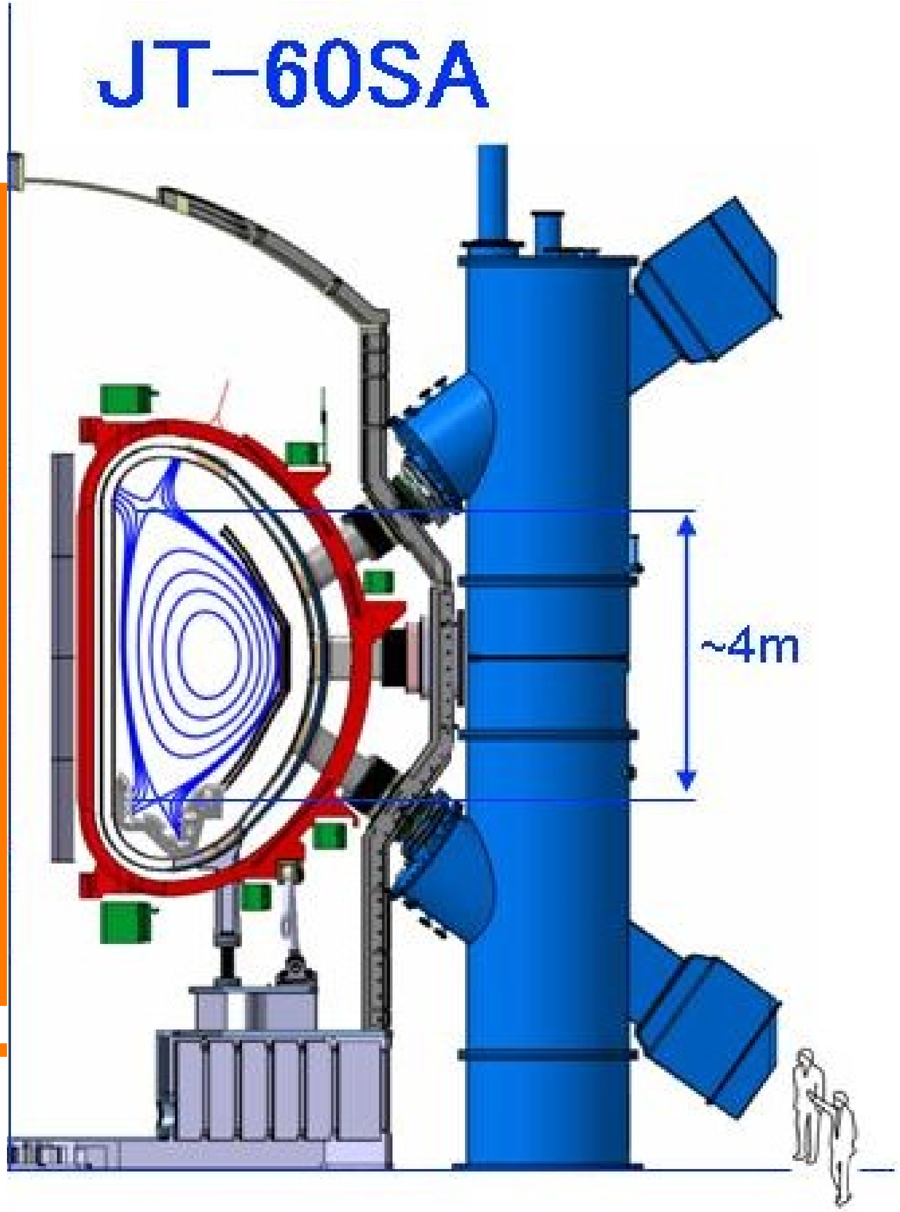
Runaway electrons and JT-60SA

Taina Kurki-Suonio
Aalto University

REM 2017, Prague, 8.6.2017



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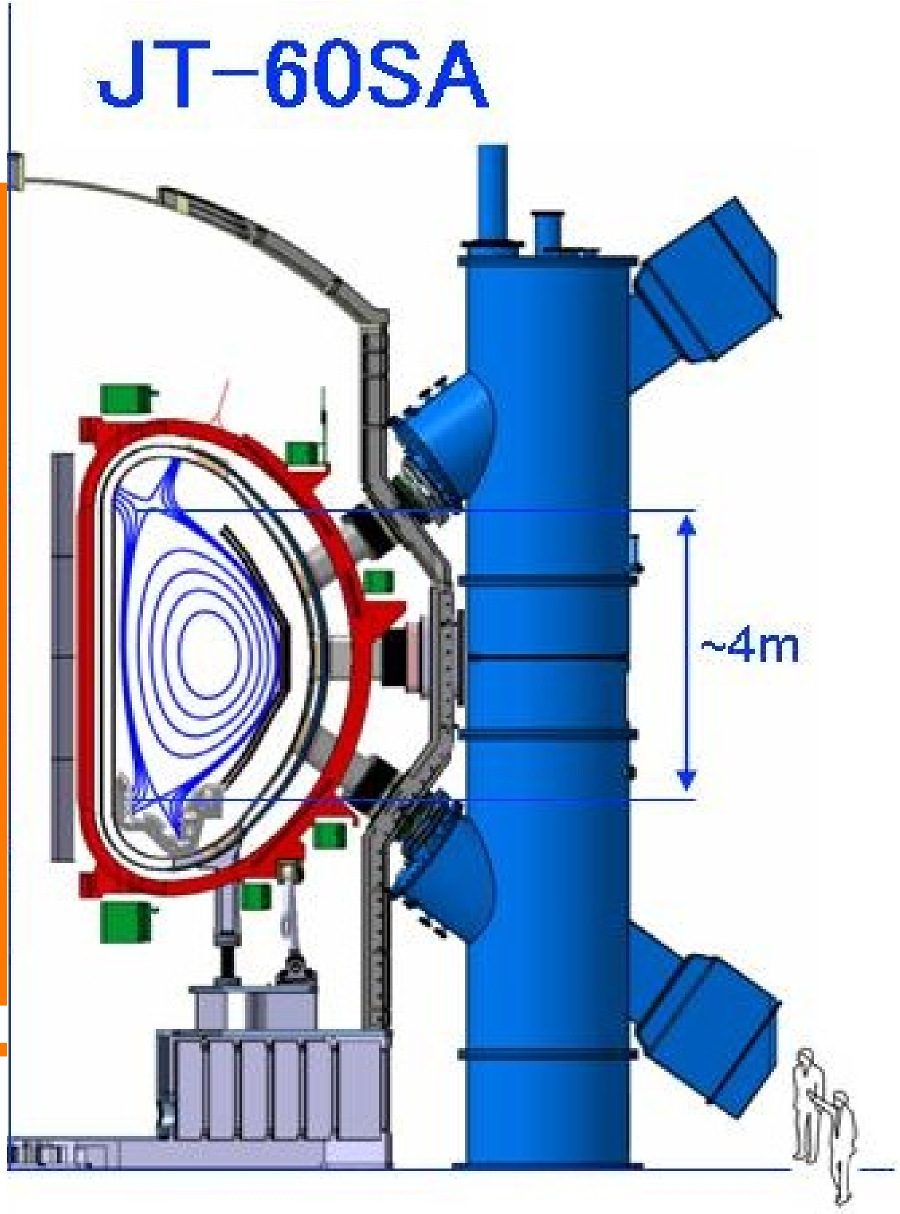
Konsta Särkimäki

REM 2017, Prague, 8.6.2017

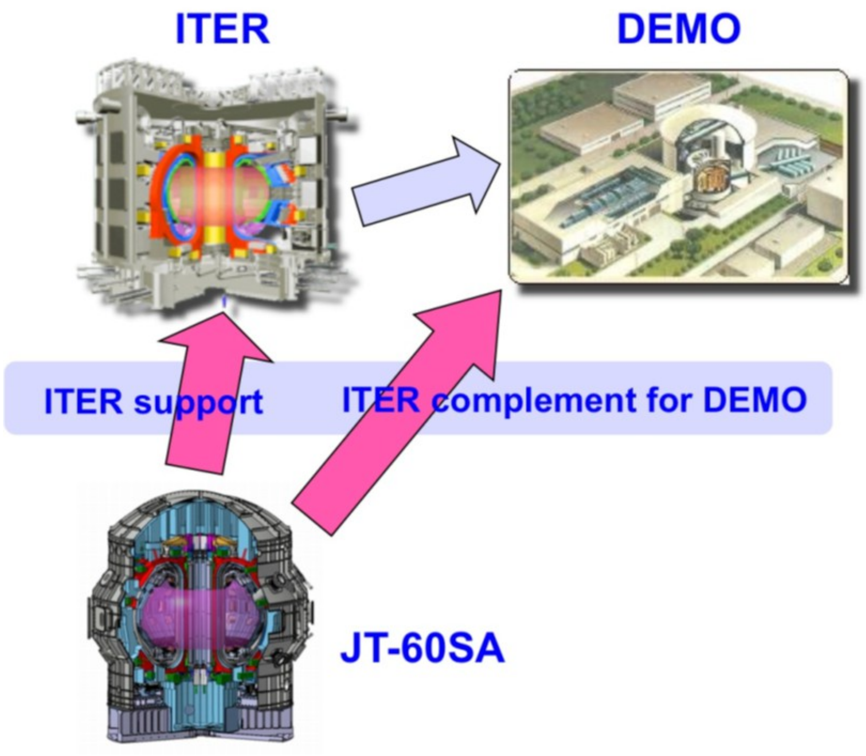


- REEs were recognized as one of the major threats/unknowns at project-planning meeting
- Currently no RE-modelling (at least from the European side)
- JT-60SA plans to study RE mitigation but they would rather avoid them

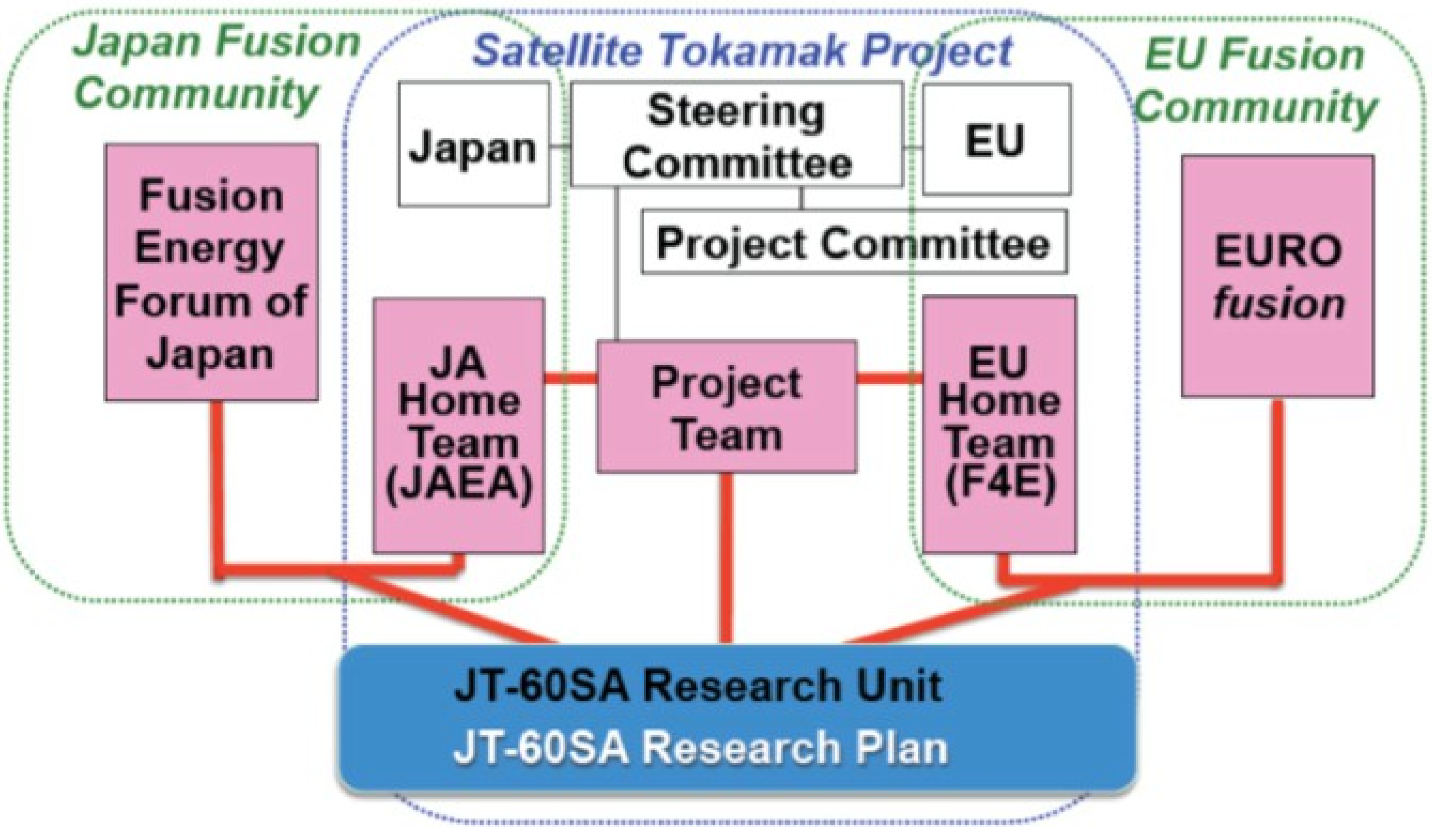
JT-60SA
”the best thing since sliced bread” (read: W7-X)

- ★ JT-60SA is The Device to
  - ★ prepare for successful operation of ITER
  - ★ develop diagnostics for ITER
  - ★ test predictions for ITER
  - ★ prepare for problem situations in ITER

⇨ take a *comprehensive* advantage of JT-60SA
  – not just for ITER but even for DEMO



What does Europe have to do with a Japanese device?



i.e., JT-60SA is a *joint* device for Europe and Japan

Main features of JT-60SA

S=superconducting, A= advanced

Physical dimensions:

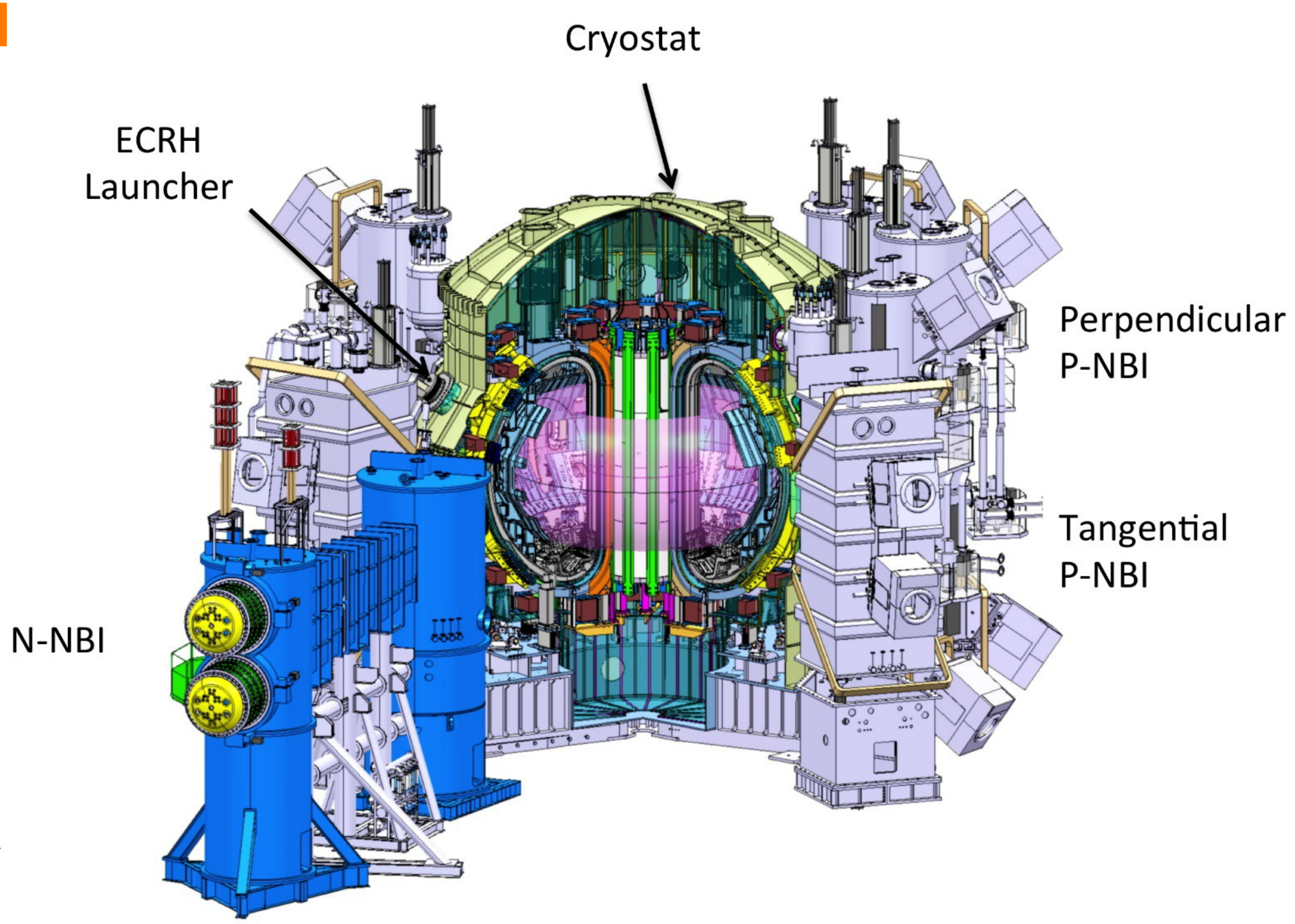
- ★R = 2.93 – 2.97m
- ★a = 1.11 – 1.18m
- ★elongation: 1.80 – 1.91
- ★triangularity: 0.41 – 0.5

Magnetic cage:

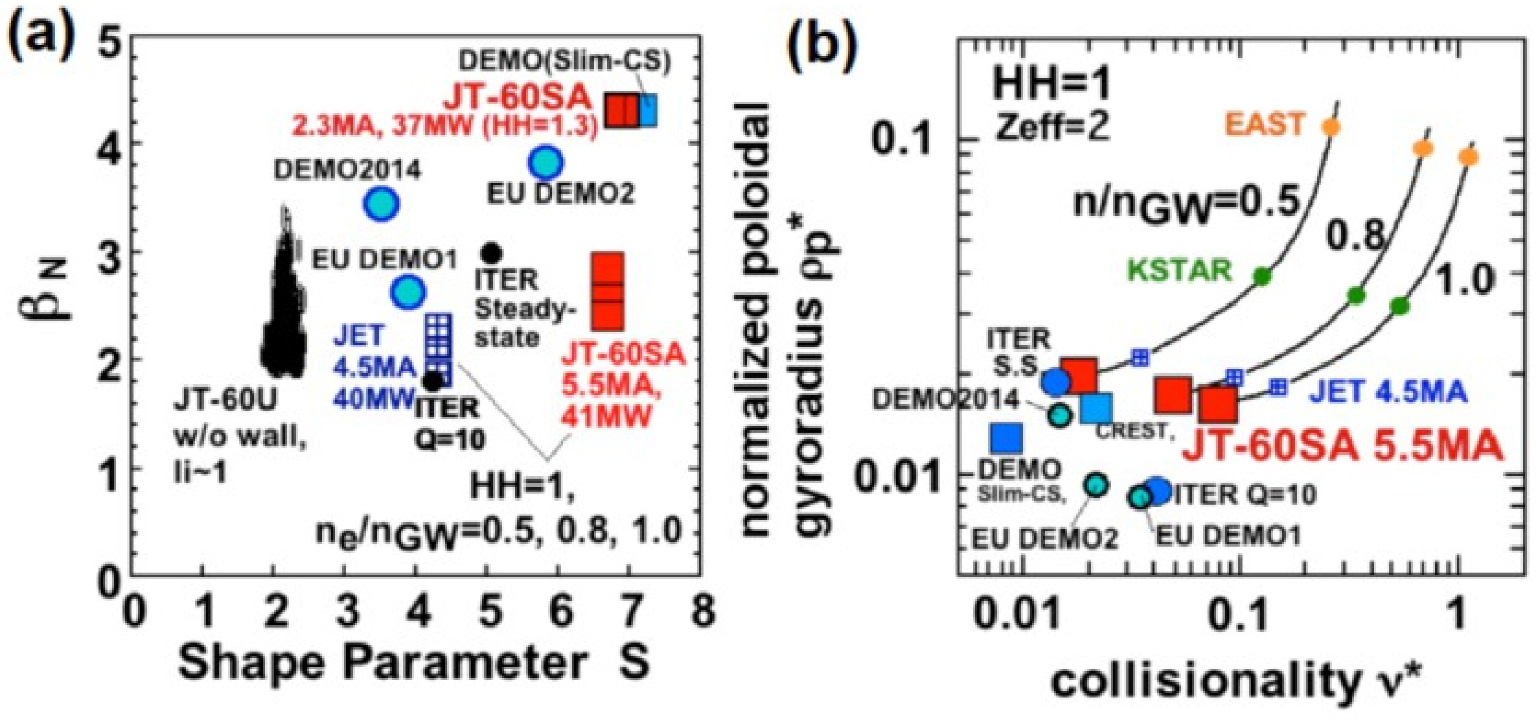
- ★B_T ~ 2.28 T
- ★I_p ~ 5.5 MA

Plasma heating:

- ★7 MW of ECRH
- ★24 MW of conventional (P) NBI @85keV
- ★10 MW of negative (N) NBI @500keV



In dimensionless parameters, JT-60SA reaches towards ITER and DEMO



$\rho_p^* = 0.46\times10^{-2}\,(A_i)^{1/2} \langle T_i\rangle^{1/2} / (B_p\, a)$ w/ $A_i=2$; $\nu^* = 0.8\times10^{-2}\, q\, R\, A^{3/2} Z_{eff} \langle Te\rangle^{-2} \langle n_e\rangle$

Figure 2-4 in JT-SA Research Plan
www.jt60sa.org/pdfs/JT-60SA_Res_Plan.pdf

Special (= interesting) features of JT-60SA

- ★ High plasma current:
  - 5.5 MA in a low aspect ratio configuration (R_0 =2.96 m, A=2.5)
  - 4.6 MA in the ITER-shaped configuration (R_0 =2.93 m, A=2.6)
- ★ Long pulses (100s) due to super-conducting coils
- ★ High energy *negative* neutral beams: 10 MW of 500 keV N-NB
- ★ JT-60SA goal for DEMO: demonstrate and sustain *integrated performance*
  - ***high*** H-factor, β_N, f_{BS}, non-inductively driven current fraction, normalized plasma density, fuel purity, and radiation power

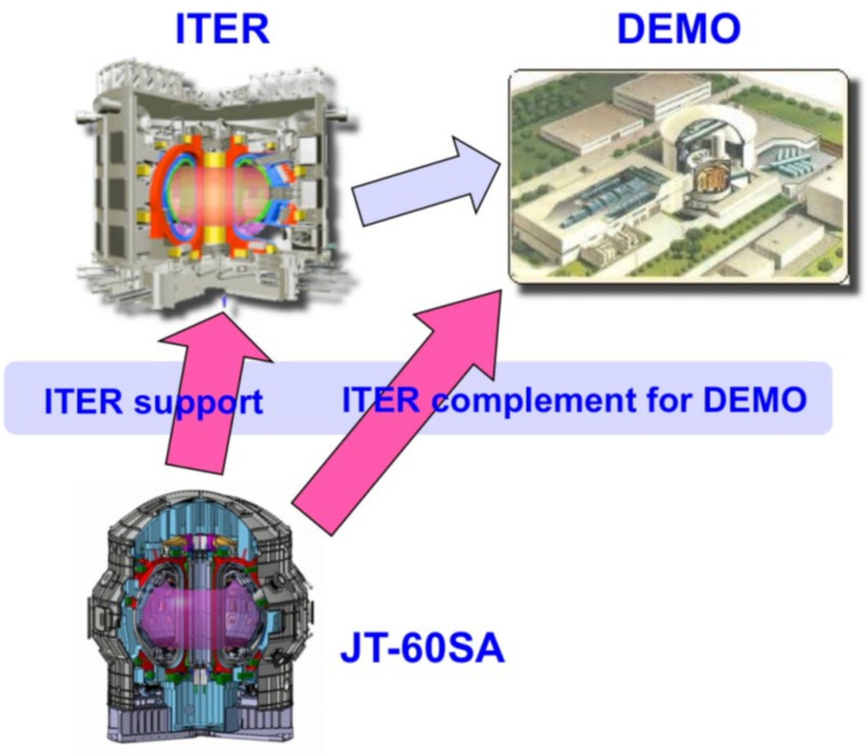
For more details, see *www.jt60sa.org: Research Plan*

Parameters	#2 Full Ip Inductive 41MW	#4-1 ITER-like-Shape Inductive 34MW	#4-2 Advanced inductive (hybrid) 37MW	#5-1 High βN Full CD 37MW	#5-2 High βN Full CD 31MW
Plasma current, I_P (MA)	5.5	4.6	3.5	2.3	2.1
Toroidal magnetic field, B_T (T)	2.25	2.28	2.28	1.72	1.62
Major radius, R_P (m)	2.96	2.93	2.93	2.97	2.96
Minor radius, a (m)	1.18	1.14	1.14	1.11	1.12
Aspect ratio, A	2.5	2.6	2.6	2.7	2.6
Elongation, κ_x , κ_{95}	1.87, 1.72	1.81, 1.70	1.80, 1.72	1.90, 1.83	1.91, 1.84
Triangularity, δ_x, δ_{95}	0.50, 0.40	0.41, 0.33	0.41, 0.34	0.47, 0.42	0.45, 0.41
Safety factor, q_{95}	3.0	3.2	4.4	5.8	6.0
Shape Parameter (=q_{95}Ip/(aBt))	6.3	5.7	5.9	7.0	7.0
Plasma Volume (m3)	131	122	122	124	124
Heating Power, Pheat (MW)	41	34	37	37	31
Temperature (Vol-ave.), <Ti>,<Te> (keV)	6.3, 6.3	3.7, 3.7	3.7, 3.7	3.4, 3.3	3.1, 2.9
Electron Density, Vol-ave. (E20/m3)	0.56	0.81	0.62	0.42	0.43
Stored Energy (Thermal, Fast ion) (MJ)	22.2, 4.0	18.0, 1.5	13.4, 2.1	8.4, 2.7	8.1, 1.7
Thermal Energy Confinement Time τE(s)	0.54	0.52	0.36	0.23	0.25
Current DiffusionTime (s)	32.7	15.2	14.6	12.6	10.8
Assumed Confinement improvement, HHy2	1.3	1.1	1.2	1.3	1.38
Normalized beta, β_N	3.1	2.8	3.0	4.3	4.3
Bootstrap current fraction, fBS	0.28	0.3	0.4	0.68	0.79
Non inductive CD fraction, fCD	0.5	0.43	0.58	1	1
Normalized density, ne/ nGW	0.5	0.8	0.8	0.85	1.0

Fast particles issues with eyes on fusion reactors (including ITER and DEMO)

Fast particles in tokamaks:

- Fast ions (100keV – MeVs)
  - Plasma heating = fusion conditions
  - Current drive
  - Plasma rotation
- Fusion neutrons (1 … 10 MeV)
  - tritium breeding,
  - DPA, activation of surrounding materials
  - energy carriers
- **Potential run-away electrons (1 …10 MeV)**
  - **An enormous (undesired) welding torch**



Run-away electrons

Key questions on REs in large tokamaks

- Under which conditions do disruptions give rise to a runaway beam?
- Can this process be prevented or mitigated?
- Is it possible to transport runaway electrons as soon as they are generated?
- If a runaway beam nonetheless forms, what are its characteristics?
- Is it possible to slow the beam down progressively?
- What are the effects of mitigation techniques such as MGI?

- JT-60SA:
  - At a major disruption w/ $\mathbf{I_p = 5.5}$ **MA** and τ_{CQ}=10 ms, E_{tor} > 100 V/m > $E_{Dreicer}$

JT-60SA research on REs

"JT-60SA investigates … runaway electron mitigation by applying killer pellet (KP) or massive gas injection (MGI) and/or application of helical fields (RMP) by in-vessel coils …"

Proposed methods to avoid/mitigate REs:

- Unconditionally(?) *avoided* by massive Ne and/or Ar injection with > 5 kPam^3
- RE generation can(?) be *mitigated* by applying helical fields with fast response time.
- *Controlling* REs:
  - confine(?) RE beam with isolating first walls
  - Mitigate(?) with time by MGI and KP.

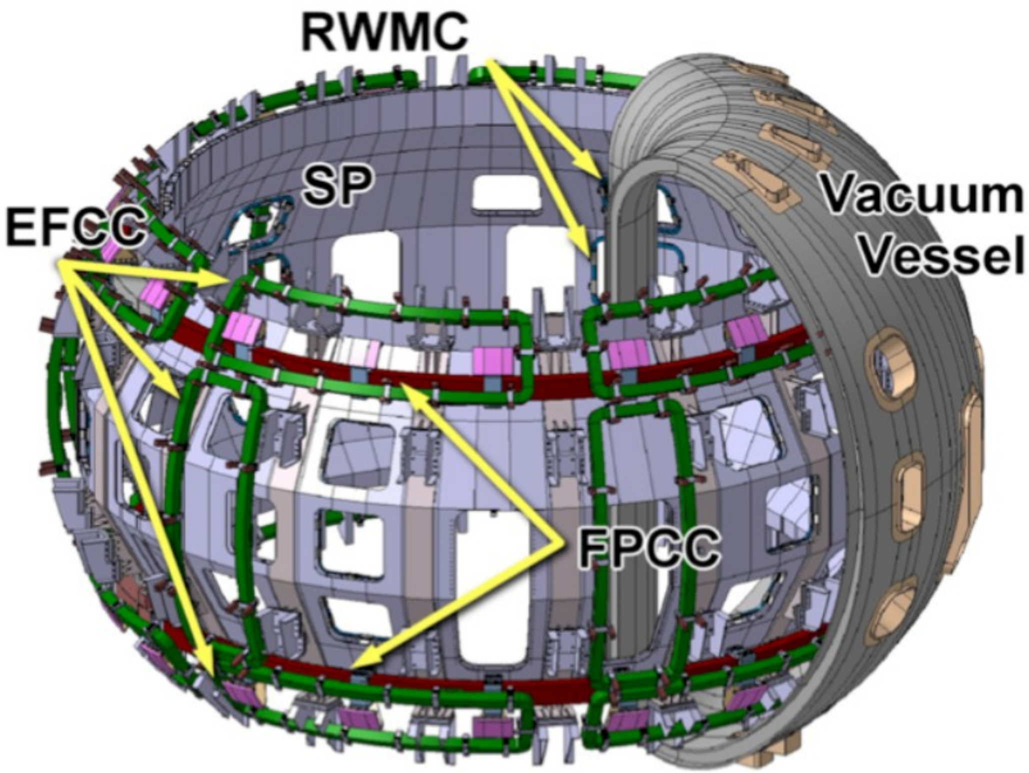
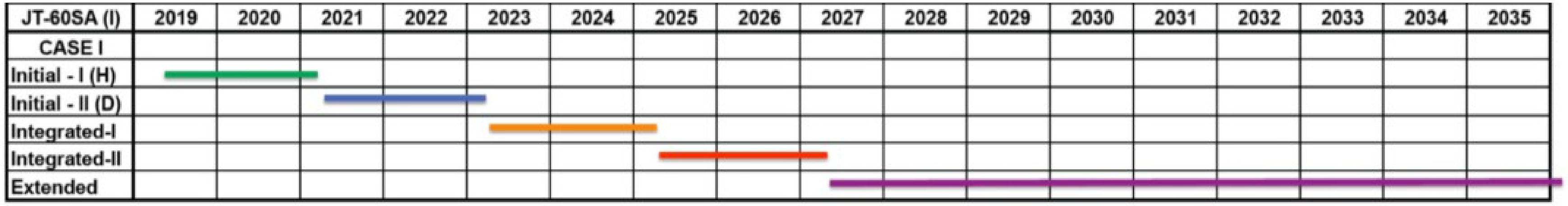


Table 2-5 Research phases and status of the key components

	Phase	Expected Duration		Annual Neutron Limit	Remote Handling	Divertor	P-NB 85keV	N-NB 500keV	ECRF 110 GHz & 138GHz	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 ECRF: 100s
	phase II	2-3y	D	4E19			Perp. 13MW Tang. 7MW			33MW	
Integrated Research Phase	phase I	2-3y	D	4E20		LSN full-monoblock Carbon Div. Pumping			7MW	37MW	
	phase II	>2y	D	1E21	Use						
Extended Research Phase		>5y	D	1.5E21		DN/SN full-monoblock Metal or Carbon Advanced Structure	24MW			41MW	41MW x 100s



** Each phase includes device up-grade period.*

News from SARP (Super-Advanced research plan) 4.0 meeting in Naka 22.-26.5.2017

★ The Big News (R. Pitts):

__ITER__ has decided that the Shattered Pellet Injection will be the ITER Baseline DMS

Reason(?): MGI found inefficient at JET ☹ [C. Reux et al., NF **55** (2015)]

(This might affect also the decision ”MGI ↔ SPI” in JT-60SA)

★ Status of diagnostics (Naoyuki Oyama)

–Due to double seal structure, the diameter of flange for each diagnostics is quite large ⇨ Number of diagnostics in one port is limited

–higher priority assigned to diagnostics for machine protection and operation

⇨ No room for new diagnostics

SARP expected at fall 2017

List of diagnostics for main chamber (in 18 Ports)

- ★ Laser interferometer (P1, P8)
- ★ Thomson scattering (P1, P2, P5, P8)
- ★ CXRS (P2, P5, P6, P7)
- ★ Neutron emission profile (P4, P10)
- ★ Neutron monitors (P6, P10, P18)
- ★ NPA (P4, P8)
- ★ Infrared TV camera (P6, P15, P18)
- ★ Visible TV camera (P6, P15, P18)
- ★ Zeff monitor (P1, P8)
- ★ ECE diagnostics (P9, P11)
- ★ VUV & crystal spectrometer (P10)
- ★ Bolometer (P16, P17, P18)
- ★ Soft X-ray detector array (P14)
- ★ Motional Stark effect polarimeter (P17)
- ★ EDICAM (P18)
- ★ Li beam probe(?), reflectometer (?) (P18)