Physics challenges of a W JT-60SA

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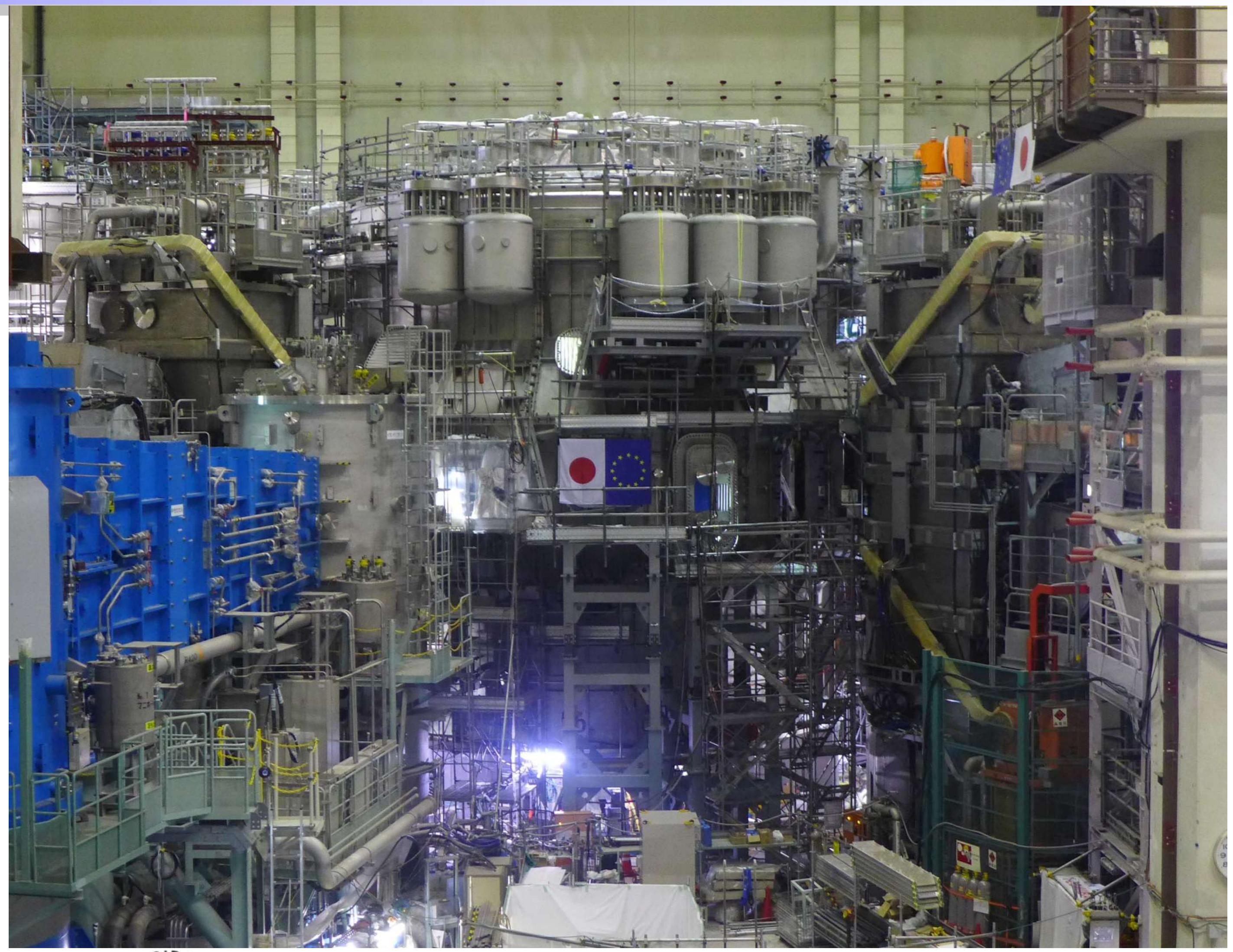
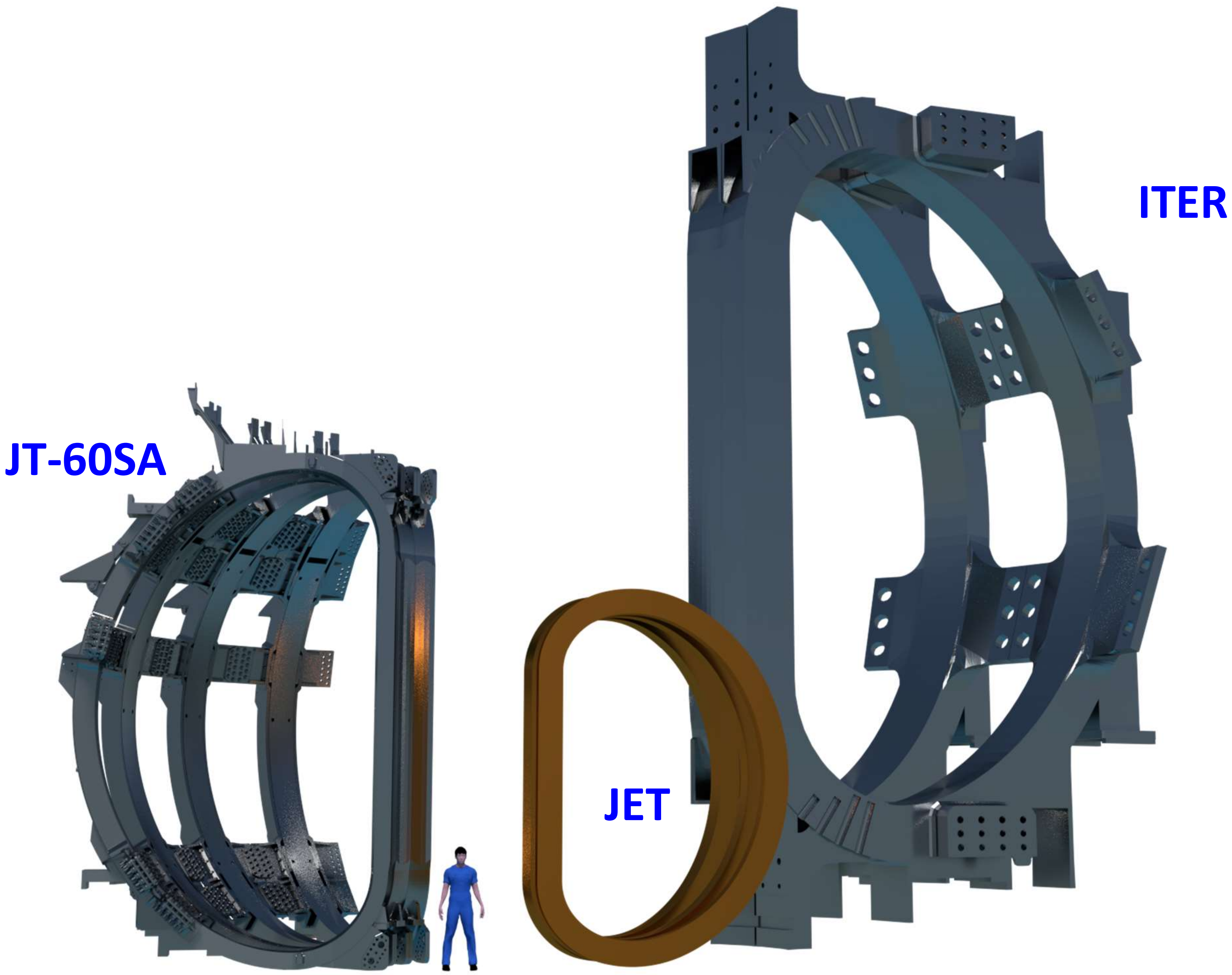
On behalf the JT-60SA Experiment Leaders

Outline

- The JT-60SA tokamak
- Objectives, programme: role of W
- Conclusions

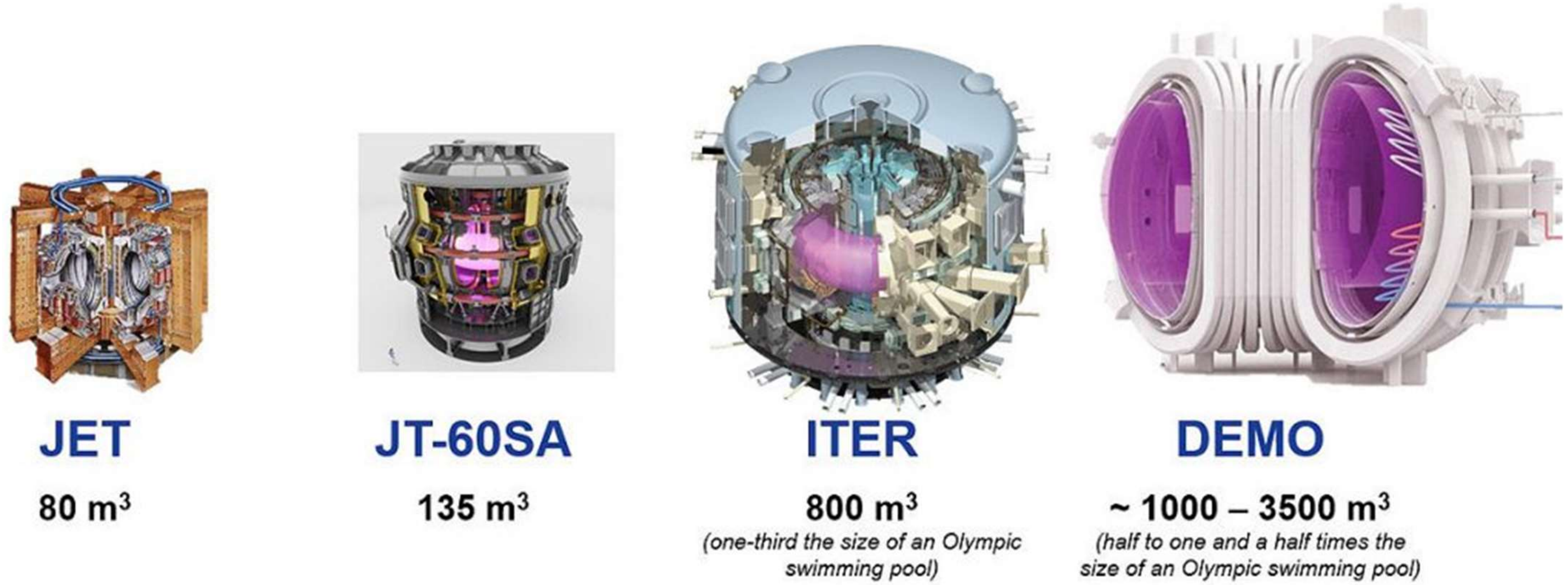


JT-60SA: big step beyond JET towards ITER



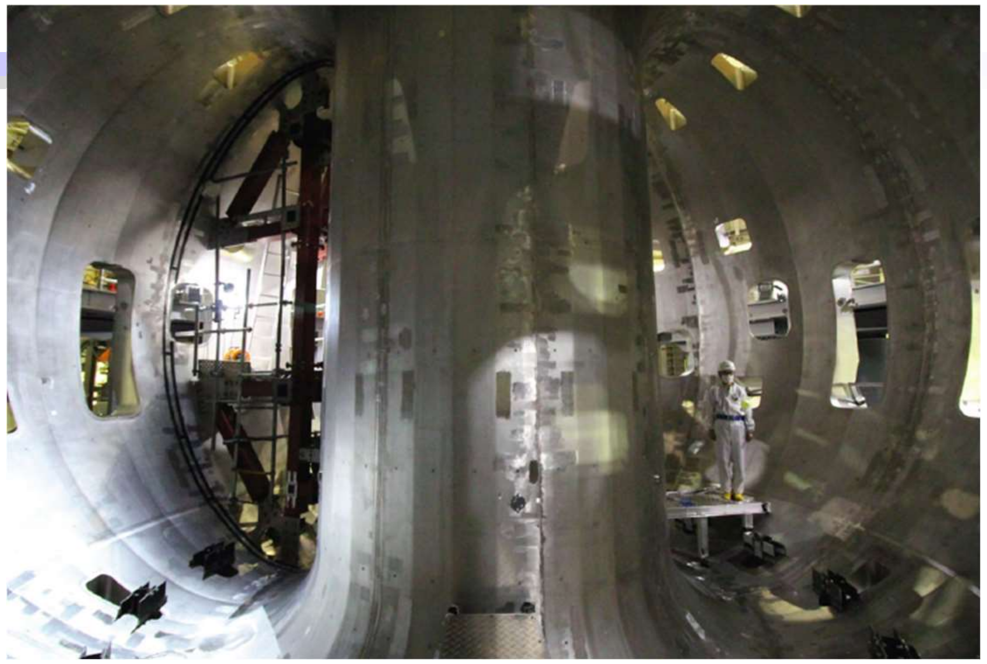
- JT-60SA is the **largest** tokamak before ITER
- JT-60SA represents an intermediate step between JET and ITER

JT-60SA: big step beyond JET towards DEMO



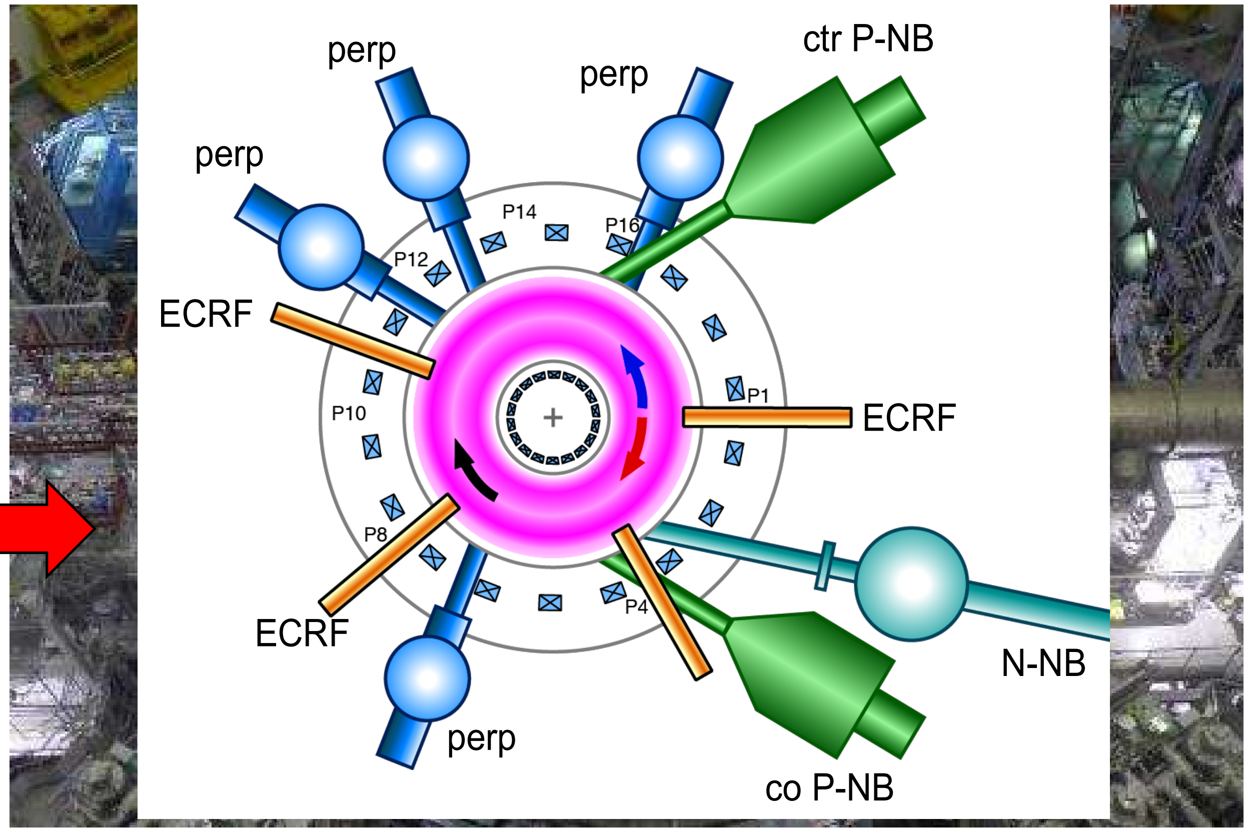
- JT-60SA is the **largest** tokamak before ITER
- JT-60SA represents an intermediate step between JET and ITER
- Unlike JET, JT-60SA can address long pulse sustained operation
- Continuous operation is necessary for DEMO

The JT-60SA tokamak

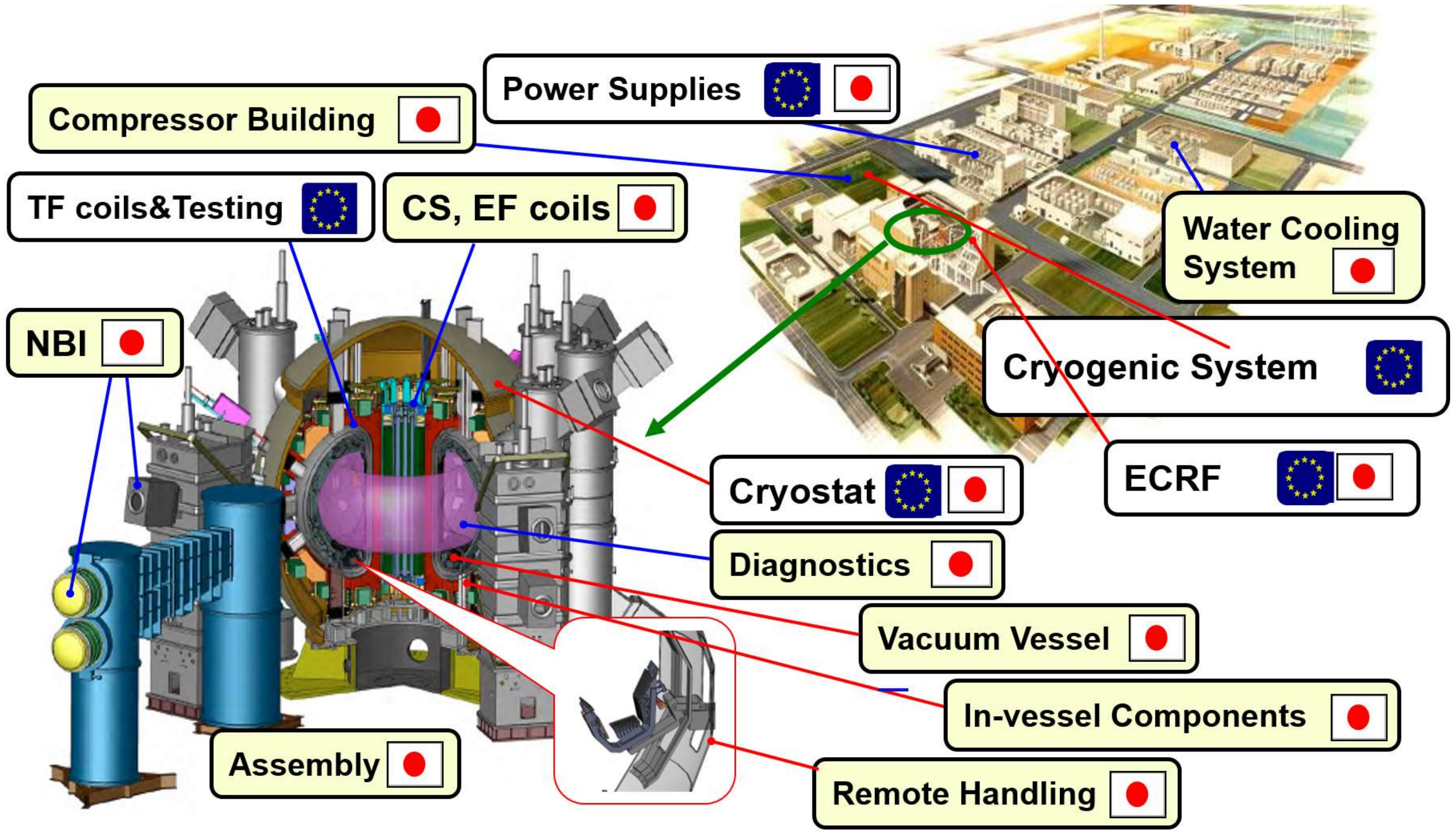


- Designed and built **jointly** by **Japan** and **EU** at the Naka site under the Broader Approach agreement
- Fully **superconducting**, high **current**, highly **shaped**
- **High input power flexibility**
- **Jointly exploited** by Japan and EU

B_t	2.25 T
I_p	5.5 MA
R / a (A = 2.5)	2.96 / 1.18 m
κ / δ	1.93 / 0.5
t (flat-top)	100 s
N-NBI (500 keV)	10 MW
P-NBI (85 keV)	24 MW
ECRH (82, 110, 138 GHz)	7 MW

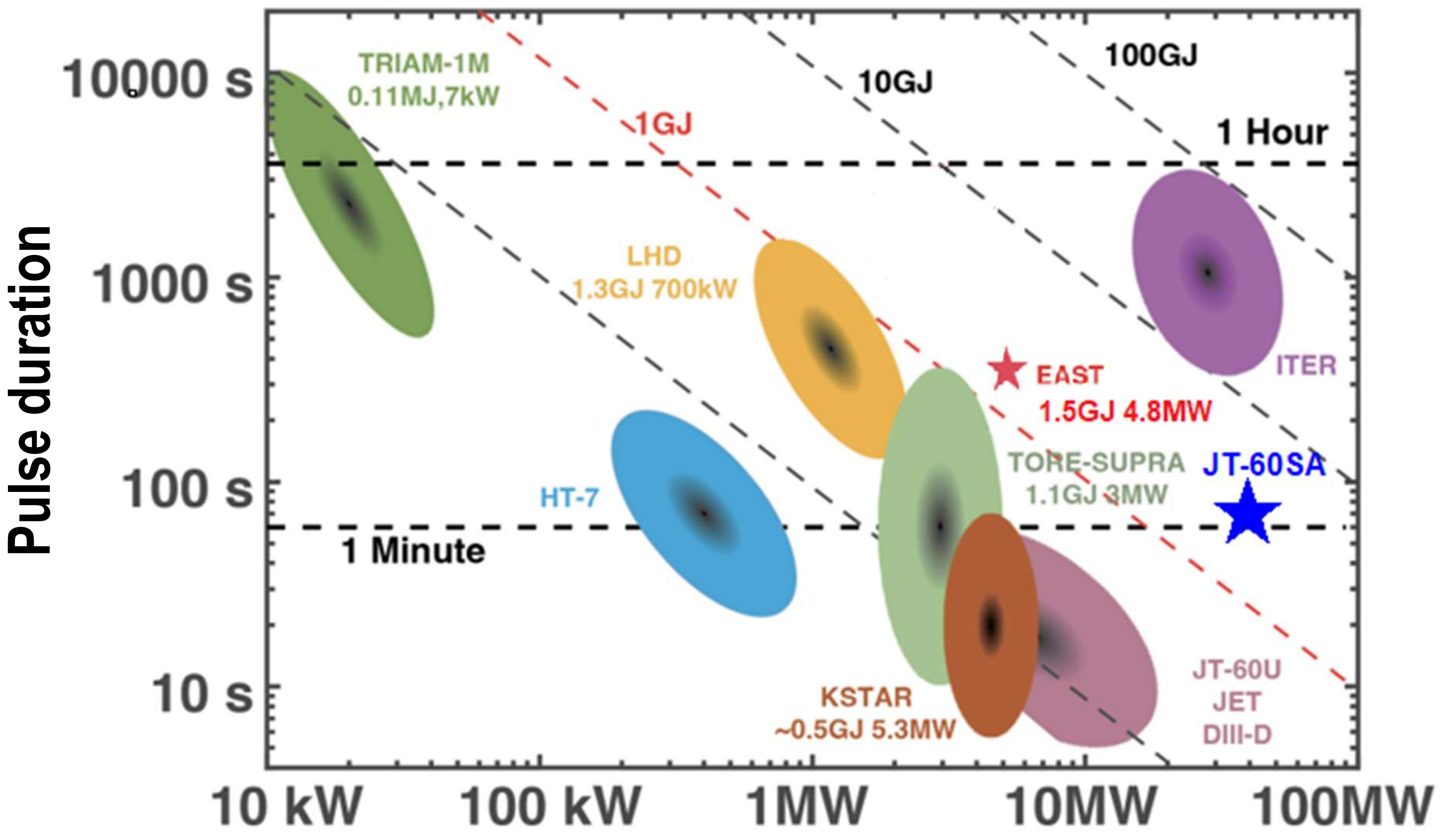


JT-60SA: A technological challenge



- JT-60SA operation requires cutting-edge technology:
  - Precise large machine assembly
  - Cryogenic systems
  - 500 keV N-NBI
  - Remote Handling

JT-60SA: A technological challenge

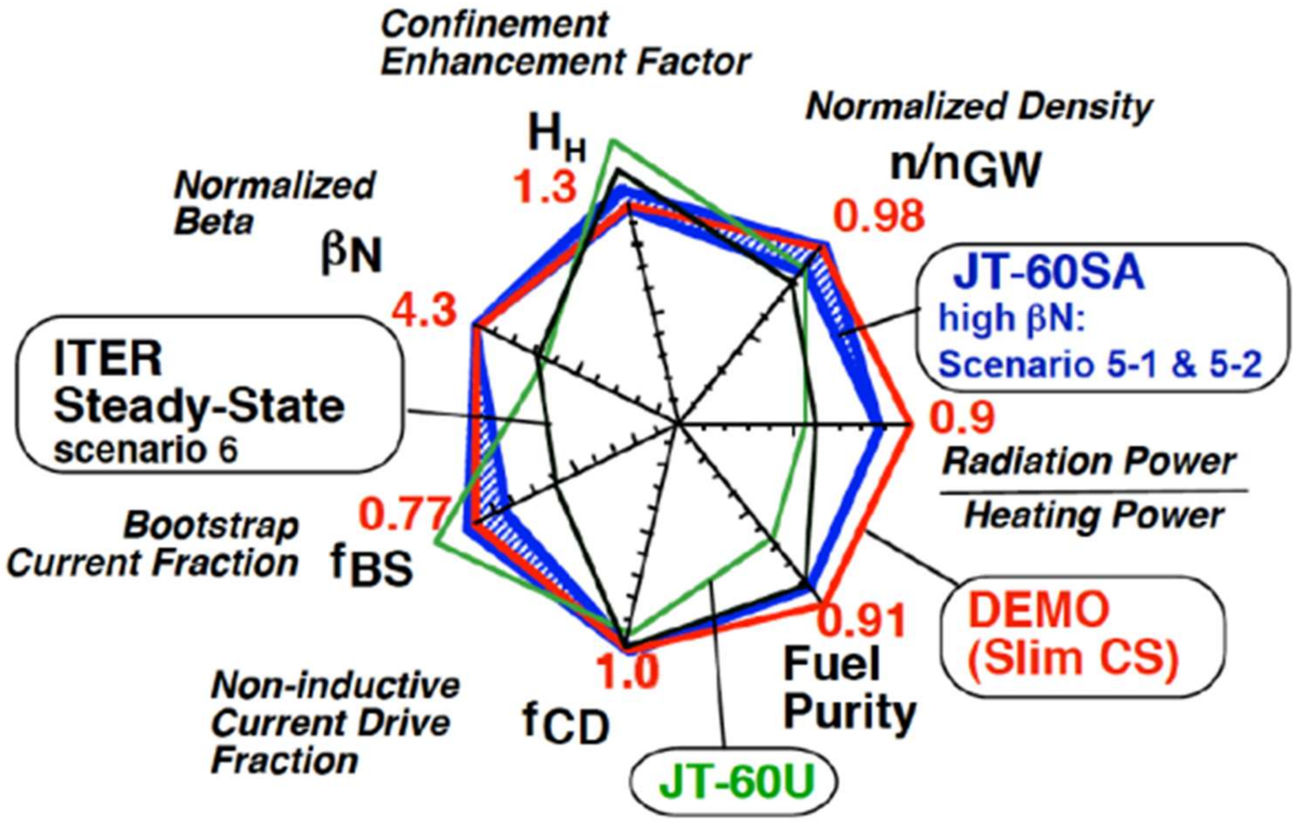


- JT-60SA operation requires cutting-edge technology:
  - Precise large machine assembly
  - Cryogenic systems
  - 500 keV N-NBI
  - Remote Handling

- Unexplored technological space:

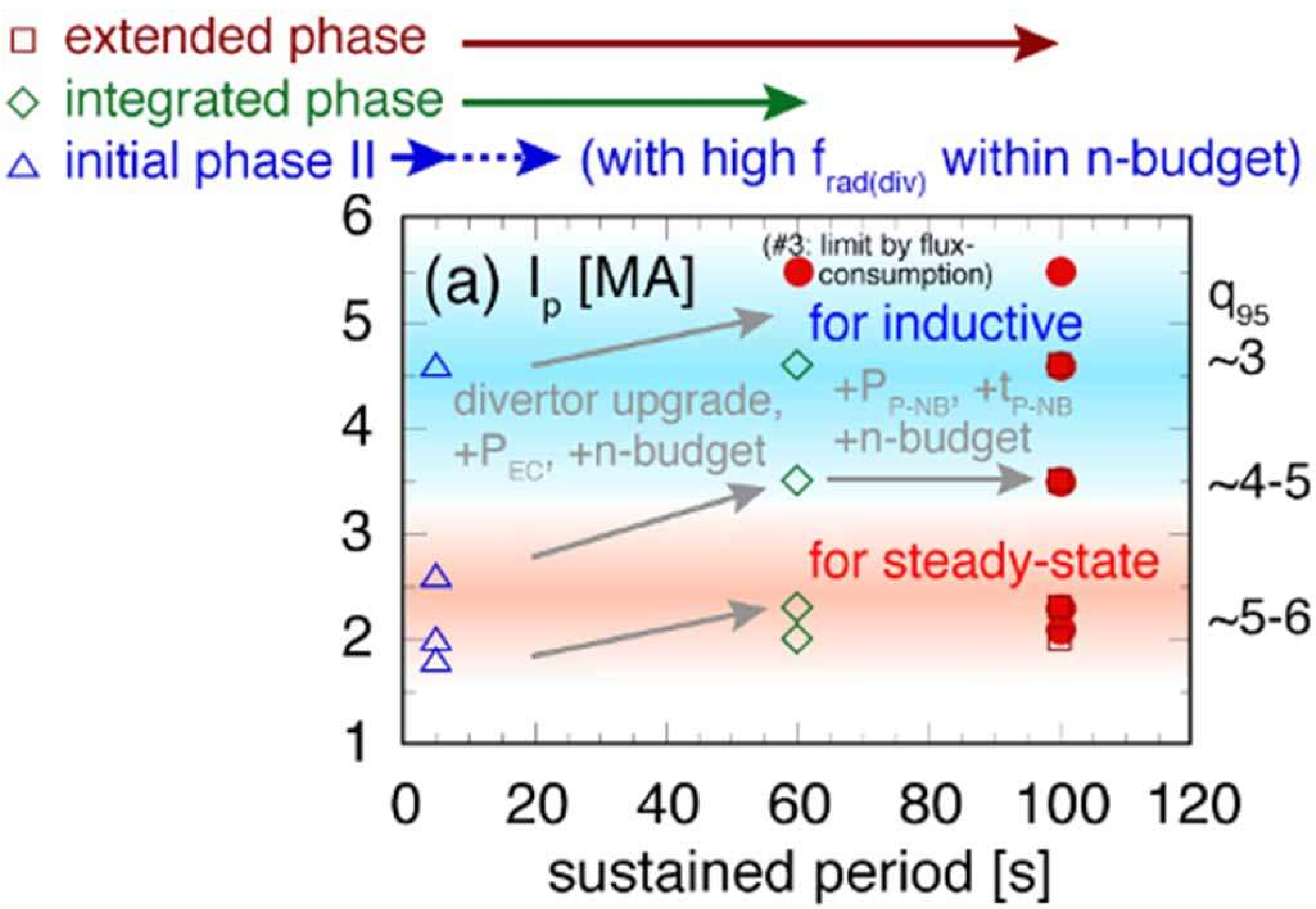
Closing the gap with ITER

JT-60SA: A scientific challenge



- JT-60SA aims at DEMO and ITER normalized plasma parameters
  - High: beta, non-inductive current fraction, normalized density, confinement

JT-60SA: A scientific challenge



- JT-60SA aims at DEMO and ITER normalized plasma parameters
  - High: beta, non-inductive current fraction, normalized density, confinement
- While working at high absolute plasma parameters:
  - Ip, Wdia, Wth, Neutron rate, pulse duration
- *Caviat: No Tritium operations*

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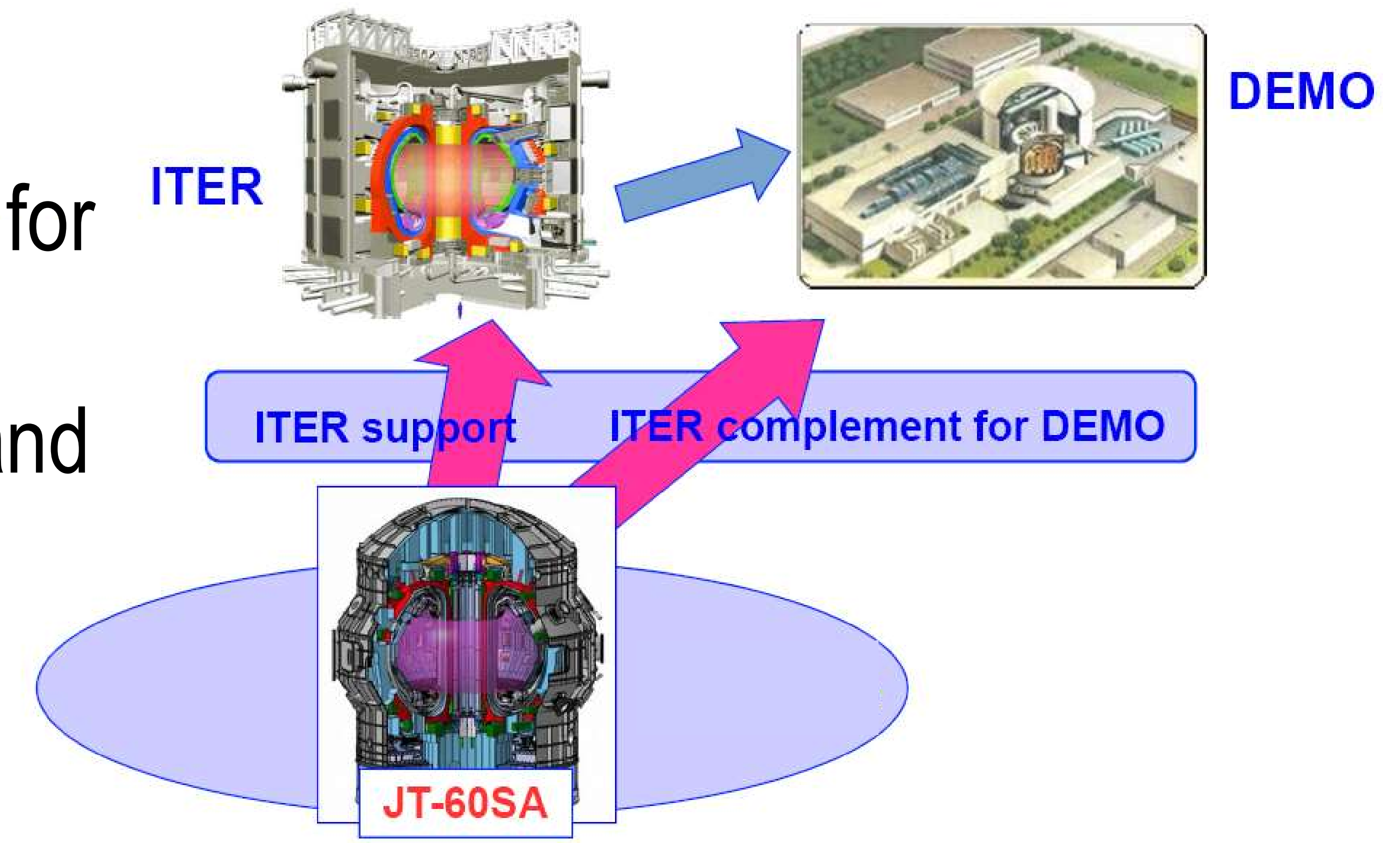
The JT-60SA project objectives

- Contribute to early realization of fusion energy by:
  - **supporting** the comissioning, start-up and exploitation of ITER
  - **complementing** ITER in resolving key issues for DEMO
  - **train** the next generation of fusion physicists and engineers



- The most important goal of JT-60SA is:
  - to **decide** the practically acceptable DEMO plasma design
  - including practical and reliable **plasma control** schemes

High level JT-60SA project summary

Research phase	Focus of exploitation	Operation Campaign	Expected operation schedule		RH	Divertor	Installed NB power	ECRF	Max. usable aux. power
-	Integrated pre-plasma Commissioning	Op-1	2020-2021 (6M) 2023 (6M) First plasma 2023	H	R&D	Open upper inertially cooled carbon	0	1.5 MW (2 Gryo.)	1.5MW
Initial research phase I	Initial stable and reliable operation • H operation for commissioning towards D operation. • Stable operation at high current heated plasma	Op-2	2025-2026 (9M)	D		Inertially cooled lower pumped carbon	16MW (with H) 23.5 MW (with D) PNB 8 units, plus NNB)	3.0 MW (4 gyro)	19MW ~26MW (limited by divertor cooling)
Initial research phase II	ITER and DEMO regime access (high power and high Ip with short pulses) • Acces to the ITER standard scenario	Op-3	2026-2027 (9M)						
	• High beta access • ITER risk mitigation (ELM, disruption)	Op-4	2027-2028 (8M)				30 MW (PNB 12 units, plus NNB)		33 MW
Integrated research phase I	High beta long pulse Burning plasma relevant • ITER standard and hybrid stationary (~2-3tR) • High beta steady-state (~2-3tR), DEMO contribution	TBD	TBD			Actively cooled lower pumped carbon		7MW (9 gyro.)	37MW
Integrated research phase II	High beta and metal wall compatibility • Radiative divertor with impurity seeding • Impurity pumpout from core	TBD	From ~2030 (TBC)		Use	Actively cooled lower pumped tungsten			
Extended research phase		TBD	>5y			Actively cooled tungsten advanced structure (Upper div. TBC)	34MW		41MW

Considerations

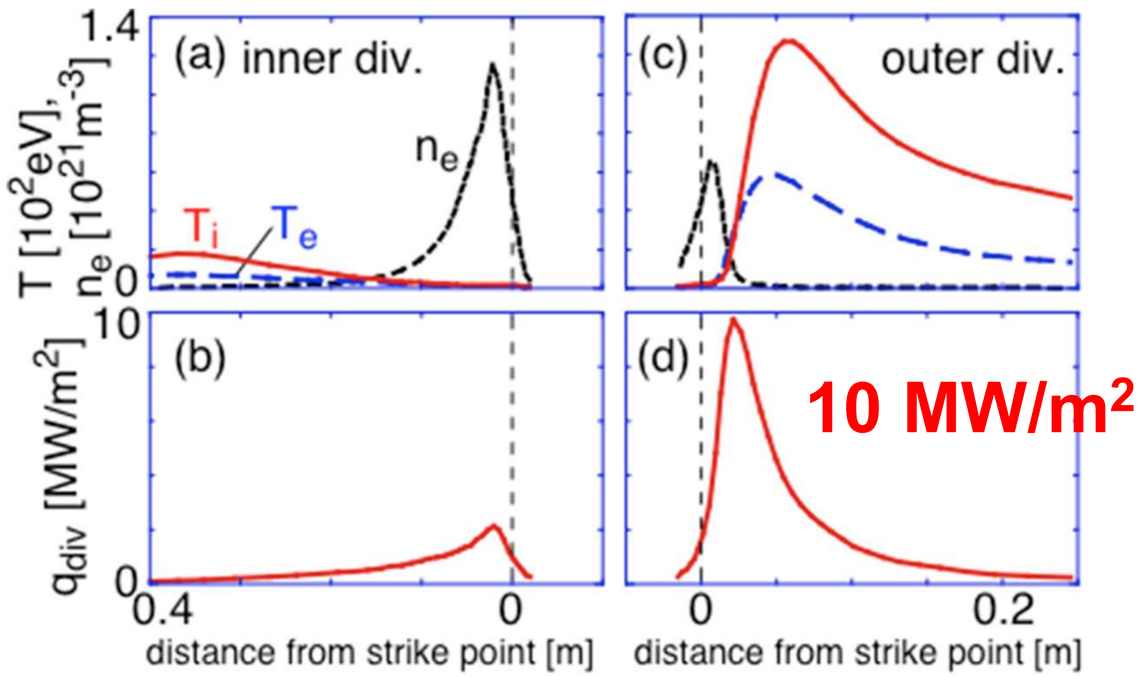
- JT-60SA project has had significant delays
- ITER project also is expected to have significant delays
- ITER project has gone into a phase of rebaseline and change of approach to its research plan
- Private companies are pushing the field towards earlier scientific results
- Global anxiety as big projects look too slow to be completed

New proposal for early W transition

Research phase	Focus of exploitation	Operation Campaign	Expected operation schedule		Annual neutron limit	RH	Divertor	Installed NB power	ECRF	Max. usable aux. power
Initial research phase I	Integrated Commissioning	Op-1	2020-2021 (6M) 2023 (6M) First plasma 2023	H	-	R&D	Open upper inertially cooled carbon	0	1.5 MW (2 Gyro.)	1.5MW
	Initial stable and reliable operation • H operation for commissioning towards D operation. • Stable operation at high current heated plasma	Op-2	2026~	D	3.2e19		Lower pumped carbon with intershot cooling (limits high power heating duration)	PNB 8 units, plus NNB Total 16MW (with H) 23.5 MW (with D)	3 MW (4 gyro)	19MW 26.5MW
Initial research phase II	**ITER and DEMO regime access** (high power and high Ip with short pulses) • Access to ITER-relevant high confinement H-mode at high Ip • High beta access • ITER risk mitigation (ELM, disruption)	Op-3	TBD							
		Op-4	TBD					PNB 12 units, plus NNB Total 30 MW		33 MW
		No. of campaigns to be confirmed	TBD							
Integrated research phase I	**High beta and metal wall compatibility**	TBD	TBD		4.0e20		Actively cooled lower pumped tungsten		7MW (9 gyro.)	37MW
Integrated research phase II	**High beta long pulse** **Burning plasma relevant** • ITER standard and hybrid stationary (~2-3τ_R) • High beta steady-state (~2-3τ_R), DEMO contribution	TBD	TBD		1.0e21	Use				
Extended research phase		TBD	TBD		1.5e21			34MW		41MW

Steady-state high beta scenario for JA-DEMO

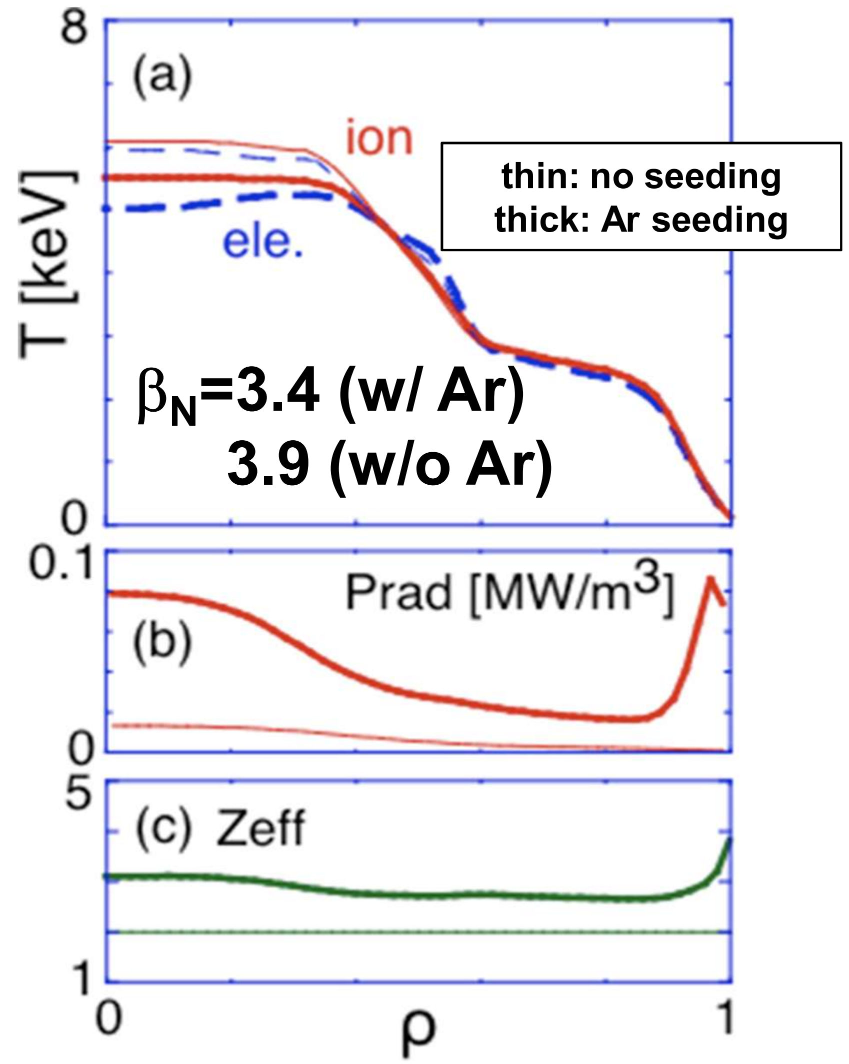
Compatibility between high β and metal wall for long time will be the role of JT-60SA



DEMO Scenario #5 (high beta steady-state)

I_P/B_T=2.3 MA/1.72 T, q_{95}~5.8, β_N~4

P_{in}=24 MW: P_{NNB} = 5 MW, P_{PNB} = 12 MW, P_{EC} = 7 MW



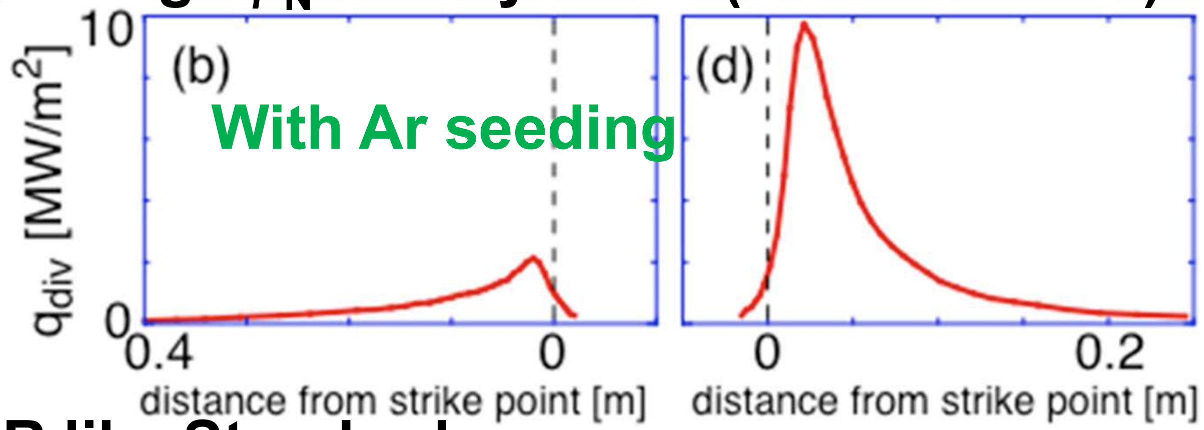
- As part of scenario integration high beta long pulse operation is important
- Ar seeding and impurity accumulation studied with SONIC code in C-divertor. [Hayashi NF 18]
- Impact of W in other scenarios studied with COREDIV [Gałązka PPCF 17]

Specs of Heat Load Resistance are Key

General request of divertor

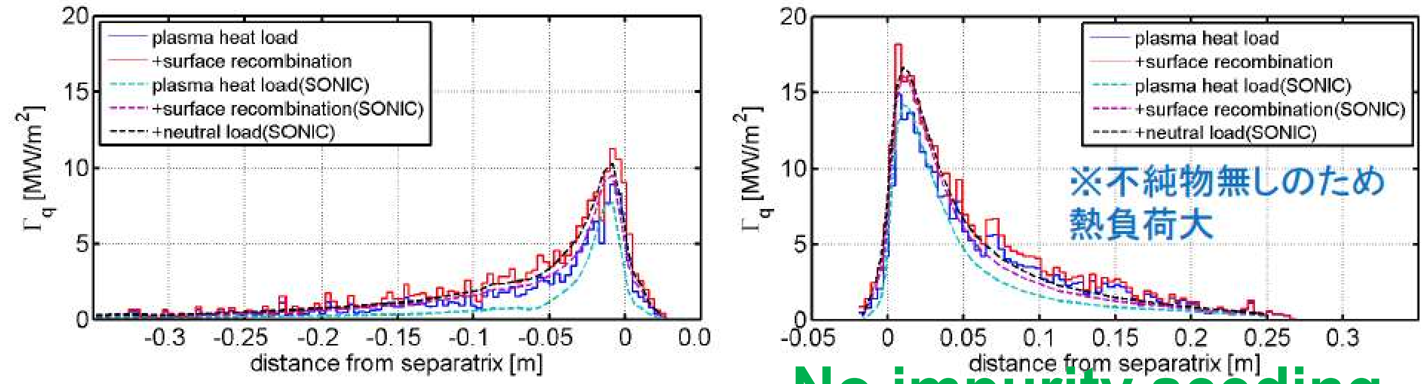
- High β_N steady-state: ~10 MW/m^2 for long time
- ITER like standard op.: ~15 MW/m^2 for long time
- Risk mitigation/physics: ~20 MW/m^2 for a few secs?
- W-divertor should demonstrate this capability
- Integrated core-edge assessment is necessary

High β_N Steady-State (Scenario #5-1)



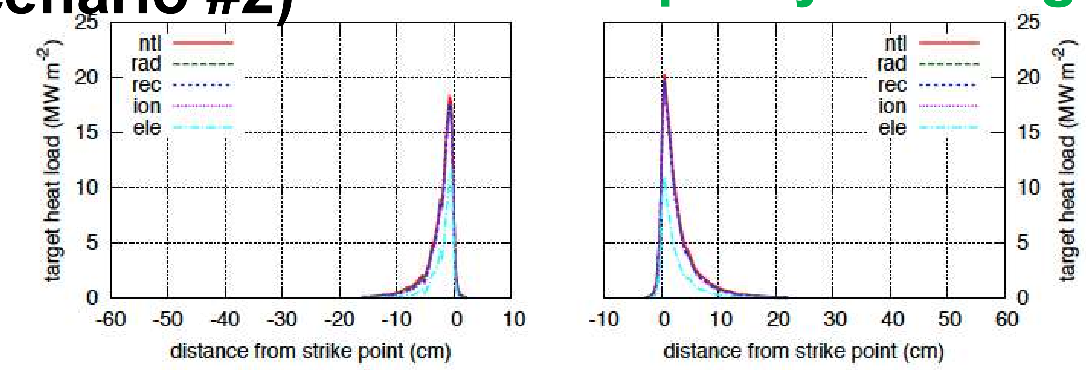
ITER like Standard Operation (Scenario #4-1)

No impurity seeding



High Ip (Scenario #2)

No impurity seeding



Machine Upgrades

- Prepartion for working in a W enviroment may require extensive JT-60SA upgrades/studies/actions:
  - Based on JET results 3-7MW of central ECRH might be needed (total ECRH planned now is 7MW)
  - Dedicated diagnostics upgrades (e.g. W flux monitor, W density measurement, Visible camera, etc)
  - Test of W transport in JT-60SA conditions can be performed during C ICD by using TESTPEL
  - Self-consistent modelling exploring the possibility of W screening at the pedestal, as it happens in JET, will be performed.
  - Specific experiments can be performed during the C ICD to assess some of the previous points. Additionally, experiment in other devices with a W-divertor and wall could assess some of the specificities of the JT-60SA scientific programme

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Conclusions

- High beta, high confinement long pulse operation is the main JT-60SA goal
- General consensus in JT-60SA project that early transition to W environment would be beneficial, but:
  - Significant amount of scientific topics can be studied initially in the inertial cooled C divertor
  - W-divertor should be compatible with the main JT-60SA scientific goals
  - Installation of W-wall has not been properly analysed
  - JT-60SA would require some important upgrades to avoid potential W pollution in the plasma core
  - Experiment Team will encourage W related scientific activities