A Major Step for Fusion Energy

AN R&D 100 Award-winning technology will help the world move away from a fossil-fuel-based electricity supply. Sustaining natural resources, reducing carbon emissions, and stabilizing greenhouse gas levels are essential in the face of global warming.

One of the most attractive solutions for humankind's future energy needs is controlled thermonuclear fusion. Controlled fusion with magnetically confined plasmas in a doughnut-shaped tokamak is actively being pursued by countries worldwide to bring this energy source to fruition.

However, one problem that has yet to be resolved is the safe dissipation of the power exhaust from the hot plasma in a commercial tokamak reactor: hundreds of megawatts of power are released in the form of charged particles that must be accommodated in the reactor chamber. The general approach to solving this problem was identified decades ago and consists of creating a magnetically guided exhaust channel that diverts the plasma from the walls of the chamber and directs it to thermally and mechanically hardened and actively cooled absorbers. This component of a tokamak reactor is called the "divertor."

The design of a standard divertor is sufficient for the lower power densities of existing experimental tokamak research facilities. However, despite significant effort, a steady-state, practical method has not been found to spread the heat over a large enough surface to reduce the power density to a manageable level for a future commercial reactor. The characteristic power load would be about 100 megawatts per square meter—more than is generated on the surface of the Sun. No materials could survive the exposure to such heat fluxes.

> *". . . the heat flux to the material [divertor plates] was reduced by an order of magnitude . . . the core plasma behavior was not influenced by the snowflake divertor at the edge [a critical result because in fusion plasmas the edge can strongly affect behavior in the core], and . . . harmful impurity concentration in the core was reduced by the snowflake.*
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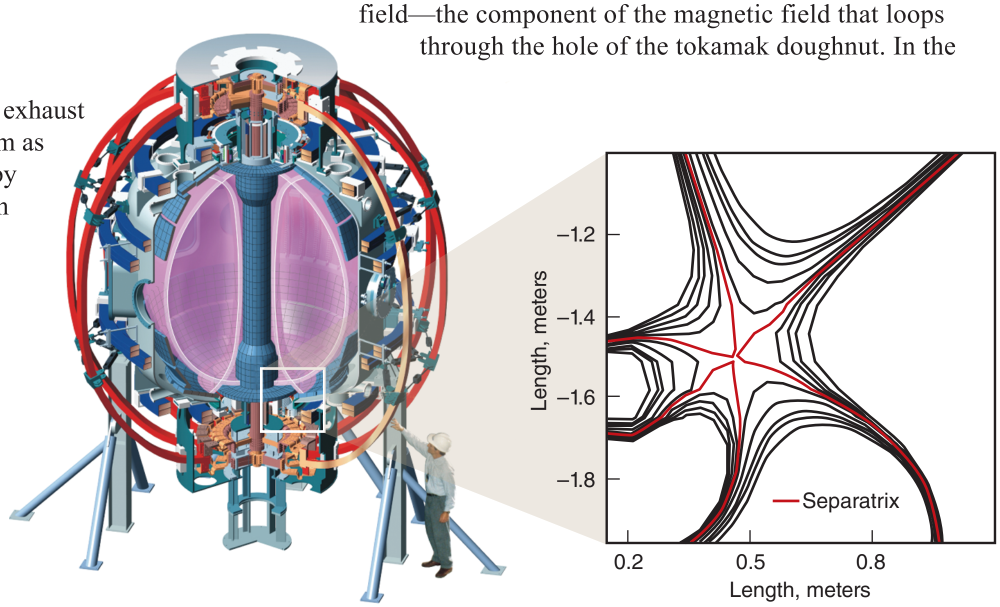
> **—S. Prager, Director**
> Princeton Plasma Physics Laboratory

A Simple Solution

Various efforts are under way to handle the exhaust blast. But none addresses this daunting problem as well as the solution discovered by a team led by Livermore physicist Dmitri Ryutov. In addition to scientists from Livermore, Ryutov's team includes researchers at Princeton Plasma Physics Laboratory (PPPL), the École Polytechnique Fédérale de Lausanne Center for Research in Plasma Physics (CRPP) in Switzerland, and Oak Ridge National Laboratory.

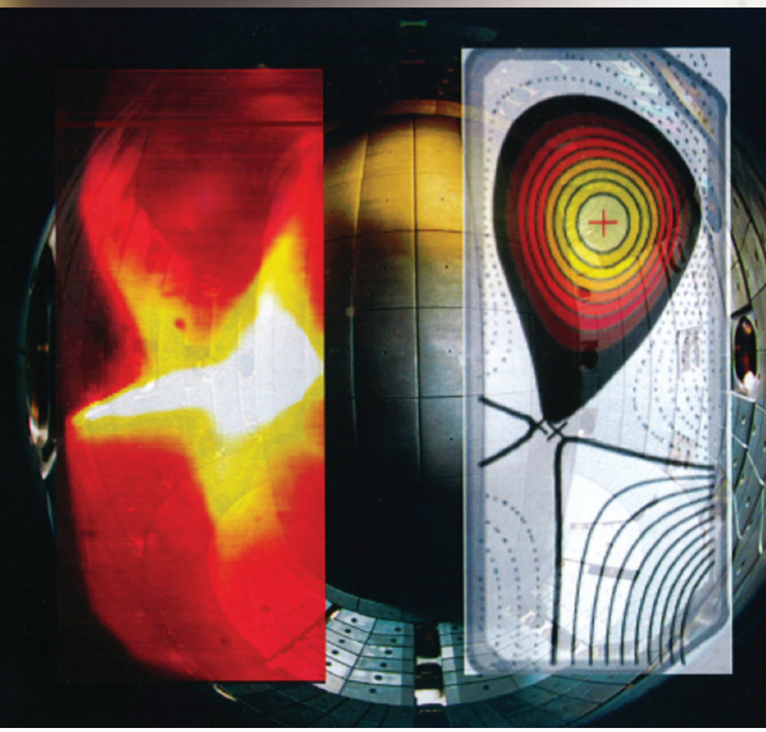
"Our 'snowflake' power divertor uses a newly discovered configuration of the divertor magnetic field," says Ryutov. This configuration spreads out the magnetic field in a shape reminiscent of a snowflake. The magnetic field lines spread the exhaust over a larger area, effectively reducing the heat flux by a factor of 10 to a manageable 10 megawatts per square meter.

The distribution and magnitude of the heat fluxes in the divertor are determined by the shape of the poloidal magnetic field—the component of the magnetic field that loops through the hole of the tokamak doughnut. In the



A "snowflake" power divertor is installed at the bottom of the tokamak at the National Spherical Torus Experiment at Princeton Plasma Physics Laboratory (PPPL). (inset) A snowflake magnetic configuration shows the characteristic hexagonal shape of the separatrix, which is the singular magnetic field line that determines the overall field geometry.

Livermore development team for the snowflake power divertor: (from left) Thomas Rognlien, Maxim Umansky, Dmitri Ryutov, and Ronald Cohen; (inset) Livermore team member Vsevolod Soukhanovskii. (Not shown: Stefano Coda, Basil Duval, Jean-Marc Moret, and Francesco Piras of CRPP; Egemen Kolemen and Jonathan Menard of PPPL; and Joon-Wook Ahn of Oak Ridge National Laboratory.)



A vertical cross section of the divertor region of the experimental tokamak at the École Polytechnique Fédérale de Lausanne Center for Research in Plasma Physics (CRPP) in Switzerland shows (left) the snowflake-shaped spreading of the exhaust plasma and (right) its magnetic field lines on the background of the confining vessel.

new configuration, a large zone of a very weak poloidal magnetic field is created in the divertor. This zone induces a large flaring of the plasma flow and dramatically decreases the heat fluxes in the divertor.

"The redistribution is technologically simple but remained unnoticed prior to our discovery and subsequent publications," says Ryutov. The figure on p. 4 illustrates the snowflake power divertor at work on the National Spherical Torus Experiment at PPPL. This effort was led by Livermore's Vsevolod Soukhanovskii, who is on a long-term assignment at PPPL.

The snowflake divertor also has been tested on an experimental tokamak at CRPP. (See the figure above.) The tokamaks at PPPL and CRPP have quite different plasma shapes, but in both of them, the confinement of the hot core plasma remained good when the snowflake configuration was achieved. In both facilities, the control systems allowed experimentalists to maintain the plasma configuration close to the snowflake shape for extended periods. Says Ryutov, "We are pleased that the snowflake configuration has proven to be so flexible."

Wide Acceptance

The beauty of the snowflake power divertor is that it does not require any expensive or complex changes to the overall configuration of a tokamak. Nor does it call for significant changes in the already well-developed scenarios for operation of a commercial tokamak.

This exciting technology has been well received. Several new experimental tokamak facilities plan to install the snowflake power divertor. One facility is an upgraded version of the existing experimental facility at PPPL, whose higher magnetic current and power will serve as a testing ground for fusion reactors still in the planning phase. Other tokamaks that will incorporate the snowflake power divertor are being designed in Italy and China.

—Katie Walter

Key Words: fusion energy, R&D 100 Award, snowflake power divertor, tokamak.

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