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The NSTX-U program on integration of attractive core operation with high heat flux exhaust

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The NSTX-U device is making good progress in a device upgrade that will enable 10 MW of neutral beam heating and 4 MW of 30 MHz fast wave heating with a design plasma current and toroidal field up to 2 MA and 1 T respectively, for a 5 sec pulse length [J.E. Menard *et al.*, *Nucl. Fusion* **52** (2012) 083015]. At full performance, NSTX-U will be able to produce surface normal heat fluxes above 90 MW/m^2 in certain equilibria and assuming Eich/Goldston scaling of the scrape-off layer power decay length. This will make NSTX-U a great technology testbed for advanced plasma-facing materials, such as liquid lithium (Li), and an excellent scientific testbed for optimized core performance with simultaneously high power exhaust.

Three main thrusts for the NSTX-U scientific program include core turbulence and transport, integrated scenario development, and innovative and conventional power and particle handling techniques. With an increasing emphasis on liquid Li technology, NSTX-U should be able to access lower collisionality and potentially much higher energy confinement than with boron wall coatings [S.M. Kaye *et al.*, *Nucl. Fusion* **53** (2013) 063005].

To enable a technology and science testbed emphasis, NSTX-U will in the future transition from carbon PFCs to high-Z PFCs which will serve as a substrate for liquid Li. A design to flow hot He through the cooling lines behind the plasma-facing components (PFCs) to heat Li above the melting point is being initiated. Example systems to be tested include the Li vapor box [R.J. Goldston, R. Myers, and J. Schwartz, *Phys. Scripta* **T167** (2016) 014007], in which Li vapor supplied either from external evaporation into the divertor leg or evaporation directly from the divertor target is used to radiate reduce heat fluxes from ~ 100 MW/m^2 down to 5-10 MW/m^2. Here the Li can be constrained near the divertor strike point by hydrogenic flows. Figure 1a shows a Li vapor box design for NSTX-U that is predicted to reduce the peak heat flux from > 90 MW/m^2 to < 10 MW/m^2 [E. Emdee and R.J. Goldston, *Nucl. Fusion* **63** (2023) 096003]. Similar results can be obtained with a Capillary Porous System with Flow (CPSF) [A. Khodak and R. Maingi, *Phys. Plasmas* **29** (2021) 072505] with a Li flow speed of 4 m/s (Figure 1b). Electrical current flowing vertically into the CPSF drives the required radial liquid Li flow. A CPSF system can be used as an evaporator for a vapor box, creating a synergistic system where Li evaporates directly into the divertor high heat flux region [E. Emdee *et al., Nucl. Fusion* **64** (2024) 086047; A. Khodak *et al.*, *IEEE Trans. Plasma Sci.* (2024) at press]. In addition, a "divertorlets" system (Figure 1d) in which jxB forces drive Li flow in a row of vertical cascades instead of flowing radially, could also be tested [F. Saenz *et al.*, *Nucl. Fusion* **62** (2022) 086008]. Due to the shorter exposure time to the plasma in each cascade, the flow required to exhaust the incident heat flux can be reduced by about 90%, compared with fast flow systems. Finally concepts for a free-flow Li divertor can also be explored, as can first wall components for sustaining an absorbing surface and entraining deposited Li, such as the FLiLi [L.E. Zacharov *et al.*, *IEEE Trans. Plasma Sci.* **48** (2020) 1849; Q.X. Yang *et al.*, *Fusion Eng. Des.* **124** (2017) 179] and LiMIT concepts [D.N. Ruzic *et al.*, *Nucl. Fusion* **51** (2011) 102002], both of which have been studied in the EAST tokamak [J.S. Hu *et al.*, *Nucl. Mater. Energy* **18** (2019) 99; G.Z. Zuo *et al.*, *Nucl. Mater. Energy* **33** (2022) 101263].

The designs and program are informed by recent experiments in LTX-β that have extended the duration, performance, and diagnosis of the flat-temperature profile, low-recycling regime first observed in LTX, in which energy confinement in LTX-β can exceed Ohmic and H-mode scaling by factors of 2–4 [D.P. Boyle *et al.*, *Nucl. Fusion* **63** (2023) 056020]. Designs of Lithium vapor box and fast flowing Li PFCs will be presented, along with the envisioned core-edge integration program, and the status of the in-progress NSTX-U recovery.

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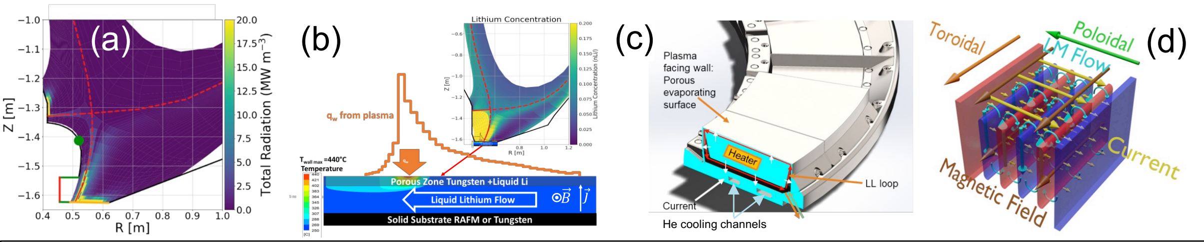

Fig. 1: Liquid metal divertor concepts that may be tested in NSTX-U: (a) vapor box, (b) vapor box with CPSF evaporator, (c) CPSF concept in NSTX-U tile envelope; (d) divertorlets.