Update on CFETR Concept Design

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2nd IAEA DEMO Programme Workshop

Outline

- ☐ Introduction
- ☐ Progress of CFETR design
  - ➢ Overview and machine layout
  - ➢ CFETR physical design
  - ➢ Magnet, cryostat and vacuum system
  - ➢ Divertor and blanket system
  - ➢ Heating & current drive, diagnostic & CODAC
  - ➢ Tritium technology
  - ➢ Remote handling
- ☐ Summary

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Task and schedule of CFETR concept design

China **F**usion **E**ngineering **T**est **R**eactor

☐ **To provide two options of concept design of CFETR (2011- 2014) which should include:**

- Missions, type, size, main physics basis, main techniques basis
- The concept engineering design for all sub-systems
- Budget & schedule, location, management system

☐ **To complete proposals in 2015 :**

- “Key R&D Items for CFETR”
- “Construction Proposal for CFETR”

based on the concept design, and to submit them to the government to try to get the construction permission.

Many upgrades on EAST tokamak have been developed towards CFETR R&D items recently.

Missions of CFETR

☐ **In general, the goal of CFETR is to bridge the gap between ITER and DEMO and to realize the fusion energy in China.**

Objectives of CFETR:

- A good complementary with ITER
- Demonstration of the fusion energy with a min P_{fus} = 50 ~ 200MW
- Long pulse or steady-state operation with duty cycle time ≥0.3 ~ 0.5
- Demonstration of full cycle of T self-sustained with TBR ≥1.2
- To relay the existing ITER physical and technical basis
- To explore options for DEMO blanket & divertor with a easy changeable core by RH
- To explore the technical solution for licensing DEMO fusion plant

Operational phase of CFETR

☐Phase I: 2030~2038

- ITER baseline H-mode
- P_{fus}=50~200 MW
- H, D, DT-1
- Tritium self-sustained and steady state operation

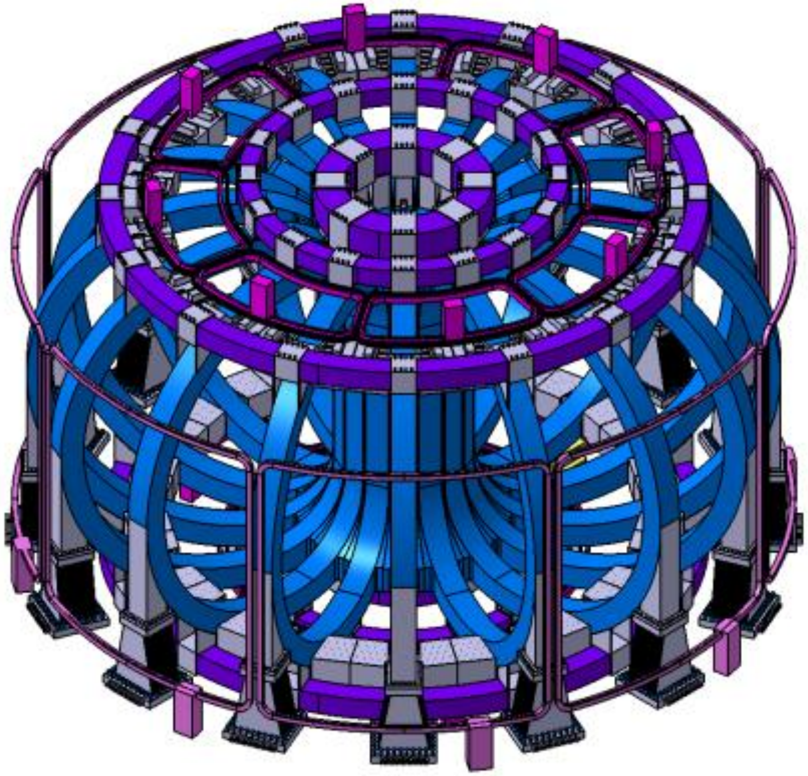
☐Phase II: 2038~2045

- AT H-mode
- Upgrade of CFETR
- DT-2
- Q~10, P_{fus}~1 GW

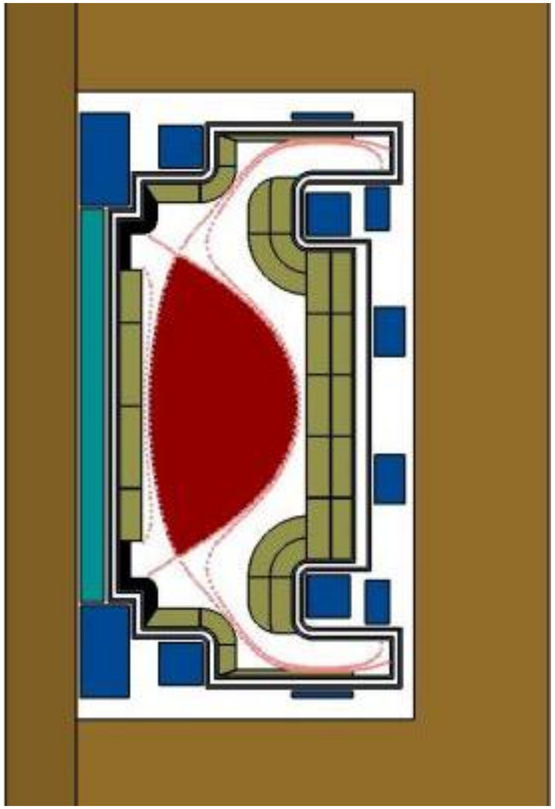
J. Li et al, ASIPP report, 2013

Options of CFETR

Option 1:
Full superconducting Tokamak



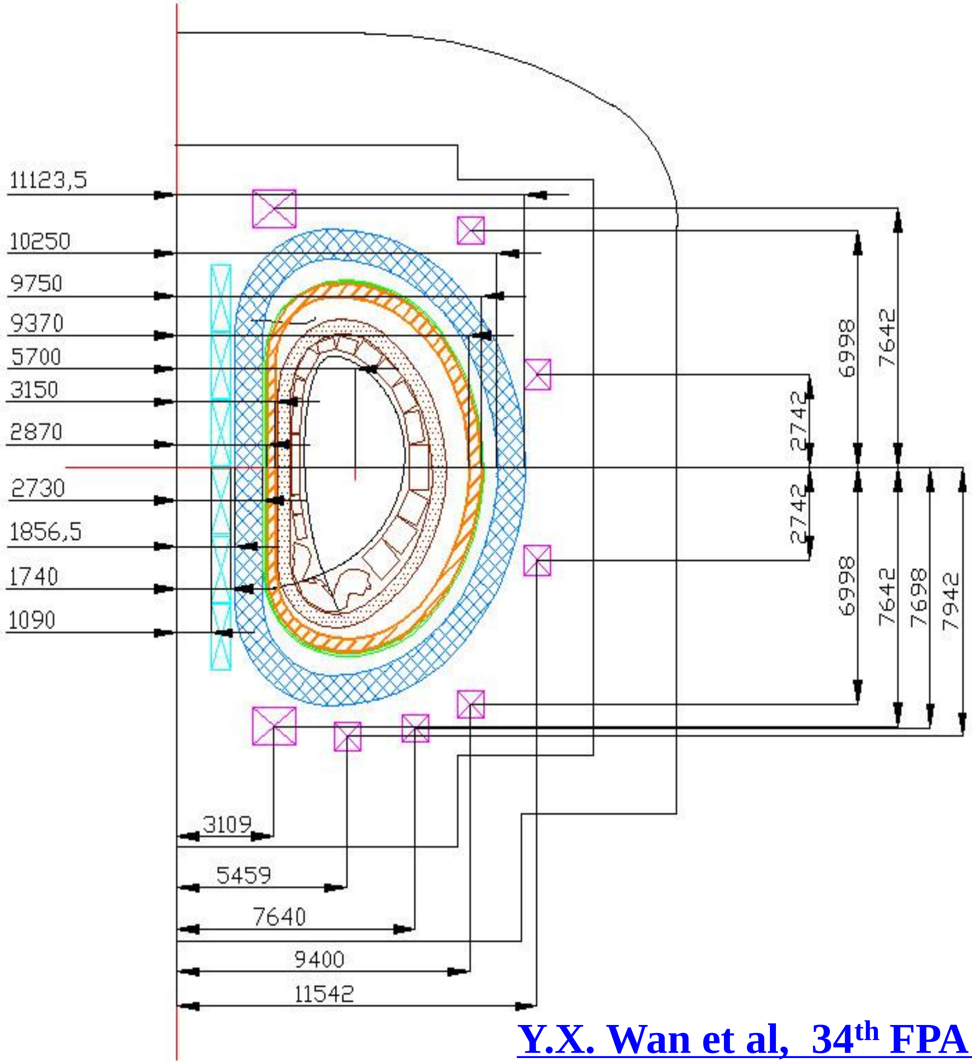
Option 2:
Water-Cooling Cu Magnets Tokamak



Option 1: Full superconducting Tokamak

Main parameters:

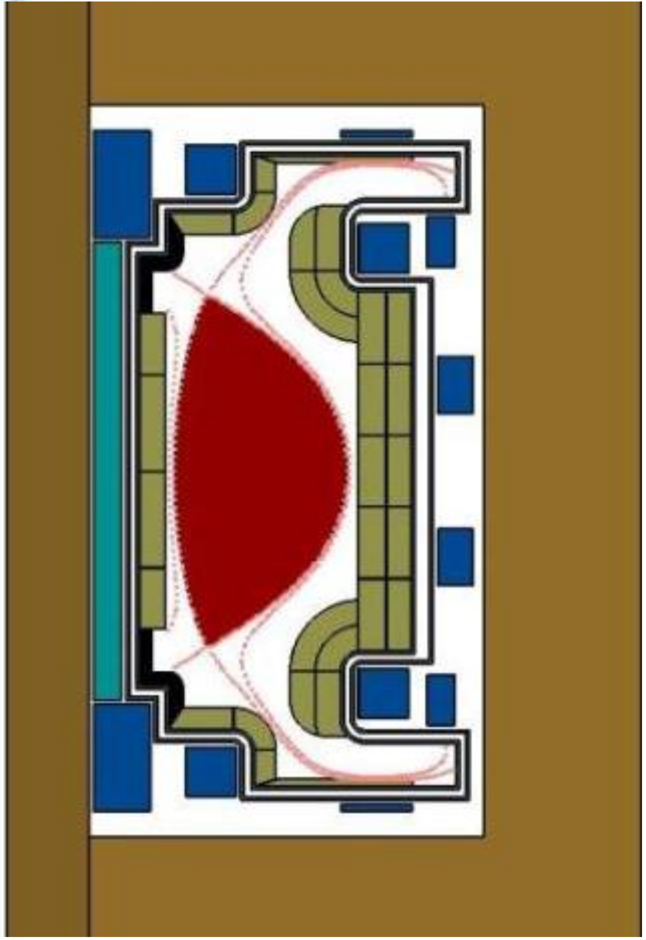
R(m)	5.7
a(m)	1.6
A	3.56
κ	2.0
δ	0.4
V(m^3)	576
S(m^2)	587
B_0(T)	5.0
Ip(MA)	10~8
P(MW)	80



Y.X. Wan et al, 34th FPA 2013

Option 2: Water-Cooling Cu Magnets Tokamak

	Opt1	Opt2
R(m)/a(m)	3.7/1.2	3.7/1.2
I_p(MA)	9.0	8.5
β_N	2.0	2.8
κ	2.0-2.2	2.0-2.2
δ	0.6-0.8	0.6-0.8
B_0(T)	4-4.5	4-4.5
Safety factor	4.0	4.2
P_{fus} (MW)	115	200
$n_e(10^{19}/m^3)$	8.5	9.5
NWL(MW/m^2)	0. 32	0.56
f_{BS}	19%	31%
P_{CD}(MW)	80	80
$HH_{(y2,98)}$	0.90	1.15
Operation mode	hybrid	SS
Burning time(s)	6000	



G. Zheng et al, 25th SOFE 2013

16 TF coils, 6 CS coils, 12 PF coils. The coil material is copper alloy conductor.

Options of CFETR

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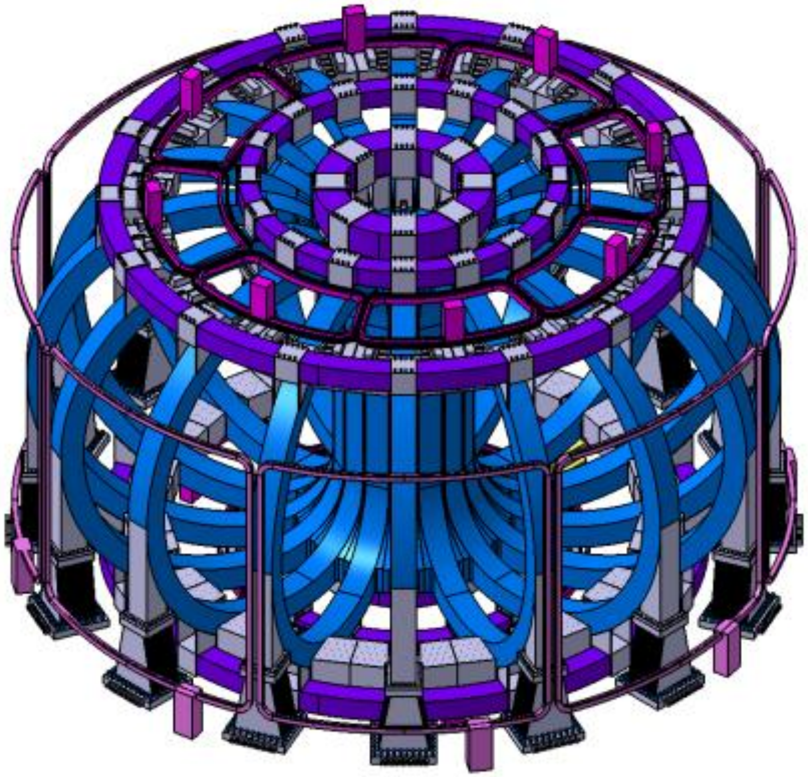
Full superconducting Tokamak



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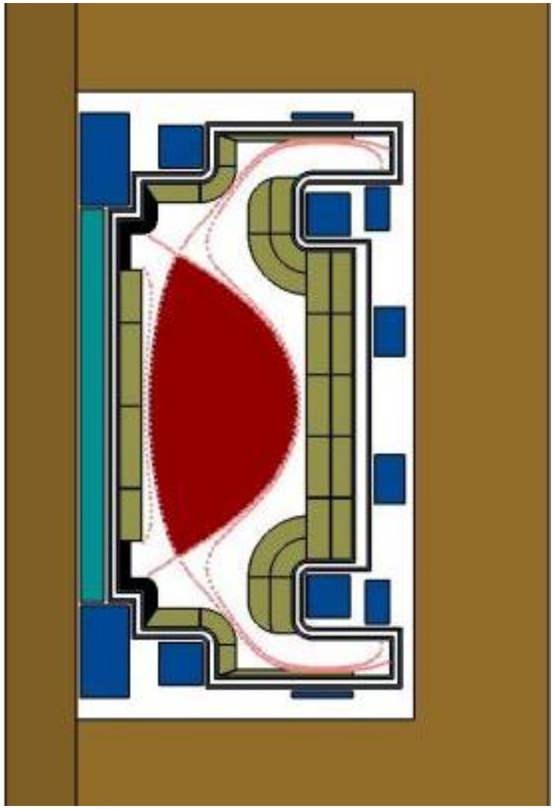
Water-Cooling Cu Magnets Tokamak



Option 1 will be discussed in this talk in detail.

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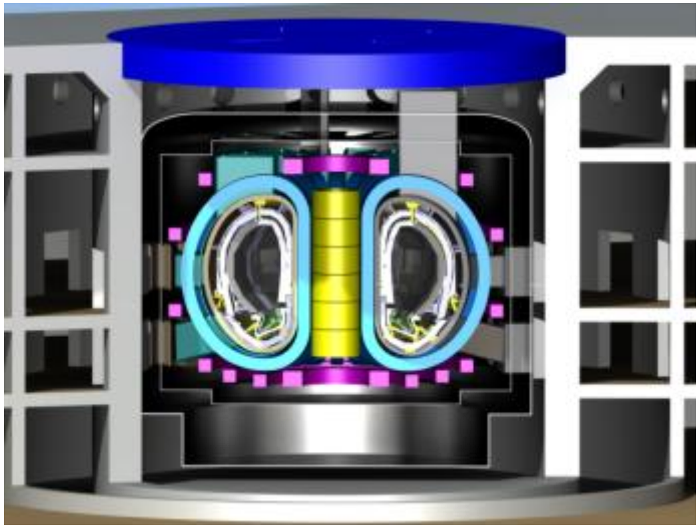
Integrated configuration design

Sub-systems for the Integration Design for CFETR

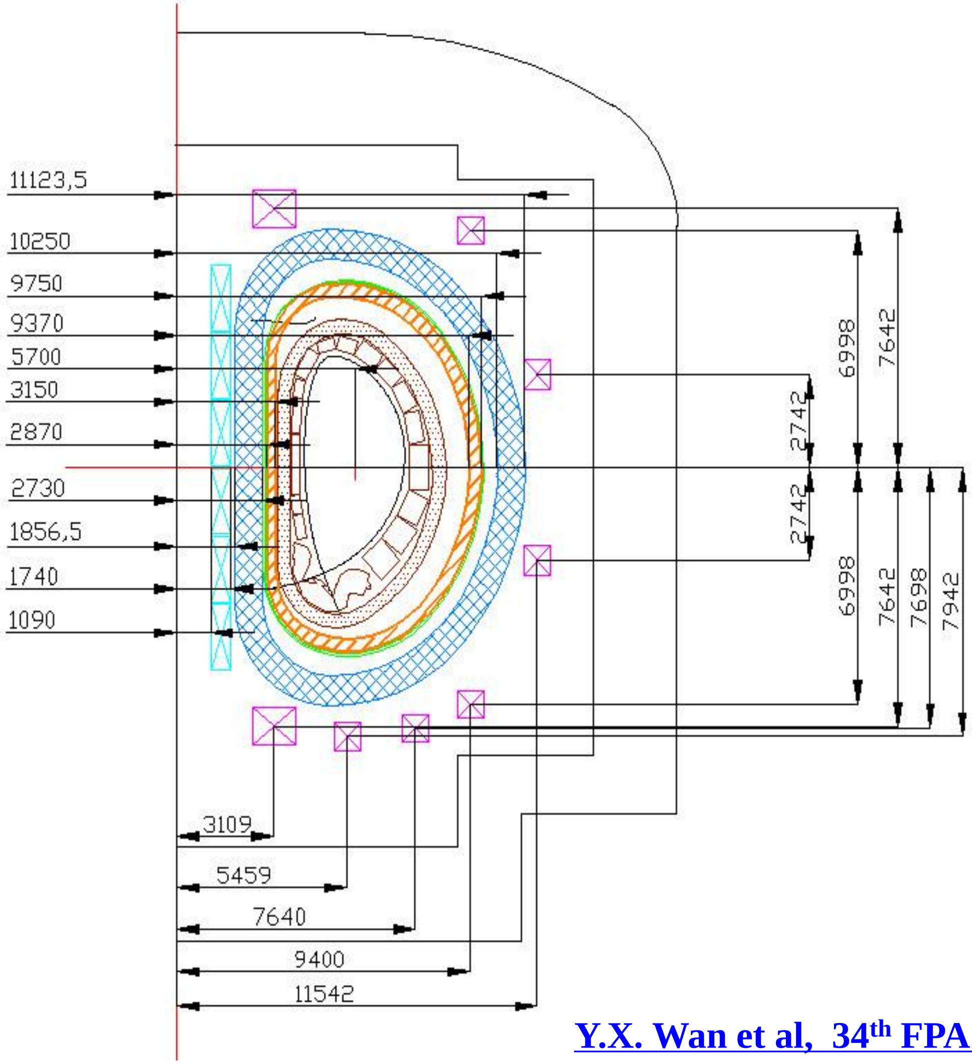


1. Layout Design and System Integration
2. Plasma Physics and Technology
3. Superconducting Magnet and Cryostat System
4. Vacuum Vessel & Vacuum System
5. In-vessel Components & Blanket System
6. Heating & Current Drive System
7. Diagnosis & CODAC
8. Electrical Power & Control System
9. Fuel Circulation System & Waste Disposal
10. Radiation Protection & Safety
11. Remote Control and Maintenance System
12. Auxiliary Supporting System
13. Project Management

CFETR machine configuration

Main parameters:

R(m)	5.7
a(m)	1.6
A	3.56
κ	2.0
δ	0.4
V(m^3)	576
S(m^2)	587
B_0(T)	5.0
Ip(MA)	10~8
P(MW)	80



Y.X. Wan et al, 34th FPA 2013

Radial size of CFETR

Size at equatorial plane (mm)

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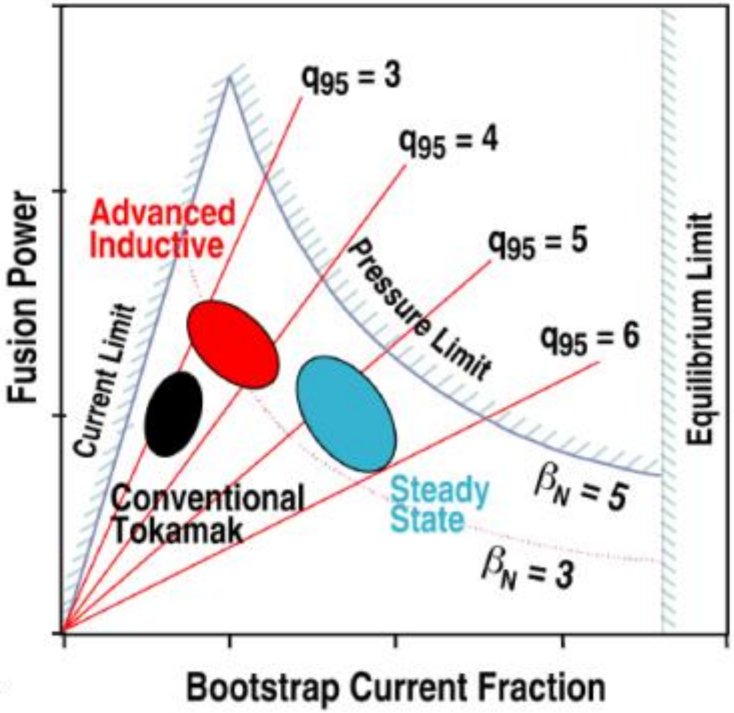
CFETR physical design (1)

Fusion energy:

$W_{fus}=P_{fus}*t_b \propto (\beta_N{}^7 B^9 a^9/f_{DL}{}^3)^{1/2} (\psi_{CS} - \psi_I)/q_{95}(1 - f_{BS} - f_{CD})$

favor high β_N and low density

- At low q_{95}, higher P_{fus}, expensive for SSO
- At high q_{95}, easier SSO, but lower P_{fus}
- At modest q_{95}, possible SSO with high P_{fus} (only operating near the pressure limit)



T. C. Luce, Phys. Plasmas 18, 030501 (2011)

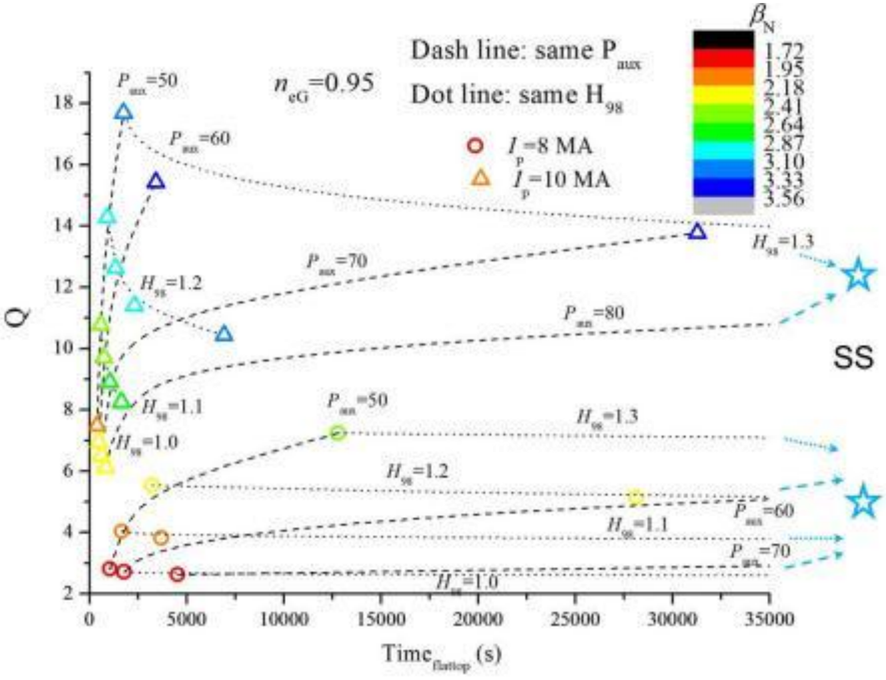
CFETR physical design (2)
Operating Modes

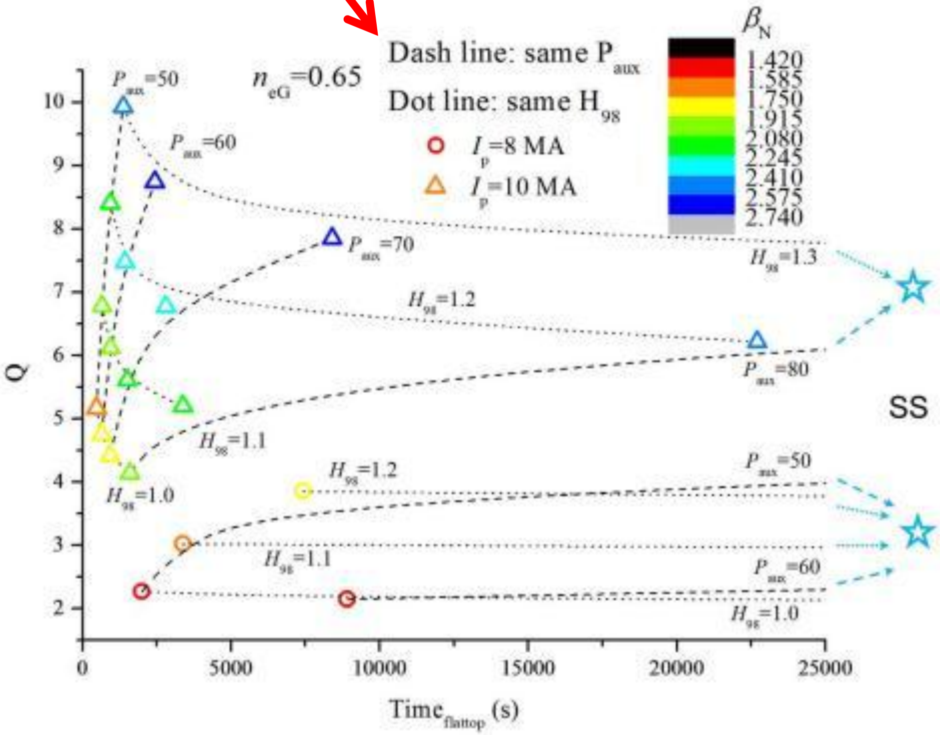
Operation mode	A	B	C	D	E	ITER-SS	Upgrade
I_p(MA)	10	10	10	8	8	9	15
P_{aux}(MW)	65	65	65	65~70	65	59	65
q_{95}	3.9	3.9	3.9	4.9	4.9	5.2	3.9
W(MJ)	171~174	193	270~278	171	255	287	540
P_{Fus} (MW)	197~230	209	468~553	187~210	409	356	1000
Q_{pl}	3.0~3.5	3.2	7.2~8.5	2.7~3.2	6.3	6.0	15
T_{i0}(keV)	17.8~18.5	29	19.8~20.8	20.6~21	21	19	25
$N_{el}(10^{20}/m^3)$	0.75	0.52	1.06	0.65	0.94		1
n_{GR}	0.6	0.42	0.85	0.65	0.95	0.82	0.85
β_N	1.59~1.62	1.8	2.51~2.59	2	2.97	3.0	2.7
β_T(%)	~2.0	2.3	3.1~3.25	2	2.97	2.8	4.2
f_{bs}(%)	31.7~32.3	35.8	50~51.5	50	73.9	48	47
τ_{98Y2}(s)	1.82~1.74	1.55	1.57~1.47	1.37	1.29	1.94	1.88
$P_N/A(MW/m^2)$	0.35~0.41	0.37	0.98	0.33~0.37	0.73	0.5	1.38
I_{CD}(MA)	3.0~3.1	7.0	2.45	4.0	2.76		3.0
H_{98}	1	1.3	1.2	1.3	1.5	1.57	1.2
$T_{burning}$(S)	1250	SS	2200	M/SS	SS		??

B.N. Wan et al, 25th SOFE 2013

CFETR physical design (3)

Operational modes at high/low density





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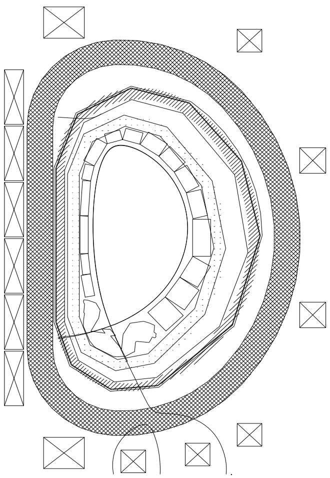
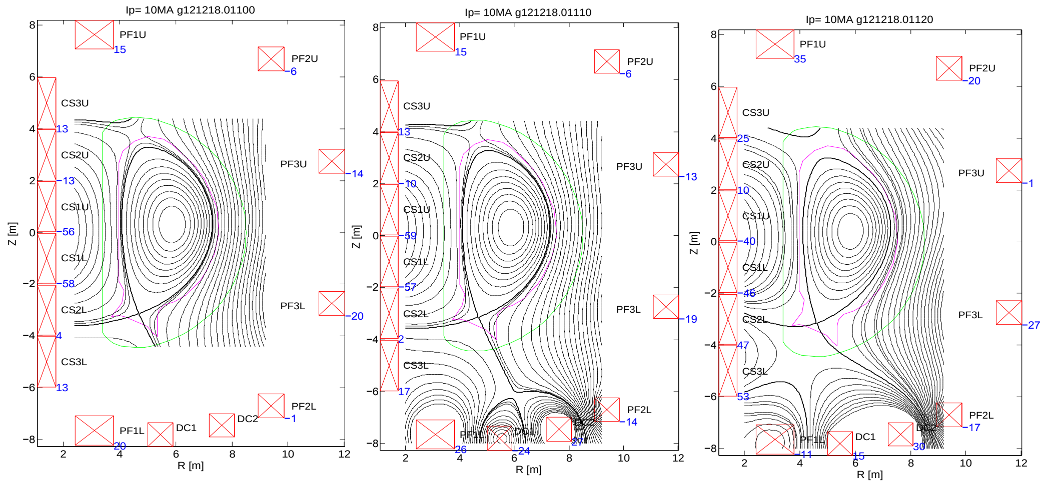
Magnet system (1)

Poloidal field and equ. design:



Equ. Calculation (5.0T, 10 MA)



(a) ITER-Like

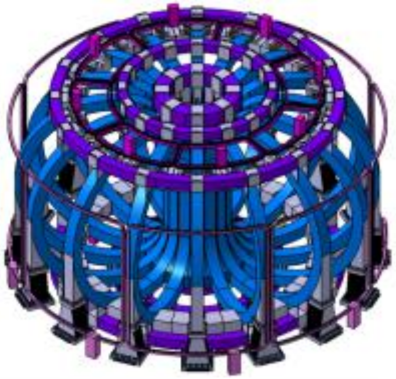
(b) Super-X

(c) snowflake

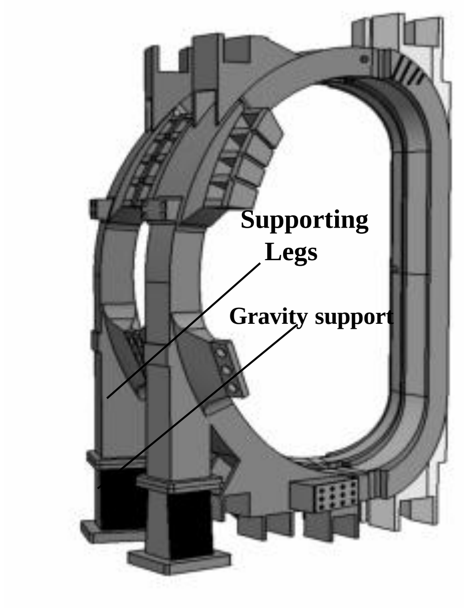
coil	R(m)	Z(m)	△R(m)	△Z(m)	turns	Current (kA/turn)		
						ITER-like	Super-X	Snowflake
CS1U	1.415	0.999	0.650	1.938	374	-56	-59	-40
CS2U	1.415	2.997	0.650	1.938	374	-13	-10	10
CS3U	1.415	4.995	0.650	1.938	374	13	13	25
CS1L	1.415	-0.999	0.650	1.938	374	-56	-57	-46
CS2L	1.415	-2.997	0.650	1.938	374	4	2	47
CS3L	1.415	-4.995	0.650	1.938	374	13	17	53
PF1U	3.109	7.642	1.382	1.111	616	15	15	35
PF2U	9.400	6.698	0.909	0.909	324	-6	-6	-20
PF3U	11.554	2.742	0.909	0.909	324	-14	-13	-1
PF1L	3.109	-7.642	1.382	1.111	616	20	26	-11
D1	5.459	-7.792	0.909	0.909	324	-1	-24	15
D2	7.640	-7.448	0.909	0.909	324	-20	27	30
PF2L	9.400	-6.698	0.909	0.909	324	-56	-14	-17
PF3L	11.554	-2.742	0.909	0.909	324	-13	-19	-27

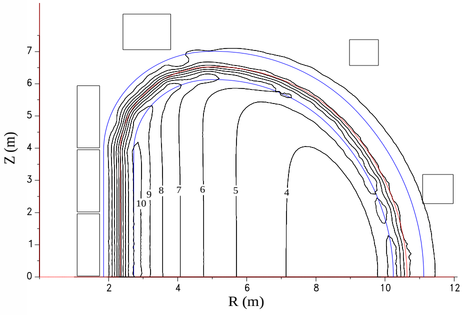
Magnet system (2)

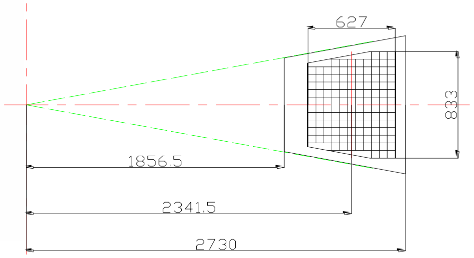
Y. T. Song et al, ASIPP report, 2013



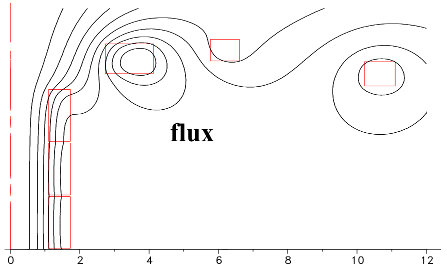
CFETR main parameters (ITER-Like/Super-X/Snowflake)				
parameters	ITER-Like	Super-X	Snowflake	ITER
No. of TF coils	16	16	16	18
Plasma current（MA）	10	10	10	15
Central field(T)	5.0	5.0	5.0	5.3
Max. current of TF coil magnet	67.4 kA/turn	67.4 kA/turn	67.4kA/turn	68 kA/turn
R(m)	5.7	5.7	5.7	6.2
a(m)	1.6	1.6	1.48	2.0
Radius of Ohmic coil(m)	1.415	1.415	1.415	2.055
Max. CS flux	160	160	160	240-250
κ	1.8/2.0	1.8/2.0	2.17/2.14	1.70/1.85
No. of PF coils	6	8	8	6

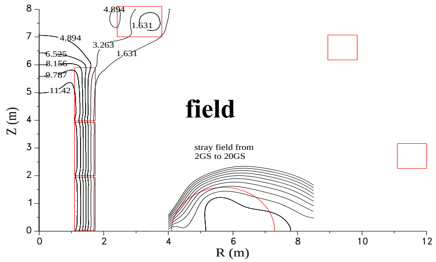






TF magnet optimization

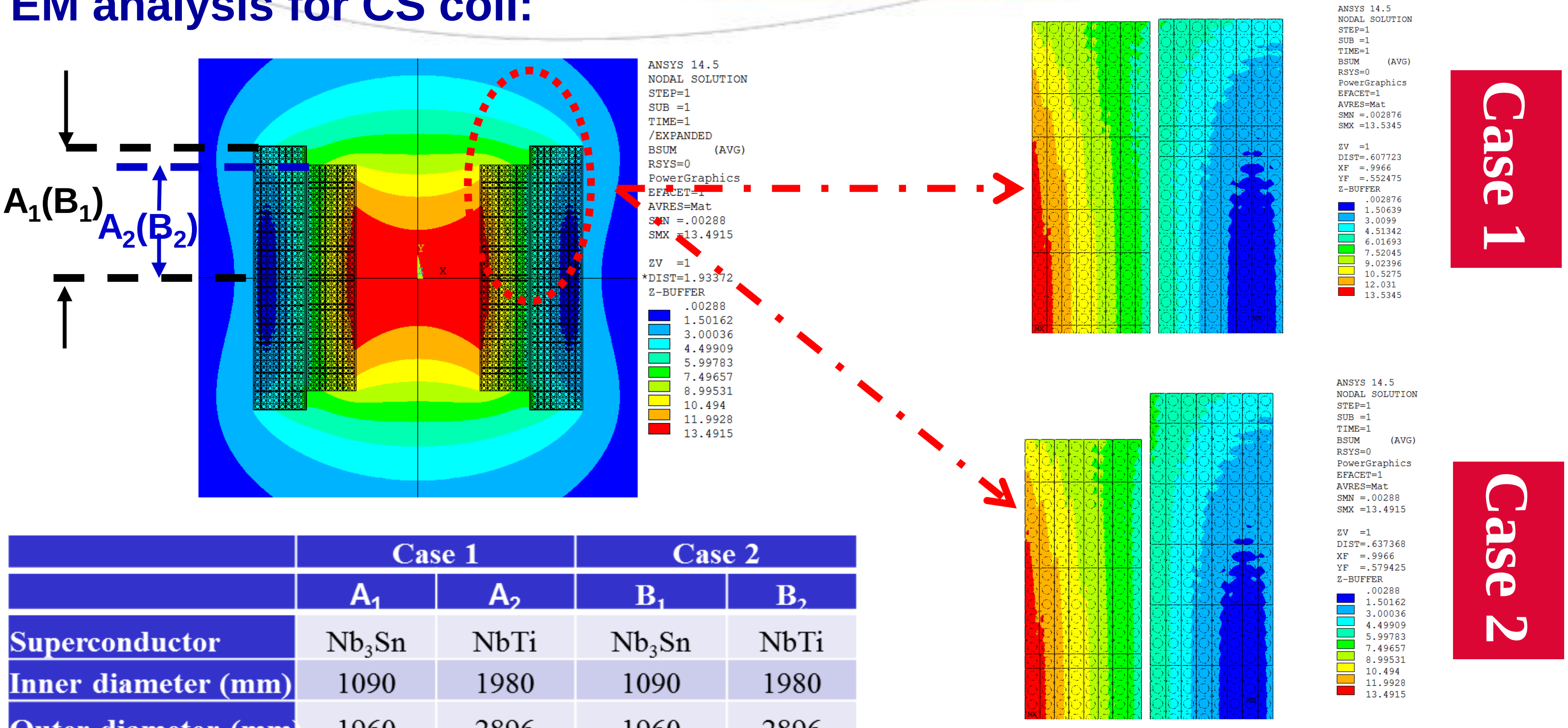




CS magnet optimization

Magnet system (3)

EM analysis for CS coil:



	Case 1		Case 2	
	A_1	A_2	B_1	B_2
Superconductor	Nb_3Sn	NbTi	Nb_3Sn	NbTi
Inner diameter (mm)	1090	1980	1090	1980
Outer diameter (mm)	1960	2896	1960	2896
Height (mm)	2213	2230	2009	2392
Layer	8	8	8	8
Turns/Layer	43	41	39	44
Coil Mass (ton)	76.8		77.6	
Current (kA)	45	45	45	45
Max. Field (T)	13.51	6.15	13.53	6.46

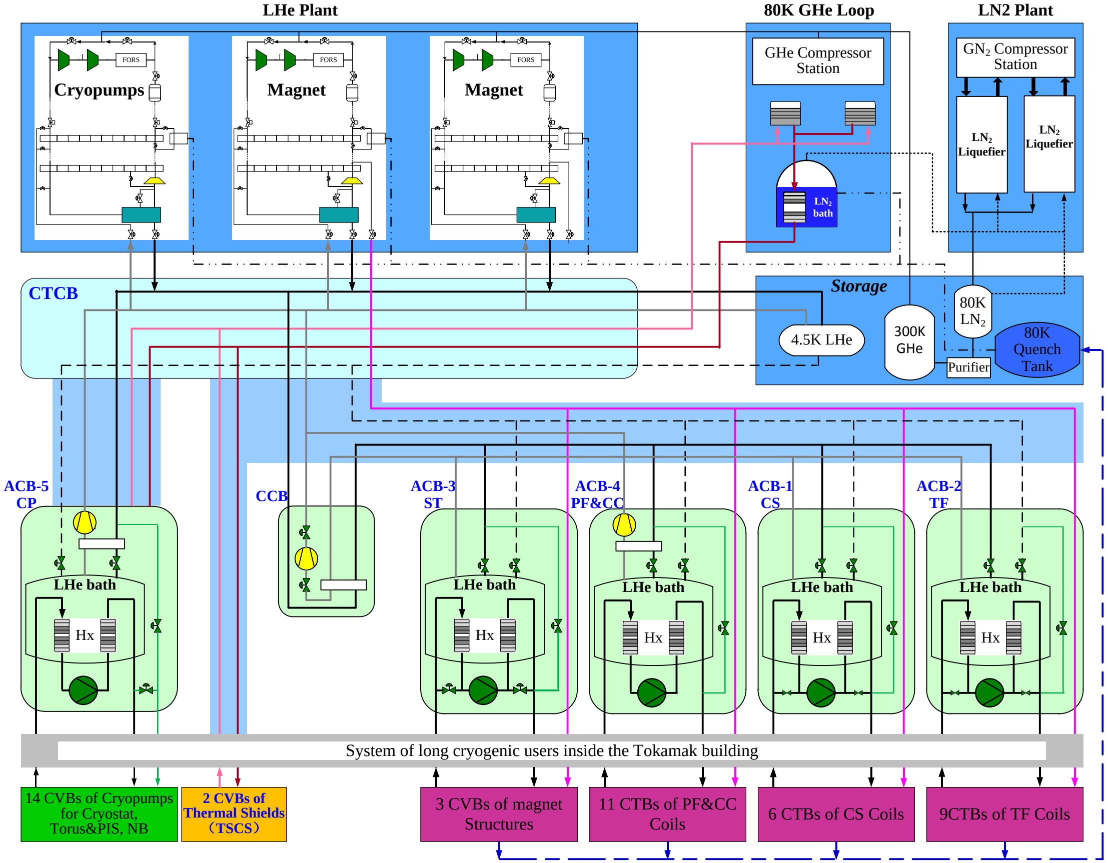
Peak Field (T)	Case 1	Case 2
HF	13.51	13.53
LF	6.15	6.46

Y. Ren et al, ASIPP report, 2013

Cryostat system

Users of CFETR Cryostat System:

- 16 TF coils ;
- 6 CS coils ；
- 8 PF and 18 CC ；
- Encasing and supporting structures ；
- Cryopumps for Torus, Cryostat, NBI ；
- HTS current leads ；
- Thermal Shield system of the tokamak ；
- Other small users.

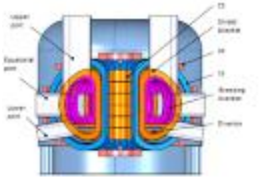


X. G. Liu et al, ASIPP report, 2013

Vacuum system

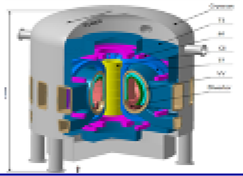
Vacuum vessel and window configuration:

ITER-like



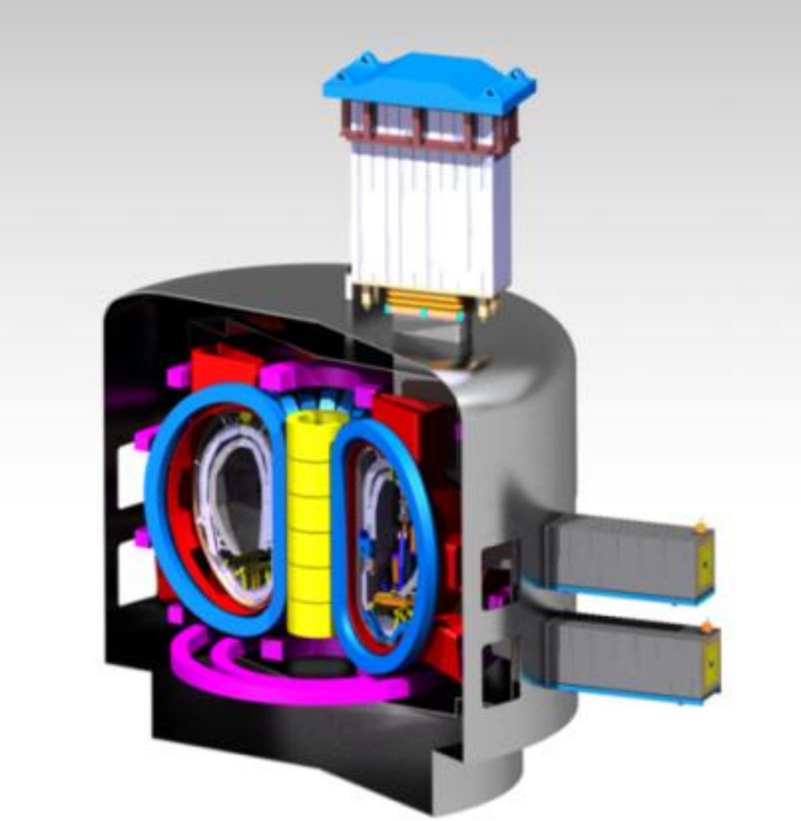
Overall large window

Large middle window



The vacuum vessel:
4 upper ports
8 equatorial ports
8 lower ports.

These ports are used for equipment installation, vacuum pumping, maintenance, etc.



A new design of large- vertical window scheme was selected by discussing the advantages and disadvantages of the three conceptual CFETR design.

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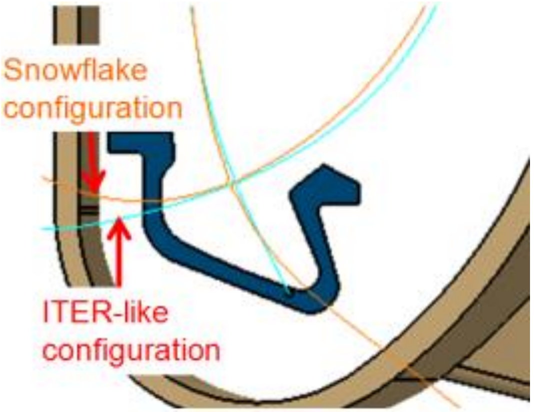
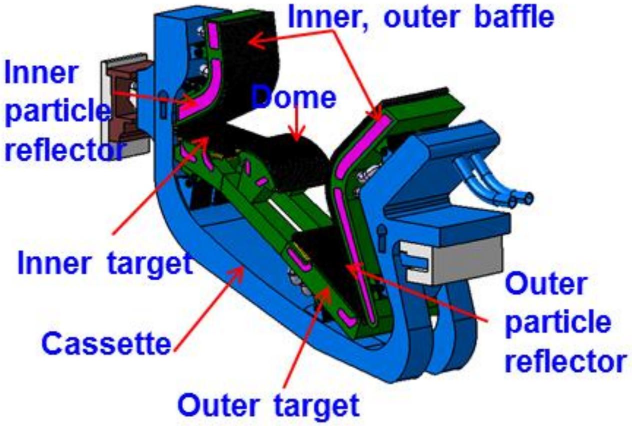
Divertors

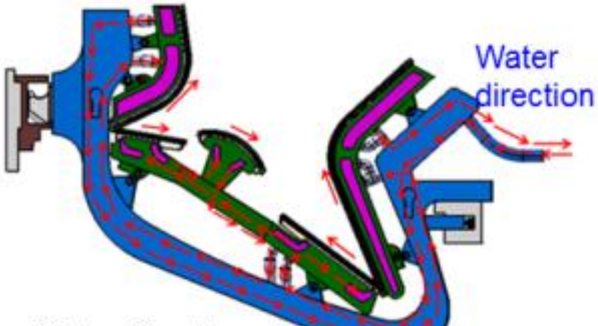
Divertor design:

- ITER-like or Snowflake (Super-X configuration not available)
- mono-block design of first wall
- Space for shielding blanket reserved between divertor support structure and vacuum vessel
- Pumping channel between Dome and target plates
- Space for diagnostic reserved between cassette and first wall
- 60 modules in toroidal direction, 9.5 t weight each
- length×width×height (mm): 2834×650×1713.

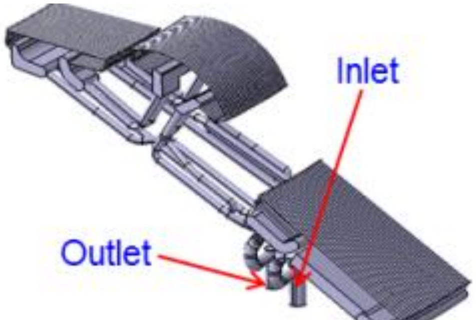


Divertor plasma configuration





Water direction of snowflake divertor



Cooling channel model

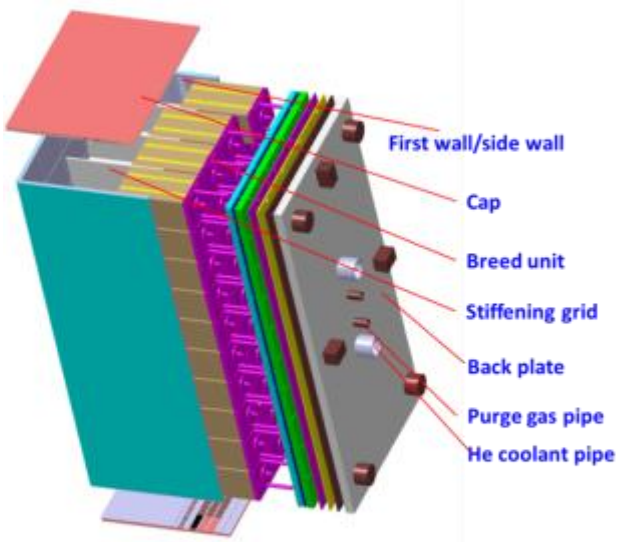
Blanket system

☐ Blanket design:

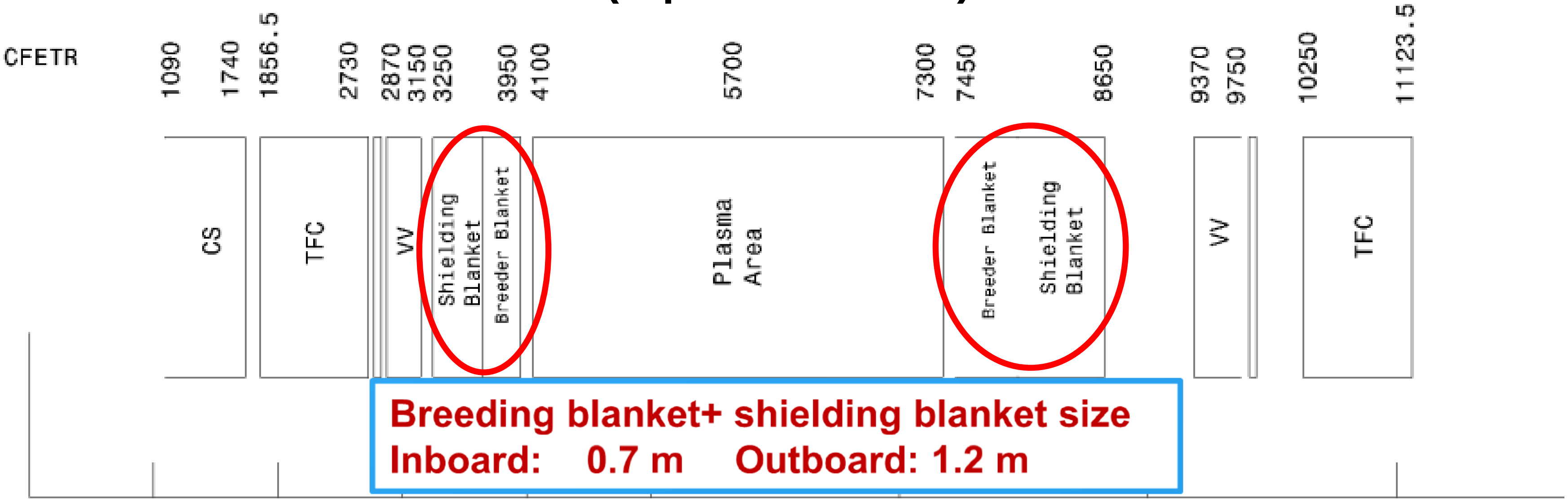
Group I: Helium cooling solid blanket
- 1) HC (8MPa, $300/500^0$C), Li_4SiO_4 (Li_2TiO_3), Be , RAFM

Group II : Liquid blanket
- 1) SLL (~150 ^{0} C) , CLAM
- 2) DLL(~700 ^{0}C), CLAM

Group III : Water cooling solid blanket
- 1) HC, Li_4SiO_4 , Be , RAFM
- 2) WC, Li_2TiO_3, $Be_{12}Ti$, RAFM



☐ Radial sizes of the CFETR (Equatorial Plane)



Breeding blanket+ shielding blanket size
Inboard: 0.7 m Outboard: 1.2 m

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Heating & Current drive

Heating & CD system currently planned:

- NBI: 500 keV, 20 (potential upgrade to 40) MW, negative ion source, off-axis injection
- LHW: 4.6 GHz, 15 MW
- ICRF: 30-50 MHz, 25 MW
- ECW: 170 GHz, 20 MW

Diagnostics

Phase I (H, D, DT-1)

☐ ~26 diagnostics

☐ For machine safety and additional control in some scenarios

One example of diagnostic design in CFETR phase I:

position	Diag.	Windows taken
Inner wall of VV	magnetic	
Outer wall of VV	magnetic	
Vertical window	Visible/IR camera(4), Visible/UV spec., bolometer, neutron monitor, CXRS, MSE,etc…	1(4)
Mil-plane window	Reflectometry, FIR inter./polor., neutron monitor, ECE, TS, CXRS, neutron spec., hard X-ray spec. etc…	2~3(8)
Divertor window	Visible/IR camera(4), Visible/UV spec., bolometer, neutron monitor, divertor thermocouples, erosion& dust analysers, residual gas analysers, etc…	3~4(8)

Phase II (DT-2)

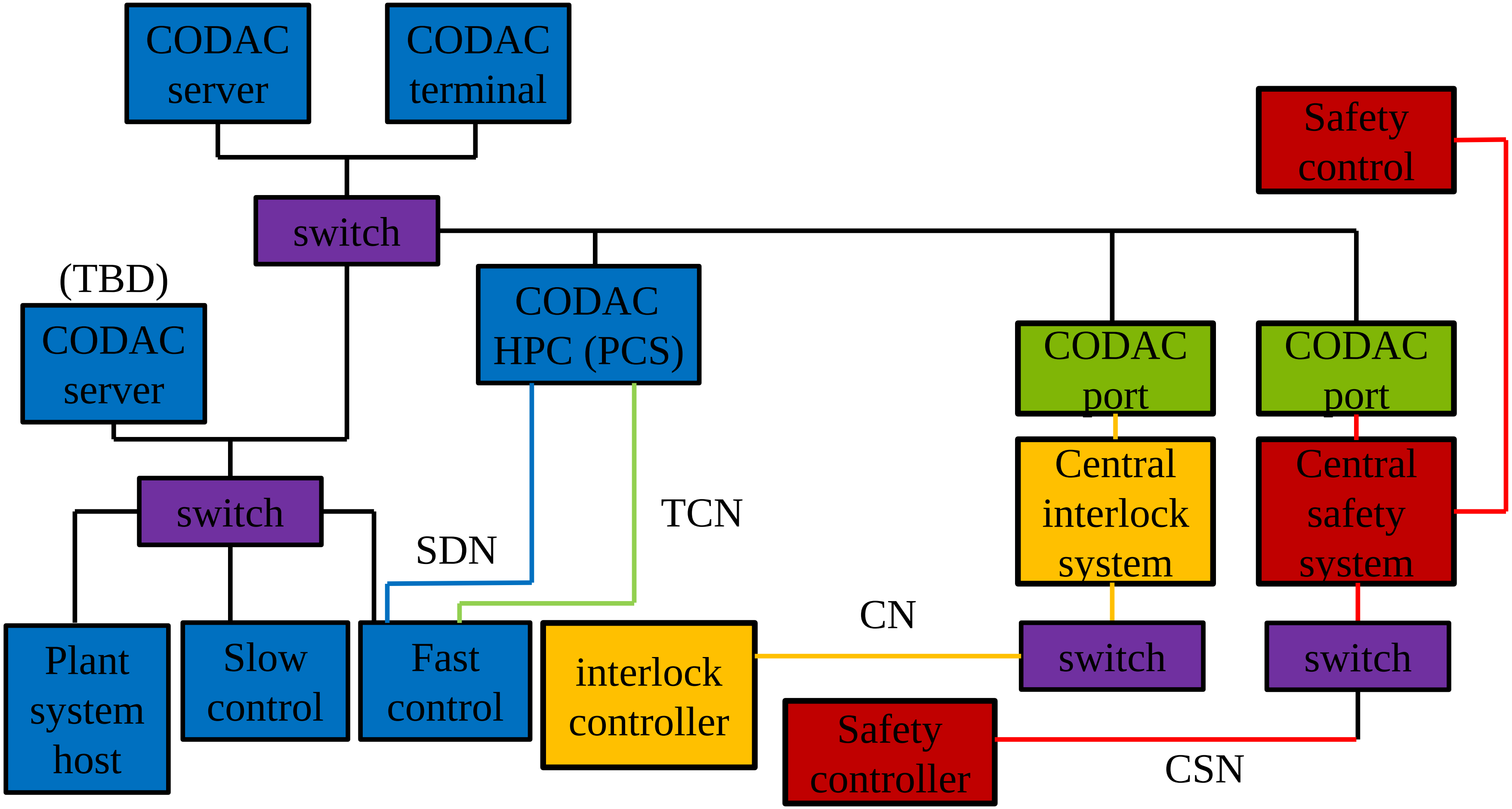
☐ ~16 diagnostics

☐ Only for machine protection and basic control

(Maybe an additional phase between phase I and II is needed. To test the diag. reliability under fusion environment, to reduce the number of diagnostics.)

Y. Yang et al, 25th SOFE 2013

CODAC system concept design



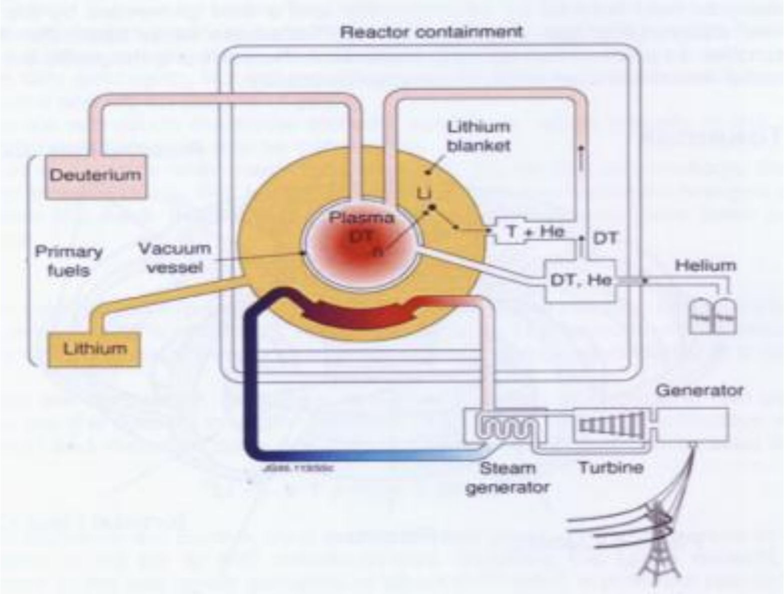
Outline

- ☐ Introduction
- ☐ Progress of CFETR design
  - ➢ Overview and machine layout
  - ➢ CFETR physical design
  - ➢ Magnet, cryostat and vacuum system
  - ➢ Divertor and blanket system
  - ➢ Heating & current drive, diagnostic & CODAC
  - ➢ Tritium technology
  - ➢ Remote handling
- ☐ Summary

Fusion reactor T-plant technologies

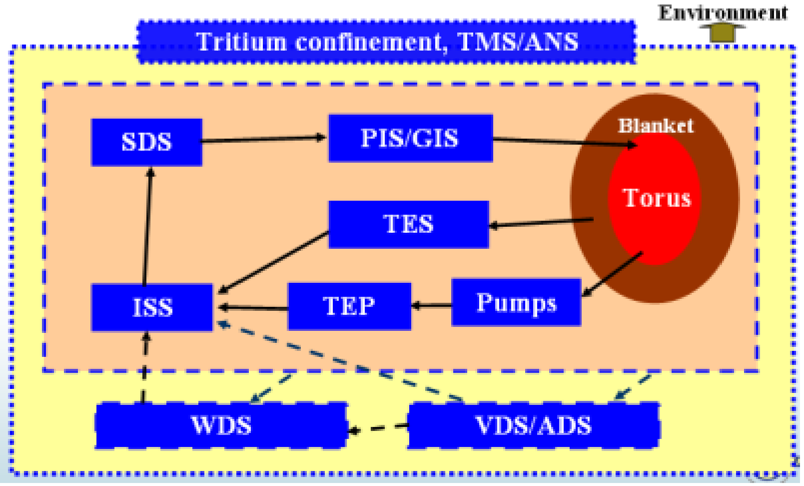
☐ Concept design of T-plant for CFETR

- Launched in 2012
- Key issues:
  - ➢ Start-up tritium preparation
  - ➢ Plant breakdown structure (PBS)
  - ➢ Technological principle, parameters for each PBS
  - ➢ Tritium safety measures
  - ➢ Preliminary safety analysis
  - ➢ R&D scheme



☐ Preliminary fuel recycling for CFETR

- Concepts of the main processes (TES, TEP, ISS, WDS, VDS and ADS) have been finished.


Environment
Tritium confinement, TMS/ANS
SDS
PIS/GIS
Blanket
Torus
TES
ISS
TEP
Pumps
WDS
VDS/ADS

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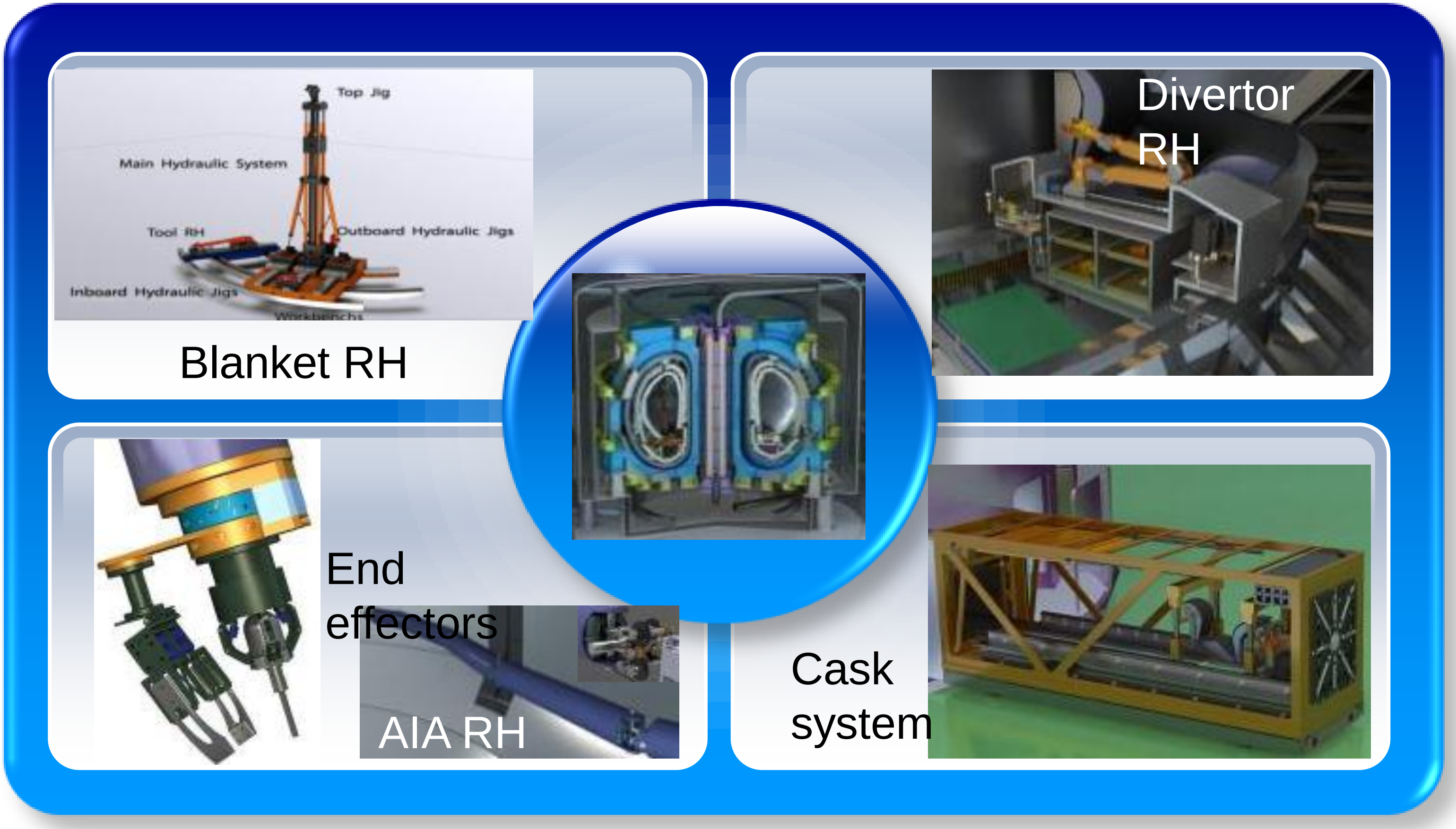
Consideration of remote handling system

- Duty cycle: 0.3-0.5
- Fusion power: 50-200 MW
- High dosage of neutron: 2-3 orders of ITER in amplitude
- To meet CFETR design parameters
- Prevention of diffusion of Radioactive dust

- Big modules (divertor, blanket, etc..)
- High decay heat needs to be removed
- To reduce the quantity of middle plane port
- High magnetic field intensity of CS (max: 13T)
- Radiation resistance of RH devices

- High load for RH and less maintenance time
- Forced cooling needed after SD
- High utilization of port (diagnostic integration, reduction of maintenance port)
- New superconducting material for magnet
- High safety and availability requirement

Remote handling system



Blanket RH

Divertor RH

End effectors

AIA RH

Cask system

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Summary

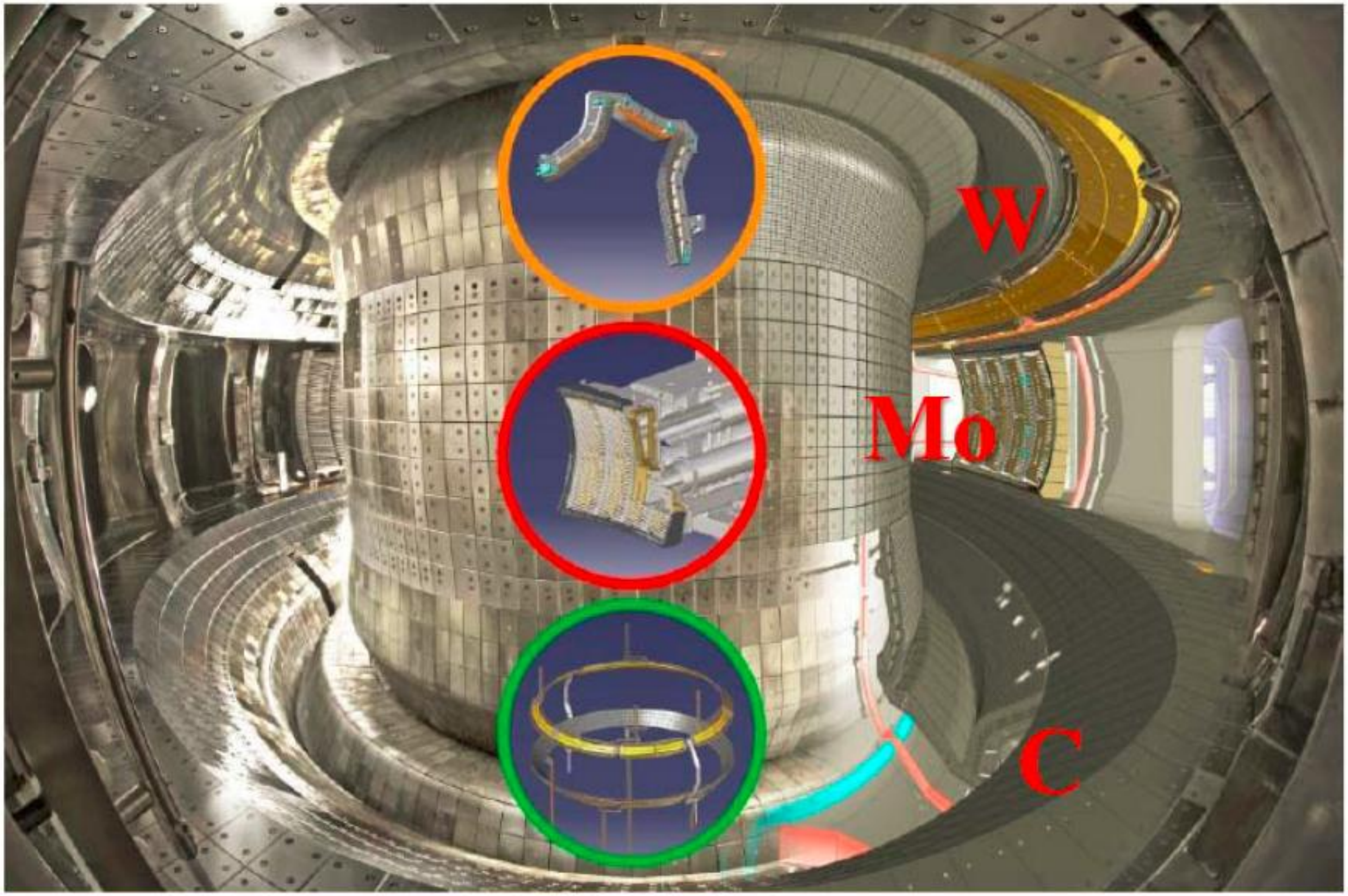
- Concept design of CFETR which includes (1) full superconducting magnets and (2) water cooling Cu magnets is well progressing. The engineering parameters of the device has been determined by considering engineering constraints. The two design options will be finished by Sept. 2014.

- CFETR operation modes have been studied. SSO is proved to be possible. More detailed 1.5D calculation needs to be done.

- A new design of large vertical window scheme was selected by discussing the advantages and disadvantages of the three conceptual CFETR design. Vacuum vessel and window configuration by considering remote handling technology have been decided.

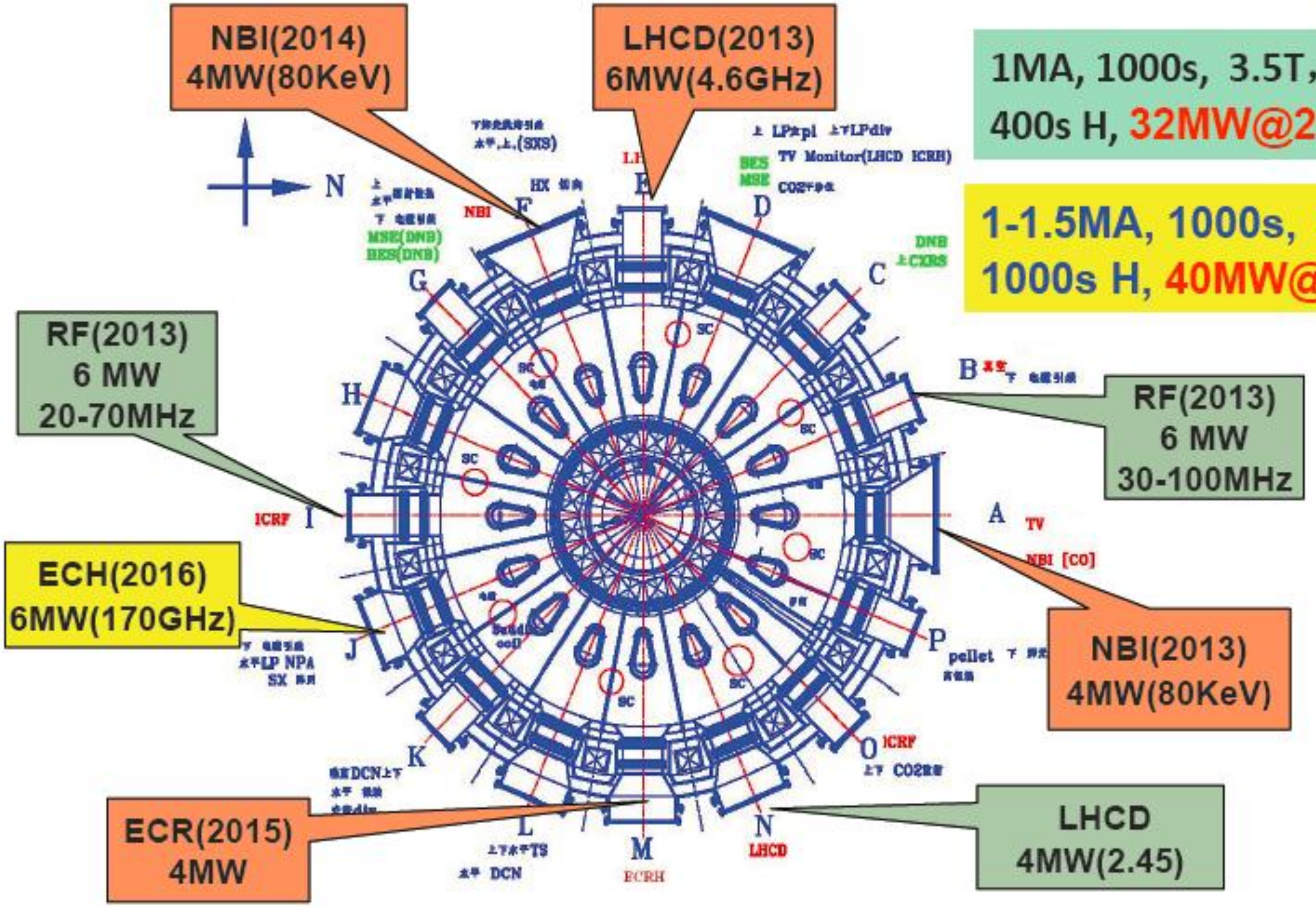
- ITER-like, snowflake, super-X divertor configurations have been studied. Integration design of divertors for ITER-like and snowflake configurations has been done. Many upgrades on EAST tokamak have been developed towards CFETR R&D items recently.

Upgrade on EAST for CFETR R&D



divertor scenarios compatible with high performance core plasma for SSO

Heating and CD on EAST for CFETR R&D



NBI(2014)
4MW(80KeV)

LHCD(2013)
6MW(4.6GHz)

RF(2013)
6 MW
20-70MHz

ECH(2016)
6MW(170GHz)

ECR(2015)
4MW

RF(2013)
6 MW
30-100MHz

NBI(2013)
4MW(80KeV)

LHCD
4MW(2.45)

1MA, 1000s, 3.5T， 70Dia.
400s H, 32MW@2014

1-1.5MA, 1000s, 3.5-4T,
1000s H, 40MW@2016

Thank you for your attention !