JT-60SA scientific programme toward ITER and DEMO

P. Barabaschi[1], T. Bolzonella[2], G. Giruzzi[3], S. Ishida[4], Y. Kamada[5], K. Lackner[6], G. Matsunaga[5], T. Nakano[5], F.P. Orsitto[7], K. Shinohara[5], T. Suzuki[5], H. Urano[5], M. Yoshida[5], and the JT-60SA team

[1]*JT-60SA EU-Home Team, Fusion for Energy, Boltzmannstr 2, Garching 85748, Germany*

[2]*Associazione EURATOM-ENEA, Consorzio RFX, corso Stati Uniti 4, 35127 Padova, Italy*

[3] *CEA, IRFM, 13108 St Paul-Lez-Durance, France*

[4]*JT-60SA Project Team, 801-1 Mukoyama, Naka, Ibaraki 311-0193, Japan*

[5]*JT-60SA JA-Home Team, 801-1 Mukoyama, Naka, Ibaraki, 311-0193 Japan*

[6]*Max-Planck Institut für Plasmaphysik, EURATOM Association, 85748 Garching, Germany*

[7]*Associazione EURATOM-ENEA, CR ENEA Frascati, C.P. 65, 00044 Frascati, Rome, Italy*

JT-60SA (Super Advanced) is a large fully superconducting new tokamak device [1, 2] being developed under the Broader Approach Satellite Tokamak Programme jointly by Europe and Japan, and under the Japanese national program. First plasmas are foreseen in 2016. This device is intended to play a key role to prepare and accompany the ITER programme in the prospect of DEMO. The design of an early DEMO will very likely start before ITER D-T campaigns and for that reason important information will have to come from existing devices. JT-60SA is a tokamak with major radius R=2.96 m and minor radius a=1.18 m, aspect ratio A=R/a=2.5 (Figures 1 and 2) which is intended to complement similar existing and near term international efforts. With plasma current capabilities up to 5.5 MA (at B_t=2.25 T) and an envisaged heating power of up to 41 MW it will operate in DD, aiming at reaching break-even equivalent regimes. Final goal of the JT-60SA research program is to prove the integration of all the requirements needed in a high-performance DEMO scenario, having as main reference a low-aspect ratio, high performance, steady state DEMO prototype [3].

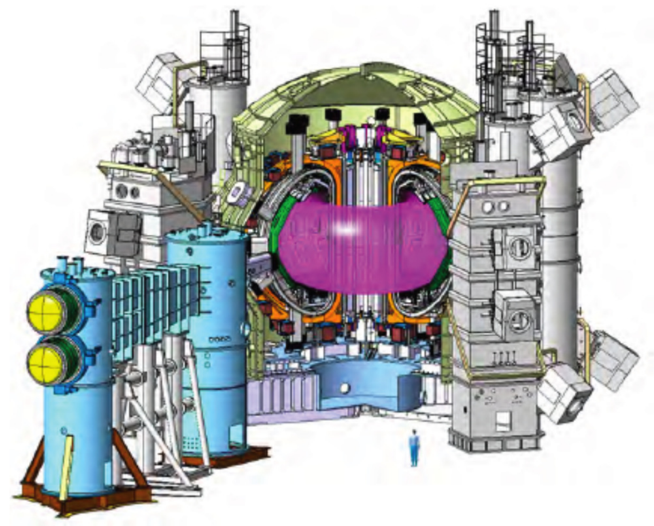

Figure 1: JT-60SA device.

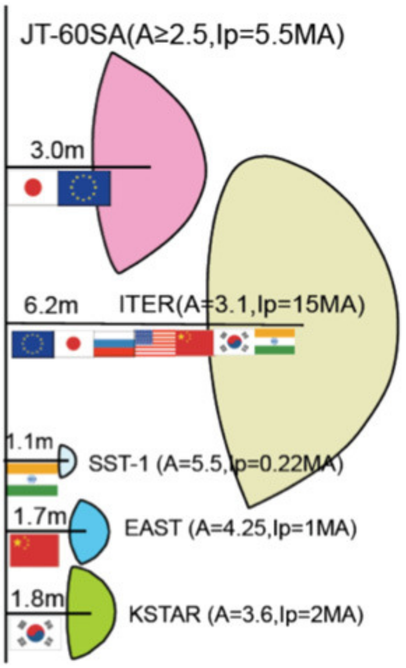

Figure 2: Plasma cross-section of world non-circular superconducting tokamaks.

To realize that, in its final research phases, JT-60SA will extend integrated experiments to pulse durations (up to 100 s) long compared to all plasma physics and most plasma-wall interaction characteristic time-scales. In particular, the flexibility of the device will allow operations at normalized beta values exceeding the no-wall limit ($\beta_N \geq 2.8$) testing different possibilities for passive and active control techniques of Advanced Tokamak stability (see Figure 3 for the active coil systems designed for plasma equilibrium and stability control). The Heating and Current Drive mix present in the device relies mainly on a powerful and flexible Neutral Beam injector system supported by an Electron Cyclotron Wave system. Capabilities of the two systems during the different exploitation phases will be described below.

One further important point to be noticed is the low aspect ratio of the device that will complement the geometry of present devices (and of ITER). In fact the aspect ratio of a fusion device from a system analysis point of view can be regarded as the main free parameter in the design of any new device when Q, peak toroidal field and burn flux are fixed [4]. Needless to say, different aspect ratio choices for DEMO design naturally involve very broad operational and economical consequences.

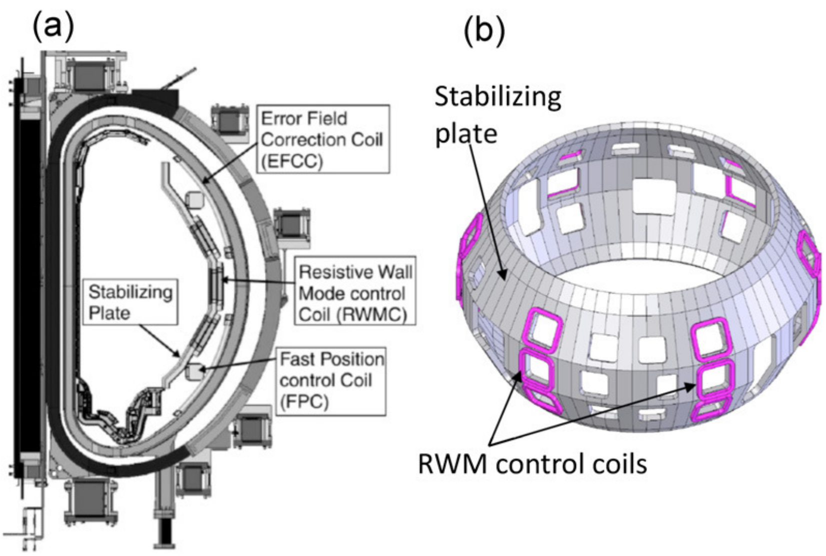

Figure 3: Present design of the main active stabilisation coil systems for plasma position (FPC), error fields and RMP (EFCC), and RWM (RWMC).

Different research phases are foreseen during the life of the machine depending on the availability of key components such as heating systems and divertor materials (Table 1). After an Initial Research Phase, where the main device components will be tested and the basic plasma scenario assessed, an Integrated Research Phase will follow, with full-monoblock carbon divertor, extended pulse durations and increased annual neutron limit. After these first operations, important upgrades of the device can be imagined, such as moving to a metallic first wall, and could take advantage of fully operational remote handling equipment.

	Year	Expected Duration		Annual Neutron Limit	Remote Handling	Divertor	P-NB	N-NB	ECH	Max Power	Power x Time
Initial Research Phase	phase I	1-2y	H	-	R&D	LSN partial monoblock Carbon Div. Pumping	10MW	10MW	1.5MW x100s + 1.5MW x5s	23MW	NB: 20MW x 100s 30MW x 60s duty = 1/30 ECH: 100s
	Phase II	2-3y	D	4E19			perp 13MW Tang. 7MW			32MW	
Integrated Research Phase	phase I	2-3y	D	4E20		LSN full-monoblock Carbon Div. Pumping			7MW	37MW	
	Phase II	2-3y	D	1E21	Use						
Extended Research Phase		>5y	D	1.5E21		DN full-monoblock Metal or Carbon Div. Pumping	24MW			41MW	41MW x 100s

Table 1: Research phases for JT-60SA operations.

Given the present ITER, and possibly DEMO, timeline, the first research phase ("Initial Research Phase" in the JT-60SA Research Plan) will be critical for both developing and assessing ITER scenarios and for building up a consistent scientific base in view of DEMO design. In fact that period lasting 3-5 years compares well with the beginning of first extensive ITER campaigns and DEMO project(s) definition.

JT-60SA Initial Research Phase will start with hydrogen plasmas and will be followed by deuterium experiments, this mainly to keep a low annual neutron production ($4x10^{19}$ in the D phase) during the preparation of full performance campaigns and in view of easy (i.e. no remote handling needed) maintenance and substitution of machine components.

Main characteristics of this phase are the presence of full carbon first wall and divertor targets, full power negative ion source neutral beams (10 MW), somewhat reduced power for ECRF and positive ion source NB systems. Lower single null divertor configurations with a partial mono-block target will be tested. Divertor power handling in this phase will allow 10 MW/m^2 x 5 s (1 MW/m^2 x 100 s) for the lower divertor and 3 MW/m^2 x 100 s for the upper divertor. Heating and CD systems will provide, in addition to the full power 10 MW N-NB, 30 MW x 60 s (20 MW x 100 s) P-NB and 3 MW x 5 s (1.5 MW x 100 s) ECH.

During the initial research phase the scientific community will be already able to take advantage of some of the unique capabilities of this new device such as the presence of high energy particles generated by the fully operational negative ion source based neutral beam system (two units, upper and lower, with 500keV beam energy and 5MW/unit beam power,

Figure 4) providing flexible current drive control by on- and off-axis injection and dominant electron heating mechanism.

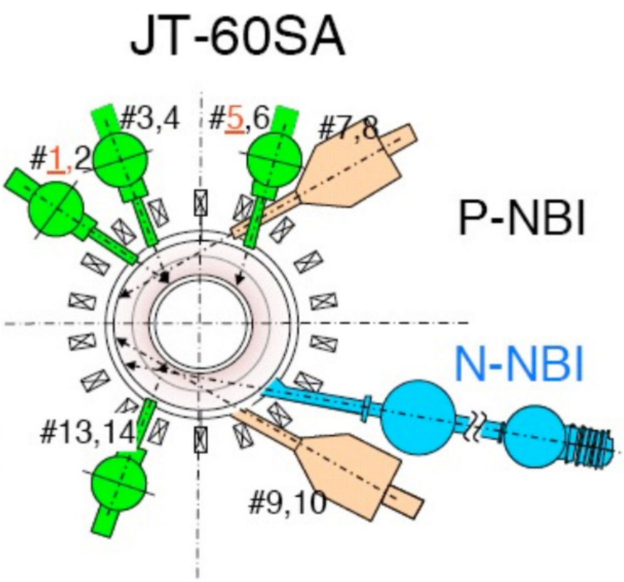

Figure 4: Layout of the NBI Systems in JT-60SA

In this way, already during the early deuterium experiments many of the target scenarios will be developed and tested for reduced pulse lengths. The number of long pulse discharges will be mainly determined by the constraints on the annual neutron production. In this early period of operations, key ITER and DEMO relevant issues could be already explored. A detailed planning and definition of them should go in parallel and complement similar efforts to be done in other devices. Important initial issues where JT-60SA can play a leading role include the development of reliable start-up scenarios with and without ECRF application at breakdown and taking into account the limited one-turn voltage available (relevant for low aspect-ratio DEMO concepts [3]), development of real time plasma control schemes for MHD control and scenario sustainment, H-mode threshold studies and ELM mitigation via magnetic perturbations. Last but not least, in this phase important advances in disruption mitigation and control have to be foreseen, paving the way toward effective disruption avoidance strategies to be implemented in DEMO.

In summary, the new JT-60SA device is ready to play an important role in defining future directions for fusion energy exploitation since its early operational phases and well complementing other international efforts. A growing interest and participation in both Japan and EU fusion communities to the definition of its Research Plan is of maximum importance for its success.

References

[1] S. Ishida et al., Fusion Eng. and Design, **85**, 2070 (2010)
[2] Y. Kamada et al., Nucl. Fusion **51** 073011 (2011)
[3] K.Tobita et al., Fusion Eng. and Design, **81**, 1151 (2006); K. Tobita et al., Nucl. Fusion **49** 075029 (2009)
[4] P. Barabaschi, Nucl. Fusion **41** 155 (2001)