SAND2009-5590C

Results for the First Approach-to-Critical for the Seven Percent Critical Experiment at the Sandia Pulse Reactor Facility

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Abstract

Currently commercial reactors have an enrichment limit of five weight percent ^{235}U. It has been shown that is would be very beneficial to increase that enrichment limit. With an increased enrichment, the reactor fuel would be able to be burned for a longer period of time and decrease the frequency of outages for power plants.

I. INTRODUCTION

The Seven Percent Critical Experiment was designed to gain benchmark data for the higher enrichment of uranium, greater then five weight percent ^{235}U, to validate reactor physics and criticality safety codes for the purpose of commercial reactor design. Pressurized water reactors and boiling water reactors were the two main commercial target designs. The experiments will be preformed at Sandia Pulse Reactor Facility at Sandia National Laboratories. The first experiment is a 3 × 3 array of 15 × 15 square pitched fuel assembly, with a pitch of 0.800 cm and water moderator. The second experiment is a 3 × 3 array of 15 × 15 square pitched fuel assembly, with a pitch of 0.855 cm and water moderator. The value of the pitch was chosen to have a particular fuel to moderator ratio which represents current light water reactor design. The fuel rods are composed of 6.93 wt% ^{235}U, with an active height of 50 cm, and aluminum clad with a thickness of 0.0363 cm.

The completion of these experiments will offer new data to ensure that reactor physics codes are correctly modeling higher enrichments. Although there are a large number of benchmarks in the International Handbook of Evaluated Criticality Safety Benchmark Experiments that have been shown to correlate well with the experimental model through TSUNAMI analysis, the experimental model for Severn Percent directly represent a commercial reactor fuel design.

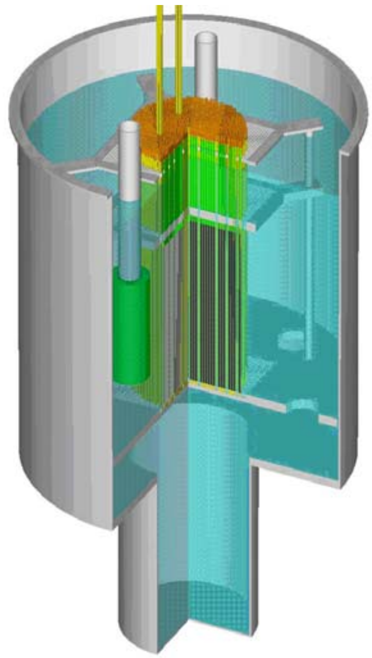

Figure 1. Cross Section of Critical Experiment

II. BACKGROUND

The completion this critical experiment is a very important and exciting moment. The last DOE critical experiment performed was the Burnup Credit Critical Experiment (BUCCX) in the Sandia Pulsed Reactor Facility, in 2002. This project was performed under Nuclear Energy Research Initiative Project 01-124 Reactor Physics and Criticality Benchmark Evaluations for Advanced Nuclear Fuel, under Areva in collaboration with Sandia National Laboratory, Oak Ridge National Laboratory and University of Florida. The funding was provided by NERI and has support of NCSP. The main objective of the NERI project was to design, perform and analyze critical benchmark experiments for validating reactor physics methods and models for fuel enrichments greater then five weight percent ^{235}U. (Ref. 2) The computer codes used for the analysis are APOLLO2-F/NEMO (JEF-2 99-Group), KENO V.a (CSAS25 analysis sequence, ENDF/B-V 238-Group (SCALE)), NEWT (ENDF/B-V 4-Group (SCALE)), HEILOS (ENDF-B-VI 190-Group), CASMO3/SIMULATE-3 (ENDF/B-VI 40-Group), MCNP (ENDF.B-VI Continuous Energy). A description of the code uses can be found in Ref. 2.

The fuel was obtained from Pennsylvania State University (PSU), and is unirradiated. The Pathfinder fuel was designed for a hexagonal pitch with wire wraps and thus need to be unloaded and re-fabricated for the square-pitched arrays. 2,200 cylindrical fuel rods were fabricated from the Pathfinder fuel.

The critical assembly from the BUCCX experiment was able to be reused for this critical experiment, however new grid plates were necessary and as well as other hardware.

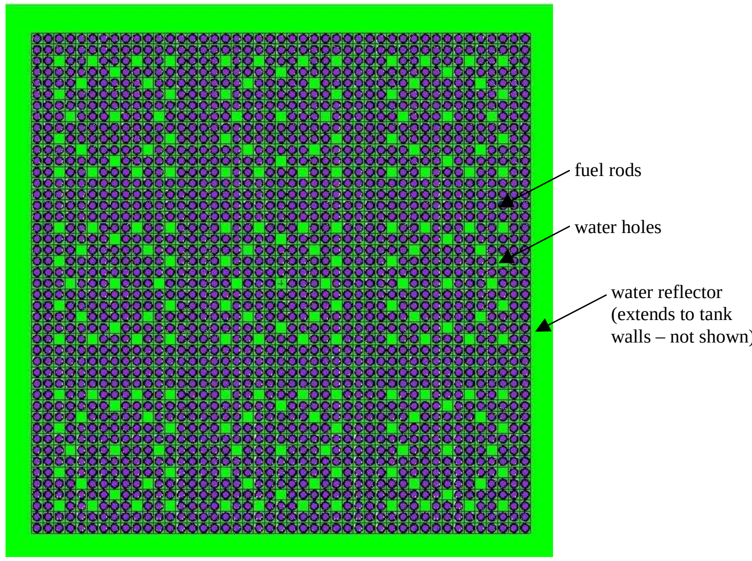

Figure 2. Full Loading Fuel Element Design

The standard Light Water Reactor fuel assembly design can be seen as a 3 X 3 array of 15 X 15 fuel elements. This particular core model with be preformed at a later time. The first loading is to fill the holes with fuel elements leaving the water holes shown, until the system is critical.

III. PRCEDURE

An approach on inverse multiplication, using number of fuel elements as the approach variable, was used in the start up of the 7uPCX experiment. The first of many experiments is the 0800 square pitch design, water moderated. As discussed previously the goal of this set of experiments is obtain data for seven weight percent enrichment applicable to commercial reactor designs.

The array of fuel elements is fully reflected, such that the fuel only sees water. The state in which count rates were taken was with the highest amount of reactivity available. The control elements and the safety elements were all raised to be above the core. The control element and safety elements are fuel-followed.

The first loading was N=740 (k_{eff} ~ 0.90) and the second loading was N=956 (k_{eff} ~ 0.95). The number of rods for k_{eff}=0.90 and k_{eff}=0.95 was predetermined from SCALE KENO V.a code evaluation and an estimate of the number of fuel elements required to obtain a critical system was evaluated in detail. From the second fuel loading, fuel was added based on the inverse multiplication method, to approach to critical. The following plots display the incremental steps. Once the initial data was taken, a line of the 1/M data was projected to 1/M=0. The fuel loading was determined to be one-half of the difference between the current loading and the projected loading for 1/M=0.

The set of equations by which the inverse multiplication is determined are shown below.

$$M = \frac{1}{1-k} \quad (1)$$

Equation 1 holds only for k less then one, and when k equal one M equals infinity, or the inverse multiplication is zero. The relative count rates are assumed to approximate M when keff is close to (but less than) one.

$$\frac{1}{M} = \frac{C_0}{C} \quad (2)$$

In equation 2, M is the subcritical multiplication factor, k is the reproduction factor, C_0 is the reference count rate at N_0 fuel elements, and C is the current count rate at N fuel Elements. For the first experiment C_0 is the count rate at the initial loading of 740 fuel elements.

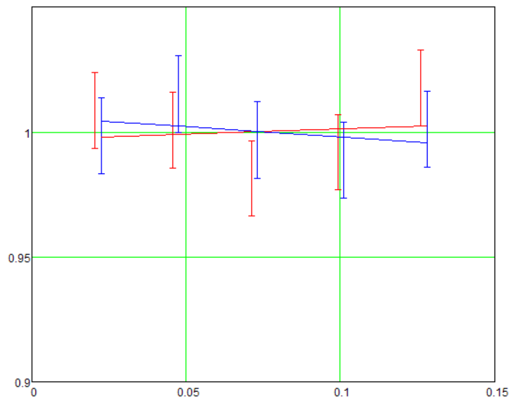

Figure 3. N=740 k=0.90

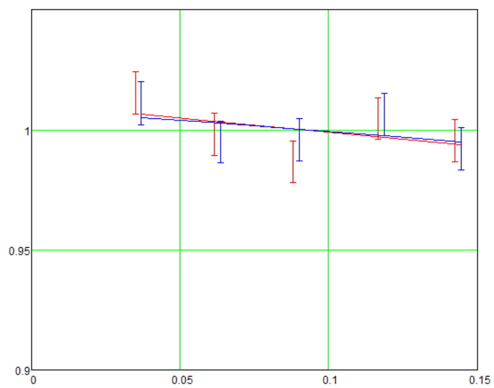

Figure 4. N=956 k=0.95

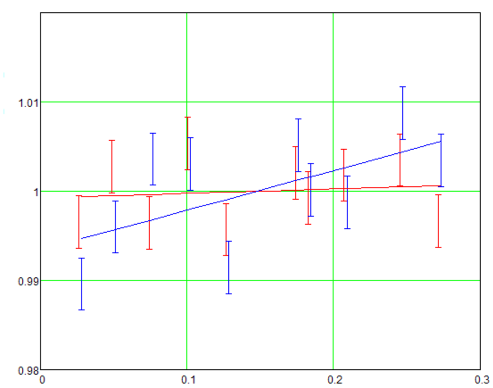

Figure 5. N=1115

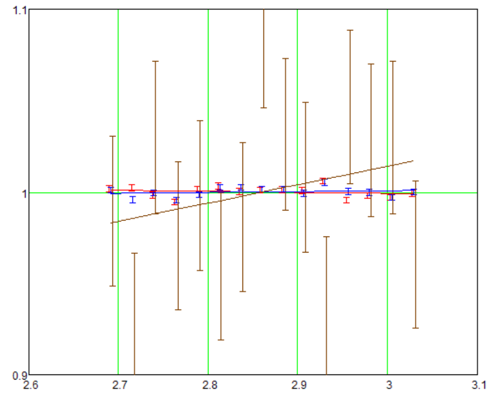

Figure 6. N=1136

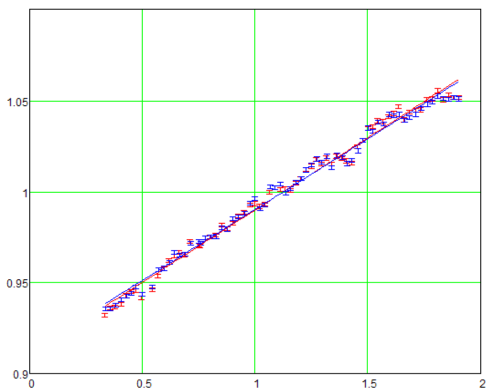

Figure 7. N=1140

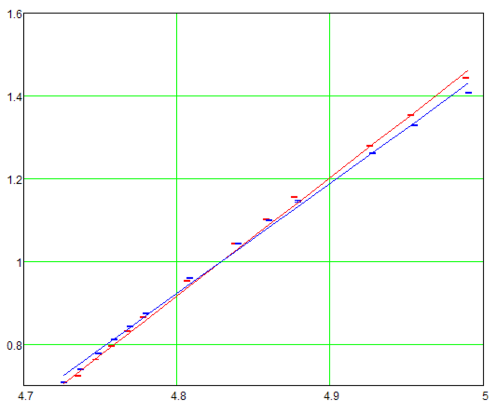

Figure 8. N=1144

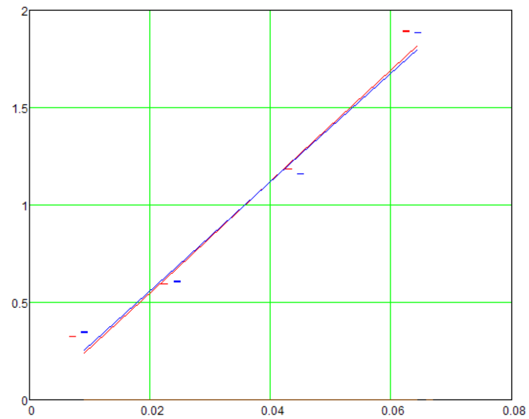

Figure 9. N=1148

The above figures display the counts taken for different fuel element additions. The goal was to obtain a flat horizontal line with the count data with little standard deviation. As time progressed this trend should have been seen. It should be noted that this data was taken with a source in the center of the core. The last two plots are rather different from the first set of data. For the N=1144 plot, the count rate is steadily increasing and tends to suggest a slightly sub-critical system. The N=1148 has the shape of an exponential increase and therefore is a supercritical system.

The inverse multiplication is plotted versus number of fuel elements in the figure below. As the experiment approaches critical the 1/M data approaches zero.

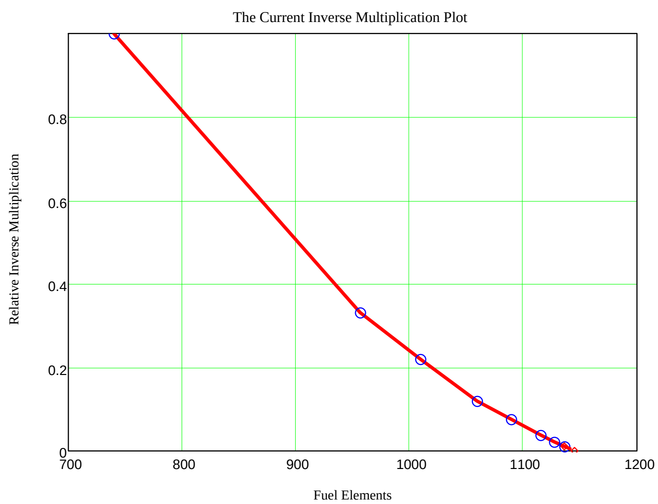

Figure 10. Inverse Multiplier Plot

Figure 11 is a MathCAD drawing of the fuel elements in the core. The black circles are the control and safety elements. The red and blue circles are both fuel rods.

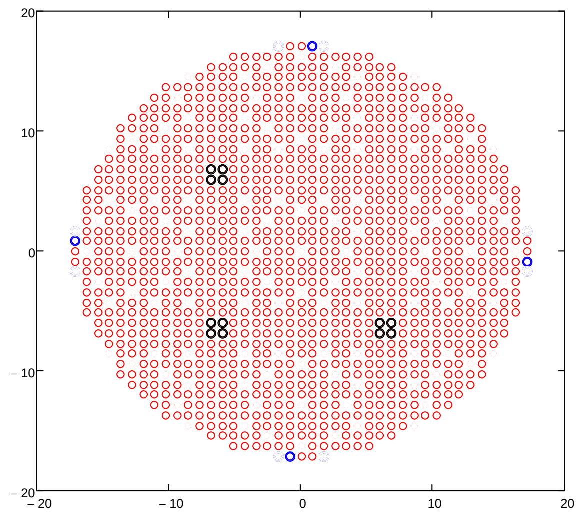

Figure 11. Fuel Element Loading N=1148 from MathCAD

IV. RESULTS

The first core of 7uPCX went slightly supercritical on Friday May 15 2009 at 14:48 with 1148 fuel elements in the core.

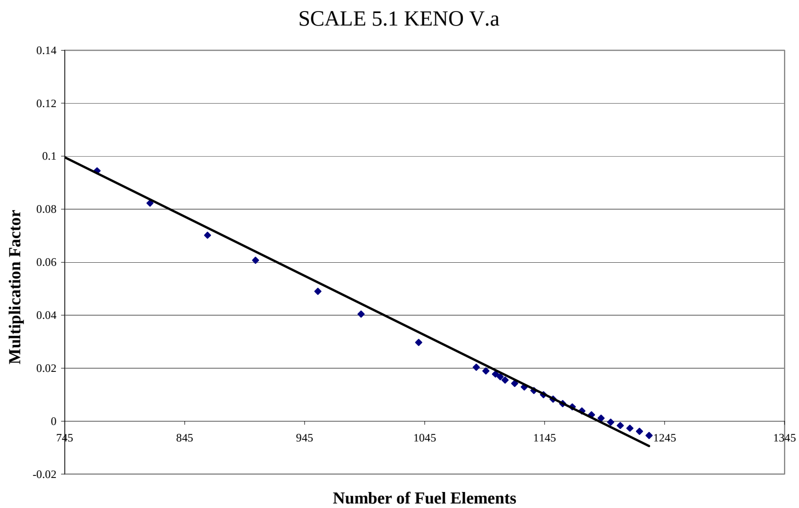

Figure 12. SCALE 5.1 KENO V.a Inverse Multiplier Plot

Figure 4 shows the multiplication factor resulting from the SCALE 5.1 KENO V.a evaluation. As mentioned in the introduction one of the main goals of this experiment is to validate existing criticality codes. The figure predicts that the system will be critical with approximately 1168 fuel elements. Although there is always a given uncertainty in how well k is known, this is a large difference between the computer modeling and the critical experiment. Work is currently being done to evaluate a reason for the difference.

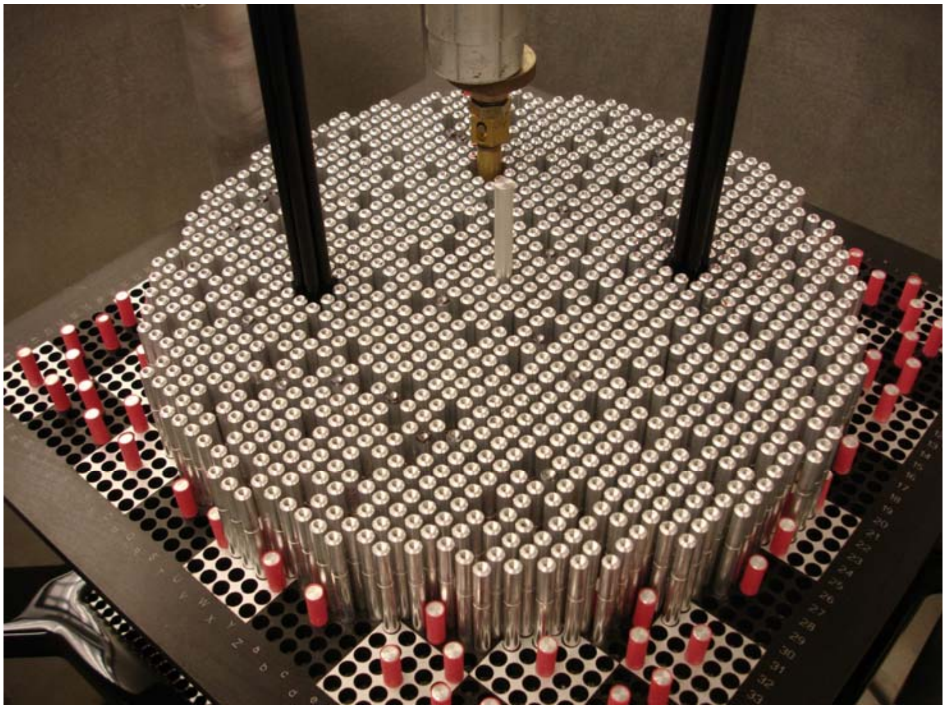

Figure 13. Core Loading in SPRF N=1148

V. ACKNOWLEGMENTS

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

VI. REFERENCES

1. Rearden, B. T. *, Anderson, W. J., and Harms, G. A., "Use of Sensitivity and Uncertainty Analysis in the Design of Reactor Physics and Criticality Benchmark Experiments for Advanced Nuclear Fuel." **Nuclear Technology**. Vol. 151, Number 2, August 2005 (pp. 133-151).

2. "Reactor Physics and Criticality Benchmark Evaluations for Advanced Nuclear Fuel, Final Technical Report." TDR-30000849-000, Areva Federal Services, LLC (2008).

3. Harms G. A., Ford J. T., Barber A. D. "Restart of the Sandia Pulsed Reactor Facility Critical Experiments." American Nuclear Society June 2009.