HIGH-FLUX REAL-TIME ADVANCED SENSORS FOR DYNAMIC CORE-SYSTEMS TO IMPROVE SECURITY, SAFETY AND OPERATIONS IN ADVANCED REACTOR DESIGNS

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Program: Advanced Reactor Safeguards

Mission Relevance and Importance: Advanced reactor designs that propose online (re)fueling such as, X-energy's Xe-100, Kairos Power's fluoride salt-cooled high-temperature reactor (KP-FHR), and Southern Company &Terra Power's molten chloride reactor experiment (MCRE), are rapidly being developed for demonstration in the near-term. For instance, Xe-100 is a winner of the Advanced Reactor Demonstration Program (ARDP) by the Department of Energy (DOE) and has been awarded $80 million in government funding for reactor demonstration within 5 years. The Nuclear Regulatory Commission (NRC) is currently engaged in several pre-application activities with X-energy LLC and Kairos Power. Similarly, KP-FHR and MCRE have been supported by DOE-ARDP's Risk Reduction for Future Demonstration Projects program for demonstration within 10-14 years.

Some of these reactors are pebble-bed-reactors (PBR) where fuel in solid pebbles flow in and out of the fuel, one at a time, giving a short amount of time for measurement after cooling (10 s). Others contain fuel dissolved in the coolant, such as, most molten salt reactors (MSR). Both, PBRs and MSRs are different from existing light water reactors (LWR) because:

i. These advanced designs comprise of truly dynamic cores where fresh fuel or irradiated fuel constantly moves in and out of the reactor vessel;
ii. Their enrichment levels are typically greater than 10% ^{235}U, which moves them from category III to category II for materials control and accounting (MC&A) as per the NRC;
iii. They are candidates for additional scrutiny for design basis threat (DBT) from theft/diversion, whereas, existing LWRs are only required to meet DBT from sabotage.

Scope and Objectives: In this work, advanced sensor system prototypes will be developed for advanced reactors designs with online refueling and moving fuel capabilities, such as, pebble-bed-reactors (PBR) and molten-salt reactors (MSR). This system will allow burnup and special nuclear material (SNM) measurements of fuel during loading and unloading from with high precision which will improve reactor safety, nuclear safety, and operations. These developments will be shared with nuclear engineering students using a virtual reality module and will be developed by students from diverse backgrounds. Our objectives are to:

Objective 1. Develop a radiation tolerant advanced sensing system capable of performing *on-the-fly* fast gamma-ray measurements in *high-flux environment* for burnup determination;

Objective 2. Develop an enrichment detector using a fast neutron active interrogation method for pebbles in *high-flux environment* to determine fissile and special nuclear material concentration;

Objective 3. Understand and measure detector precision deployed outside molten-salt loops, and characterize performance metrics, such as, time taken to detect changes in fuel concentration, impact of molten salt flow-rate and temperature.

Objective 4. Develop a neutron imager for MSR hold-up measurements of uranium in pipe-bends for varying flow-rates, temperature, and uranium concentration in a fluorine-based salt; and

Objective 5. Develop an Android/iOS virtual and augmented reality (VR/AR) education platform for undergraduate and graduate nuclear engineering students with training for minority students.