New simulations confirm efficiency of waste-removal process in plasma device

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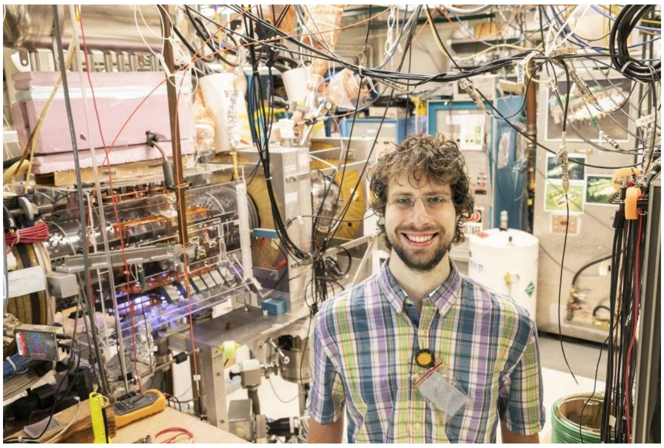

Graduate student Eugene Evans in front of PPPL's field-reversed configuration device. Credit: Elle Starkman

Just as fire produces ash, the combining of light elements in fusion reactions can produce material that eventually interferes with those same reactions. Now, scientists at the U.S. Department of Energy's (DOE) Princeton Plasma Physics Laboratory (PPPL) have found evidence suggesting that a process could remove the unwanted material and make the fusion processes more efficient within a type of fusion facility known as a field-reversed configuration (FRC) device.

Within all fusion machines, electrons and atomic nuclei, or ions, swirl in a kind of soup known as plasma. During the fusion process proposed for an FRC, the nuclei of deuterium and helium-3, hydrogen and helium atoms with one neutron each, combine and in the process release large amounts of energy. Physicists are currently studying how best to trap the fuel particles within magnetic fields to maximize the number of fusion reactions while simultaneously preventing damage to the machine's walls from energetic particles that escape the magnetic bottle. The goal for any fusion energy experiment is to mimic on Earth the fusion process within the sun and stars to produce virtually boundless energy.

FRC machines differ from doughnut-shaped tokamaks and twisty, cruller-like stellarators that are currently the go-to designs for fusion facilities around the world. FRCs confine plasma at higher temperatures than tokamaks but require only one set of electromagnetic coils shaped in simple circles. In addition, instead of the circular containers in tokamaks and stellarators, FRCs create fields extending between two endpoints that are almost linear, making a low-power FRC device potentially suitable as a fusion-powered rocket engine for spacecraft propulsion.

Recently, however, new research at PPPL has hinted that, with the right design, FRCs could produce stable plasmas. And because the PPPL variant of the FRC is forecast to produce far fewer high-energy neutrons than tokamaks do, that type of FRC reactor would require less shielding to protect internal and surrounding equipment.

The research began five years ago when undergraduate student Matt Chu-Cheong and Samuel Cohen, principal investigator of the Laboratory's FRC experiments, started thinking about how the ash particles created in hypothetical future FRC reactors could be removed. Their calculations suggested that the unwanted particles would slowly migrate to the "scrape-off layer" that connects the plasma to the material surfaces of the vessel. Passing in and out of this relatively cool region, the particles would lose energy and slow down, much as spacecraft can reduce speed by dipping into the atmosphere of a planet. Eventually, the particles would lose enough speed to remain in the scrape-off layer and be funneled to an exhaust system that removed them from the plasma.

The particles would automatically enter the scrape-off layer because of their high energy. "This is a neat way to remove fusion products from the core and prevent them from building up," said Evans, a lead author of a paper in Physics of Plasmas that rigorously examined the processes.

Evans and Cohen feared, however, that if the electrons in the scrape-off layer were too cool, they might not move quickly enough to trap the ions and cause their removal. "If the electrons are moving too slowly," Cohen said, "they are not able to keep up with the fast ions and the ions don't feel much of a dragging force."

Evans formulated a hypothesis and then performed detailed simulations on high-performance computers at the National Energy Research Scientific Computing Center (NERSC), a DOE Office of Science User Facility at Lawrence Berkeley National Laboratory. The simulations, which factored in the magnetic fields of the hypothetical FRC machine and the effects of the cold electrons, produced data suggesting that ash particles in an FRC reactor would be removed from the plasma, though slower than the theories created in 1960 predicted. Nevertheless, the predicted removal rate was enough to exhaust the ash ions and keep them from interfering with fusion reactions in future FRC plasmas.

The results were extremely encouraging. "My main reaction was relief that the simulations worked out, that our previous estimates were okay, and that at least in these simulations we saw no reason why this process wouldn't work," Evans said. "In other words, so far, so good."

Provided by US Department of Energy

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