1 Final Project Proposal: Point Kinetics

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1.1 Point Kinetics

The dynamics of a nuclear reactors are governed by computationally intractable quantum mechanics tightly coupled with thermalhydraulic responses from the fuel and supporting materials. Consequently, no tool exists to model reactor core state with the fidelity to track individual neutrons as well as thermal responses at the macroscopic fuel level. So, engineers have developed some simplifying assumptions to make the computation more efficacious. One such example that gives quite good results when compared to experimentally measured reactor physics is the point reactor.

The point reactor is not a simplification where all the fuel is considered to be colocated at one point. Rather, it is an assumption that the reactive properties of the fuel are spacially independent. This is a relatively safe assumption for most reactors under slow (normal operational) transients. The equations are reproduced below:

$$\frac{dn}{dt} = \frac{\rho - \beta}{\Lambda} n + \Sigma_i \lambda_i C_i$$
$$\frac{dC_i}{dt} = \frac{\beta_i}{\Lambda} n - \lambda_i C_i$$

Where n is the normalized reactor power (as a function of the number of living netrons in the core), and each C_i is the concentration of the ith precursor group. The remaining values are parameters defining average neutron lifetimes, external reactivity, etc. Each of those parameters is precomputed using some higher fidelity (static) tool and then piped into this model to determine reactor dynamics.

Additionally, reactor engineers have explored coupling thermal feedback into the above equations. A lot struggle with a two-part, lagging solution where neutronics and thermalhydraulics are calculated separately, and their nonlinear interactions are inadequately simplified. There are many documented attempts at compensating for this with adaptive timestepping, JFNK, Backward Euler, etc. Regardless, these equations are still incredibly stiff, and fast implementations are not readily available.

1.2 Improvements and Project Ideas

First, this project will cover an optimized implementation of the primitive point kinetics equations (without thermal feedback). Once this baseline has been acheived, advanced coupling techniques can be added to the solver to include temperature-reactivity feedback. Python implementations with black-box equation solvers do exist, but have bottlenecked research through their slow solution convergence, and lack of reactor generality. It is against these public implementations that the optimized implementation can be benchmarked. Finally, with a working reactor simulator, core responses to various control sequences can be examined. From these data, intelligent controllers can be trained for deployment in commercial power reactors.