Missions & integration design of CFETR

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Mission

- A good compliment with ITER
- Demonstration of full cycle of fusion energy with a minim P_f = 50 ~ 200MW
- Demonstration of full cycle of T self-sustained with TBR ≥ 1.2
- Long pulse or steady-state operation with duty cycle time ≥ 0.3 ~ 0.5
- Relay on the existing ITER physical （k<1.8, q>3, H~1) and technical (higher BT, diagnostic, H&CD) bases
- Exploring options for DEMO blanket&divertor with a easy changeable core by RH
- Exploring the technical solution for licensing DEMO fusion plant
- With power plant potential by step by step approach.

Targets and Challenges

Physics:

- Creating predictable, high-performance steady-state plasmas
- Demonstrating and exploring the burning plasma state
- Taming the plasma-material interface
- Harnessing fusion power

Engineering:

- ➢Complete fusion energy cycle.
- ➢Complete T fuel cycle.
- ➢long pulse or SSO
- ➢Material Validation
- ➢Component Validation
- ➢RAMI for power plant
- ➢Necessary date for safety & licensing of power plant.

Approach a very attractive and delivery milestone step by step

- B_{to} = 5.3 / 4.5 T
- I_p = 12 / 10/ 07 MA
- R_o = 5.5 m
- a = 1.6 m
- K = 1.8

Phase1: (incl. non- nuclear 6-8 y)

Q~1, t> 2 hours - SSO

Pfusion ~ 50-100 MW, 3~5dpa

Ip = 6-7MA, B_T=4.5T, BetaN=1.5

H&CD: 50-60MW

FTBM, mid-plan FFH BM (T>1.2)

SN, DN, ITER-W divertor

Phase 2: AT H-mode (DT-2 6-8 y)

Ip=10MA; B_T=5.3T, BetaN=2.5

Q~ 6-8, Pfus =300- 400MW,

H&CD: 80-100MW, nw: 1MW/m2

FTBM, mid-plan FFH BM (T>1.2)

SN, DN, ITER-W divertor

2-5 hours long pulse - SSO, ~ 20dpa

Phase 3: AT H-mode (DT-3 6-8 y)

Ip=12MA; B_T=5.3T, BetaN=3.5-4

Q~ 10, Pfus = 800MW,

H&CD: 80-100MW, nw: 2MW/m2

SN, DN, DEMO-divertor, >50 dpa

FTBM, (T>1.1)

Qeng>1, long pulse - SSO.

Burning time

- **ITER:**

120wb, 90wb for ramp-up, burn, 400s-3000s

- **CFETR**

~95wb, Ip=7,10,12 MA

OH startup will need 40,60, 80wb

burn time is not sufficient.

Solutions:

- ➢ **Ramp-up: 10MWEC+15MWLH: 20% saving: 10-20 wb**
- ➢ **Nb_3Al CS: 30% higher 120wb**

For Nb_3Al CS: 120 wb

Ip = 6-7MA, Pfu = 50-100MW

Ramp-up: 10MWEC+15MW LH: 30wb,

Burn time: 90wb, t > 3600s-SSO

at beta N =1.5, fbt=0.25-0.5

Ip = 10 MA, Pfu=400MW

Ramp-up: 45wb,

Burn time: 45 > 3600s -SSO

at beta N =2, fbt=0. 5-0.75

Difficulty of steady-state operation

Different physics – different CD efficiencies

	LHCD	ECCD	FWCD	NBCD
γ [A/(Wm²)]	0.3-0.4 (indep. of T_e)	≥ 0.2 (ITER prediction)	0.07 (ITER prediction)	0.5 (2 MeV) (DEMO prediction)
ζ [A/(Wm² keV)]	n.a.	≥ 0.3	0.1-0.2	0.4-0.5
η_{CD}	0.3 (present) 0.5 (goal) (100 % coupling)	0.3 (present) 0.5 (goal)	0.5 (present) 0.7 (goal) (100 % coupling)	0.3 (present) 0.5 (goal)
γ*η_{CD} (compare to **0.25**)	0.09-0.2	0.09 - 0.15	0.05-0.15	0.12-0.25
Remark	n.a. for DEMO (next slide)	potential for optimisation Up to 0.3	small exp. Basis	off-axis CD not fully understood

H.Zohm

H&CD and diagnostics-Phase-I

Phase1 (H, D, DT-1)

Q~1, t> 2 hour, SSO

Pfusion ~ 50-100 MW，3~5dpa

Ip = 6-7MA, Bt=4.5T, BetaN=1.5

LHCD: 4.6GHz, 15MW(1 port)

NBI: 500keV/250keV, > 2 hours

20MW (1 port)

ECRH: 170GHz, 20MW (1 R port)

ITER-like 诊断 (26) (5 up port, 5 low port, 3 M port)

Key diagnostics:

SSO magnetic

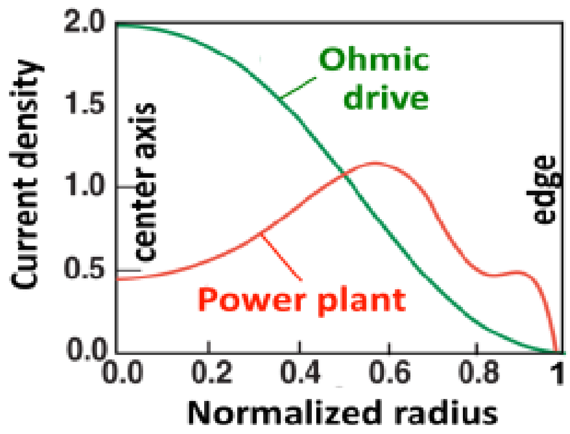
Surface monitors (camera?)

Retension&Dust

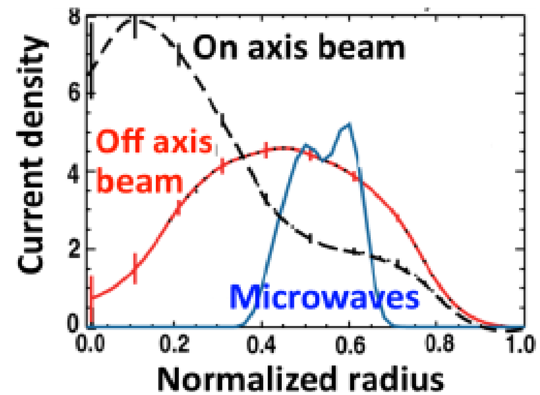
Measurements Required under Real-time Control
Plasma shape and position, vert speed, Btor, Ip, Vloop, β
Existence of locked modes, m = 2 modes, low m/n MHD modes
ELM occurrence and type, H/L mode indicator
Line-averaged density
Zeff (line average)
Runaway electrons
Surface temperature of first wall and divertor plates
Divertor detachment
q(r), Te(r) in core, ne(r) edge and core
nT/nD in core, Prad from core, Pfus

H&CD and diagnostics-Phase-II

- **Phase 2: AT H-mode (DT-2,6-8y)**
- **Ip=10MA;　Bt=5.3T, BetaN=2.5**
- **Q~ 6-8, Pfus = 400MW,**
- **NBI: 500keV, 40MW**
- **ECRH: 170GHz, 40MW**
- **Advanced fueling (CT)**
- **ITER-like diagnostics (26) + DEMO-magnetic.**
- **Extension DIII-D AT(10s) to EAST(1000s)**
- **Explore possibility for higher Ini > 0.9**
- **Explore possibility for EC (H&CD) only**

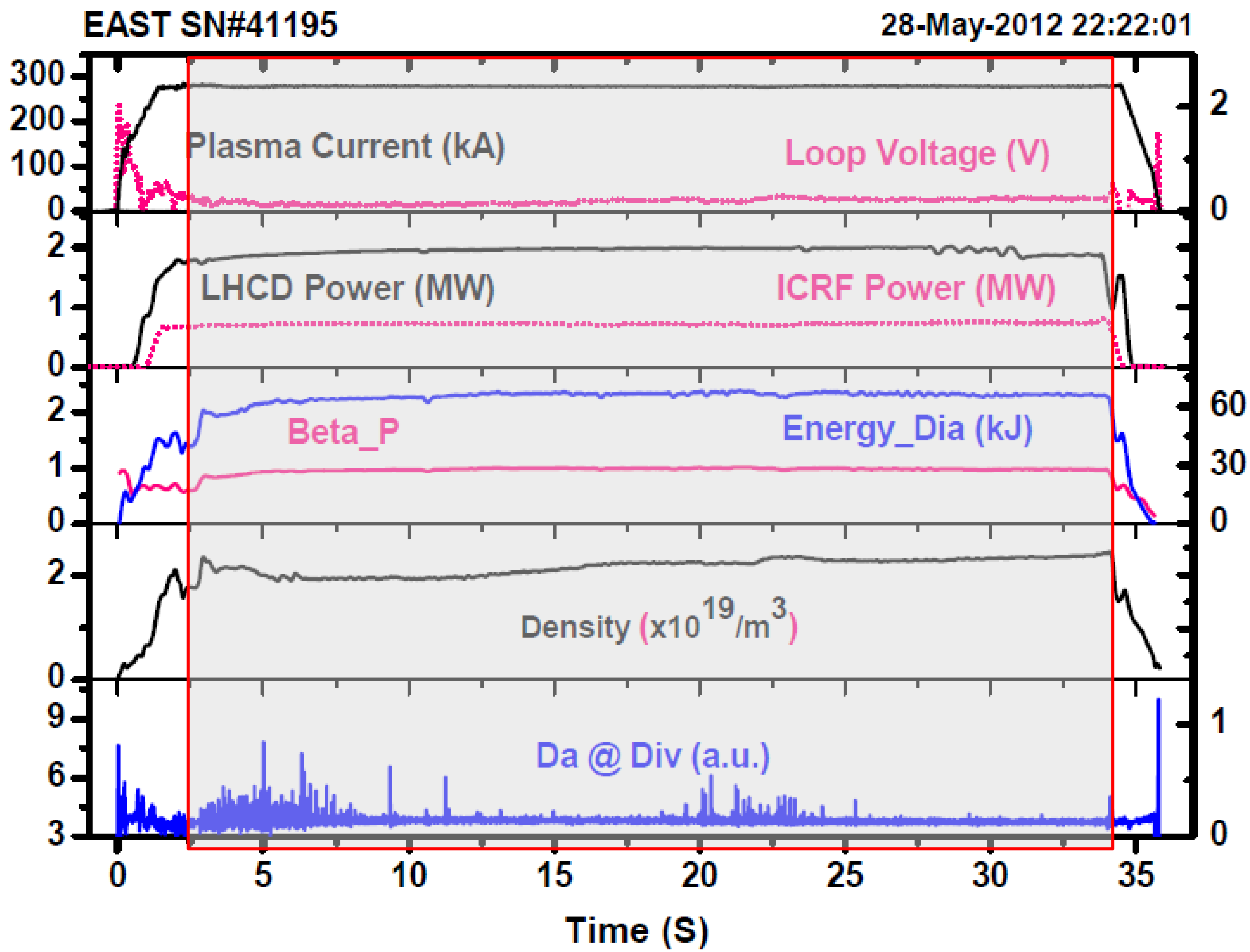


DIII-D Stationary discharges
at βN ~ 3.1, fNI ~ 0.8,



DIII-D /EAST efforts
at βN ~ 3.5, fNI ~ 0.9,

Stationary H-mode up to 32s achieved

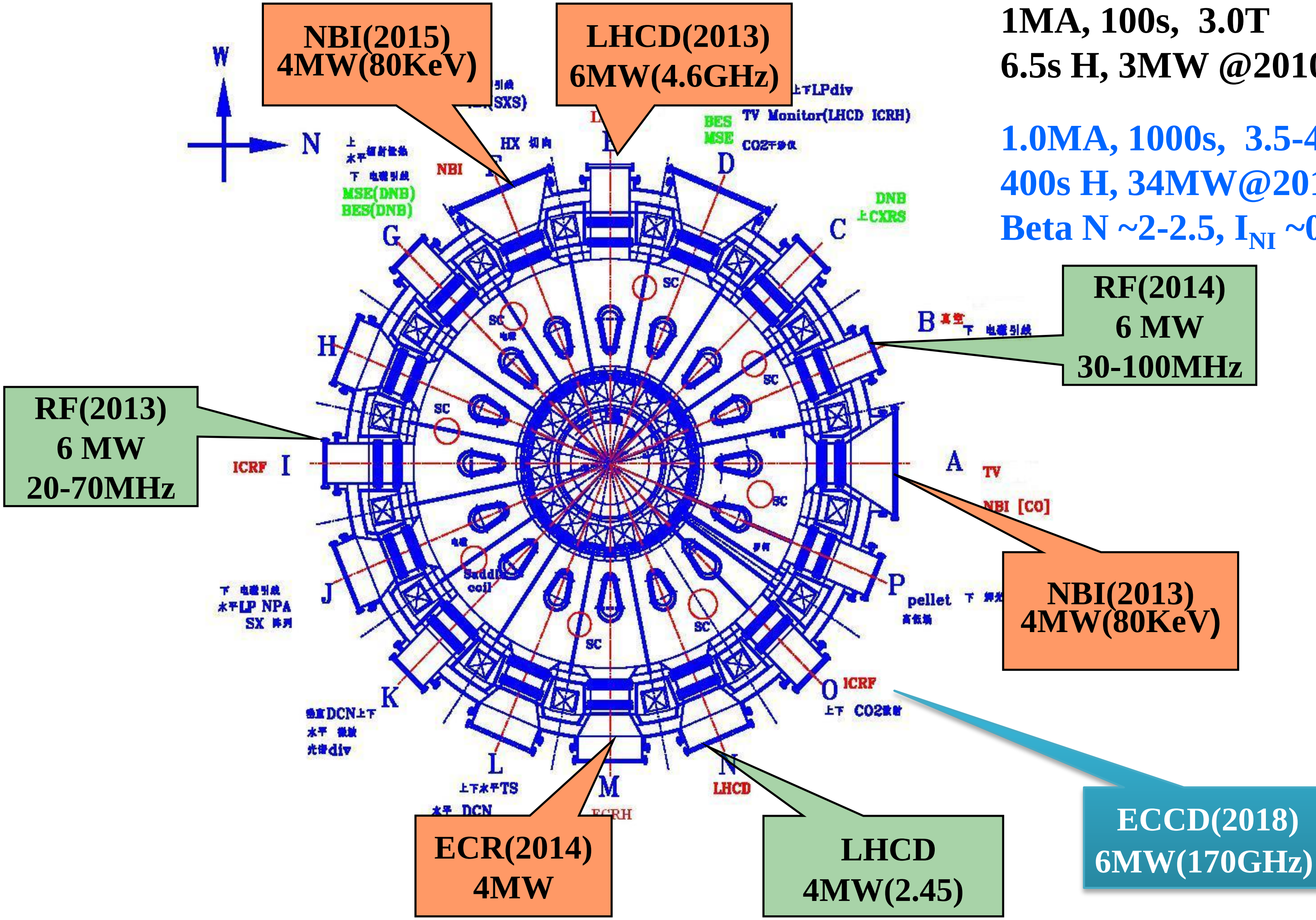


Ip ~0.28MA, Bt~1.85T, P_{LH} ~2.0 MW, P_{RF}~0.75MW, f=27MHz, Beta_P~1.0, H_{98}~0.8

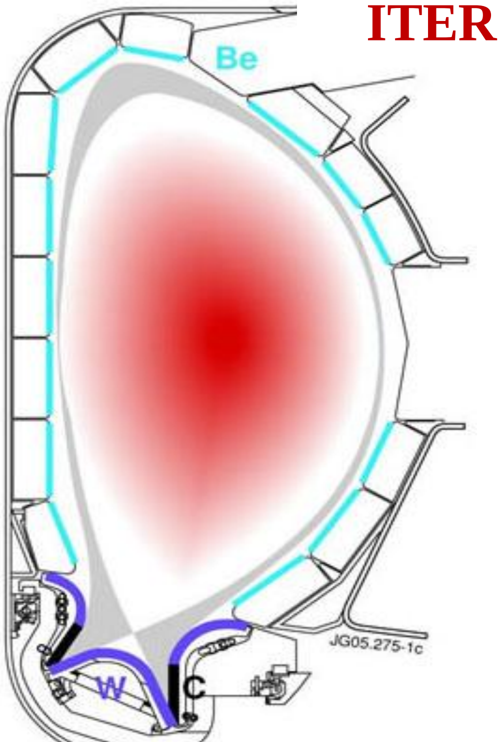
Efforts Made- EAST ATSSO

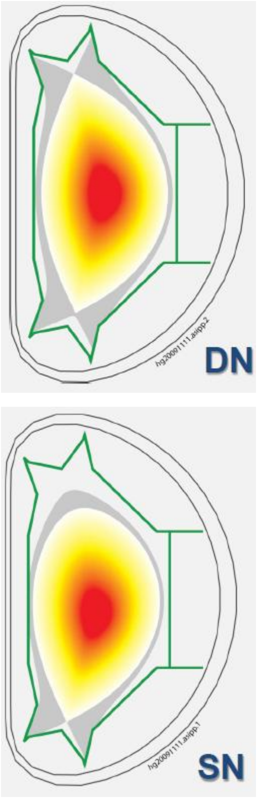
1MA, 100s, 3.0T
6.5s H, 3MW @2010

1.0MA, 1000s, 3.5-4T
400s H, 34MW@2015
Beta N ~2-2.5, I_{NI} ~0.8-1



PFC Strategy for ATSSO





- **Initial phase (2006-2007)**
  PFM ⇨ SS plates bolted directly to the support without active cooling
- **First phase (2008-2012)**
  PFM ⇨ SiC-coated doped C tiles bolted to Cu heat sink ~2MW/m^2
- **Second phase (2013-2016)**
  Full W, Actively-cooled ITER W/Cu divertor , 10MW/m^2.
- **Last phase (2017---)**
  High Tw operation (>400C) by hot He Gas 15MW/m^2.
  Flow Liqiud Li Divertor

Edge Simulation under H-mode
With LLNL, ENEA, TS, ITER-IO

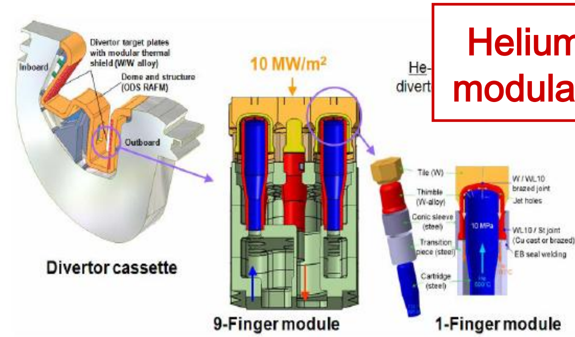
Phase-III:power plant potential testing

- Phase 3: AT H-mode (6-8y)
- Ip=12MA;　B_T=5.3T, BetaN=3.5-4, I_{NI}=0.8-0.9
- Q> 10, Pfus > 800MW, Qeng>1
- Testing EC (CD&H) only: 190GHz, 80-100MW
- DEMO diagnostics (16)
- Advanced fueling (NBI, CT)
- Full cycle of T and Electricity
- Fast change of core by RH
- Material& blanket validation

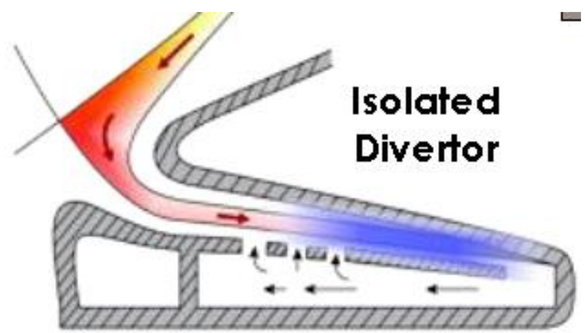
DEMO-relevant Divertor:

DEMO He-cooled Tungsten-armoured concept (KIT)

Helium-cooled modular divertor



Thimbles tested at 12 MW.m^{-2} ≤ 200 cycles

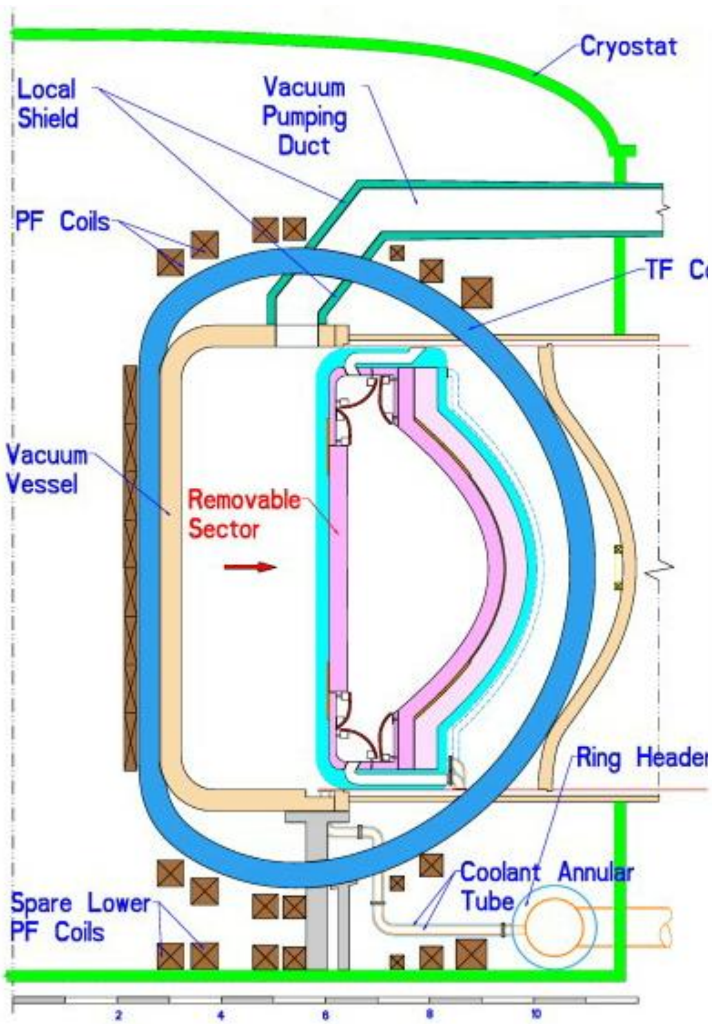


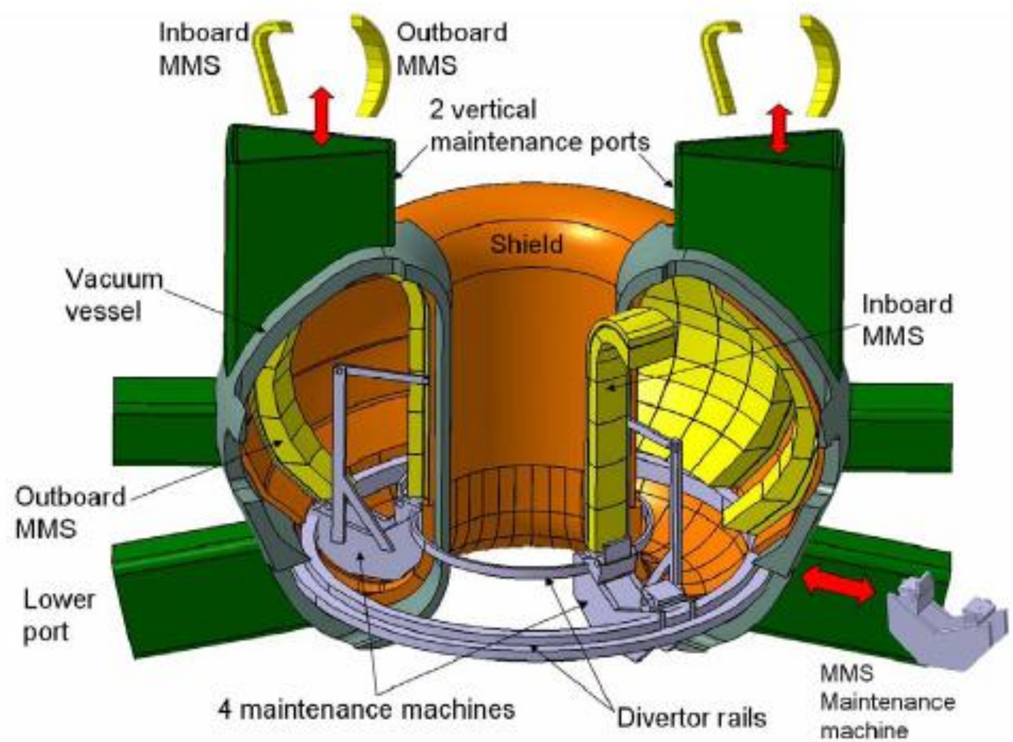
Snow flake, Super-X
Or flow liquid Li Divertor?

Key requirements for design

- **Base on ITER physics and technology**
- **Fully shielding of neutrons by blanket and VV (including divertor region, HFS ~1.1m）**
- **T-system(close cycling of T，90% of T from exhausting system，2-3 hours for T reprocessing . 10% T from TBM，6-12h）**
- **VV&pump duct：Hot wall operation (>350C) for 0 T retention.**
- **Windows：optimize for T-breeding and H&CD(diag), two Big mid plan ports for sector removing.**
- **Divertor：ITER-W divertor could be used in phase 1-2 with proper shielding block. New DEMO-relevant diverter is required in phase 3.**
- **RH：consists ITER-RH techniques（blanket, divertor）and sector removal technique (>100T)**
- **Hot cell：enough space should be built from beginning (50-100 larger than ITER)**
- **Start RAMI from very beginning**

Key of RAMI： Availability





Explore the best solution by RH
Mid-plan might be better

What We Can Deliver?

	EAST	JT-60SA	ITER	CFETR	DEMO
Disruption avoidance	**P**	P	MS	5-10 Y	Y
steady-state operation	**P**	P	MS	5-10 Y	Y
divertor performance	**P**	P	P	10-15 Y	Y
burning plasma Q>10	**no**	no	Y	15-20 Y	Y
power plant plasma performance	**P**	P	MS	15-20 Y	Y
T self-sufficiency	**no**	no	no	15-20 Y	Y
materials characterisation	**no**	no	no	20-30 Y	Y
plasma-facing surface interaction	**P**	P	P	10-20 Y	Y
FW/blancket/divertor materials lifetime	**no**	no	no	20 Y	Y
FW/blancket/ components lifetime	**no**	P	P	20 Y	Y
H/CD systems performance	**P**	P	Y	10-20 Y	Y
electricity generation at high availability	**no**	no	no	> 20 Y	Y
superconducting machine	**Y**	Y	Y	5-6 Y	Y
tritium issues	**no**	no	Y	10-20Y	Y
remote handling	**no**	P	Y	10-20 Y	Y
DEMO diagnostics	**no**	P	P	10-20 Y	Y
	2007	2017	2020	025-2030	?
Can we do it? how long?	**yes, now**	2-3Y	5-10 Y	5-10 Y for cons	
				20 years for op	

Built a superconducting R=5.5/a=1.6 tokamak is possible within 10 years

Summary

- **Fusion energy generation, full tritium cycling and power plant potential are key requirements for Chinese next step MFE device.**
- **Built a superconducting 5.5/1.6 tokomak is foreseeable within 8-10 years in China**
- **To built such device together with ITER will certainly speed up world MFE development.**
- **An international team will speed up this approach.**