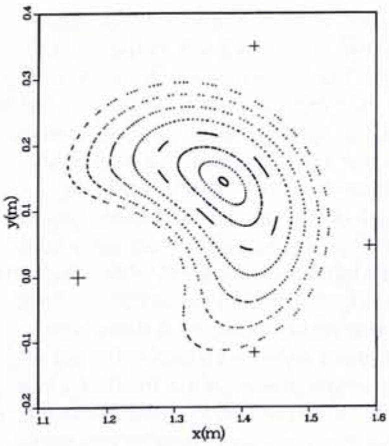

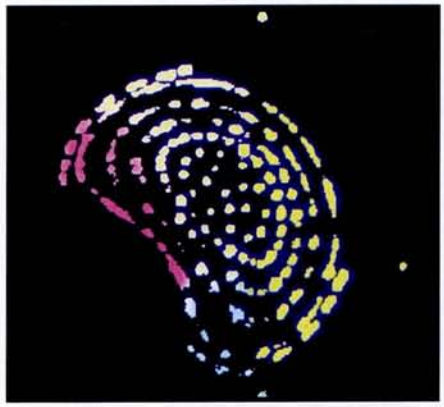

Fig 2 ***Left*** the calculated confining magnetic surfaces of TJ-II and ***right*** the experimental ones measured at 5% of the nominal field using the fluorescent rod method. The excellent agreement between both indicates that the positioning and geometry of all coils is within the specified construction tolerances (< 1 mm)

possible to its physical limits.

Main areas of research in TJ-II are: studies of plasmas in low collisionality regimes aimed at understanding the nature of transport mechanisms caused by the physical properties of magnetically confined plasmas; operational limits in high pressure regimes—in particular we plan to use the flexibility of TJ-II to experimentally validate existing theories of instability development; and studies of confinement optimization and its relationship to radial electric fields.

Encouraged as we should be by all the progress made in the last decade in magnetic confinement, one of the greatest scientific challenges confronting our community is still open: the development of models to fully explain the mechanisms underlying the transport of energy in fusion plasmas. Our hope is that the experimental flexibility of TJ-II could play an important role in finding the solution to this fundamental question. The facility is up and running and at the full disposal of our European scientific community.

MAST **The Spherical Tokamak**

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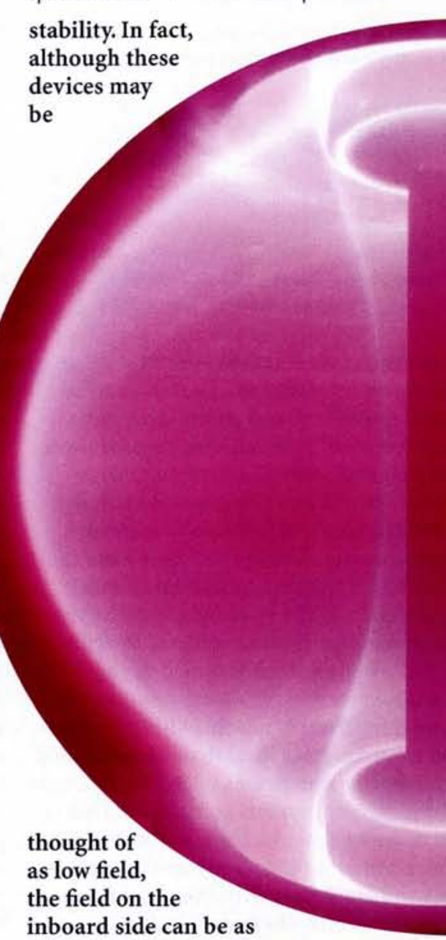
When magnetic fusion has reached such an advanced state, it is fair to ask why another variant on the tokamak is being discussed, as well as how it is possible for a torus to be spherical. *Figure* 1 addresses both questions: the simplicity and compactness of such a plasma have attractions as the core of a fusion device, and the plasma is spherical in appearance.

There is a firm database in support of a burning plasma device with a conventional aspect ratio (ratio of major to minor radius of the torus), as embodied in the ITER design for example. If, however, there are advantages in pursuing a somewhat different plasma geometry, for instance with a larger or smaller aspect ratio, then present confidence is limited by the restricted range of aspect ratio data in the experimental database. A major aim of MAST (Mega Amp Spherical Tokamak) is to broaden the tokamak database as well as to provide a novel environment in which to test many aspects of tokamak physics and operation, and transfer results to more conventional aspect ratio devices. Conversely, progress with the spherical tokamak (ST) concept has been extremely rapid as it is built on a wealth of experience from traditional tokamaks.

The ST is largely based on theoretical ideas initially developed in the late 1970s and 1980s. One of the major costs and engineering challenges for the tokamak is the production of an adequate magnetic field to confine the plasma, so it is important to make optimal use of it. This means that the plasma pressure should be as high as possible for a given field –the fusion performance can be written in terms of the product of the density, temperature and confinement (or energy replacement) time. Theoretical calculations using magnetohydrodynamic stability codes, tested against existing tokamak data, show that the highest ratio of plasma pressure to magnetic field pressure is achieved by reducing the aspect ratio as far as possible, and raising the plasma current (and/or reducing the magnetic field). Furthermore, good plasma confinement time is found experimentally to be related to high plasma current. A natural feature of ST geometry allows plasmas with very high plasma currents to be confined at low magnetic field while maintaining stability. In fact, although these devices may be thought of as low field, the field on the inboard side can be as high as on larger aspect ratio devices.

Fig 1 below Photograph of a plasma in START. A central column carries the current to make the main toroidal magnetic field, but it is so compact that the overall impression is of a spherical plasma. The diameter of the 'sphere' is about 1 m and it carries up to 300 kA



One of the traditional concerns about a

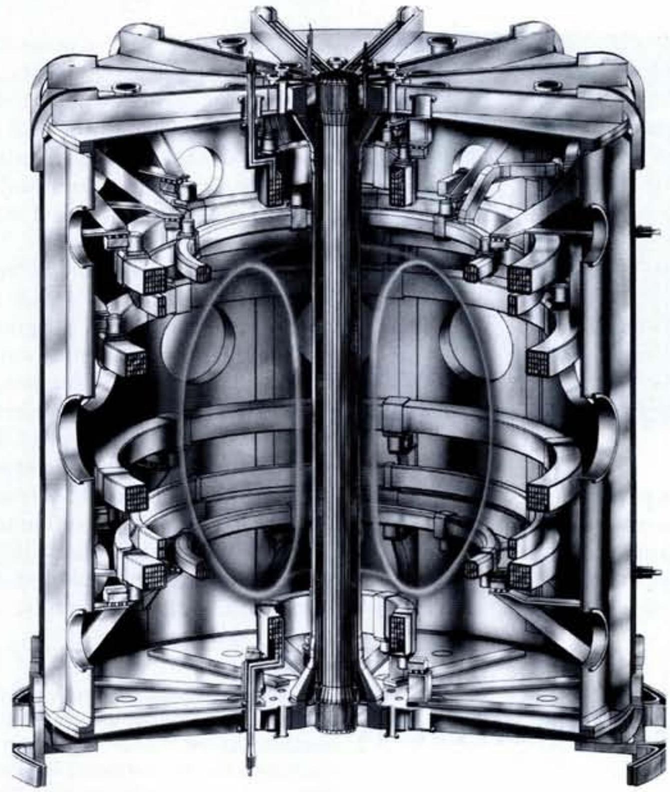


Fig 2 Above Cutaway drawing of the MAST load assembly. **Below** the nominal parameters

Plasma current	1-2 MA
Toroidal field (0.7m)	≤0.63 T
Major radius	0.7 m
Minor radius	0.5 m
Aspect ratio	≥1.3
Elongation	~2
Pulse length	≤5 s
Auxiliary heating power, NBI	5 MW
Auxiliary heating power, ECRH	≤1.5 MW

tight aspect ratio is the expectation that there will be many particles 'trapped' in the magnetic mirrors of the tight torus, and these will have large excursions from the magnetic surfaces, leading to large losses. Also, it had been thought that the bootstrap current (required for steady-state operation) would be small. Here the answer lies in the detail, and in careful application of the relevant theory to accurately computed magnetic field distributions. When the theory of neoclassical transport (originally a large aspect ratio approximation) is modified for the spherical tokamak it is found that the cross-field transport is much reduced, while the bootstrap current remains substantial. This is an ongoing research field, and includes more complex particle orbits such as 'potato' orbits to supplement the well-known 'banana' orbits. There does indeed appear to be self-consistent steady state scenarios for spherical tokamaks in relation to transport and current drive (solutions to power and particle exhaust issues are at an early stage of development).

All such theory has to be tested. During 1988 to 1990, a very low budget proof-of-principle device, Small Tight Aspect Ratio Tokamak (START) was built at Culham, UK, almost entirely from spare parts. It finally ceased operation in March 1998 after producing such an astonishing set of results that it had become abundantly clear that the ST concept had to be pursued on a larger device. These results included: the achievement of a β value (ratio of average plasma pressure to toroidal magnetic field pressure) that exceeded the record on any other tokamak by more than a factor of 3; energy confinement times in excess of that predicted for START using the latest scalings from the ITER physics R&D activities; and configurations that may, from experimental evidence on START, be free from terminal plasma disruptions (which are a serious design issue for large tokamaks). The adaptable MAST experiment is the next step in Europe and complements the similarly sized NSTX facility under construction at Princeton in the US, these being the largest ST devices in the world. It will have strong additional heating (5 MW of injected 70 keV deuterium atoms, and 1.5 MW of 60 GHz microwaves to match the electron cyclotron resonance), and will be of a size (minor radius ~50 cm) and current to allow comparison with the existing medium-sized MA-level conventional-aspect-ratio tokamaks in Europe and elsewhere. MAST is essentially a scaled up START (a factor 2 in linear dimension) with a much longer pulse length (up to 5 seconds). The 4.4 m high 4 m diameter cylindrical vacuum vessel is as tall as the JET vessel. There have been, however, some engineering challenges. Perhaps the foremost of these is the design of the centre column (comprising 24 wedge-shaped conductors and a compact high-stress solenoid) whose diameter has to be minimised subject to mechanical, thermal and electrical stress constraints in order to minimise the aspect ratio of the plasma. Since the centre rod expands during a shot, and the vacuum vessel during baking, relative motion of up to 12 mm has to be accommodated to avoid fracture of the toroidal field coils or joints: a comprehensively-tested high current sliding joint is used at the ends of the centre rod.

Since the ST is a new concept, it presents an opportunity to combine radical design solutions with the large technology database developed for the conventional aspect ratio tokamaks to produce compact low-capital cost fusion devices, once the underlying physics has been demonstrated experimentally. Potential applications include a compact volume neutron source for testing materials and large complex components (blanket modules, welded/brazed assemblies *etc*) for any fusion power plant, and a low capital cost core of a power plant as a long-term alternative. Outline designs exist for a driven component test facility (Q~1) generating some tens of megawatts of fusion power, which would enable components with a total surface area of several square meters to be exposed to neutron fluxes and fluences at power-plant-level. There are, however, some technological issues to be resolved for a ST fusion device, as might be expected with a new concept. The next step is to proceed with the physics basis, and data from START, MAST and other new STs around the world combined with accompanying theoretical studies should allow designs for fusion devices to be created based on proven physics.

The first extended physics campaign on MAST is planned for the first part of 1999.

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Further reading

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