A Controllability Study of TRUMOX Fuel for Load Following Operations in a CANDU-900 Reactor

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Summary

Using a core model of a generic CANDU-900[1] reactor in RFSP-IST[2], load following simulations have been performed to assess the controllability of the reactor due to Xenon transients. Week long load following simulations have been performed with daily power cycles 12 hours in duration. Simulations have shown that Natural Uranium fuel can be safely cycled between 100 and 90% Full Power without adjuster rod movement while TRUMOX fuel can be safely cycled between 100 and 85% Full Power.

1. Introduction

Most nuclear power plants operate as baseload plants due to the difficulties and complexities involved in altering the reactor power output over a short period of time. However, due to the limited ability to store power in the grid, it is economically feasible to explore the maneuverability of nuclear reactors to adjust to the daily power demands of the grid.

The largest factor contributing to the difficulty of altering the power of a reactor comes from Xenon-135, a fission product of Uranium. Xe^{135} has a half-life of 9.2 hours and is a very strong neutron absorbing fission product, thus greatly affecting nuclear reactor operation [1]. During normal operation at a constant power, Xe^{135} is at a stable equilibrium and doesn't present any stability problems, however during changes in reactor power, Xe^{135} concentrations increase or decrease, thus affecting the reactivity of the core.

Another area worth exploring is the use of mixed oxide (MOX) fuels in CANDU reactors. One actinide MOX bundle requires the actinide content of 13.5 regular spent fuel bundles [2] which greatly reduces the amount of nuclear waste to dispose of in addition to reducing the risk of nuclear proliferation.While CANDU reactors have been shown to be able to utilize transuranic mixed oxide (TRUMOX) fuel without physical plant modification, the fuel characteristics of TRUMOX are quite different from the conventional NU fuel being used in CANDU reactors today. The flux distributions in CANDU differ quite drastically for the two fuels due to the different elemental compositions. In addition to flux distributions, reactivity device worths for the control devices (zone controllers, adjuster rods, etc.) differ quite drastically between the two fuel types.

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[1] CANadian Deuterium Uranium (CANDU) is a registered trademark of Atomic Energy of Canada Limited (AECL)
[2] RFSP was developed by AECL, RFSP-IST Version DEV_3-04-05 was used for all simulations

2. Simulation Methodology

The simulations for this controllability study are being performed with RFSP-IST using a generic CANDU-900 model. RFSP (Reactor Fuelling Simulation Program) is a computer program that uses two-group, three dimensional neutron diffusion theory to calculate neutron flux and power distributions to preform fuel management calculations for CANDU reactors [3]. By changing the reactor power at set time intervals, we can simulate load following operations in a CANDU reactor using both the NU and the TRUMOX fuel.

While RFSP has the built in ability to adjust the zone controllers to preform spatial and bulk control, all other reactivity control devices (adjuster rods, control absorber rods, etc.) must be manually moved in and out of the core with commands in the input file. This can present as a problem since a long load following simulation will require many input files to run sequentially to account for power changes and refuelling in addition to the need to move reactivity devices. For this reason, an external Reactor Regulating System (RRS) emulator was developed to move the reactivity devices as well as preform refuelling and power change adjustments autonomously.

The RRS emulator[3] was written in Python and the control logic is based on CANDU-900 logic. Modifications were made to account for the different reactivity worths of the adjuster rods and control absorber rods while using TRUMOX fuel. It should be noted that the adjuster rods are typically withdrawn from the core during normal operation of TRUMOX fuel since there is no need for flux flattening as well as to achieve a higher burnup of the actinide content of the fuel.

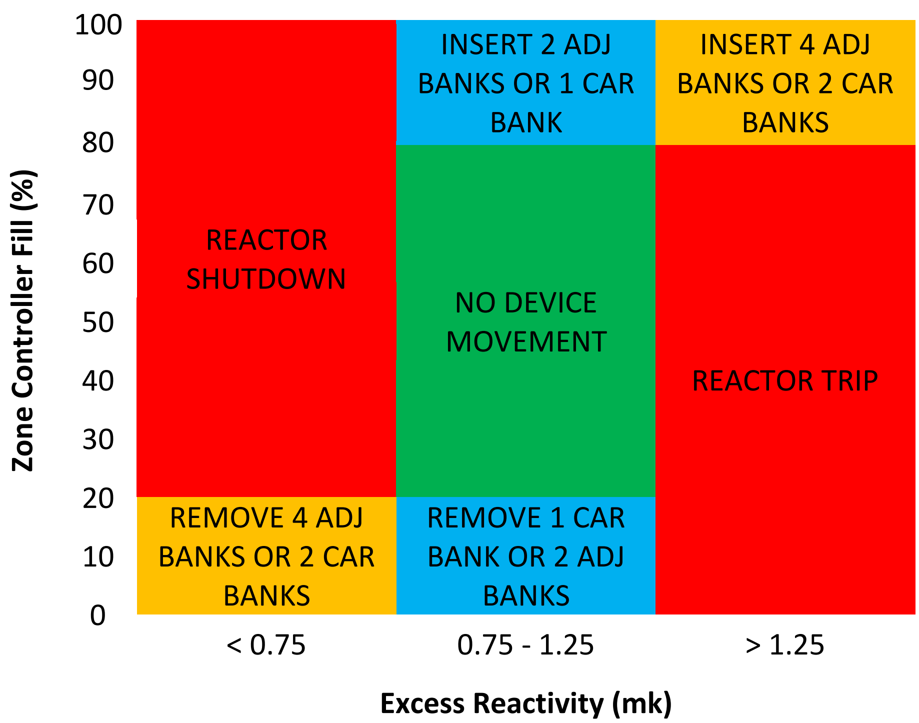

Figure 1 RRS control logic for TRUMOX fuelled core

[3] The RRS emulator was developed by David A. Trudell while at McMaster

There are two types of fuel that are being used in the load following simulations. The natural Uranium (NU) fuel is composed of Uranium Oxide which contains 88.15% Uranium by weight, 0.71% of this being U^{235}. The TRUMOX fuel being used is composed of 96.9 % UO_2 by weight, the other 3.1% being composed of various Actinide Oxides, the fissile ones being isotopes of Plutonium (Pu^{239} and Pu^{241}). Overall, the fissile elements in the TRUMOX fuel (U^{235}, Pu^{239} and Pu^{241}) make up 2.239% of the total weight, compared to only 0.626% fissile material by weight in the NU fuel (U^{235}) [4].

The simulations are designed to follow a realistic load following schedule based on the demands of the power grid. As less power is used in the night as opposed to peak power during the day, current simulations are being performed in 24 hour cycles with power set points being changed every 12 hours. By fluctuating power between 100% full power and various lower power set points, we can determine the limits of reactor stability and control for load following operations.

3. Results

Although simulations are currently on going, preliminary results are suggesting that TRUMOX fuel has an equal if not greater range of controllability and stability compared to NU fuel for load following operation in CANDU. In the diagram below we have a 3-day load following simulation for NU and TRUMOX fuelled cores with refuelling. During this simulation, output power was lowered to 90% FP for 12 hour periods, followed by 12 hours at 100% FP. As can be seen from the chart, there was less variation in the liquid zone controller fills for the TRUMOX fuelled core compared to the NU core. This translates to a larger range of stability for the TRUMOX core without the need for adjuster rod movement compared to the NU core. It shall be noted that this simulation was performed with the adjuster rods in their default locations for normal operation (in-core for NU and withdrawn for TRUMOX).

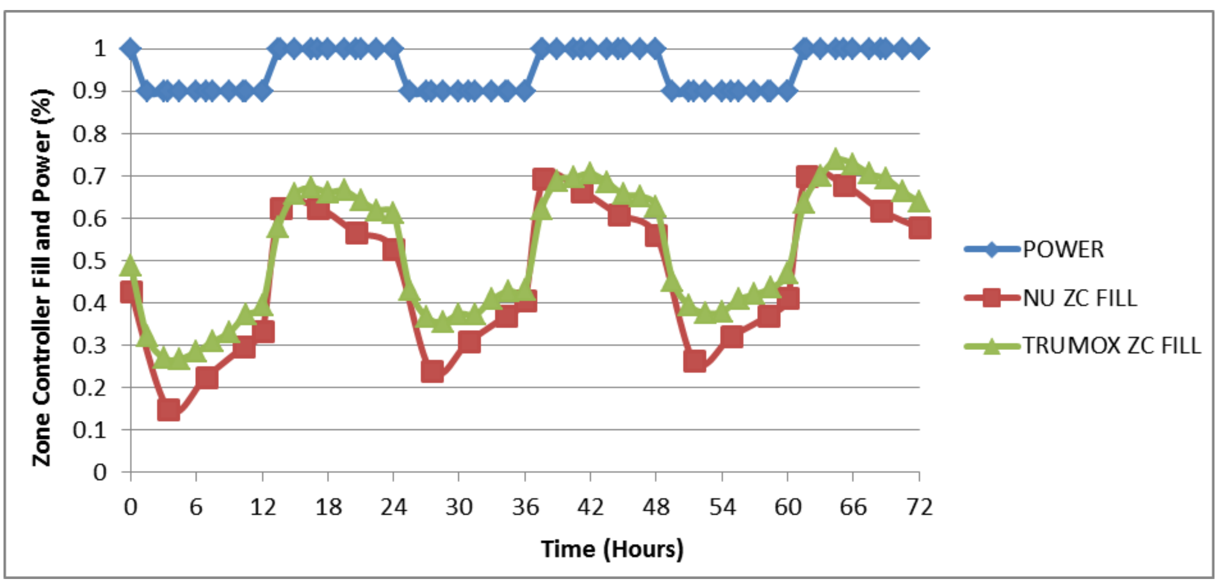

Figure 2 Three day load following cycle

From simulations preformed thus far, the range of controllability for the zone controllers in the TRUMOX core during load following is between 100%FP and 85%FP which keeps the individual zone levels between 15% and 85% full. For the NU fuelled core, the range of controllability for the zone controllers during load following is smaller with the lower limit of 90% FP required to keep the zone fill levels within the 15-85% operational range. The operational limits for the zone controller fill levels has been established to be between 15% and 85% full providing an adequate safety margin. These results are shown in the diagram below.

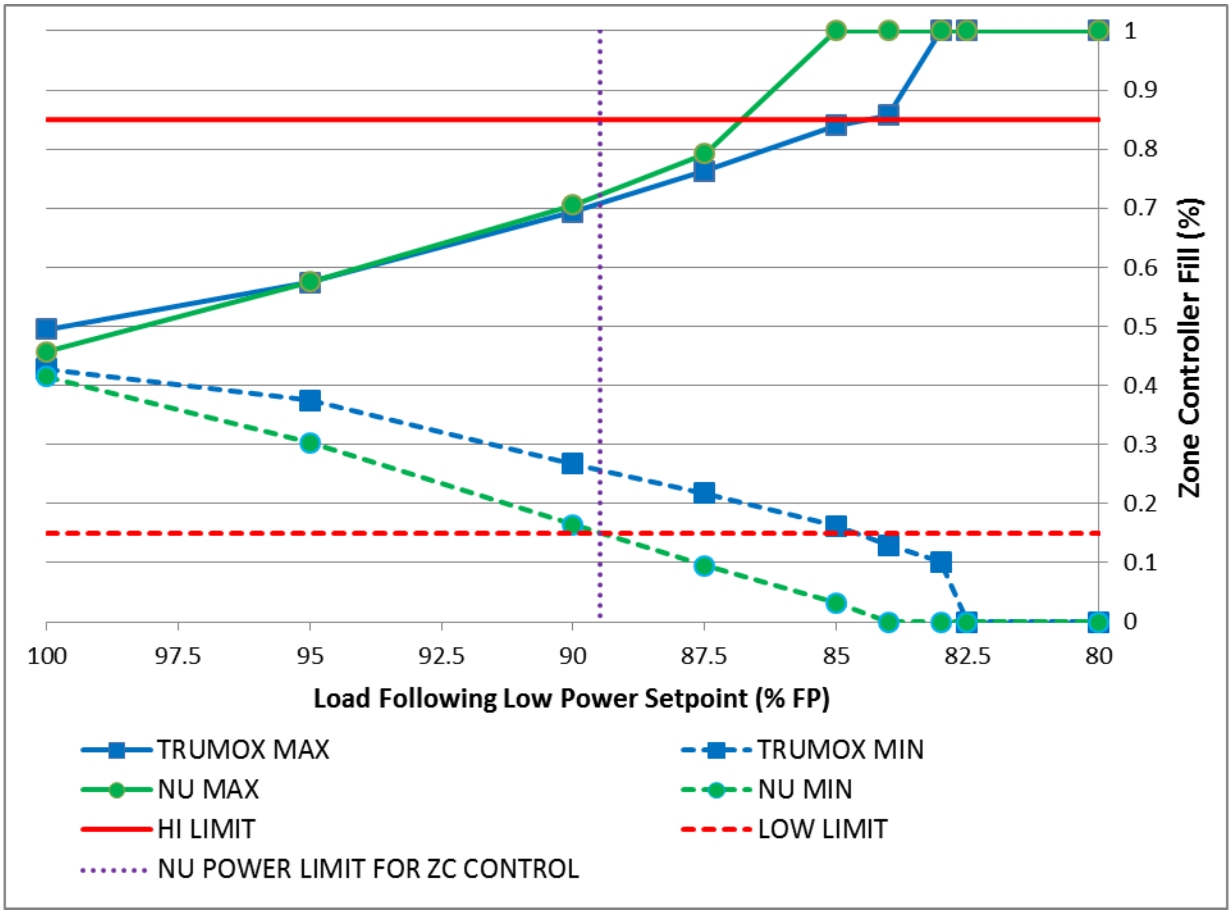

Figure 3 Maximum and minimum zone controller fills during load following

Unlike the TRUMOX core, the NU core has the ability to add reactivity to the core by withdrawing adjuster rods and thus is able to handle larger Xenon transients. However this does affect the axial flux profile and excessive use of the adjusters for load following may complicate day to day fuelling and operations. Load following strategies with power targets of less than 90% FP for an NU fuelled core would require the removal of adjuster rods from the core to prevent the zone controller fills from exceeding the stability limits of between 15% and 85% full.

4. Conclusion

Although results are only preliminary at this point, the data suggests that load following operation of a TRUMOX fuelled core would be just as controllable and stable as that of an NU fuelled core. Power cycles down to 85%FP for TRUMOX and 90%FP for NU appear to be stable without the use of adjuster rod movements or zone controllers being within 15% of their limits. For power cycles down to 90% FP, the zone controller fills for the TRUMOX fuelled core don't exceed 25% of the fill limits while the NU fuelled core is right near the established 15% fill controllability limit. Week long simulations are currently being performed to assess the long term controllability of the Xenon transients due to repeated power cycles, but results are expected to be similar to those that have been performed for shorter durations.

5. Acknowledgements

The financial support of the Natural Sciences and Engineering Research Council (NSERC), the University Network of Excellence in Nuclear Engineering (UNENE) and Nuclear Ontario, an Ontario Research Fund (ORF) research network, is gratefully acknowledged.

6. References

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