Thermonuclear fusion 25 years on

Princeton's claim to have made its new tokamak function deserves acclaim. The meaning of this event is merely that the odds (against) viable fusion have lengthened — and that the decision time is closer.

THERE is, of course, no doubt that thermonuclear fusion can be made to work: such doubts as there are concern the feasibility of producing thermonuclear power economically. That is the aphorism against which must be assessed the significance of the report, elsewhere on this page, that the Princeton tokamak machine sprang into life last Christmas Eve.

In the year that happens to be the 25th anniversary of that in which Sir John (later Lord) Cockcroft announced that he was "99 per cent certain" that fusion had been demonstrated at the Harwell laboratory of the UK Atomic Energy Authority (see *Nature* **181**, 217; 1958), it is natural that the people at Princeton should seek applause for having commissioned a machine that will probably (a few years from now) demonstrate that fusion can produce more energy than it consumes. Then, a few years later, the economist-minded engineers will come into their own and will be required to say whether expenditures perhaps ten times as large as at present each year will be justifiable: fusion will have moved from being a zero-odds gamble on an infinite pay-off to being a ten-to-one (against) chance that industrialized countries will be able to save a substantial fraction of, say, ten per cent of their gross domestic products.

Those who accuse governments of shortsightedness in the pursuit of research should think again; the motives of those that continue generously to support close on a hundred thermonuclear machines of various kinds and scales cannot be simply electoral.

Meanwhile, there is a case for admiring (in the Latin sense of "to wonder at") what has been accomplished. A quarter of a centry ago, the neutrons emitted from Harwell's experimental machine turned out to be neutrons produced in predictable kinds of nuclear reactions; it is remarkable that people did not promptly give up and turn to solid-state physics or something even safer. With the passage of time and thus the accumulation of experience, the criteria for success in the chase towards the Holy Grail have become more clearly understood. Nobody now supposes that it will be possible to make an artificial sun that will sustain itself in being until its light-element fuel is exhausted; the best hope is to create a transient sun that will operate at higher temperatures than the sun that keeps us warm (ideally, at ten times the central temperature of 15 million K), do so for a few microseconds at a time and allow the unburned materials to be recycled.

The appropriate "figure of merit", as the engineers say, is the product of the average ion (i.e. nuclear) density and the confinement time, otherwise the Lawson number. In all schemes for making thermonuclear fusion possible, the guiding principle has so far been that only magnetic fields are so immaterial as to be undamaged by the impacts of material particles bent on escape. The ZETA machine, called a "fast-pinch machine", made the ions of a plasma into what was nothing but the (single-turn) secondary of an electrical transformer, with positive and negative ions (electrons) travelling in opposite directions, and producing its own magnetic field with a rapidly increasing radial gradient so as to compress the plasma in the middle.

Tokamaks are different. Given the knowledge that plasmas may be confined by patterns of magnetic force running axially around toruses, it was possible (but not easy) to predict that such a pattern of forces artificially created would provide a means of confining a hot plasma, whence the tokamak. The essential trick is to accelerate the particles of the plasma, the ions in one direction and the electrons in the other, in such a way as to increase their mutual temperature.

Most magnetic confinement machines in which hot plasma is confined by toroidal patterns of magnetic fields work in the same way. While the past quarter of a century has shown that, in devices of this kind, it is possible to predict what modes of instability are likely to occur and to take steps to keep them small, the magnitude of these effects and their interactions can be understood only by building a machine and seeing how it works. More recently, it has been recognized that turbulence as distinct from gross instability is important even when every step has been taken to prevent a nominally toroidal plasma turning into a corkscrew turned in upon itself.

Thus it has come to be recognized that fast-pinch machines are at one end of the spectrum (high turbulence), stellerators (like the original Princeton machine) at the other and tokamaks somewhere in between. For the time being, however, the need that there should be some kind of a machine that will make possible experimental study of thermonuclear fusion on a substantial scale is sufficient to justify the building of compromise tokamaks — at least a dozen of various sizes in Europe alone.

In the end, however, it could well turn out that some quite different machine — a "mirror" machine in which magnetic confinement requires that particles should bounce from one end of a magnetic "bottle" to another, or something involving a giant laser, for example, may offer the best chance of thermonuclear power. One recent trouble is whether magnetic fields capable of containing plasmas at a pressure sufficient to yield usable amounts of thermonuclear power can be generated by magnetic coils with reasonable mechanical strength. For the time being, then, the question is not whether the machine at Princeton, or which other machine, will function economically but whether any will. Only time, and quite a lot of it, will give the answer.

US tokamak starts up

Washington

SCIENTISTS at Princeton's Plasma Physics Laboratory have successfully started up the first of a new generation of tokamak fusion devices. The $314 million Tokamak Fusion Test Reactor (TFTR) is expected to attain scientific break-even — the point at which as much energy is produced by the fusion reaction as is applied to the plasma — by 1986.

The initial test of the machine, on Christmas Eve, produced a hydrogen plasma that lasted only 1/20th of a second. Its temperature of 100,000 °C was two orders of magnitude below that needed to attain break-even. The director of the laboratory, Dr Harold Furth, warned that some press reports of the event may have exaggerated its significance. "It's not a scientific event", he said, 'but we were absolutely astonished that it worked on the first shot." The enthusiastic reporting was probably not dampened by the timing of the event, which fell on the slowest news week of the year, nor by Dr Furth's earlier statement, "It's like Columbus finding the New World".

TFTR is, however, the first tokamak machine that will be able to produce a plasma substantial enough to attain scientific break-even. "At the present rate, TFTR should reach reactor parameters in 1986", Furth said.

Initial testing will be done with hydrogen and deuterium plasmas. By the end of the year, the Princeton team expects to have ready the powerful heating method that uses energetic neutral beams to raise the plasma to the required temperature for fusion to take place.

The final step towards the break-even point should come in 1986, when deuterium/tritium plasma — which undergoes fusion at a lower temperature than straight deuterium, but also produces radiation in the form of alpha particles — is introduced into the machine.

TFTR's closest competitor will be the Joint European Torus (JET) at Culham in the United Kingdom, which is due to come on line this summer. Japan's JT-60 and the Soviet Union's T-15 are due to be completed in 1985. Stephen Budiansky