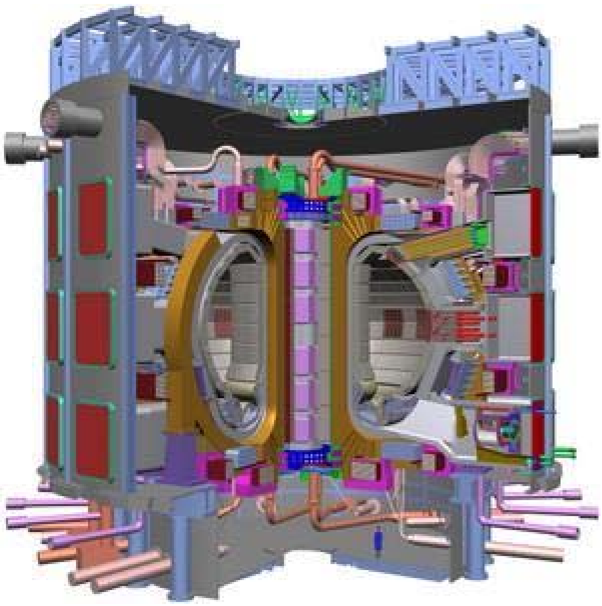
The roadmap to magnetic confinement fusion



Cutaway of the ITER tokamak. *(© ITER)*

There are two ways to achieve controlled nuclear fusion, by *magnetic confinement* and by *inertial confinement*. Magnetic confinement fusion uses a magnetic field to contain a hot plasma. Inertial confinement fusion uses an intense pulse of laser light to compress and heat a small capsule of fuel. The fuel in both cases is usually a deuterium-tritium mixture, because that combination is the easiest to fuse.

Most research effort has been directed towards magnetic confinement technology. The plasma geometry is usually based on the toroidal “tokamak” configuration invented by Tamm and Sakharov in 1950 and declassified in 1957 [1]. Over 198 tokamaks have been built [2].

Four large tokamak projects were built in the 1980s. Two of these, the American TFTR [3] and the European JET [4] reactors, were aiming for breakeven fusion energy generation when first conceived, but both fell just short of this goal. Energy breakeven occurs when the energy released by the fusion reaction equals the energy put in to heat the plasma. The Japanese JT-60 tokamak [5] lacks tritium-handling facilities and is restricted to deuterium-only plasmas, but the plasma conditions it has achieved would have yielded break-even fusion output if a deuterium-tritium mix had been used [5]. The Russian T-15 tokamak [6] has explored the use of large superconducting magnets.

Table 1. Recent and future tokamak reactors:

The road to ITER and beyond ITER

Project	Country	Operation	Fuel [(a)]	Fusion Power MW	Energy gain
TFTR [3]	U.S.A.	1982 – 1997	D–T	10.7	0.3
JET [4]	E.U.	1983 – ongoing	D–T	16	0.6
JT-60 [5]	Japan	1985 – ongoing	D–D	-	(1.25) [(b)]
T-15 [6]	Russia	1988 – 1995	H–H	-	-
ITER [8]	Intl.	2018 – 2036	D–T	500	10
DEMO [10]	Intl.	2032 – 2050 ?	D–T	2000	25
PROTO [10]	?	2050 – ??	D–T	4500 [(c)]	25

Figures for ITER, DEMO and PROTO are projected.

Notes:

(a) H is hydrogen; D is deuterium; T is tritium;

(b) This is the energy gain that would have been obtained with a D-T plasma, rather than D-D.

(c) Figure derived from the 1500MW(e) power output given in reference [10].

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These large tokamaks, and several smaller projects, notably the spherical tokamak experiments such as MAST and NSTX, have paved the way for a next-generation project, ITER. This $5 billion [7] international collaboration draws together the world’s tokamak research community in a single megaproject. ITER, to be built in Cadarache, France, will be several times larger than any previous tokamak. Scheduled for completion in 2016, It will burn a deuterium-tritium fuel mix to produce 500 MW of fusion power with 10-fold energy multiplication [8]. That is, ITER is intended to generate ten times more fusion energy than the energy put in to heat the plasma. It will also demonstrate the superconducting magnets and remote maintenance technologies needed for an operational reactor, and test tritium breeding concepts [8].

Roadmap beyond ITER

The ITER project has mapped out a road map to a commercial fusion power reactor, if ITER continues to demonstrate that the tokamak line of magnetic confinement is the most promising for power generation (Table 2) [9].

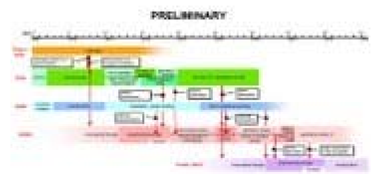
A project called the International Fusion Materials Irradiation Facility (IFMIF) will develop and test radiation-resistant and low-activation materials that can withstand the high neutron fluxes in a fusion reactor. IFMIF will operate concurrently with ITER. Results from these two projects will feed into the DEMO [9] prototype power reactor. DEMO will have four-fold higher power output [10] than ITER, and aims for an energy gain of 25. Experience with this will feed into the first commercial fusion power reactor [9], scheduled for operation in 2050 in this "fast-track" scenario.

This scenario assumes that ITER will deliver on the promise of tokamak-based fusion. That isn't guaranteed. Magnetic confinement fusion remains a scientific research problem rather than an engineering problem, and the engineering issues have barely been touched.

Table 2.

"Fast track" fusion roadmap

Facility	Date
ITER	2016
IFMIF	2016
DEMO	2032
Power plant	2050



"Fast track" roadmap to fusion power (click image to enlarge) © *ITER [9]*

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