Scientists demonstrate how low the cost of thermonuclear fusion energy will be

by Charles B. Stevens

Dr. John H. Nuckolls, one of the world's leading nuclear scientists and the director of the Lawrence Livermore National Laboratory's X Division, presented a new, revolutionary analysis of the economic prospects for nuclear fusion at the London, England European Laser-Matter Interaction Conference held the first week of October.

Presenting results from recently completed advanced reactor designs, Dr. Nuckolls demonstrated that fusion has the ultimate economic potential of generating electricity for half the cost of the currently cheapest methods—nuclear fission and coal. Dr. Nuckolls states: "Relative cost escalation would increase this advantage. Fusion's potential economic advantage derives from two fundamental properties: negligible fuel costs and high quality energy (which makes possible more efficient generation of electricity)."

All previous fusion reactor studies have come in with projected costs 25 to several hundred percent greater than fossil and fission. As Dr. Nuckolls concludes in his report, "This is a remarkable and exceedingly important result. . . . This low cost economic potential would provide strong commercial incentives to accelerate the pace of fusion development in the near term, and to install a fusion energy system in the long term."

Magnetic fusion and inertial confinement fusion (ICF) are the two general approaches to fusion energy. While Dr. Nuckolls primarily focuses on ICF, which he helped pioneer, he notes: "These remarks about the economic potential of fusion apply to all of fusion not just inertial fusion." He concludes that development of both general approaches to fusion to should be accelerated.

In detailing the scientific prospects for ICF, Dr. Nuckolls identifies the crucial benefits of polarizing fusion hydrogen fuel. This can lead to a threefold decrease in the laser energy required to achieve ICF and to the development of entirely new approaches to ICF target design. *Fusion* magazine was the first to point out the unique applications of polarized fusion for ICF in the analysis that was published in a special issue in September of last year.

In his economic analysis, Dr. Nuckolls shows that spending a few billion dollars to accelerate the development of fusion now will pay off in the tens of trillions of dollars in the 21st century in the world-energy market and will guarantee the technological pre-eminence of U.S. industry. Dr. Nuckolls concludes that because of this tremendous payoff, the United States "has strong incentive to accelerate fusion research—other nations have similar incentives."

How ICF works

In ICF, intense beams of lasers or particles, which are often referred to as drivers, are used to compress and heat small pellets of hydrogen fuel to the super-high densities and temperatures at which nuclear fusion reactions are ignited. Because the rate of reaction is a function of fuel density, by compressing the hydrogen to super densities, the fuel pellet "burns up" before it blows up. Only the inertia confines the burning fuel.

Scientific and technological status of ICF

Besides developing the new analysis of the economic potential of ICF, Dr. Nuckolls also reviewed its current scientific and technological status: "Inertial fusion must demonstrate that the high target gains required for practical fusion energy can be achieved with driver energies not larger than a few megajoules. Before a multi-megajoule scale driver is constructed, inertial fusion must provide convincing experimental evidence that the required high target gains are feasible. This will be the principal objective of the NOVA laser experiments. Implosions will be conducted with scaled targets which are nearly 'hydrodynamically equivalent' to the high gain target implosions. . . .

"Since the inception of the first experimental laser fusion program at Livermore in 1963, the long range strategy has been to build a sequence of successively larger lasers until thermonuclear ignition is finally achieved. Beginning with the few-joule laser in 1966, we have progressed to the 10-kilojoule Shiva laser in 1978 and the 10-kilojoule Novette short wavelength laser which was completed last year. Next year the 100 kilojoule NOVA laser will be come operational. Each laser in this sequence has been used to conduct critical experiments, and to develop new technologies, which made possible building of the next tenfold-larger laser. Beyond NOVA, a multi-megajoule driver will be required to demonstrate that high gain targets required for practical energy applications are feasible."

But in formulating his economic analysis, Dr. Nuckolls utilizes only the most conservative estimates for target gains, and points to the more advanced possibilities, such as polarized fusion, as providing a general backup.

Why fusion is cheaper

Dr. Nuckolls begins by taking nuclear fission, which is significantly cheaper than coal, at its best, i.e., by assuming an infinite fuel supply, possibly provided by a fission-fusion hybrid breeder, and with an advanced reactor design which can be constructed within five years: "Fusion has two principal assets which could potentially confer a factor of two advantage. First, the typical fuel cycle cost for a light-water [fission—CBS] reactor is approximately 20 percent of the total busbar cost [cost at the point of transmission] of fission energy. With the hybrid 20 percent escalation factor, the fission fuel costs would give fusion a 40 percent advantage since its fuel costs are negligible. Second, there is another possible 40 percent advantage which derives from a combination of two factors: the high quality of fusion energy and the fluid insulation of fusion reactor walls [the magnetic fields in magnetic fusion reactors and liquid jets of lithium in ICF reactors—C.B.S.]. These two factors taken together make possible a 40 to 50 percent increase in the electrical generating efficiency. Multiplied together, fusion's two 40 percent assets provide a twofold advantage over fission."

Dr. Nuckolls goes on to show that these assets far outweigh fusion's liabilities.

MHD electricity generation

The most important new point raised by Dr. Nuckolls in his London presentation is that inertial fusion can utilize the far more efficient MHD method of electricity generation in a manner that is not only technologically feasible but also simultaneously successful in overcoming the difficulties inherent in high energy neutrons produced in Deuterium-Tritium (DT) fusion, that form of fusion involving two isotopes of hydrogen. While Dr. Nuckolls presents two reactor designs which make use of MHD electrical generation, here only one of them will be described in detail: the "neutron pillbox MHD" system.

It has often been pointed out that if there existed some process for directly converting high-temperature
ergy output into electricity, then efficiencies of 99.99 percent could be achieved. Dr. Nuckolls has detailed a process which can attai
the potential electrical output of an inertial fusion reactor. This process is technologically straightforward and solves the neutron damage problem.

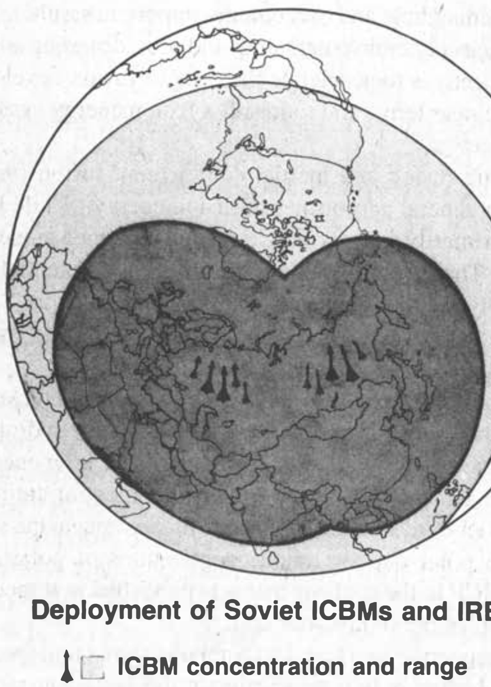
Dr. Nuckolls and his collaborators at Lawrence Livermore have turned the neutron problem on its head. The solution is to surround ICF exploding pellets with a pill-shaped mass of solid lithium. The fusion-generated neutrons are then captured within this solid mass, causing it to blow up. But because neutrons deposit throughout the volume of the lithium pillbox, the second explosion can be shaped by properly arranging the geometry of the pillbox. For example, the neutron deposition can be made to generate converging shock waves. And the energy density of the neutron deposition is still sufficient to transform the pillbox lithium into a high temperature plasma. The final result is that the vast majority of the fusion energy output can be transformed in straightforward manner into directed plasma jets.

High-temperature plasma jets greatly simplify MHD electricity generation. And, in general, plasma jets are ideal for all kinds of energy transformations, such as microwave generation. The reasons are easy to detail in the specific MHD case, but it should be noted that the general point of transforming a high temperature "thermal" fusion output into a slightly lower temperature "directed" plasma jet has profound theoretical implications.

Beam weapons and ICF

An important point not reviewed by Dr. Nuckolls is the close connection between ICF and the entire beam-weapons technology of energy concentration—pulsed power. One leading member of the President's special task force on beam weapons stated to this author last May that "ICF is in the bag, given the President's beam weapon program." The beam-weapon program is directed toward developing efficient high-power lasers and particle beams, which are the drivers for inertial fusion.

CORRECTION: Due to a production error, the following map appeared with an incorrect key in our Oct. 25 Special Report. The map should be read as follows:



Deployment of Soviet ICBMs and IRBMs

ICBM concentration and range
IRBM concentrations and range