The Z Machine

Powering up a miniature accelerator to target nuclear fusion

By IVARS PETERSON

The surprising revival of a venerable, nearly abandoned technique for creating a hot, dense plasma of ionized gas has produced a new contender in the effort to achieve sustainable nuclear fusion.

Located at the Sandia National Laboratories in Albuquerque, the Z machine sends an enormous blast of electricity through an array of parallel wires a few centimeters across, vaporizing the strands and generating a powerful magnetic field that dramatically compresses the resulting plasma. The pinched plasma, in turn, emits a burst of high-energy X rays.

In less than 2 years, researchers have increased the machine's output of X rays from 40 terawatts to more than 210 terawatts. Temperatures at the core of the compressed plasma have reached at least 1.5 million kelvins. Nuclear fusion requires temperatures in the range of 2 million to 3 million kelvins.

"The results so far have been spectacular," says physicist David A. Hammer of Cornell University.

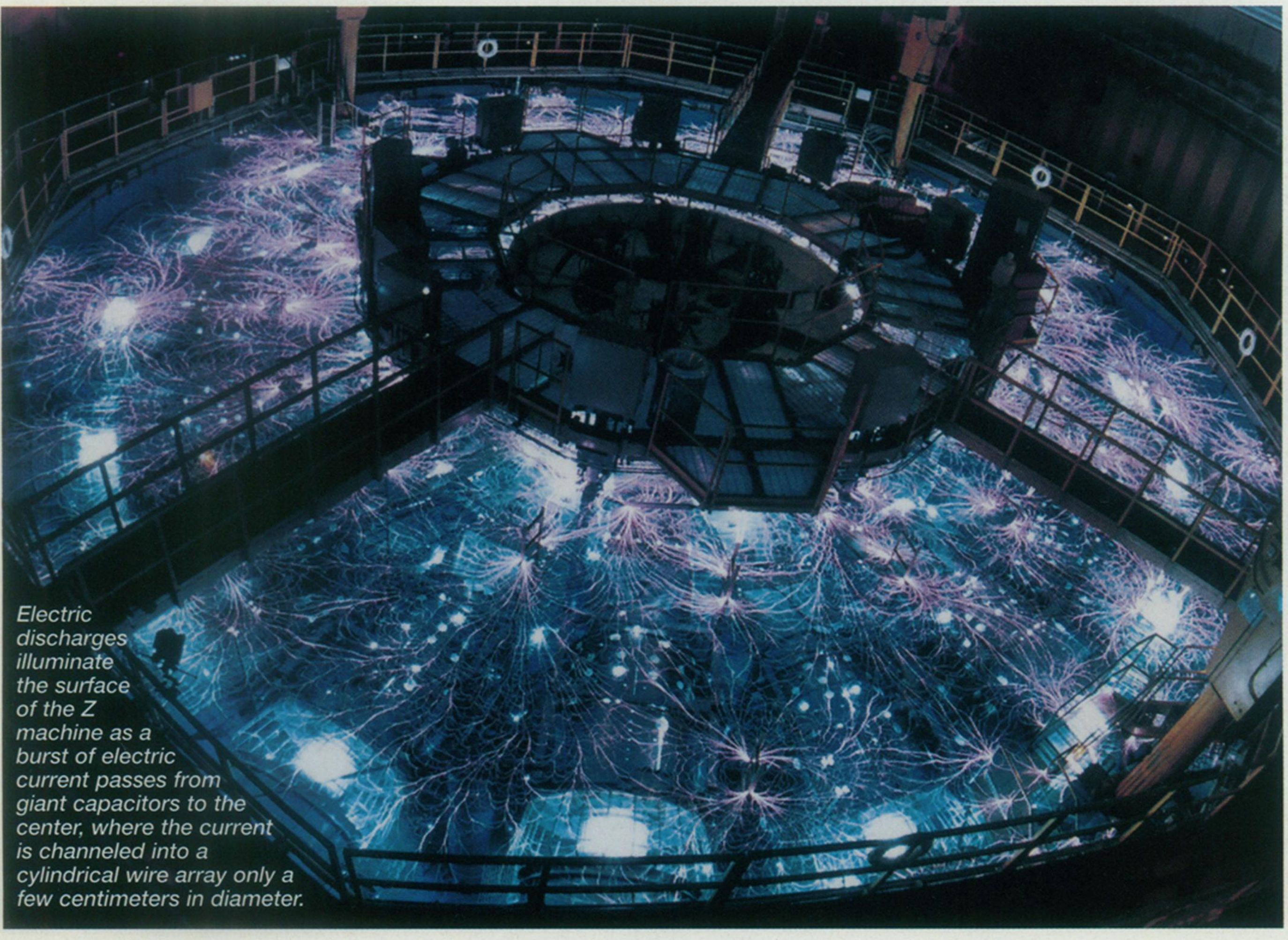
The Z machine is already the world's most powerful generator of X rays. Moreover, the central temperatures are high enough to be of interest for studying the behavior of materials and devices under extreme conditions. Such applications might include testing astrophysical models of the interior of stars and developing methods for ensuring the safety and integrity of an aging nuclear stockpile without conducting full-scale tests that involve detonating warheads (SN: 7/5/97, p. 5).

"It's a unique environment for doing experiments that involve the interaction of radiation and matter," says Sandia's M. Keith Matzen.

A number of presentations at last November's meeting of the American Physical Society's division of plasma physics, held in Pittsburgh, highlighted recent Z machine results.

The idea of electrically or magnetically pinching a gas to create a hot, dense plasma goes back to the 1960s. An intense electric current is chan-

Photos: Sandia



Electric discharges illuminate the surface of the Z machine as a burst of electric current passes from giant capacitors to the center, where the current is channeled into a cylindrical wire array only a few centimeters in diameter.

neled through wires arranged to form a cylindrical cage. Current flowing through the parallel strands generates a magnetic field around each wire. The wires attract each other, and the entire array implodes toward the center of the cage.

The wires vaporize immediately, cutting off the electric current and causing the magnetic fields to collapse rapidly. Metal atoms and ions caught in this collapse accelerate to an extremely high speed before crashing together at the center. The sudden deceleration heats the plasma, causing energetic electrons to emit X rays.

At Sandia in the early 1990s, researchers used such a device, made up of a few dozen wires several centimeters long, to produce an output of about 20 terawatts. For several years afterward, however, they failed to progress beyond that power.

The abrupt advance to much higher powers and energies started about 2 years ago, when the Sandia team decided to use cylindrical arrays made up of as many as 300 narrow wires. The researchers were surprised that increasing the number of wires could make an enormous difference. In their earlier experiments, merely doubling the number of wires had little or no effect.

By using hundreds of wires, scientists can cause the very high currents available at Sandia to transform into an enormous radial implosion velocity and, as a result, a higher temperature for a given mass, Hammer says.

With the capacitors now available, the Z machine can deliver in a few hundred nanoseconds a pulse of as much as 20 megamperes of electric current to the wire cage. The result is a 7.5-nanosecond burst of X rays amounting to about 2 megajoules of energy.

"It can produce a higher temperature over a larger volume of plasma that radiates more energy than any other source," Hammer notes.

Scientists have been testing a variety of cage configurations to improve both the X-ray output and their understanding of the implosion process.

"The physics of how the plasmas from the individual wires form and merge to create a cylindrically symmetric plasma is not understood in detail," Hammer points out. Such knowledge is needed if the process is to be scaled up to get closer to the conditions necessary for nuclear fusion.

In recent experiments, the researchers have auditioned cages ranging from 1.5 to 6.0 centimeters in diameter and consisting of from 90 to 300 wires composed of tungsten, aluminum, or titanium.

"The principal focuses are now on applications and on innovative techniques to optimize the radiation output," Matzen says.

Recently, researchers have tried nesting an array consisting of 120 wires inside another made up of 240 wires. Such an arrangement does boost the X-ray power, Matzen says.

Similarly, placing foam or metal cylinders inside the wire cage also shows promise for increasing X-ray output and raising the temperature at the center.

A cylindrical array of parallel wires—like the one shown as it is being fabricated—sits at the center of the Z machine.

At present, the Z machine can produce about 20 percent of the energy, 40 percent of the power, and 33 to 50 percent of the temperature required for nuclear fusion to produce more energy than it consumes.

The Sandia team has proposed building a new machine, called X-1, which would aim for a power of 1,000 terawatts, an energy of 16 megajoules, and temperatures in the range of 2 million to 3 million kelvins, says Jeffrey P. Quintenz, who heads Sandia's inertial confinement fusion effort.

Such capabilities would make an electric-pulse-powered approach competitive with other proposed methods of achieving sustainable nuclear fusion. Those alternatives include magnetically confined plasmas in doughnut-shaped reactors known as tokamaks (SN: 12/6/97, p. 366) and laser-driven fusion (SN: 10/19/96, p. 254).

In the meantime, the Z machine has attracted a lot of attention from researchers interested in taking advantage of the powerful radiation and extreme conditions already accessible. □