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Fusion reactor designs with 'long legs' show promise

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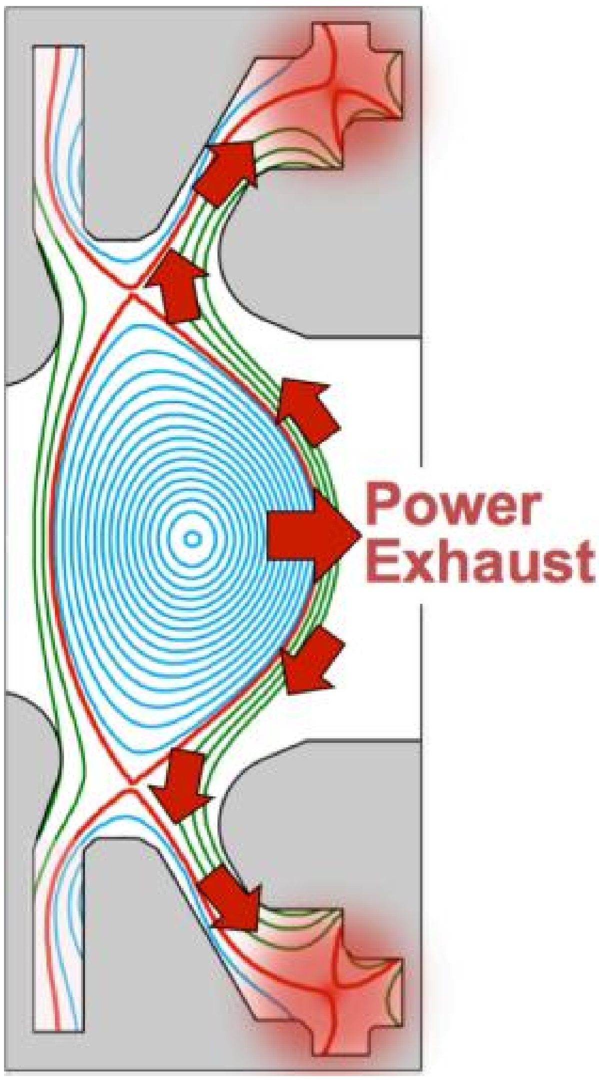


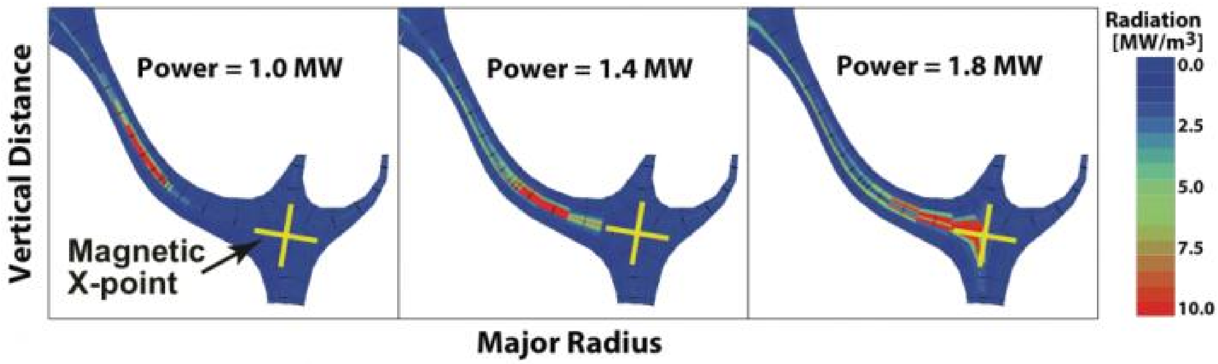
Cross-section of a tokamak plasma, with cylindrical symmetry axis at left side, showing a potential solution to the fusion power exhaust challenge: (1) top-bottom symmetric core plasma, defined by magnetic x-points and (2) specially designed, long-leg exhaust channels to dissipate the power via radiation, interaction with gas and a secondary magnetic x-point in the leg. Credit: MIT

Magnetic fusion is all about managing the interface between hot plasma and ordinary materials. The strong magnetic field in a tokamak—the vessel used in this fusion approach—is a very effective insulator; it is able to reduce the plasma temperature by a factor of 100, from over 100 million degrees Celsius at the center to "only" 1 million degrees at the edge. However, this is not low enough. Therefore, it's the job of the boundary plasma to reduce the temperature by another factor of 100 before it contacts the wall.

Unfortunately, this boundary layer tends to be very thin, focusing the power onto a small area. Power plants are projected to have exhaust power densities greater than 100 times the surface of the sun and a factor of 10 higher than present experiments, far exceeding the limits that material surfaces can handle. Moreover, extreme levels of power exhaust can arise abruptly, presenting a very difficult control challenge.

Fortunately, researchers are finding now that long-leg plasma exhaust channels (or divertors) may provide the solution needed for fusion power plants. These make clever use of x-points: special locations where the magnetic field topology is able to expand and redirect the plasma exhaust flow into multiple channels.

First, a top-bottom symmetric core plasma is created, defined by two primary magnetic x-points. In this configuration, experiments indicate that approximately 90 percent of the heat exits the core plasma on the outer half of the device along the two outer legs [Abstract 1]. Extending the length of the outer channels and embedding secondary x-points in them will then enhance power exhaust handling. In addition, this configuration promotes the build up of high gas pressures in the legs.



Simulation of power exhaust and radiation in a long-leg plasma exhaust channel that contains a secondary magnetic x-point. Plasma heat exhaust is fully accommodated by a passively-stable radiating layer, keeping the hot plasma from coming into contact with material walls. As exhaust power is increased, the location of radiating layer moves down the leg. The embedded magnetic x-point acts as a backstop to handle the most intense power levels. Credit: MIT

A recent assessment of the power handling capabilities of long-leg divertor configurations was performed and compared to conventional configurations using an edge plasma simulation code developed at Lawrence Livermore National Laboratory that could handle magnetic x-points in the leg [Abstract 2]. The combined effects of long-leg magnetic geometry, enhanced gas-plasma interactions and the presence of a secondary magnetic x-point are found to increase the peak power handling ability by up to a factor of 10 compared to conventional divertors—an unprecedented result.

Most importantly, the secondary x-point produces a stable radiating layer that fully accommodates the plasma heat exhaust, eliminating hot plasma contact on the material walls even when the plasma exhaust power is varied by a factor of 10. This makes the power exhaust easy to control.

As power is varied, the location of the radiation layer simply moves up or down the leg as needed to match the incoming power (Figure 2). The radiating layer stays in the divertor leg and does not impact the primary x-points, which would degrade core plasma performance.

These results, combined with others, are contributing to planning for next step experimental devices that would test power exhaust ideas at reactor-level power densities [Abstract 3].

More information: meetings.aps.org/Meeting/DPP16/Session/NO4.14
meetings.aps.org/Meeting/DPP16/Session/JI3.3
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