Controlling the Thermonuclear Fusion Reaction

Control of the thermonuclear fusion reaction that produced the hydrogen bomb has been the "holy grail" of applied physics since the early 1950's.

In a world where demands for electrical power are expected to multiply fivefold by the year 2000, development of a fusion reactor seems the answer to all energy deficiencies. Such a reactor would "burn" deuterium, a heavy isotope of hydrogen; and there is enough deuterium in the water of the oceans to meet the world's energy needs for more than 1 billion years. (The energy from the fusion of the deuterium in a gallon of water—less than an eighth of a gram—is equal to that from 300 gallons of gasoline.)

In the 1950's and early 1960's, after a series of tantalizing research approaches had turned sour, many scientists wondered if it would ever be possible to control the fusion process in the same way that atomic fission is controlled. Now, however, it is not a question of *if*, but *when*, according to Roy Gould, professor of electrical engineering and physics. On leave from Caltech to serve as director of the Atomic Energy Commission's fusion research division, he was on campus recently to address a joint Physics-Applied Physics Research Conference about progress in that field.

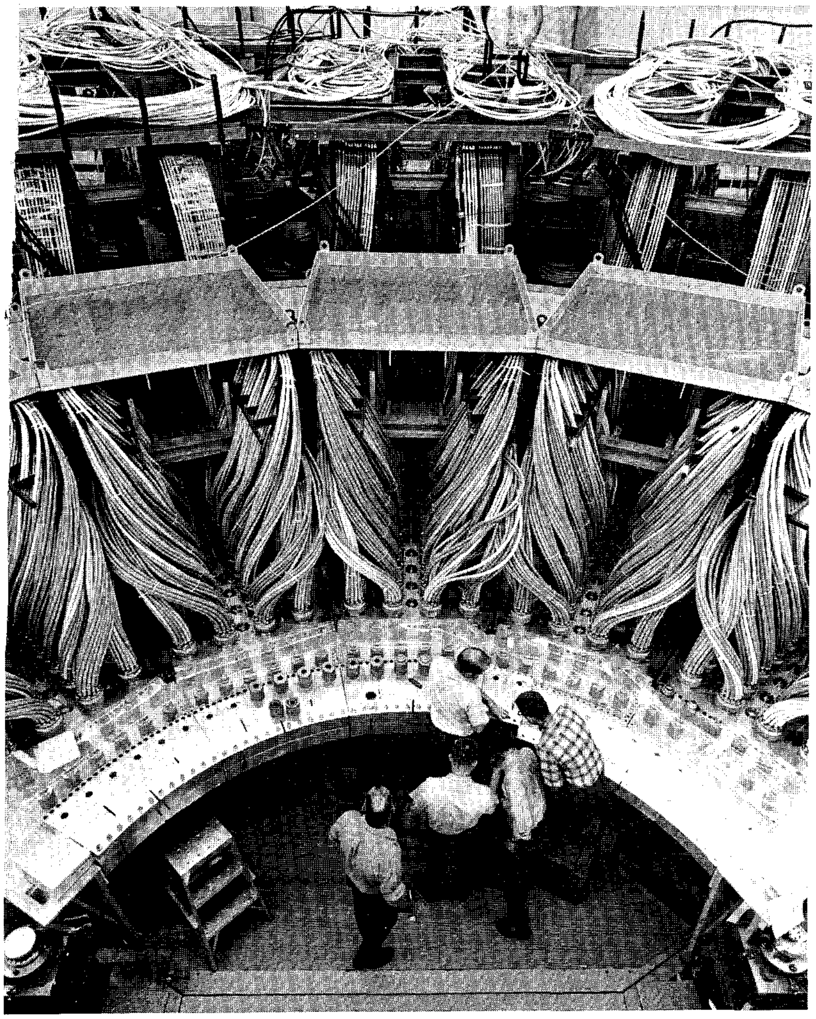
In Gould's opinion, the reason for the renewed optimism about controlling fusion processes has been the Russian success with their Tokomak-3 high-energy plasma machine, and subsequent good results in this country at the Lawrence Livermore, Los Alamos, Oak Ridge, and Princeton University fusion research centers.

To achieve useful power from controlled fusion reactions, it is necessary to heat dilute gas of fusion fuel to temperatures of hundreds of millions of degrees, until it is in the plasma state; then to contain it, free from any contact with material walls or from contamination by impurities, long enough for a significant fraction of the fuel to react; and finally, to extract the energy released and convert it to a useful form.

Progress toward this goal is dependent on what we know about the behavior of high-temperature plasmas, together with the means of heating and confining them. Using any material for a container to confine the plasma would lower the temperature of the plasma below the critical point, so scientists have made use of magnetic fields to "bottle" the electrically charged particles. Because of the interaction of magnetic and electrical fields, a particle—in theory—could not leak out of a properly shaped bottle.

Two basic magnetic bottle configurations have been developed to confine the plasma: the open-ended mirror machines and the toroid, or doughnut-shaped, machines. Mirror machines are straight tubes with magnetic fields that are stronger at the ends than in the center. The stronger fields act as mirrors, reflecting plasma particles back into the tube. In the toroid design the ends are eliminated, wrapping the tube—and also the magnetic field—around on themselves in the form of a doughnut.

These bottles are not perfect. A slow leakage occurs, due to collisions between plasma particles. For many years there has been a theory which predicted that the loss of plasma particles by diffusion out of the magnetic field would be low enough to allow a steady, energy-producing fusion reaction to go on. But experiments in the fifties and sixties repeatedly failed to confirm the prediction. In the last few years, results from a toroidal device called the Tokomak, developed in the Soviet Union, have shown that diffusion rates approaching the prediction can be achieved. Consequently, the Princeton plasma machine—the Stellarator—has since been converted to a Tokomak. In addition, two other magnetic confinement approaches are emerging—the steady state magnetic mirror and the pinch device, which operates in cycles, heating and constricting the plasma for only short periods.



Scyllac—with its complex twisted coils—is an example of one of the "new breed" of controlled thermonuclear research devices. Located at Los Alamos Scientific Laboratory, it represents one of four or five major efforts to come up with the correct configuration of magnetic fields to hold a plasma of excited atomic particles long enough for a fusion reaction to occur.

If any of these approaches can attain a plasma density of about 1,000 trillion particles per cubic centimeter for a tenth of a second at a temperature above 60 million degrees, a fusion reaction is assured. The Soviet Tokomak has attained temperatures of 10 million degrees at close to reactor densities for about one-hundredth of a second. The Princeton Tokomak has reproduced the Russian results and is now being used in a program to further extend these results and our understanding of them.

A second promising effort is the 2X mirror experiment at Lawrence Livermore, which has achieved temperatures of 100 million degrees at about the same density and a little less confinement time. A pinch device at Los Alamos —Scyllac—has reached temperatures of about 35 million degrees at the right plasma density but a very low confinement time.

Despite these promising results, Gould—even at his most optimistic—does not think fusion will do much to ease our power crisis until the year 2000. The scientific feasibility of a controlled fusion reaction could be demonstrated within five years—provided the resources for the research were available. With luck, break-even plasma conditions—the point at which a plasma creates more energy from the fusion reaction than is invested in producing the plasma—can be achieved by the end of this decade. Beyond that would lie an extensive, and expensive, engineering development period in which experimental fusion reactors would be built and operated. A demonstration fusion power plant would appear in about the mid-1990's at the earliest. Introduction of significant amounts of power into the economy would take even longer.

But it will take money. It is estimated that a modest program would require doubling the current budget of $32 million a year to $64 million by 1975, and more gradual increases to reach $89 million a year by 1980. A crash program would involve doubling and redoubling to $143 million in 1974 and more increases to $237 million a year in 1980.