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Establishing fusion reactor control scenarios based on information from a reduced set of nuclear-compatible diagnostics

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Existing magnetically confined plasma devices benefit from an extensive array of diagnostics, commensurate with the R&D function of these plasma devices. While increased diagnostic coverage, and access to information relevant to the plasma, first-wall components, and plasma-material interactions is always desired, the harsh nuclear environment of future fusion reactors is more likely to result in the situation where operators (AI or human)1,2 will have access to less information, compared to what is currently measurable in existing pathway research devices. Future fusion reactors will be industrial, energy-production devices, and operate in a functionally reduced area of parameter space, which may be consistent with the limited information that will be available. Stated as a question: what is the least/critical amount of information that industrial fusion reactors will need to operate robustly and safely? And consequently, what nuclear compatible diagnostic systems are needed to make the measurements that will provide that information?
Answering these questions requires demonstration of a burning plasma, which is within the goals of the ITER Research Program3 and devices planned by private industry. While ITER aspires to achieve a sustained Q=10 fusion plasma, it will also have a diagnostic set that is similar to that found on R&D devices. Moreover, diagnostic technology will evolve as a result of experience in the nuclear environment of ITER. And data analysis techniques (ML, integrated modeling, etc.) will redefine what information can be derived from the available set of physical measurements. A successful US fusion pilot plant (FPP) design will need to incorporate knowledge gained from ITER in these areas: 1) nuclear compatible diagnostic designs, 2) integrated modeling that can extract critical, indirect information from direct measurements using those diagnostics, and 3) reactor control scenarios that utilize that information to operate robustly and safely in a specific configuration for fusion energy production.
This presentation will describe the efforts at ORNL that endeavor to address the research that is needed in these areas for long-pulse fusion plasma devices.

1 A. Katwala, "DeepMind has Trained an AI to Control Nuclear Fusion", WIRED, Feb 16, 2022. https://www.wired.com/story/deepmind-ai-nuclear-fusion/
2 J. Degrave, F. Felici, J. Buchli, et al. "Magnetic control of tokamak plasmas through deep reinforcement learning."Nature 602, 414–419 (2022). https://doi.org/10.1038/s41586-021-04301-9
3 ITER Organization, "ITER Research Plan within the Staged Approach (Level III –Provisional Version),"ITR-18-003, Sep 17, 2018.

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