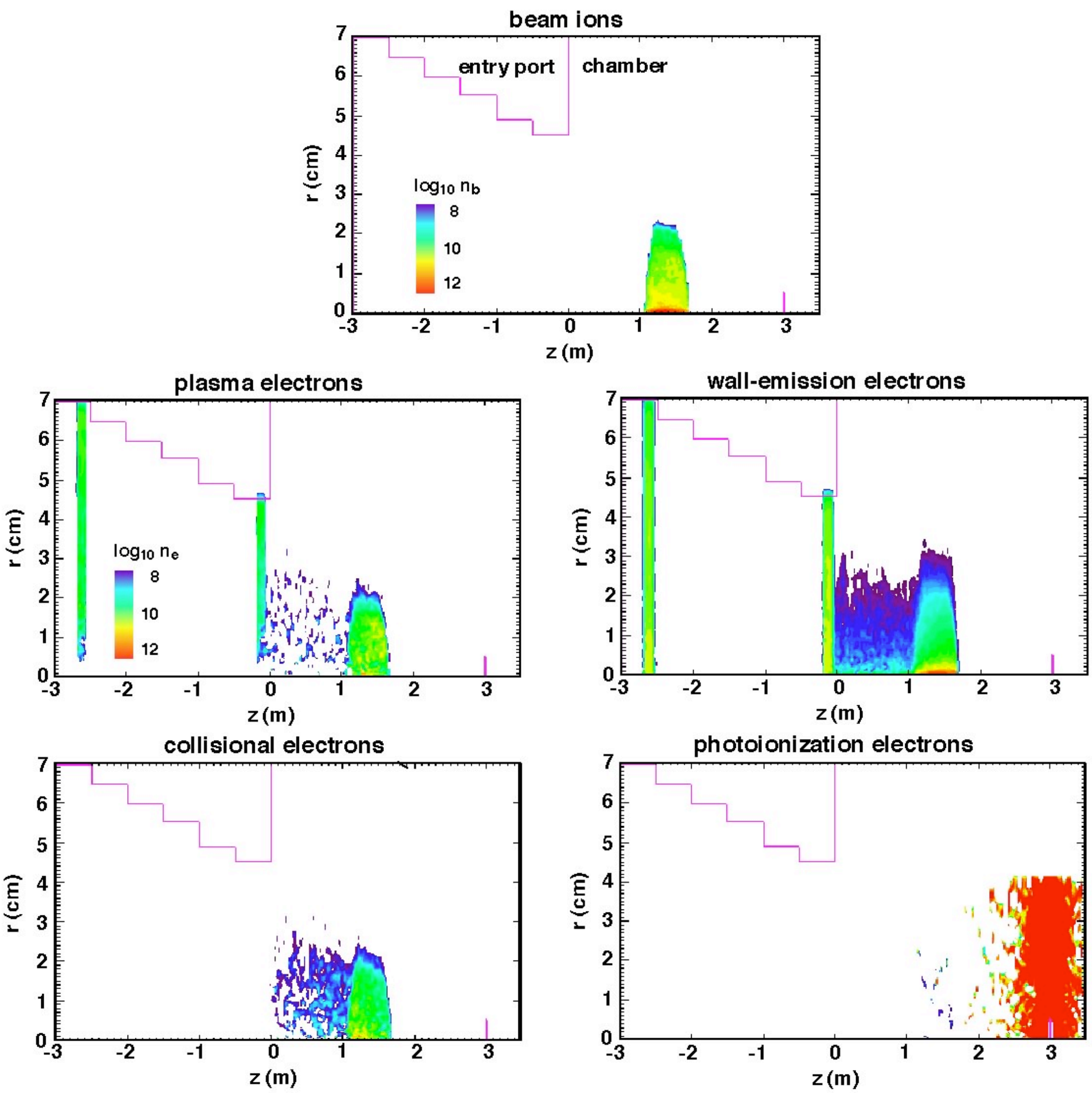
Plasma Improves Prospects for Heavy-Ion Fusion

Plasma neutralization may improve beam focus for heavy-ion fusion.

A promising approach to generating electricity from nuclear fusion proposes using intense beams of ions to detonate small targets in rapid succession. Each target contains a capsule of fusion fuel, normally the hydrogen isotopes deuterium and tritium. The beams heat the fuel to several million degrees Celsius and initiate a small-scale fusion reaction, turning the hydrogen into helium. The fuel is confined by its own inertia long enough for most of it to "burn" before the capsule disassembles, releasing a substantial amount of energy. Beam ions with a high atomic mass are favored in this concept because they carry more energy per particle than lighter ones, so the approach is called "heavy-ion" fusion

A critical step in this process is focusing the ion beams, each with a current of several thousand amperes, to the 2-mm spot size required by typical targets. Computer simulations have shown that the high electrical charge of such beams makes them difficult to focus in vacuum, leading to a focal-spot radius that is too large for standard target designs. A further factor is the residual gas in the fusion chamber, due to the molten-salt jets needed to protect the chamber wall. Although the vapor pressure from the jets is orders of magnitude less than atmospheric pressure, it is nonetheless sufficient to strip electrons from beam ions and further increase the beam charge. Unless the beam electrical charge is somehow neutralized, a good focus can only be obtained by using a substantially higher beam energy, which would drive up the accelerator cost, or by dividing the current between more beams, increasing the system complexity.

Recent simulations using the particle-in-cell code LSP, developed by Mission Research Corporation, have investigated a new method for neutralizing heavy-ion beams. If a hydrogen plasma is injected onto the beam path between the final-focus magnets and the chamber, a beam can pull enough electrons from the plasma to remain effectively neutral as it traverses the fusion chamber, greatly improving the beam focus. The accompanying figure shows beam and electron densities for a typical case using parameters similar to those in a recent fusion power-plant study. A 2.8-kiloampere beam of singly charged 2.5-GeV xenon ions enters from the left, passes through a 10-cm wide layer of fully ionized hydrogen plasma near each end of the three-meter beam port, then traverses the final three meters to the target. Electron emission is allowed from the beam port walls and maintains approximate plasma neutrality as electrons are trapped by the beam electrical charge and carried away. The simulation also includes realistic collisional ionization between the beam and the background gas, as well as photoionization of both species by X rays from the heated target. Due to electrons pulled out of the two plasma layers and those encountered near the target from photoionization, the beam neutralization remains near the theoretical maximum in the chamber, so that about 90% of the beam energy is deposited within a 2-mm radius spot. Provided that there are enough plasma electrons along the beam path to neutralize the beam charge, good focusing is found for a wide range of beam currents, a fact that should simplify optimization of power-plant designs and lead ultimately to more economical fusion-power generation. (Posters RP1.055 and RP1.057; contact W. M. Sharp at wmsharp@lbl.gov and D. R. Welch at drwelch@mrcabq.com)



Contour plots of the densities of beam ions and electrons from various sources when the beam is four meters past the final focus. The beam drags along a substantial density of plasma and wall-emitted electrons, giving it nearly complete charge neutralization. Here, n_b and n_e are respectively the beam and electron densities in number of particles per cubic centimeter. The 5-mm line at the 3-meter point represents one end of the cylindrical fusion target, and the stair-stepped boundary approximates the conical wall of the beam entry port.