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Demonstrating Reactor Autonomous Control Framework using Graphite Exponential Pile

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ABSTRACT:

Advanced autonomous control technology has been utilized in many modern industries, including self-driving vehicles and intelligent robotics. However, most nuclear reactors feature rudimentary levels of autonomous control that rely on zero-dimensional measurements from a single neutron detector channel located outside the active zone. Such an engineering setup typically involves a simple PID controller, which has certain difficulties in addressing non-linearity for reactor control. In recent years, considerable research efforts have been made to explore modern autonomous control framework for nuclear industry. Nevertheless, the community lacks testing capability to produce an engineering demonstration.

The proposed research aims for a first-of-a-kind engineering demonstration of autonomous control on a real nuclear fission system. The MIT Graphite Exponential Plie (MGEP) has been selected as the testbed. Compared to a full-scale research reactor, the pile features an inherently safe subcritical configuration, and more importantly, a lenient regulatory approval process. The plan is to fabricate a pair of control rods and connect them to computer-controlled actuators. One rod will serve as the “unknown” source of the initiating event; whereas the other will be fed with the control signal and complete the feedback motion. Multiple ^{3}He detectors will be inserted in the graphite stringers. These locations are within the active zone (in contrast to the reflector region for most reactor zero-dimensional channels) and will be sufficiently sensitive to spatially dependent perturbations. The measurement data will be transferred to a central cluster, which is capable of performing high-fidelity predictions as well as making decisions in real-time.

Autonomous control is a key technology for the Special Purpose Reactors R&D. It supports the reactor operation with enhanced safety and reliability under normal and off-normal (accident) conditions. More importantly, such technology could help in reducing the operational cost. The above demonstration plan primarily involves three technical challenges that require in-depth research investigations: 1) high-fidelity prediction with real-time response capability, 2) spatially dependent reactor kinetics for dynamic system perturbations, and 3) fault diagnosis and tolerant control under off-normal operating conditions. Overall, the established facility at MGEP, as one of the major deliverables in this research project, will become a prototype for nuclear system autonomous control. It can also serve as a testbed for cutting-edge technologies such as advanced instrumentation, novel surrogate models, and modern control approaches.