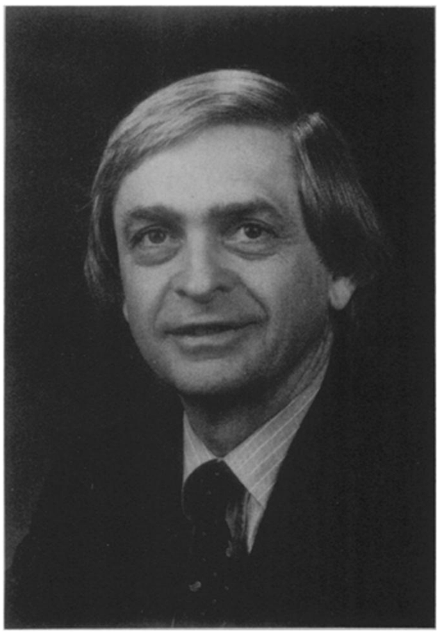
Economy of Fusion

Promised fusion reactors have yet to materialize. We need them, says physicist John Nuckolls, but they must be engineered with an eye on price.

By DIETRICK E. THOMSEN

Photos: Lawrence Livermore National Laboratory



John Nuckolls

As 1984 begins, so do the inevitable reminiscences of George Orwell. But while Orwell was composing his pessimistic view of his future (our present), others were advancing optimistic ones either to boost the morale of those involved in a world war or to amaze those attending a world's fair. The optimistic genre tended to share certain assumptions: Clothing would be light and abbreviated. Giant domes built over whole cities would control microclimates. Public transport would be readily available and well patronized. And power for all this would be generated by smokeless means.

Of these predictions the only one that has come true is the one about abbreviated clothing. In any North American city, numbers of people can be seen running around the streets or lying in parks in their underwear (or what seems to be less), an activity for which they would have been arrested during the 1940s. Nobody has yet domed a city. Public transport in the United States is in terrible shape. And most of our electricity still comes from fossil fuels.

The smokeless power was supposed to come from nuclear fission or nuclear fusion. Fission reactors were available in the 1940s and were expected to sweep the power industry. They have not done so. Ironically the economics seem more against them than for them. Fusion reactors don't yet exist, though by 1940s predictions they should exist by now. Scientific difficulties and the example of nonproliferation of fission power reactors have led to questioning of the fusion program. People wonder particularly whether fusion economics would be similarly disappointing. Even most researchers in the field tend to talk diffidently about its prospects.

One who is not diffident is John Nuckolls, who was recently promoted to be director of physics at the Lawrence Livermore National Laboratory in Livermore, Calif. Nuckolls has called for a crash program, like the Manhattan District Project that got us both fission bombs and fission reactors, to get us fusion reactors. Having made that call, he decided to study what the economics of fusion power are likely to be. He discussed that study in a recent interview with SCIENCE NEWS.

Nuckolls is concerned that his colleagues in the fusion effort, who are busily working toward a scientific demonstration of the feasibility of fusion, are not paying enough attention to what happens afterward.

If I were in [Presidential Science Advisor George A.] Keyworth's position, he says, *I would get the fusion community together and say, "You people have to worry that you're going to get into the same boat as NASA was when it got a man on the moon. It will be a great triumph when the tokamak works and you get breakeven or whatever it is..."*

But what comes after that?

If you look at what happened to the NASA budget for the next decade, it didn't go up, it sort of went down, and people haven't been back to the moon since. I'm afraid that fusion is racing toward another anticlimax because they're not putting enough effort into what happens after [breakeven].

The world is going to need increases in available power, he contends. Even assuming that the world population levels off after another doubling and that the average person makes only a modest increase in power demand, he quotes estimates of 10,000 fission reactors. Multiplying by an estimated unit cost of a billion dollars means $10 trillion are at stake.

All those "world of tomorrow" brochures assumed that the smokeless power was going to be cheap.

When fusion was first getting started, why it was cheap, clean and inexhaustible. Fusion and fission were both the same, except that fission wasn't clean.... They weren't even going to charge you for it. Now we're in a world where economics really matters. It is more of a zero-sum game.

It's not sufficient for fusion to be the same price as fission or coal or whatever the competition is. It has got to be substantially cheaper, or the utilities are not going to want to go to the trouble to install a new energy system.... I think the nature of technology is that nobody can make a perfect product. You sort of do it by iteration, by trial and error, and it's pretty expensive to do that on half billion and billion and two billion dollar facilities, particularly when you've got environmental groups nipping at your heels.

Coal is not going to escape. All these developing countries are not going to rush to buy an expensive fission or fusion plant if they can burn their own coal, which they mine with cheap labor. The world is doomed to fall into the CO_2 trap [the *greenhouse effect]. Unless we can come up with something that's cheaper both capital-wise and busbar [current carrier] -cost wise, then even if the United States stops burning coal, we're not going to save the world from the CO_2 problem.*

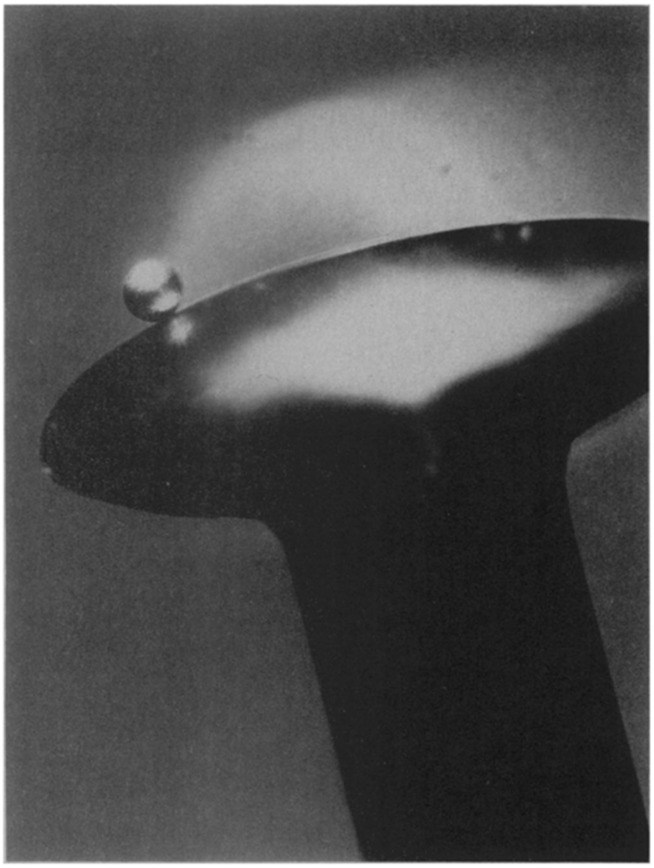
So for both the economic viability of the country and for the future of mankind, I believe that fusion literally has a holy cause. We ought to put the cheap back in fusion. Is that really feasible?

At this point, he says, he came up against a prevalent attitude in the fusion community that it's not yet the time to talk about costs. Estimations are too difficult, people say. And anyhow all the fusion people have to do is wait: The uranium will run out, according to the argument, and the environmentalists will succeed in killing off fission. Then the world will turn to fusion no matter what the cost. Nuckolls believes this is an illusion, and that talking costs is an urgent question.

Suppose this government really believes there is a chance that fusion reactors would turn out to be cheaper than fission reactors, and they calculate that this is a matter of $10 trillion to $100 trillion. If you got busy and worked on this and got the lead—as IBM did in computers—you are likely to end up with a 50 percent market share. Having convinced myself that fusion may indeed have this potential, I think that Keyworth may be making a serious mistake in saying "let's internationalize this thing." He loses either way. The Japanese are awfully good about taking American ideas and commercializing them. The only way to get ahead of them is to get in there and lean on your technological lead.

It generally takes 40 years after you've got the first power plant running before you can install a technology and get it up to a substantial fraction of the grid, 30 or 40 percent. If you want this thing to happen in 2023, you've got to have the [first] power plant sitting now. The schedule we're on, the power plant is not going to be run until 1993. So this is the right time to get serious about it. We can say the same thing about the CO_2 problem. Better begin to get serious now.

Nuckolls did a "minimax" analysis of the fusion/fission problem, giving fission every possible advantage and thereby assuming only a 20 percent rise in the cost of fission reactors over the period under discussion. He can see two main advantages for fusion: cheap fuel and the Carnot cycle. Twenty percent of the busbar cost of fission power goes to the fuel. Fusion fuel (mostly deuterium) would be so cheap as virtually to eliminate this cost. Give fusion an advantage amounting to a factor of the square root of two, 1.4 (20 percent plus 20 percent).



How many fuel pellets can sit on the head of a pin? Huge lasers blast pellets like this one to induce nuclear fusion. Will this satisfy world power needs?

The Carnot cycle comes in by way of the high temperatures at which fusion occurs. Conventional power plants have energy conversion efficiencies about 30 or 40 percent, generating the energy in the hundreds of kelvins and bringing it out at 373 K, the boiling point of water. If one eliminates the boiler and takes the energy out at a higher temperature, greater efficiency will result. The fusion power plants that are on the drawing boards, however, all use boilers, and hardly one has more than 40 percent efficiency.

The way to get rid of the boiler, Nuckolls says, is to use magnetohydrodynamics (MHD). To do this requires a more exotic reaction (perhaps deuterium-deuterium) than the deuterium-tritium usually regarded as the first step. In the d-t reaction, neutrons carry off the energy. They won't work an MHD generator. The d-d reaction would yield energetic charged particles that would run into an MHD generator, where they would induce electric currents directly without the intervention of a boiler and turbine. Nuckolls can see no way of making this work for magnetic fusion, but he thinks it will work for inertial confinement fusion, in which small fuel pellets are hit with blasts of energy carried by a driver (either energetic ions or laser light) and compressed and heated until a miniature fusion explosion occurs.

If MHD is to be used, the charged particles should come out of the target in flat jets, not in all directions. This means substituting discus-shaped targets for the spherical ones now used in experiments. If it pays off, it's about another 1.4 advantage factor for fusion, he says.

The cost of a target factory is well in hand, $50 million to $100 million, so Nuckolls is concentrating on the driver. Polarized fuel, in which the spins of the nuclei are all lined up in the same direction, gives an energy advantage, and so lowers the cost of the driver. The cost of the driver is further lowered by the switch to disc-shaped fuel pellets. Finally the driver can be switched and time-shared to drive two power plants. All this results in a driver that costs 10 percent of the total of the plant. The total price of the plant is half that of the cheapest fission plant.

Nuckolls didn't think anybody would believe this, so he did a sensitivity analysis to see which of the costs was most sensitive to unforeseen changes in the economics. The big-ticket items turned out not to be very sensitive; the main sensitive item was the time-sharing.

If I couldn't time-share, [the total cost] came to 60 percent. It's a result that should be investigated further. In 50 years the world will have to burn 10 times as much coal as now. □