INTRODUCTION

Computational simulation of nuclear reactors for design and analysis requires accurately modeling several different interrelated physical processes including neutronics, heat production, fluid/thermal physics, structural mechanics, fuel behavior, chemistry, and balance-of-plant. Modern codes have been developed which couple together the behavior of these different physical models to accurately consider the feedback effects between different physical effects. The SHARP toolset, part of the Nuclear Energy Advanced Modeling and Simulation (NEAMS) project, is an example of an effort to combine models of neutronics, thermal-hydraulics, and structural mechanics in a coupled simulation to model any type of nuclear reactor [1].

The multi-physics coupling in these codes required experimental validation that is in addition to the validation data that exists for the individual physics routines, with benchmark experiments specifically designed for that purpose [2]. The purpose of this work is to develop a set of experiments at the Walthousen Reactor Critical Facility (RCF) at Rensselaer Polytechnic Institute (RPI) that will provide data for multi-physics coupling validation of the SHARP toolset, and which may be applied to other code sets as well. The RCF is uniquely suited to these types of experiments, due to its flexible configuration, low power, and detailed instrumentation [3].

The reactor consists of UO₂ fuel pins, containing a total of 35.2 grams of U-235 each (4.81 % enriched). The pins are arranged in a regular lattice with a pitch of 1.6256 cm. The number and configuration of these pins are flexible, and the reactor’s overall thermal power is limited to no more than 15 W. Experiments involving standard core configurations and changing temperatures have been previously reported [4].

To expand that range of parameters that can be addressed in the neutronics and thermal hydraulics coupling effects in the reactor, a circulating fluid loop test section has been designed and installed in the center of the reactor, as seen in Figure 1. The addition of this loop to the core increases the moderator temperature range that can be achieved and increases the speed at which the temperature change can evolve.

EXPERIMENTAL TEST SECTION DESIGN

Test Section Description

The test section consists of a central stainless steel pipe, surrounded by 4 smaller pipes connected through a welded manifold to it at the bottom. These pipes are placed in the center of the core, where a 5 by 5 array of fuel pins has been removed. The assembly is connected via flexible hoses to an 82 gallon water tank and pump, equipped with 16 kW immersion heaters. With this system, a circulating flow of water is obtained at the center of the core.

![Fig. 1. RCF fuel pins lattice top view (test section configuration).](image)

Inside the central stainless steel pipe, four additional fuel pins are added to achieve core criticality. These fuel pins are fixed in place with an aluminum pin holder, as seen in Figure 2. The system permits multiple neutronics and thermal hydraulics coupled experiments through varying parameters, as summarized in Table I.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Range</th>
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<tbody>
<tr>
<td>Temperature of circulating water</td>
<td>20 to 70 °C</td>
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<tr>
<td>Circulating water flow rate</td>
<td>3 to 12 GPM</td>
</tr>
</tbody>
</table>

To control and record the test section parameters, temperature (4 type T thermocouples) and pressure (1 pressure transducer) sensors have been installed. There are 3 thermocouples and 1 pressure transducer on the inlet leg of the loop at the top of the central pipe, and the last thermocouple is on the outlet part of the loop, as seen in Figure 3. The thermocouple probes are inserted at three different depth inside the pipes (at the pipe center, at one-half the radius, and at the flow edge), allowing for a radial measurement of the water temperature.
To provide effective uncertainty quantification of the thermal-hydraulic behavior of the test section, it will be necessary to include more detailed temperature and pressure instrumentation of the test section. However, the space limitations of the fuel lattice do not allow such instrumentation to be installed within the active core volume. Subsequent to the completion of the critical experiments, we will add instrumentation to the test section and collect data without the fuel installed to improve the thermal-hydraulic inputs to the simulations.

Temperature Dependent Measurements

As heated water circulates through the loop, heat will be transferred to the surrounding reactor water resulting in a drop in temperature along the test section. A heat loss model of the test section has been developed to predict the temperature profile. For a loop inlet temperature of 70 °C and reactor tank water temperature of 20 °C, the temperature drop along the test section length is shown in Figure 4.

Data Analysis

The test section instrumentation feeds a set of digital recorders that are used with the reactor instrumentation. Data values can be recorded at a user-selectable rate and time-stamped for correlation between sensors. Reactor power and flux measurements will be fitted to a function corresponding with changes in the circulating water temperature profile for comparison with the coupled simulations being developed separately.

CONCLUSIONS

A test apparatus has been designed for performing measurements of neutronic and thermal-hydraulic properties in the RPI RCF. The experiment has been commissioned and shown to behave within the restrictions of the reactor technical specifications. The data generated will be used with reactor simulations being developed separately to provide benchmark comparisons for multi-physics coupling routines.

ACKNOWLEDGEMENT

This project is funded in part by Department of Energy, Nuclear Energy University Programs, DE-NE008439.

REFERENCES