Enabling a Low-Recycling Regime with Novel Divertor Design: Concept, Experiments and Simulations

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Fusion reactor operation in a low recycling regime has many possible advantages over the standard reactor designs with high recycling. To achieve low recycling, a reactor would need a divertor covered with lithium without evaporation. Given the reactor heat fluxes, this can only be achieved with a recirculating flowing liquid metal (LM) divertor. The major studies in the field show that lithium flow over the divertor requires thick (>m/s) velocity flows. Moreover, in these designs, the separation of tritium embedded in lithium is solved by pumping the entire liquid mix out of the reactor for distillation, which requires long piping. Under these conditions, the lithium inventory easily exceeds tonnes and the tritium distillation purity requirement becomes excessive, introducing many engineering challenges that rightly yield skepticism about the feasibility of such a system. These challenges can be broadly listed as: 1) Safety issues related to a high lithium inventory; 2) The power requirement for pumping of the lithium against MHD drag; 3) The stability of open channel LM flow in high speeds under MHD forces; and 4) Separation of tritium from LM.

In this presentation, we introduce the concept of “divertorlets” and in situ tritium concentration enhancement and then show how these concepts can alleviate the aforementioned issues by reducing the velocity to <<m/s, the inventory to <100 kg, and the power requirement to around 1 MW. Experimental results of these systems on Liquid Metal eXperiment (LMX) at Princeton Plasma Physics Laboratory and MHD numerical simulations are then presented. Divertorlets emerged out of the multi-year effort of our group in LM behavior control by running electric current in the LM under different divertor setups [1-5]. We divide the flow along the divertor into many uniquely shaped small divertorlets, which allows for non-evaporative flow at much lower velocities with a separate cooling system. The LM is circulated with Lorentz force achieved via novel electric current flow setups (and the magnetic field already available in the reactor) with negligible power requirements compared to the power plant balance. This setup enhances the stability of LM flow and reduces the lithium inventory substantially in the divertor. In addition, an even larger part of the lithium inventory and power requirement is due to the long piping of the LM out of the reactor for tritium separation. Tritium inside liquid lithium forms LiT crystals with twice the density of lithium when slightly cooled. A few very small electromagnetic centrifuges with no moving parts that employ the magnetic field in the reactor with minimal currents concentrate the LiT to very high levels. Only this concentrate is piped out for separation with minimal inventory and pumping power. Even though the challenges of a flowing lithium system are substantial, the novel approaches described in this presentation may reduce the engineering issues to reasonable levels and enable exploration of the advantages that a low-recycling regime brings to plasma performance and fusion reactor design.

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