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Isotopic Fuel Tailoring as Actuator for Burn Control in Tokamak Reactors

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The regulation of the amount of fusion power produced by future reactors will require precise control over the plasma density and temperature. Therefore, the control of the core-plasma kinetic state, usually referred to as burn control, arises as one of the most fundamental problems in nuclear fusion and will be critical to the success of burning-plasma devices like ITER. Due to the nonlinear coupled dynamics of the plasma, feedback control of the burn condition will be necessary to avoid undesirable transient performance and to respond to changes in plasma confinement, impurity content, or operation conditions, which could significantly alter the plasma burn. A well-design burn controller should be able not only to achieve tight regulation around a desired operating point by rejecting perturbations in temperature and density but also to drive the plasma from one operating point to another during the burning plasma mode (e.g., different Q or fusion power). Moreover, the controller should be capable of accessing to and exiting from the burning plasma mode. The isotopic fuel mix in the plasma is a critical reactor parameter as it has a major influence on the fusion power produced. Differences in deuterium (D) and tritium (T) transport and fueling efficiency, as well as perturbation introduced by other sources of particles not under the burn controller such as NBIs, may lead to a non-optimal fuel mix in the core even with an optimal 50:50 DT injection. Additionally, depending on the operating scenario, it may be desirable or even necessary to operate at a lower tritium fraction or vary the tritium fraction during operation. The regulation of the tritium ratio is possible thanks to a method of fueling referred to as isotopic tailoring, in which the relative mix of deuterium and tritium injected by the fueling system is varied in real-time. The pellet injection system for ITER will include two separate injectors—one with pellets made of primarily deuterium and the other with pellets made primarily of tritium. A gas injection system will be used to supply deuterium at the edge of the plasma. Together, these systems will allow for fuel mix regulation. The role of isotopic tailoring as an actuator for burn control will be discussed within an overall control scheme that may also include auxiliary power, fueling, impurity injection, and magnetic coils. The impact of recycling on the ability of changing the fuel mix via isotopic tailoring will also be discussed. Moreover, the accessibility of steady-state, Q=10, operation points in ITER will be analyzed for different particle recycling and confinement conditions as a function of the tritium concentration in the fueling lines, and methods will be proposed to robustify the control of the burn condition against unmeasurable variations over time (biases and drifts) in the tritium concentration of the fueling lines.

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