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# Benchmark Experiments in Water-Moderated Fully-Reflected 6.90% Enriched $UO_2$ Fuel Rod Lattices With a Fuel-to-Water Volume Ratio of 0.52

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## INTRODUCTION

The Seven Percent Critical Experiment (7uPCX) was designed to provide benchmark criticality and reactor physics data for water-moderated pin-fueled nuclear reactor cores. The enrichment of the fuel was chosen to explore the enrichment range above the current 5% ceiling for US commercial PWRs. The experiment was part of the US Department of Energy (DOE) Nuclear Energy Research Initiative (NERI) Project 01-124 titled "Reactor Physics and Criticality Benchmark Evaluations for Advanced Nuclear Fuel" [1].

The NERI project was a collaboration between AREVA Federal Services, LLC; the University of Florida; Oak Ridge National Laboratory; and Sandia National Laboratories (SNL). The experiments are currently supported by the DOE National Nuclear Security Administration Nuclear Criticality Safety Program.

## THE 7uPCX CRITICAL ASSEMBLY

A photograph of the 7uPCX critical assembly is shown in Figure 1. The critical assembly has two tanks, the core tank that hosts the assembly fuel array and the dump tank at a lower level. The two tanks are connected by two large-diameter dump lines that allow the assembly moderator to pass from the core tank to the dump tank. Each line includes a normally-open dump valve that must be held closed for moderator to accumulate in the core tank.

The assembly has two safety elements and one control element. Normally, the core tank is dry and the assembly moderator/reflector is in the dump tank. In order to make a multiplication measurement, the safety elements are raised, the dump valves are closed, the moderator is pumped from the dump tank to the core tank until the upper grid plate is covered by about 15 cm of water, and the control element is raised. With the core fully moderated and reflected and all control and safety elements withdrawn, the assembly is at its highest reactivity state. Critical operations or multiplication measurements are made in this configuration

A cutaway view of the 7uPCX core tank is shown in Fig. 2. The view of the left of the figure shows the assembly core tank dry with the fuel array in place. The view on the right of the figure shows the assembly core tank filled with water as moderator and reflector. Table I summarizes some of the design characteristics of the 7uPCX critical assembly.

### The Fuel Array

Two grid plate sets were fabricated for the assembly, each having a square-pitched 45x45 array of holes to support the assembly fuel rods. One set has a fuel rod pitch of 0.800 cm and the other has a fuel rod pitch of 0.855 cm. These pitch values were chosen so that the resulting fuel arrays would have fuel-to-water volume ratios that bracket the existing US fleet of pressurized water reactors (PWR). Both grid plates were 2.54 cm thick and were fabricated from 6061 aluminum. In the assembly, the grid plates were separated by four support posts 50.49 cm in length.

The grid plates and fuel rods are designed so that the bottom of the fuel is at the same elevation as the top of the lower grid plate. The polyethylene in the fuel rod was designed to almost exactly replace the hydrogen in the water displaced by the upper part of the fuel rod.

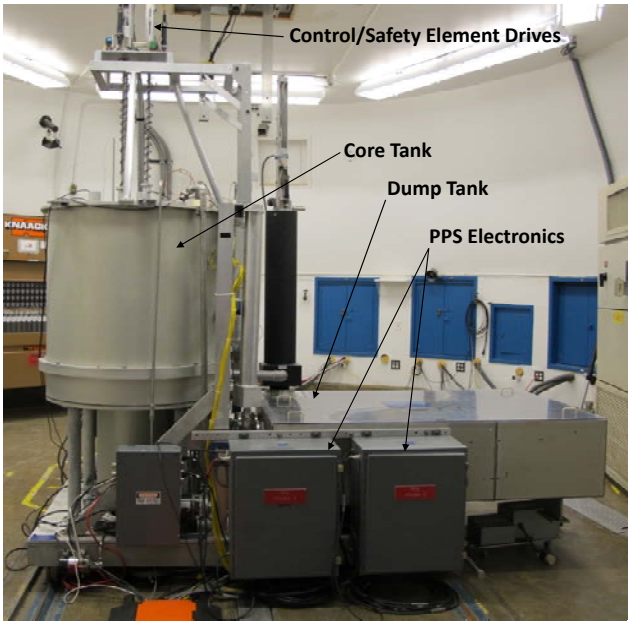


Fig. 1. Photograph of the 7uPCX Critical Assembly.

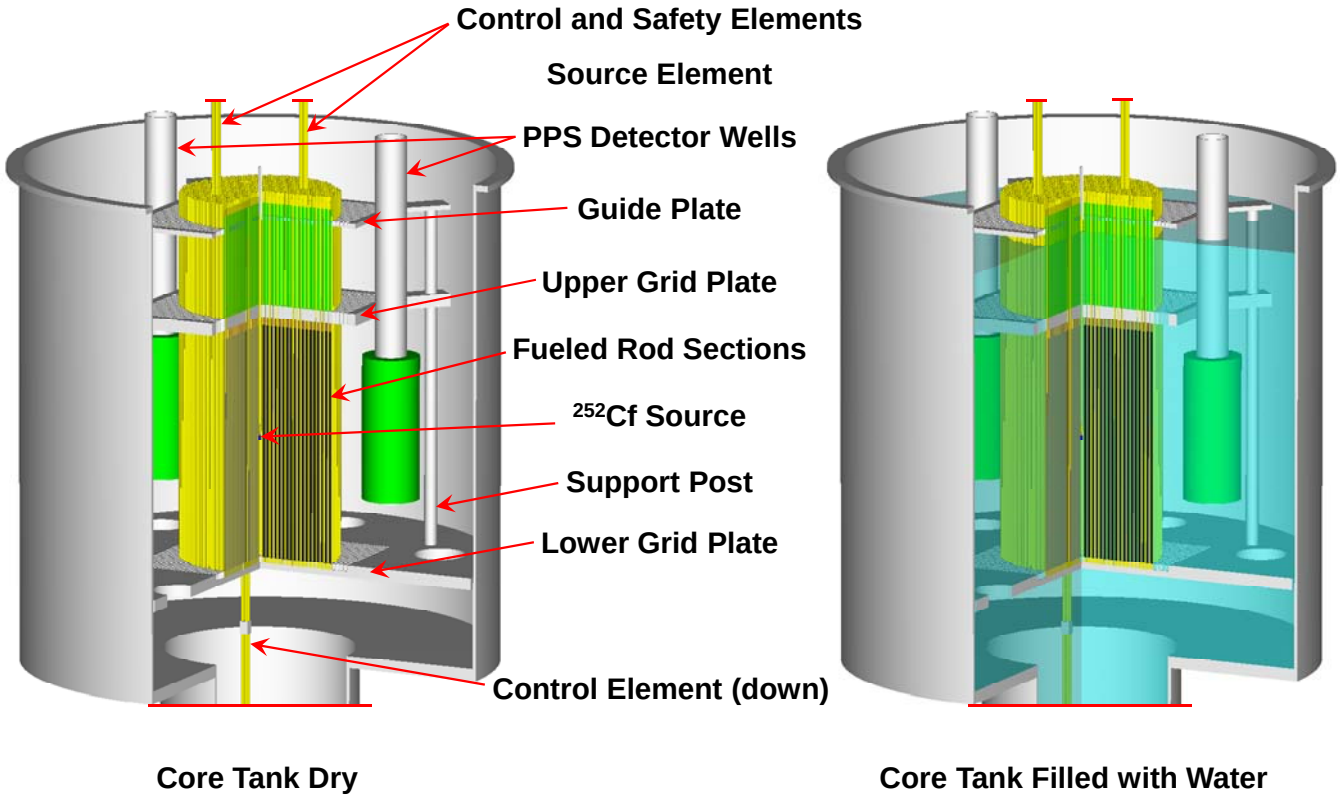


Fig. 2. Schematic cutaway views of the critical assemblies used in the 7uPCX (left) and the BUCCX (right).

Table I. Characteristics of the 7uPCX assembly used in the experiments.

| | |
|---|---|
| Fuel | $UO_2$ |
| Enrichment (%) | 6.903 |
| Moderator | Light Water |
| Fuel OD (cm) | 0.5256 |
| Fuel Length (cm) | 48.78 |
| Fuel Density (g/cm$^3$) | 10.3 |
| Fuel Rod OD (cm) | 0.6350 |
| Cladding Material | 3003 Aluminum |
| Array Configuration | Square Pitch |
| Pitch (cm) | 0.855 |
| Fuel to Water Volume Ratio | 0.524 |
| H to $^{235}$U Atom Ratio | 79.5 |
| H to U Atom Ratio | 5.55 |

**The Assembly Fuel**

The 7uPCX fuel rods were fabricated at SNL from 6.90%-enriched $UO_2$ fuel pellets that were removed from unirradiated fuel elements and placed into 3003 aluminum cladding tubes with welded end caps of the same alloy. The outside diameter of the fuel pellets is 0.5256 cm and the outside diameter of the fuel rod cladding is 0.6350 cm. The average length of the fuel column in the fuel rods was 48.78 cm. 2,199 7uPCX fuel rods were fabricated from the original fuel pellets.

A set of dummy fuel rods was fabricated from 6061 aluminum rod. These rods had an outside diameter of 0.6386 cm. The dummy fuel rods were used o replace several fuel rods in some of the experiments.

**Control and Safety Elements**

The 7uPCX core has two safety elements and one control element, each a cluster of four rods that replaces four rods in the fuel array. The control and safety elements are identical and distinguished only by the way they are used. Each has a four-rod $B_4C$ poison section followed by a four-rod fueled section. The poison and fueled sections are separated by a four-rod polyethylene-filled decoupler section 15 cm long. When fully raised, the fuel follower is in the core, the poison sections are above the water level in the core tank and the control and safety elements are neutronically identical to every other fueled position in the array.

**Assembly Instrumentation**

The assembly has two dry wells that house the two fission chambers that are part of the plant protection system (PPS). Count rates from buffered pulse trains from these detectors were used as part of the count rate data taken in the approach-to-critical experiments. While the critical assembly is often operated above delayed critical, many measurements are made with $k_{eff}$ in the assembly less than one. In this condition, the assembly is driven by a $^{252}Cf$ source that is placed in or near the fuel array.

**RESULTS OF THE EXPERIMENTS**

In a previous set of experiments [2, 3, 4], the fuel arrays were fully reflected and operated with a fuel rod pitch of 0.800 cm and a fuel-to-water volume ratio of 0.67. A benchmark evaluation of these experiments has been published [5]. The current set of experiments [6] was also fully reflected but used a fuel rod pitch of 0.855 cm with a fuel-to-water volume ratio of 0.52. A benchmark evaluation for the second set of experiments has been completed [7].

Fifteen configurations were addressed in the critical experiments. The configurations are labeled Case 1 through Case 15 using the terminology of the forthcoming benchmark evaluation [7]. Table II lists the fifteen cases and a brief description of each configuration. Fig. 3 shows quarter-core diagrams for the fifteen configurations with the $k_{eff}$ obtained as described above for the fuel array shown.

**CONCLUSION**

One goal of the Seven Percent Critical Experiment at Sandia National Laboratories is to make criticality measurements on arrays of 6.90% enriched $UO_2$ fuel rods. Fifteen roughly cylindrical arrays with pure water moderator and reflector and a fuel-to-water volume ratio of 0.52 have been measured. The results for those fifteen arrays are given in this paper.

Table II. Description of the fuel array configurations

| Case | Fuel Rods | Non-Fueled Positions | $k_{eff}$ | Description |
|---|---|---|---|---|
| 1 | 1057 | 0 | 0.9995 | Base case with all fuel rod position inside a roughly cylindrical core filled |
| 2 | 1056 | 1 Water Hole | 0.9999 | Case 1 with the central fuel rod removed |
| 3 | 1041 | 4 Water Holes | 0.9990 | Case 1 with four fuel rods 3.42 cm from the center of the array on the principal axes removed |
| 4 | 1041 | 4 Water Holes | 0.9986 | Case 1 with four fuel rods 6.84 cm from the center of the array on the principal axes removed |
| 5 | 1041 | 4 Water Holes | 0.9980 | Case 1 with four fuel rods 10.26 cm from the center of the array on the principal axes removed |
| 6 | 1041 | 4 Water Holes | 0.9974 | Case 1 with four fuel rods 13.68 cm from the center of the array on the principal axes removed |
| 7 | 1029 | 8 Water Holes | 0.9994 | Case 3 with four fuel rods 3.63 cm from the center of the array on the diagonals removed |
| 8 | 1029 | 8 Water Holes | 0.9987 | Case 4 with four fuel rods 7.25 cm from the center of the array on the diagonals removed |
| 9 | 1029 | 8 Water Holes | 0.9978 | Case 5 with four fuel rods 10.88 cm from the center of the array on the diagonals removed |
| 10 | 1029 | 8 Water Holes | 0.9969 | Case 6 with four fuel rods 13.30 cm from the center of the array on the diagonals removed |
| 11 | 1049 | 8 Aluminum Rods | 0.9994 | Case 7 with aluminum rods in the water holes |
| 12 | 1049 | 8 Aluminum Rods | 0.9993 | Case 8 with aluminum rods in the water holes |
| 13 | 1049 | 8 Aluminum Rods | 0.9993 | Case 9 with aluminum rods in the water holes |
| 14 | 1049 | 8 Aluminum Rods | 0.9991 | Case 10 with aluminum rods in the water holes |
| 15 | 872 | Water Holes as Shown | 0.9996 | Water hole pattern as shown in Fig. 3 |

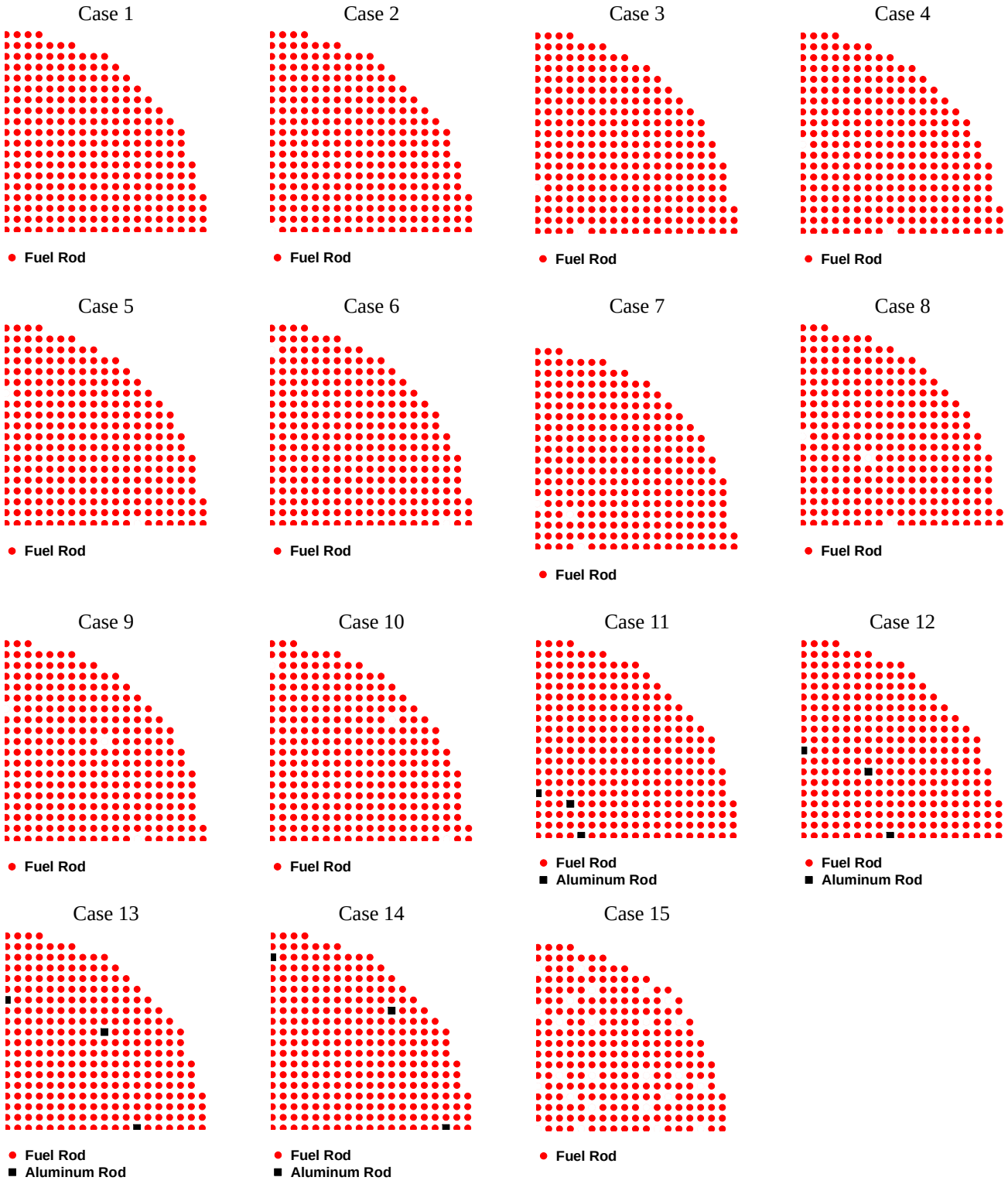


Fig. 3 Quarter-core diagrams of the fuel arrays.

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