on ion beam formation and focusing. In the spring of 1985, PBFA-I delivered an 8-trillion-watt pulse of hydrogen ions onto a spot 4 to 4.5 millimeters in diameter. This represented a power density of 50 trillion watts per square centimeter and a 33-fold improvement in focusing over the .5 trillion Proto-I experiments in 1984. These experiments demonstrated that beam focus scaling increased beam current, .4 million amperes on Proto-I to 4 million amperes on PBFA-I. PBFA-II will demonstrate beam focusing with increased beam voltage. PBFA-II will have 30-million-volt lithium ions, as compared to 2-million-volt hydrgen ions in PBFA-I.

Many of these beam-focusing experiments will be directed at demonstrating alternative applications of the PBFA-II and new beam-focusing geometries. Among the alternative applications of PBFA-II will be the demonstration of ion beam-driven x-ray lasers. Recent developments with particle beam weapons could also be included in the PBFA-II experiments. For example, following up research originally carried out at Sandia, Livermore scientists have recently shown that intense particle beams can be focused and transported over long distances, through specially prepared plasma channels. A low-energy excimer laser pulse was utilized in these experiments to successfully produce such a plasma channel.

Beam transport through laser-produced plasma channels could provide the solution to one of the only major technical problems remaining for use of the light ion beam accelerator in commercial ICF power plants—"accelerator stand-off." Currently, the beam-generating diode is placed in close proximity to the fusion pellet. As a result, the pellet implosion-explosion damages this diode and it must be replaced after each shot. By utilizing plasma channels for beam transport, the pellet could be located at a sufficiently great distance, that no diode damage would result—known as accelerator stand-off. Given the current projections for PBFA-II's extraordinarily high beam power density, proposals to experimentally demonstrate beam stand-off are currently being considered by Sandia researchers.

Fusion experiments

By 1988, PBFA-II will begin experiments with actual fusion fuel pellets. These will include both direct and indirect drive pellet target designs. If PBFA-II attains the power densities currently indicated by existing experiments, it will produce significant and possibly high-gain ICF fusion. Throughout the 1970s, electrical pulsed power made tremendous strides forward, outpacing all other high-energy technologies, as PBFA-II demonstrates. This was achieved with shoestring levels of funding. But now electrical pulsed power has become a major focus of President Reagan's Strategic Defense Initiative. The Sandia pulsed-power fusion program is only now beginning to benefit from this several-orders-of-magnitude increase in research funding for pulsed power research. Therefore, the prospects for light ion beam fusion are quite bright.

Nova laser takes first fusion shot

by Charles B. Stevens

On Jan. 13 of this year, U.S. fusion researchers at Lawrence Livermore National Laboratory in Livermore, California, achieved a world record for laser fusion energy production, surpassing the Japanese, whose experiments on the Gekko glass laser at Osaka University had held the previous record of 1 trillion fusion neutrons generated. But with anticipated cuts in funding for the American program under the new Gramm-Rudman "balanced budget" regime in Washington, the Livermore achievement could rapidly be undermined, and with it one of the best prospects for achieving the limitless energy resources of laser fusion.

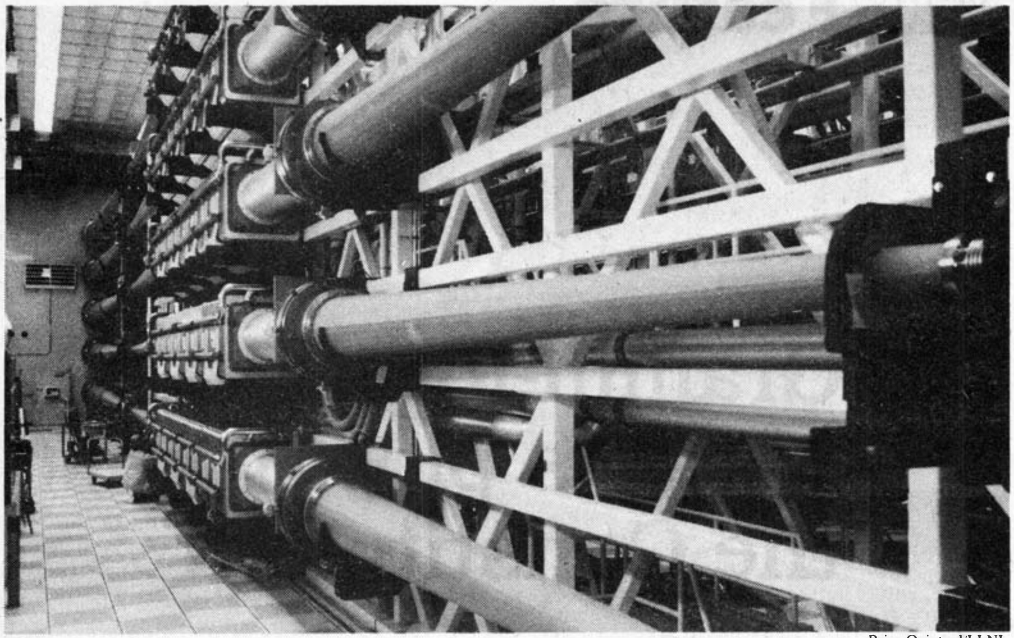
The Livermore researchers fired their newly constructed, 10-beam Nova glass laser, producing more than 10 trillion fusion neutrons. The successful result was achieved despite the fact that this was not an optimal design for fusion energy output. The small glass sphere containing deuterium and tritium fusion fuel (the two heavy isotopes of hydrogen) was primarily designed to test the various Nova fusion system diagnostics and measuring instruments. Only 18,000 Joules of the 100,000-Joule capability of the 10-beam, 100-trillion-watt Nova laser was used in the shot. The 10 ultraviolet (.35 millionths of a meter) Nova laser beams were directed onto a small sphere for one-billionth of a second, and produced 28 Joules of fusion neutrons.

In a 1984 study, laser fusion pioneer and Livermore Associate Director for Physics, Dr. John Nuckolls, showed that laser fusion has the potential of providing a virtually limitless source of electricity at half the cost of existing nuclear fission and fossil fuel energy sources. Dr. Nuckolls based his analysis on:

1) The cheap cost of fusion fuel and ready availability of hydrogen fusion fuel. One gallon of sea water contains enough fusion fuel to produce the equivalent energy of 300 gallons of gasoline.

2) The high quality and extreme concentration of fusion energy, which makes possible the efficient direct conversion of the fusion output to electricity.

As Dr. Nuckolls detailed in his study, given the fuel costs, of almost zero, and the almost-double electrical output per unit fusion input, nuclear fusion reactors would provide electricity at half the cost of existing types of nuclear fission



Brian Quintard/LLNL

The Nova laser, at Lawrence Livermore Laboratory in California. It is the world's largest optical instrument and most powerful laser, an essential laboratory tool for weapons research and the development of fusion energy.

and fossil fuel power plants. Dr. Nuckolls emphasized that nuclear fusion could provide the key to reindustrializing the United States, and making it the leader once again in technology and resources.

How laser fusion works

Laser fusion basically consists of making miniature stars, for a few billionths of a second, on Earth. Nuclear fusion is the process from which the stars derive their vast energy outputs. In the cores of massive stars, their huge gravitational pressures compress and heat the lightest element, hydrogen, to tremendous densities and temperatures. As a result, the nuclei of these hydrogen atoms are "fused" to form heavier elements, such as helium. In the process, a small portion of the hydrogen mass is converted to energy, which we see in the form of light and electromagnetic radiation.

For generating a miniature star on Earth, fusion scientists direct powerful laser beams onto a small sphere of hydrogen fusion fuel. As the laser light irradiates the surface of the fusion target, it produces converging shock waves, which crush and heat the target's interior, producing tremendous compression of the fuel, and hundred-million-degree (Celsius) temperatures, under which conditions nuclear fusion reactions are ignited. Both the compression-heating process and the fusion burn take only a few billionths of a second.

The fusion energy output is in the form of high-energy neutrons and helium ions. By surrounding the exploding pellet with appropriate material, such as solid and liquid lithium, the fusion energy can be converted into a form readily transformable to electricity. For example, the lithium, which is a metal, will generate an electrical potential as it moves through a magnetic field. This type of electricity generation cycle is called magnetohydrodynamics (MHD), and is already used in prototype form in fossil fuel power plants. The much higher temperature of the fusion process makes it much more amenable to efficient MHD generation of electricity.

The Nova laser system is primarily designed to demonstrate the scientific basis for laser fusion. It will be able to explore and simulate the essential conditions needed for developing reactor-grade laser fusion targets. But Nova is not large enough to actually generate in one experiment all the conditions needed for reactor-scale fusion energy production. The Sandia Laboratory's Particle Beam Fusion Accelerator (PBFA II) is expected to have this capability by 1988 (see accompanying article). Although the PBFA-II uses light ion beams instead of light to crush fusion fuel pellets, results from the Nova experiments will provide important information for the Sandia project.

Besides nuclear fusion research, the Livermore Nova is also used in experiments to perfect x-ray lasers. Powerful flashlamps irradiate large disks of neodymium-doped glass. The neodymium absorbs the incoherent light from the flash lamps, and the glass then re-emits this light energy input, in the form of coherent light. The powerful Nova beams can be used to generate bursts of x-rays, which can form the basis for x-ray laser flashlamps.

The Nova prototype, Novette, produced the first laboratory x-ray laser in 1984. Nova will vastly improve on those results. The Nova-powered x-ray laser will greatly extend the frontiers of laser research. Because of its shorter wavelength, the x-ray laser provides a unique means to probe both the extreme physical conditions of the fusion process, and the dynamics of living cells. In fact, the x-ray laser can be used to make atomic-scale pictures of living cells for the first time.