208 and IER-209.

The BUCCX differs from the 7uPCX in that an entirely different set of fuel rods is used. As a result, the critical assembly hardware that defines the core of the assembly is different. This includes the assembly driver fuel rods, experiment fuel rods, grid plates, control and safety rods, and source rod. The balance of the critical assembly hardware outside the core is common to the two experiments.

Proposed Experiment Concept

The experiment concept is the same as presented in LCT079 and in reference 2. No new hardware is proposed. The BUCCX uses 0.498 in diameter 4.31% enriched UO_2 fuel pellets inside 0.544 in OD Zircaloy-4 tubes. The fuel pellet stack in the fuel rods is about 19.5 in.

The material under investigation during the 2002 experiment was rhodium. Rhodium was included in some of the configurations as foils placed between the fuel pellets in a set of 36 experiment rods that filled a hexagon surrounding the central fuel element in the assembly. Four sets of experiment rods were built, one with no rhodium, one with 31 nominally 25 μm thick rhodium foils placed between the 32 fuel pellets in each experiment rod, one with 50 μm thick rhodium foils, and one with 100 μm thick rhodium foils.

Two sets of grid plates were used in the BUCCX, one with a triangular pitch of 2.0 cm and the other with a triangular pitch of 2.8 cm. The smaller pitch gave a fuel-to-water volume ratio representative of pressurized water reactors in the US. The larger pitch placed the arrays close to optimum moderation (minimum critical mass) for the fuel rods used in the experiments. Ten configurations were evaluated in LCT079, five at the 2.0 cm pitch and five at the 2.8 cm pitch. Of the five experiments in each pitch, one had no experiment rods and one had each set of experiment rods giving configurations with four levels of rhodium (0 μm, 25 μm, 50 μm, and 100 μm foils)

Anticipated Critical Configurations

The configurations investigated for the BUCCX and documented in LCT079 will be rebuilt. This will afford the opportunity to collect data on the reproducibility of the experiments.

Compliance with C_EdT Manual Requirements

Table 5.1 in the C_EdT manual [3] provides an example of required input and calculated values for design, execution and documentation of criticality (k_{eff}) measurement experiments. Table 1 replicates the columns of the table applicable to the current CED-1 status for IER-206. Also shown in the table is a brief response for this IER.

Table 1. C_EdT Manual Example Requirements for CED-1 of a Criticality Measurement Experiment. The first and second columns are replicated from Table 5.1 of the manual.

Input Parameters	**Preliminary Design CED-1** [d]	**Notes**
Masses (m, σ_m)	✓	Values and uncertainties are included in the LCT079 evaluation.
Compositions (N, σ_N)	✓	Values and uncertainties are included in the LCT079 evaluation.
Dimensions (x, σ_x)	✓	Values and uncertainties are included in the LCT079 evaluation.
Positions (y, σ_y)	✓	Values and uncertainties are included in the LCT079 evaluation.
Calculated Parameters	**Preliminary Design CED-1** [d]	
Eigenvalue (k_{eff}, σ_k)	✓	Values and uncertainties are included in the LCT079 evaluation.
Material Worth [a] (Δk_{eff}, $\sigma_{\Delta k}$)	✓ [a]	Values for rhodium are included in the LCT079 evaluation.
Neutron Energy Spectrum	✓	Values are included in the LCT079 evaluation.
Neutron Balance [b, c] (by Isotope, Region)	✓ [c]	Whole-core values are included in the LCT079 evaluation.
Isotope Sensitivities [c] (by Reaction)	✓ [c]	SCALE models available for use in TSUNAMI, if desired.

Notes a through c are from the table in the reference.
[a] If relevant.
[b] Production, Absorption and Leakage Fractions.
[c] Perhaps not required, but desirable.
[d] The first check mark indicates the value is required. A second check mark, if present, indicates the uncertainties in the parameter are required.

Experiment Uncertainties

The k_{eff} uncertainties in the LCT079 configurations were analyzed and documented in the evaluation. Table 2 lists the uncertainties in the benchmark experiments for the two fuel rod pitches. The k_{eff} uncertainties are the data listed in the last column of Tables 17 and 18 in the evaluation. The overall k_{eff} uncertainty was 0.0016 for the 2.0 cm pitch configurations and 0.0008 for the 2.8 cm pitch configurations.

Table 2. Results of the Uncertainty Analysis for the LEU-COMP-THERM-070 Benchmark Experiments.

Uncertainty Source	**k_{eff} Uncertainty**	
	2.0 cm Pitch	**2.8 cm Pitch**
Pitch	0.00074	0.00007
Clad OD	0.00123	0.00023
Clad Thickness	0.00032	0.00012
Fuel OD	0.00008	0.00005
Upper Reflector	0.00000	0.00001
Foil Diameter	0.00007	0.00011
Fuel Mass per Element	0.00003	0.00002
Fuel Enrichment	0.00045	0.00062
Uranium Mass Fraction	0.00029	0.00017
Clad Composition	0.00029	0.00020
Aluminum Composition	0.00016	0.00011
Source Composition	0.00004	0.00000
Rhodium Composition	0.00002	0.00004
Water Composition	0.00009	0.00015
Temperature	0.00008	0.00002
Sum in Quadrature	**0.00161**	**0.00076**

Figure 1 shows the components of the experiment k_{eff} uncertainty graphically. The largest uncertainty contribution in the 2.0 cm pitch experiments is due to uncertainties in the outside diameter of the fuel rods followed by uncertainties in the fuel element pitch. Both uncertainties contribute to the uncertainty in the fuel-to-water volume ratio in the undermoderated core. The experiments with 2.8 cm fuel rod pitch are very near to optimum moderation for the BUCCX fuel rods. As a result, the two uncertainty sources that dominate the uncertainty at 2.0 cm pitch are much smaller. The largest uncertainty in the experiments in the 2.8 cm pitch experiments is due to uncertainties in the enrichment of the fuel.

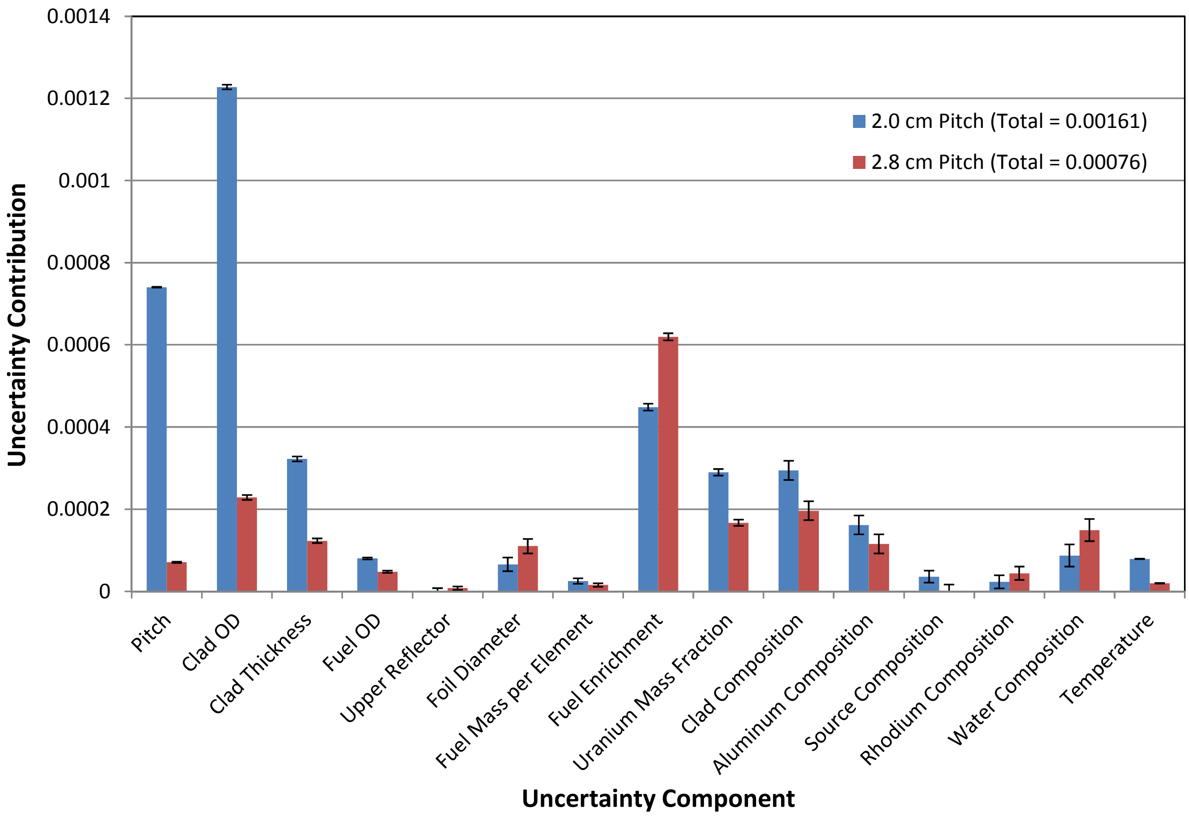

Figure 1. Graphical Comparison of the k_{eff} Uncertainty Components in the LCT079 Configurations.

Assembly Modifications for the Proposed Experiments.

There are no modifications proposed to the critical assembly beyond the restoration of the BUCCX core hardware and fuel.

As part of the development of the 7uPCX hardware, a capability was developed to accurately measure the outside diameter of the 7uPCX fuel rods using a set of laser micrometers. The laser micrometers will be used to measure the outside diameter of the BUCCX fuel rods. Assuming the uncertainties in these measurements are similar to the uncertainties achieved in the 7uPCX measurements, the dominant uncertainty (fuel rod diameter) in the experiments at 2.0 cm pitch will be made significantly smaller resulting in the k_{eff} uncertainty in those experiments being reduced from 0.0016 to about 0.0010.

The facility authorization basis was originally written for the 2002 BUCCX configurations. Since then, it has been modified to accommodate the 7uPCX configurations while maintaining coverage of the BUCCX. The BUCCX operating procedures used in 2002 will require modifications to meet current standards. A readiness activity will likely be required to demonstrate the readiness of the facility to return to the operation of the BUCCX configurations.

Conclusion

Integral Experiment Request 206 proposes resuming the use of the Burnup Credit Critical Experiment hardware. No hardware modifications are proposed though measurements of the outside diameter of the BUCCX fuel rods will likely reduce the k_{eff} uncertainties of some of the BUCCX configurations. The 2002 operating procedures will be updated and a readiness activity will likely be performed. Some or all of the LCT079 configurations will be repeated to obtain data on the reproducibility of the experiments. Once the proposed activities are completed, the BUCCX hardware will be available for other NCSP experiments.

References

1. G. A. Harms, “Water-Moderated U(4.31)O_2 Fuel Rod Lattices Containing Rhodium Foils”, LEU-COMP-THERM-079 in the *International Handbook of Evaluated Criticality Safety Benchmark Experiments*, NEA/NSC/DOC(95)3, December, 2012.
2. G. A. Harms, P. H. Helmick, J. T. Ford, S. A. Walker, D. T. Berry, and P. S. Pickard, “Experimental Investigation of Burnup Credit for Safe Transport, Storage, and Disposal of Spent Nuclear Fuel,” Sandia National Laboratories report SAND2004-0912, April, 2004.
3. A. N. Ellis, *Critical & Subcritical Experiment Design Team (C_EdT) Process Manual of the United States Department of Energy Nuclear Criticality Safety Program*, Revision 0, http://ncsp.llnl.gov/ced/NCSP_Manual_rev_0_approved.pdf, August, 2012.