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EXPERIMENTALLY VERIFYING THE EFFECTIVENESS OF FUELED CONTROL DRUMS

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Water submersion criticality is a known problem in all current LEU Nuclear Thermal Propulsion core designs. This paper concerns a new control drum design that has the required control authority to shutdown cores even when submerged in water. It then describes the design, process, and results of a low-cost experiment used to test the feasibility and functionality of this new design.

I. INTRODUCTION

In LEU nuclear thermal propulsion (LEU-NTP), one of the as-of-yet unsolved questions revolves around safe reactor shutdown in the case of a water submersion accident. Shutdown safety in any space nuclear electric power system is specifically required by the United Nations and it is reasonable to assume that this will also be the case for any space nuclear propulsion system [1]. This places this technology at a high priority level for any NTP system. The problem with the current control drum systems is that they do not contain enough worth to counteract the reactivity that is inserted during a submersion event. This work has developed a solution to this issue that works by increasing the worth of the drums. This is done through a combination of adding nuclear fuel to the drums and moving them closer into the core. In order to validate the idea of fuel-followed control drums, a low-cost experiment in the Idaho State University (ISU) research reactor was conducted which successfully validated the idea.

II. BACKGROUND

The water submersion criticality accident consists of two events that are important from a neutronic perspective. First, the reactor coolant channels fill with water, which adds a lot of moderation to the core. Secondly the reactor is surrounded by water or wet sand, creating an infinite reflector around the core. The baseline control drums in an NTP core are unable to insert enough negative reactivity into the core to counteract the positive insertions from submersion. The approach taken by USNC to counteract this is to increase the control authority of the drums so that even in the case of a water submersion accident, the drum worth is enough to safely shut down the reactor.

The drum worth is increased through the use of two mechanisms, shown in schematic in Fig. 1. The first mechanism used is the increase of the drum size such that the drum impinges in the core. The larger diameter drum mean that through a full 180 degree rotation, the poison moves further away from the core in terms of perpendicular distance. Thus the larger diameter drum will have a larger worth as compared to a smaller one with the same amount of poison. Additionally, inserting the drum poison into the core as opposed to moving it closer increases drum worth. Secondly, the inside of the drum on the side opposite the poison is fueled. This enables USNC's enhanced control drums to "remove" fuel from the core when they are rotated into shutdown position. With these two features, USNC simulations showed that the drums were able to maintain reactor shutdown with an appropriate margin during a water submersion accident.

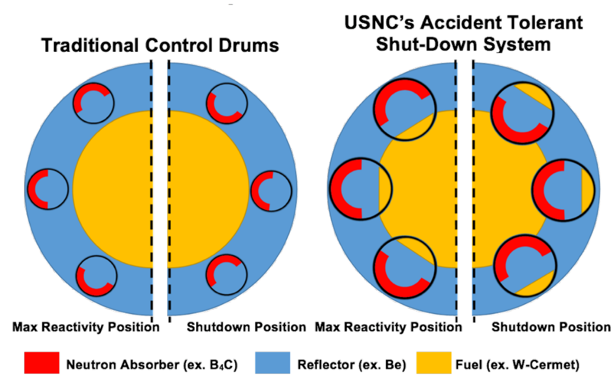

Fig. 1. Schematic showing normal control drums on the left and USNC's submersion safe drums on the right.

In order to take the next step in the development of the drums, USNC planned and executed an experiment to build and test a small scale drum mockup. From a technical perspective, this test proved out the concept of using fuel followed control drums as a way to increase total drum worth. The test results are intended to be used to prove out computer modeling approaches for fuel followed control drums, not to prove out a specific design or designs. From a programmatic perspective, another benefit of this test was that it demonstrated a low-cost path to running small-scale reactor control device tests.

III. EXPERIMENTAL DESIGN AND PROCEDURE

The experiment was sited at Idaho State University using their 5 watt AGN-201m reactor. This reactor was chosen because its low power level and strong safety case make it so that the test can be done quickly and economically and with minimal overhead. Additionally, the small size of the reactor and the lack of other experiments inside it at the time meant that the experiment could control the reactivity of the reactor, allowing for an accurate measurement of the worth of the drums. The AGN-201m has a cylindrical core controlled by two fueled controls rods at its center, a coarse and a fine one. The experiment was started with the control rod almost fully inserted, for a fully cylindrical core. The coarse rod was kept fully inserted at all times during the experiment, with the fine one being slowly removed as the experiment was rotated to more reactive positions.

The experimental hardware (CAD image shown in Fig. 2, assembled experiment shown in Fig. 3) uses beryllium rods [1], boron carbide octagonal rods[2], and uranium dioxide rods[3] held in a tight pattern to simulate a control drum geometry on a smaller scale. The overall length of the drum setup was 134mm (as seen in Figure 3 the fuel rods were allowed to protrude) and the diameter was 102mm. Both the uranium dioxide and beryllium rods were double encapsulated in aluminum as per the relevant reactor safety regulations. The drum was made in two configurations, one fueled configuration with 4 fuel rods, and one with the fuel rods replaced with an equivalent amount of beryllium rods. These configurations represent USNC's enhanced drums and a standard control drum. The drum was then attached to a long aluminum threaded rod with a digital angle measure attached at the end that was used to track the control drum angle. It is important to note that the experimental hardware is simply a mockup of a drum, and is not intended to be a prototype or model of a drum that could be used as a control actuator.

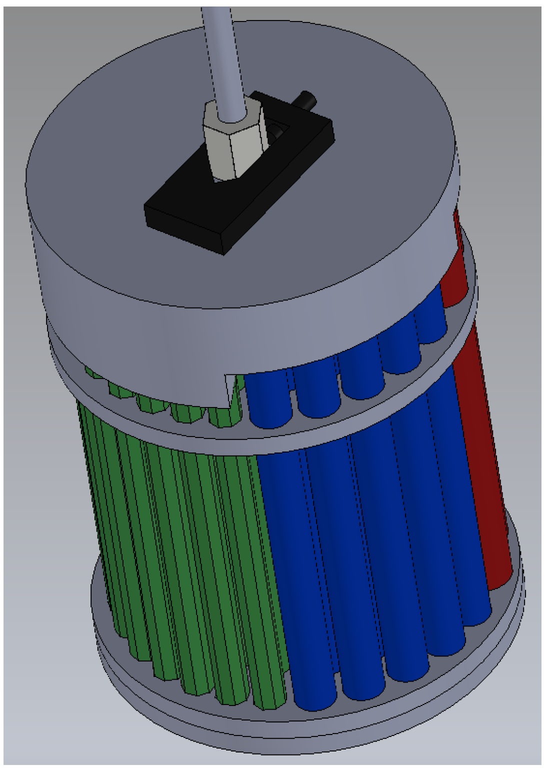

Fig. 2. CAD rendering of the control drum in the fueled configuration. Red is the fuel rods, blue is the beryllium rods, and green represents the Boron Carbide Poison.

After being assembled, the drum was inserted into reactor port 3, shown in Fig. 4. Before beginning the experiment, the drum was run through a series of safety checks to make sure that the drum insertion into the reactor did not render the reactor unable to be controlled via the normal control mechanisms. This was done through first inserting the drum with

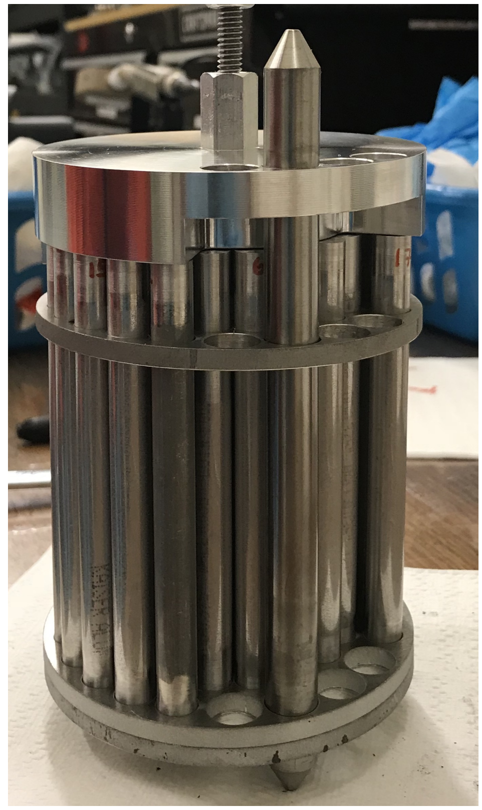

Fig. 3. Picture of the assembled fueled control drum experiment, note only one fueled rod inserted.

only all the poison loaded, then removing the drum, adding a few beryllium rods, reinserting it, and resetting the system to equilibrium. Appropriate waiting periods were used after taking the experiment out of the reactor to allow any activation to cool off. This cycle was repeated until all the beryllium and/or fuel rods were loaded.

The drum was then rotated to its least reactive position, with the poison facing directly inward towards the core, and the reactor was established at critical at a 10 mW power level. This position, with the poison facing horizontally inward, was marked as 0 degrees. All rotations were performed in the clockwise direction from the point of view in Figure 4. The drum was then rotated 30 degrees and the period measured for 10 minutes to get a significant measurement. Afterwards criticality was reestablished at the new power level using the reactor control drums so as not to move the experimental one. This was then repeated another 5 times to sweep the drum through a full 180 degree rotation. If the power ever got above about 2 watts, the reactor was brought back down to 10 mW before continuing the sweep. This commonly occurred once per 180 degree sweep. This procedure was repeated with both the fueled and unfueled drums.

IV. EXPERIMENTAL RESULTS

The results of the experiment showed that, as expected, the worth of the drums was increased by the addition of fuel. Worth in Table I was computed using the difference in reac-

[1]Dim. 109mm length by 9.7mm diameter. Sourced from Materion Inc.
[2]Dim. 100mm length by 7.0mm flat to flat. Sourced from CoorsTek Inc.
[3]Dim. 176mm length by 12.2mm diameter.

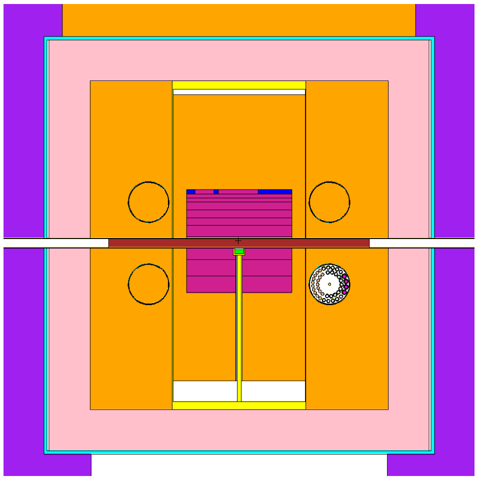

Fig. 4. MCNP diagram of the AGN reactor used for the test, showing the placement of the control drum experiment in the bottom right port. The drum is shown in the 0 degree position (poison facing inward).

TABLE I. Table showing the results of the the experiment as compared to the results of the test prediction calculations.

Case	Experimental Worth [cents]	Calculated Worth [cents]
Fueled	11.9	11.6
Unfueled	9.7	11.3

tivity between the most reactive and least reactive positions of the drum. This shows the worth of the drum as it is rotated into the core. The numerical comparison of the drum worth values is shown in Table I. The difference between the experimental and computed values in the unfueled case is an open question that is currently under investigation. The plot shown in Fig. 5 shows the computation of the drum worth versus the experimental drum worth across the 6 measured positions. For the fueled case, the experiment and the computation agree quite closely. The unfueled line is not shown due to the aforementioned issues with that particular computation. This plot shows that while there are some flaws, the computer modeling techniques used can reproduce the effects of the mockup drum to a useful degree of accuracy, accomplishing the main goal of the experiment.

V. CONCLUSIONS

In conclusion, this experiment proved out the idea of creating fuel-followed drums as a way of increasing the worth of a control drum in support of controlling a water submersion accident. It also That said, this experiment did not test the effect of moving this new drum design closer to the core, which is another important part in the proposed solution to the water submersion criticality problem. One other limitation of this experiment is that because of the low power, no active cooling of the fueled part of the drum is needed. This will not be the case in a full size system, and adds to the overall complexity of the system. That said, this experiment still provides very

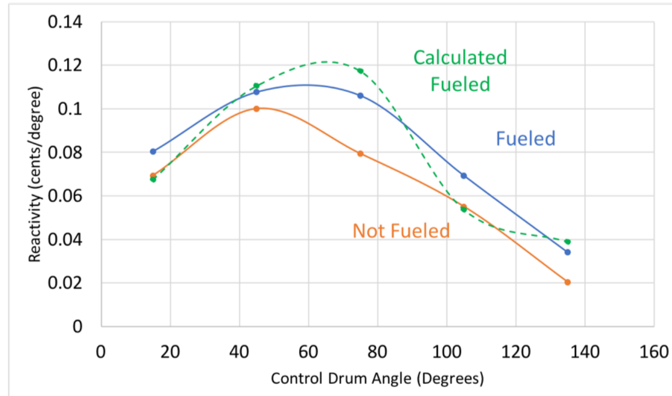

Fig. 5. Plot showing a comparison of the experimental results with the computed results from an MCNP simulation of the drum rotation.

relevant data on a key neutronic aspect of the problem. As far as the experimental setup went, the AGN-201m proved to be a great small scale testbed for the experiment. It enabled relatively quick testing and changes to the experiment as the experiment encountered problems. This enabled a successful demonstration of a pathway to low cost experimentation with reactor control systems on a small scale.

VI. ACKNOWLEDGMENTS

Thanks to Maxwell Daniels and the staff of the ISU AGN-201m for their expertise in running the reactor. Thanks as well to the staff at Howe Industries for their work on the mechanical design of the experiment.

REFERENCES

1. GENERAL ASSEMBLY RESOLUTION 47/68, “Principles Relevant to the Use of Nuclear Power Sources in Outer Space,” (December 1992).