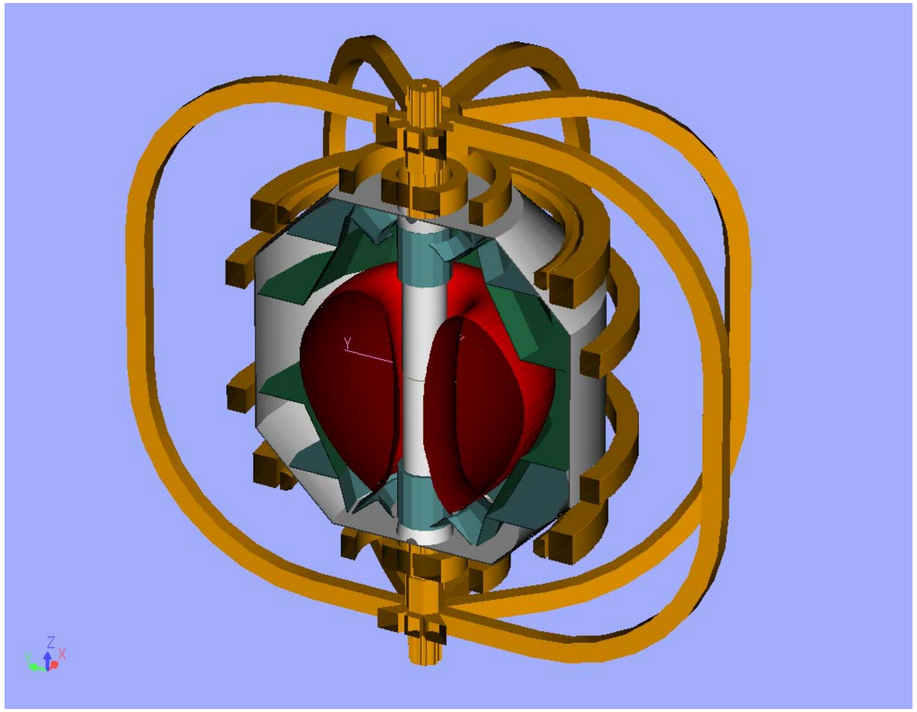
On 22, May 2007
1st NIFS-CRC International symposium & 1st Korea-Japan WS
on Edge Plasma and Surface Component Interactions in Steady State Magnetic Fusion Devices at NIFS

Design and Present status of Steady-state spherical tokamak, QUEST

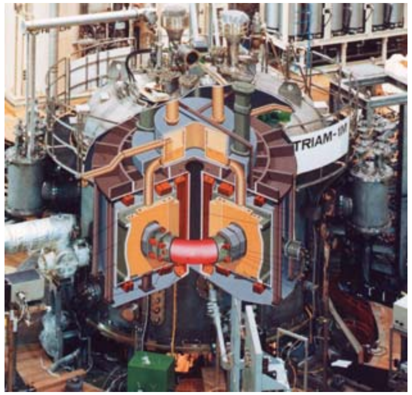


K.Hanada, H.Zushi, K.N.Sato, K.Nakamura, M.Sakamoto, H.Idei,
M.Hasegawa, S.Kawasaki, H.Nakashima, and A.Higashijima

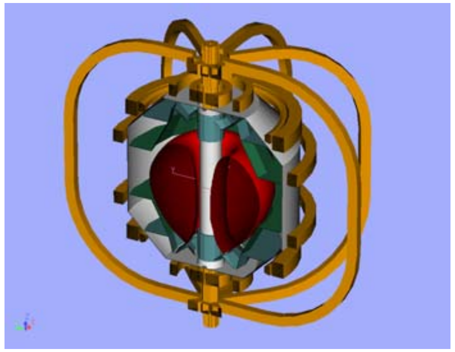
Kyushu University

Japanese Collaborators and Map of QUEST

TRIAM-1M



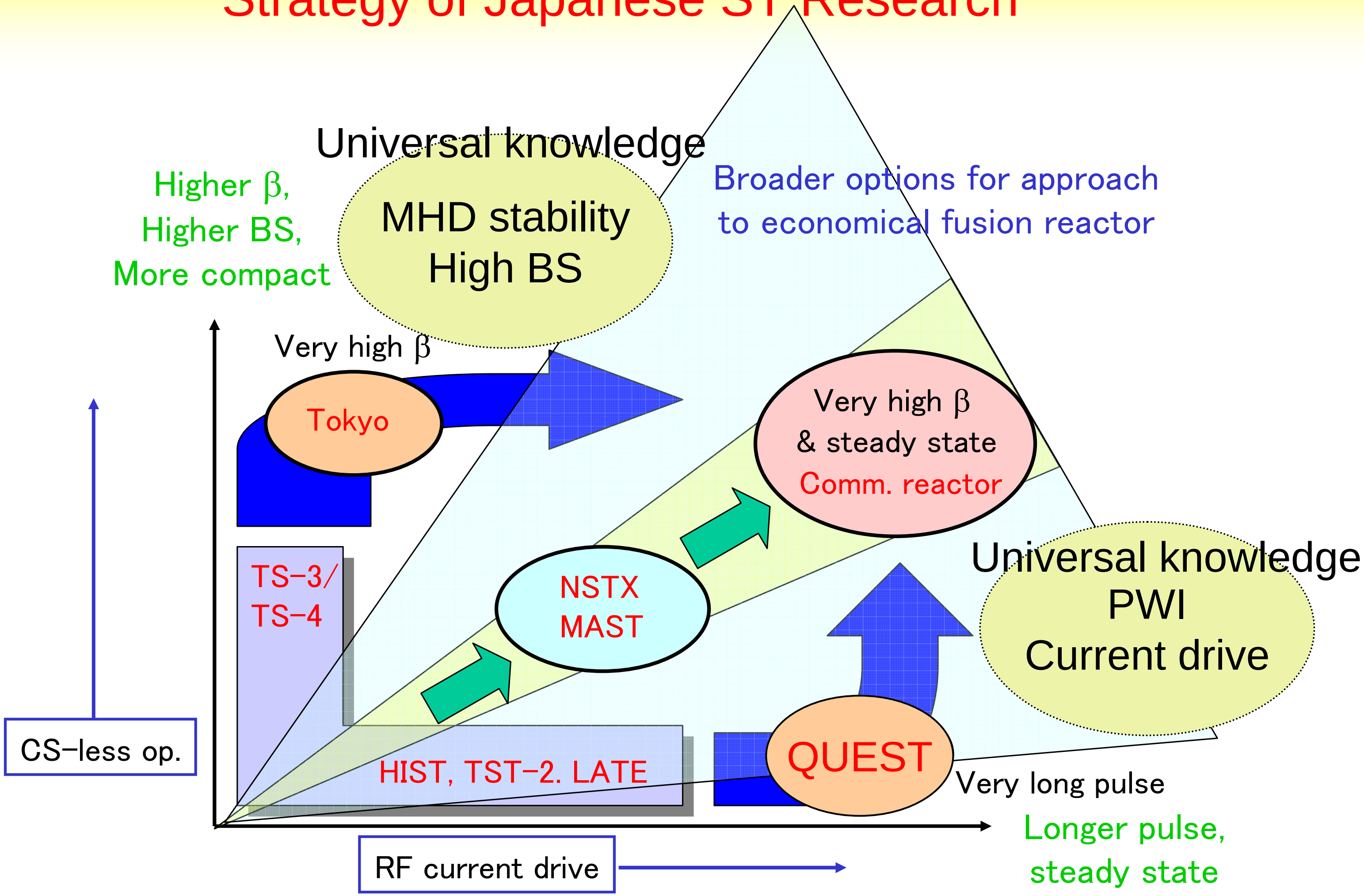
QUEST



Contents

- Frame work
- Baseline of the conceptual design
- Introduction of QUEST
- Present status of QUEST
- Future plan

Strategy of Japanese ST Research



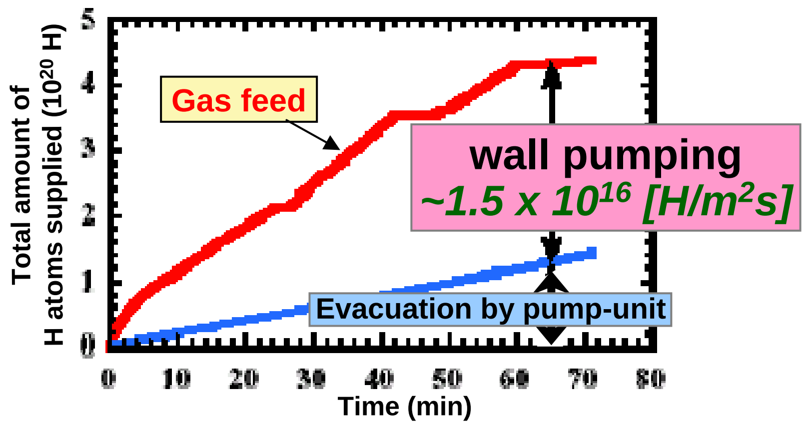
- QUEST is the main device for the research of steady state operation in this framework.

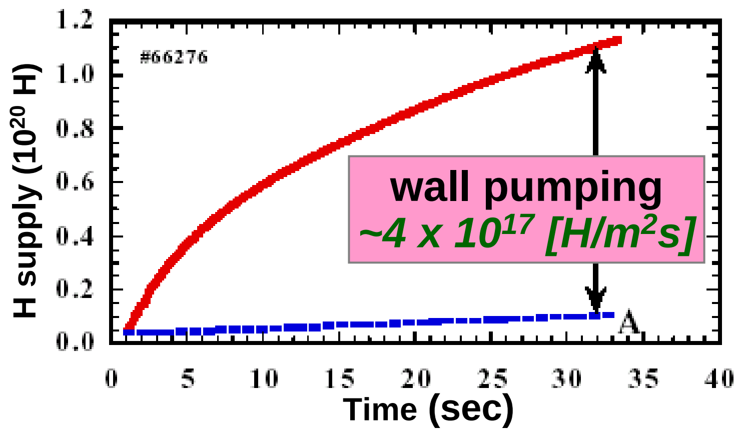
Why steady-state ?

Wall pumping in long pulse operation

M. Sakamoto et al., Nucl. Fusion 42 (2002) 165

Low density (n_e~10^{18} m^{-3})	*High density (n_e~10^{19})*



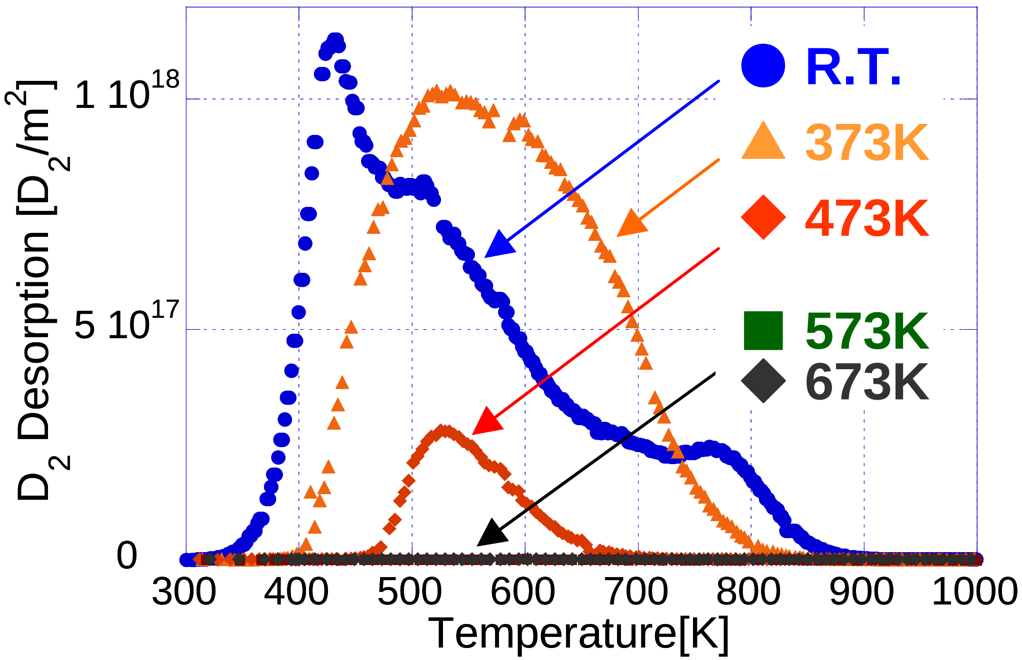


Time evolution of the total amount of gas feed and evacuation to the external pumping.

- The wall pumping depends on the plasma parameters and it leads to be difficult to control of particle balance in steady state. The co-deposition process plays an essential role in the wall pumping rate.

How to resolve

The wall pumping should be controlled. It is difficult to control the co-deposition process on the wall, therefore R=1 is the unique solution.



N.Yoshida et al.

- TDS spectrum for Mo implanted D (2keV-D+, $3x10^{21}$ D/m^2) at various temperature.
- At the high temperature region, D does not absorbed in the material.
- We consider the high temp. wall works as the reflector of the particle.

Proposed particle control in steady state

- Wall works sometimes as particle sink and sometimes as source.
- Wall pumping rate is comparable to pumping rate of external pumps.
- It is difficult to control wall pumping rate, because the effect of co-deposition is crucial.

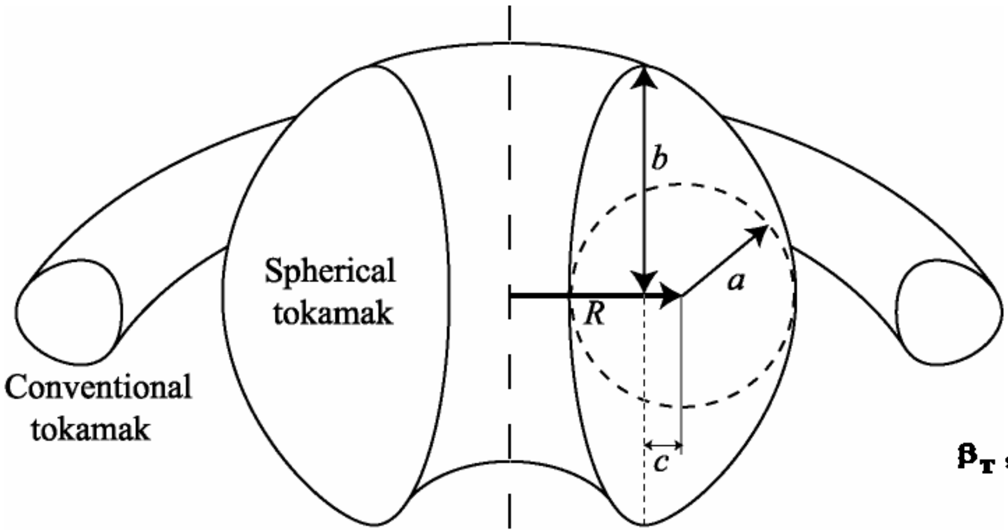
↓

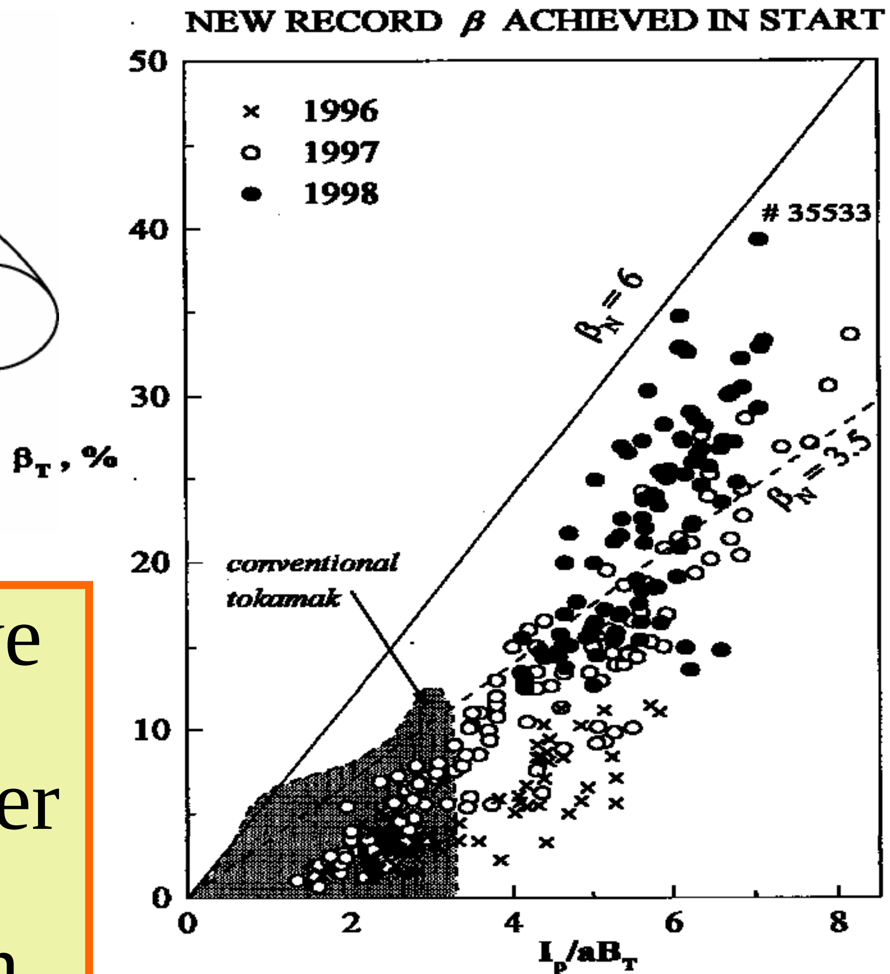
- Recycling rate will become to unity under metal high temp. wall .

↓

- It is necessary to investigate it in real-operated plasma confinement device.

Sperical toksmaks (ST)



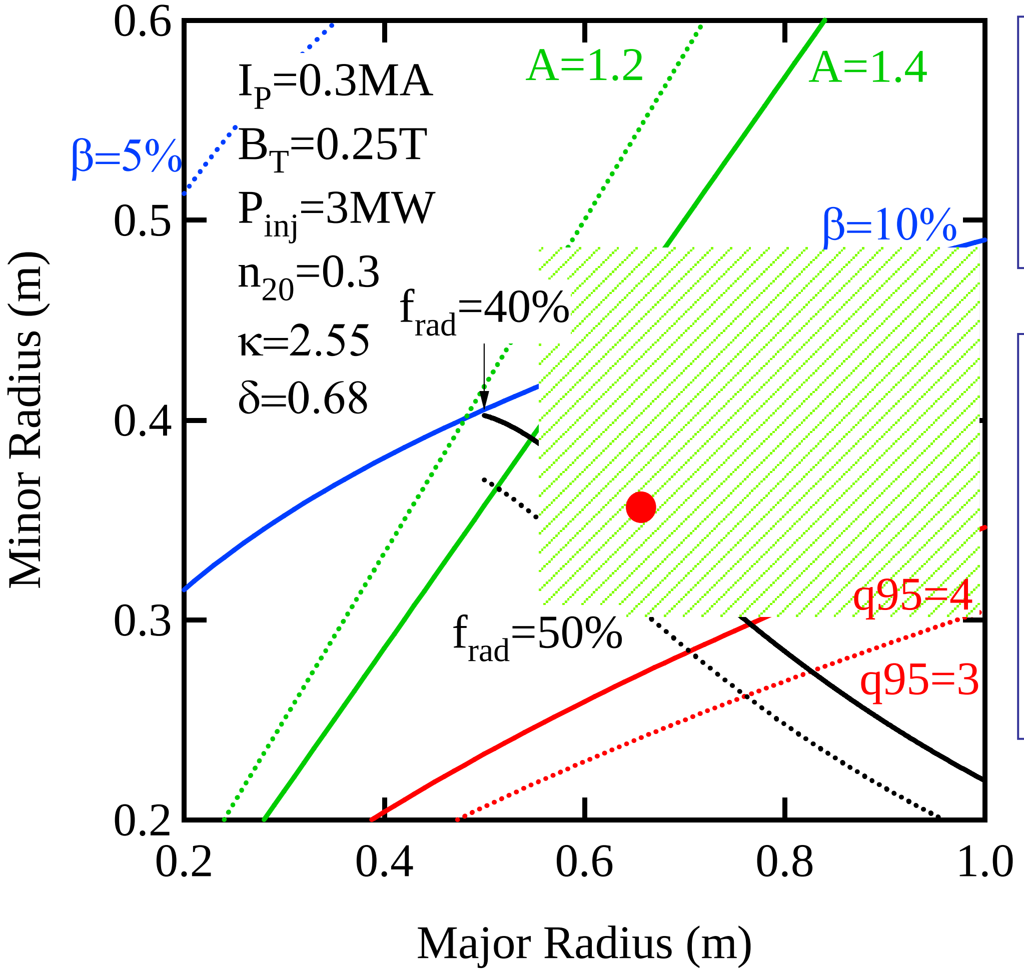


Sperical tokamaks (ST) have the possibility to realize cost-effective fusion power plants. High β (~10%) is the indispensable target in QUEST.

Mission of QUEST

- The mission of QUEST should be to develop the scientific basis for achieving a steady state condition at sufficiently high beta (~20%), with high confinement and low collisionality, in a longer term program that contains three Phases of R&D.
- The short-term goal of QUEST for Phase I (the first 2years) is to establish the basis for sustained operation at low density (~$4x10^{18}$ m^{-3}) and low current (20-30 kA).
- In Phase II (5 years) , progress towards higher current (~100 kA) in steady-state, and towards higher beta (~10%) in the pulsed operation will be pursued with an upgraded heating system.
- The goal of Phase III research is to achieve steady state operation of ST at sufficiently high beta (~ 20 %) .

Feasibility of the Mission



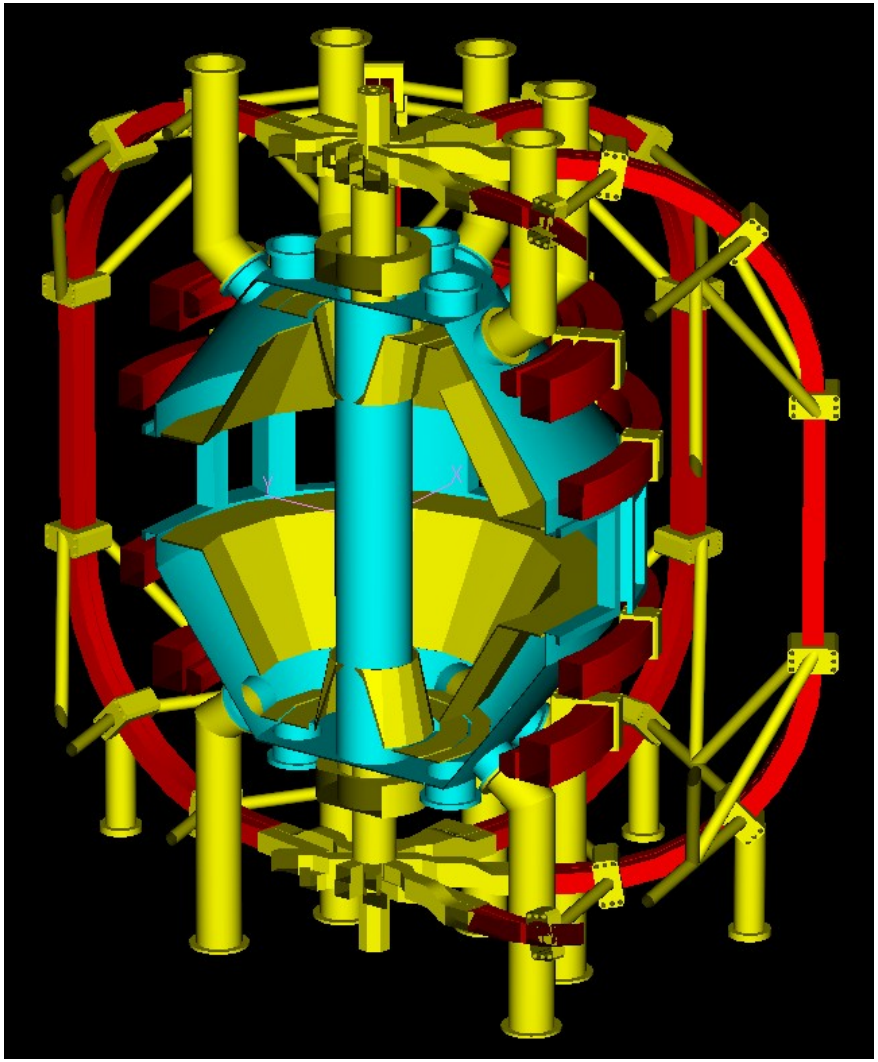
Mission in phase I

- plasma current 20kA in steady state

Mission in phase II

- plasma current 100kA in steady state
- plasma current 300kA at β>10% 1 sec

Specification and parameters



	Phase I	Phase II		Final aim
		SSO	Pulse	
R(m)	0.68			
a(m)	0.4			
A	1.78			
Radius of VV(m)	1.4			
Height of VV(m)	2.8			
BT(T)	0.25	0.25	0.5	0.25
IP(MA)	0.02–0.03	0.1	0.3	0.5
Pinj(MW)	0.45	1	3	3
k	2.5	2.5	2.5	2.5
d	0.7	0.7	0.7	0.7
<ne20>(m-3)	–	0.04	0.3	0.3
<Te>(keV)	–	0.32	0.33	0.54
<Ti>(keV)	–	0.32	0.33	0.54
τ_E(ms)	–	2.5	6.8	10.8
β(%)	–	1.6	13	21
β_N	–	1.5	3.9	3.8
β_p	–	0.33	0.29	0.17
q95	–	25	8.2	5
Γ_H (MW/m2)	–	6.5	10.1	13.6
F_{rad}(%)		20	40	40
Γ_P (Pa m3/s)	–	17.5	50	31.1
f_{GW}	–	0.16	0.41	0.24
I_{BS}(MA)	–	0.008	0.022	0.021
$\eta_{CD}10^{19}$(A/W/m^2)	–	0.026	0.19	0.32

Heating and Current drive

- Power and Required current drive efficiency

Phase I 20-30kA at low density

RF (0.45MW)

Phase II (SS) 0.026×10^{19} A/W/m^2

RF (1MW) [+ NB (2MW)]

Phase II (1sec) 0.19×10^{19} A/W/m^2

RF (1MW) + NB (2MW) with OH

EBWCD

Experimental Observations

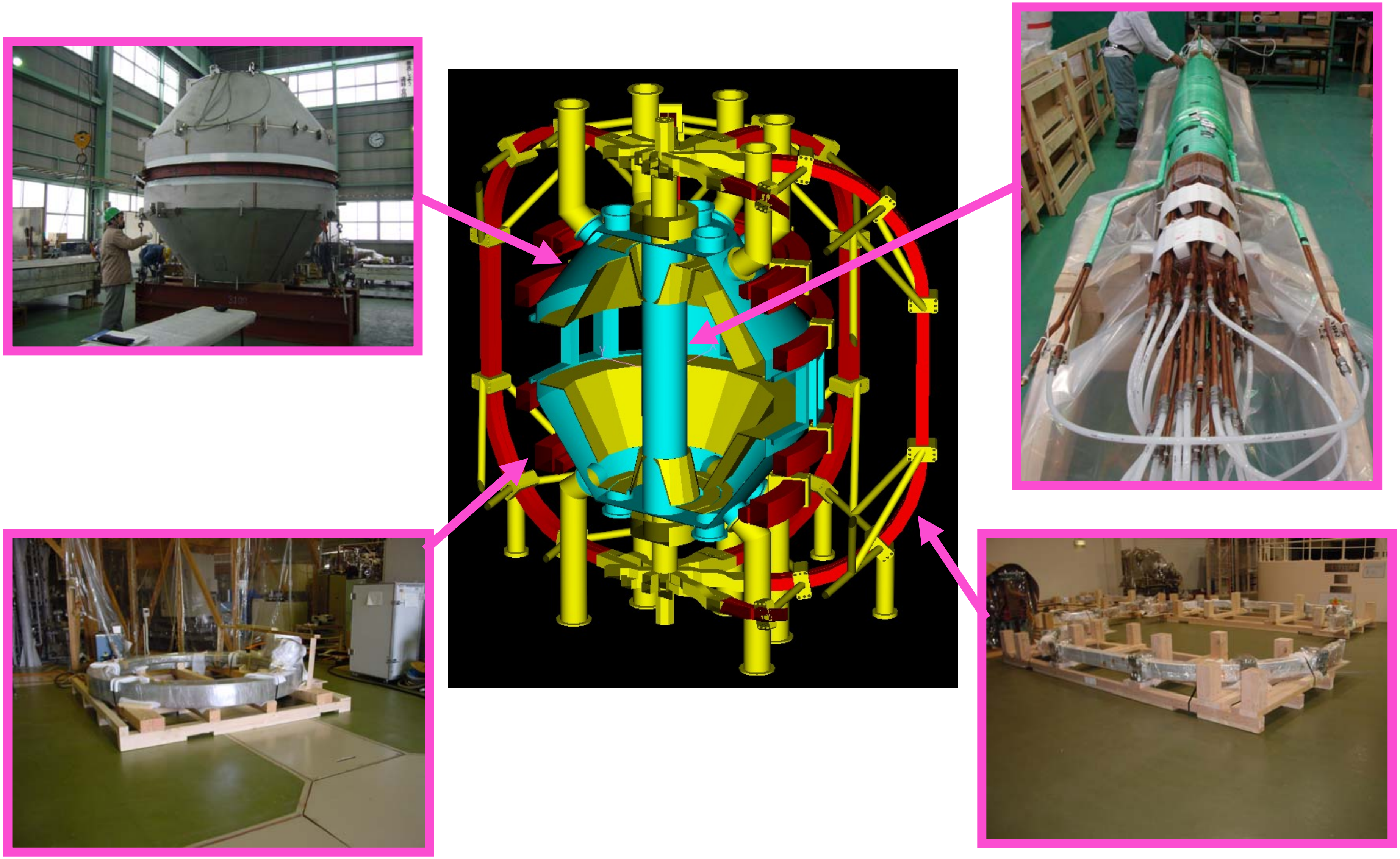
- 100kA at 60 GHz 600kW on COMPASS-D
- 15kA at 5 GHz 200kW on LATE
- 4 kA at 8.2GHz 170 kW on TST-2
- 1.2 kA at 140 GHz on W7-AS

Simulation

- 30kA at 15 GHz, 1MW on NSTX, but no optimization

- EBWCD in ST has the potential to attain the high current drive efficiency comparable to ECCD on conventional tokamaks.
- Even in ST, wave propagation of EBW has no limitations such as cut-off.
- The collaboration with LATE group will start in 2005.

Present Status of QUEST

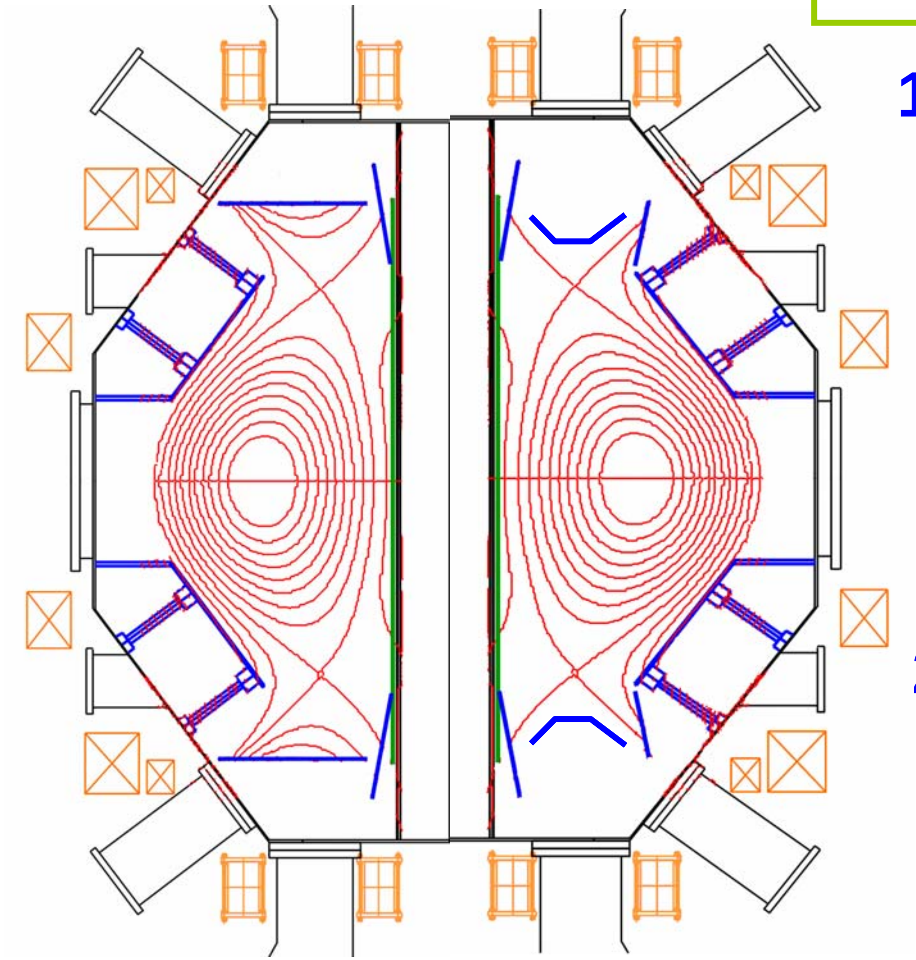


Schedule and Research items

items \ fiscal year	05	06	07	08	09	10	11	12	13	14	further
construction	(construction period)										
High β						>10% (1sec)					20%
Plasma start-up				RF+OH		RF+OH+NBI					
Current drive				RF		RF(8.2GHz)+NBI					16GHz
PWI				W		W, high Temp. wall					Control of Recycling
Divertor				open			closed				advanced
fueling				Gas puff		CT injection					pellet

We are here. (start of FY08)

Plan for divertor and 1st wall



1st step　　2nd step

Vacuum Vessel（SUS316L）150℃

1st Step（2009-10）(300~500 ℃)

Flat Open divertor（W）
High temp. wall

Controllability of Magnetic flux

- Heat and Particle flux
- Diagnostics
- Simulation（SOLDOR）

2nd Step（2010- ）

Closed Divertor（W）
High temp. wall

Controllability of particle flux

- Heat and Particle flux
- Diagnostics
- Simulation（SOLDOR）

summary

- The QUEST program starts from 2005 to develop the scientific basis for achieving a steady state condition at sufficiently high beta (~20%), with high confinement and low collisionality, in a longer term program that contains three Phases of R&D.
- The first plasma will be obtained in summer 2008.

Required research items of QUEST

- Plasma start-up
- Non-inductive current drive
- Divertor Research
- Plasma wall interaction
- Achievement of medium or high β
- Particle and heat handling
- Innovative concept

Mainly focus on the technological issue for SSO

Simulation of design of divertor structure

Using SOLDOR/NEUT2D, Investigation of the divertor structure of QUEST has been executed.

設計における検討課題

熱制御性

QUESTの加熱入力パワーは定常運転時に1MW、パルス運転時に3MWが計画されており、またダイバータ板としてタングステン板を用いることが計画されている。

ダイバータ板への熱入力評価が必要

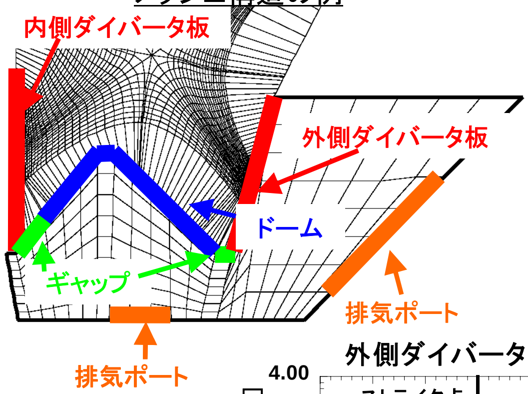
粒子制御性

QUESTは500℃の高温壁を持つ装置であり、壁排気をなくした状態での定常運転を行う。このとき、コアからの粒子束$\Gamma_{main}=\langle n_e \rangle V_p/\tau_p$を充分に排気できる排気量を持つことが要求される。

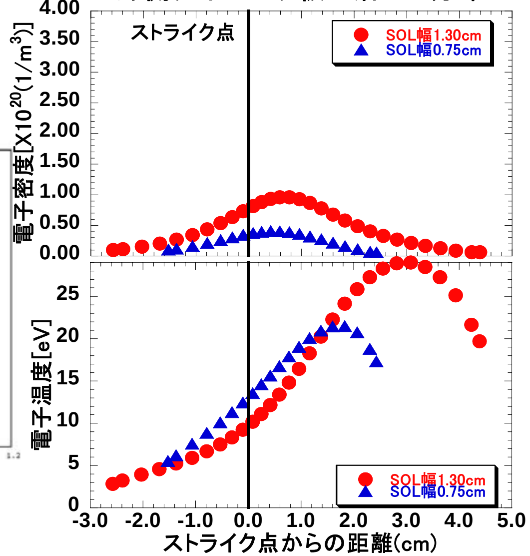
必要な排気性能の評価が必要

排気量、排気ポート位置、熱負荷などの定量的評価をおこない、設計に活かす。

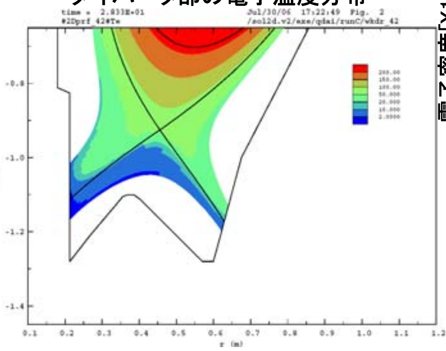
SOLDORによるダイバータ部のメッシュ構造の例



外側ダイバータ板に沿った分布



ダイバータ部の電子温度分布



QUESTにおけるダイバータの熱及び粒子制御性を、SOLDORを用いて評価し、継続して設計の最適化を行う。

EBW アンテナ開発計画

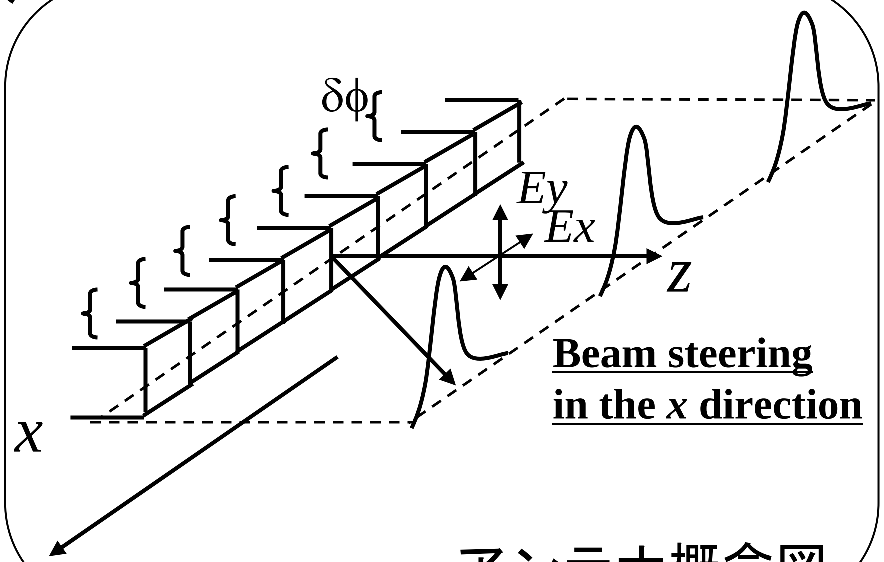
X-EBW（垂直入射）, O-X-EBW （斜め入射）、混合モードシナリオによる
加熱・電流駆動のために低周波数（~8GHz) 高周波コンポーネント開発が必要

1. X / O モード励起 ー Orthogonal Mode Transducer (OMT)の開発 ー

平成18年度:高電力仕様に向けた試作・開発、低電力試験
平成18年度:CPD／RF 伝送路での高電力試験

2. 入射角制御　ー Steering アンテナの開発 ー

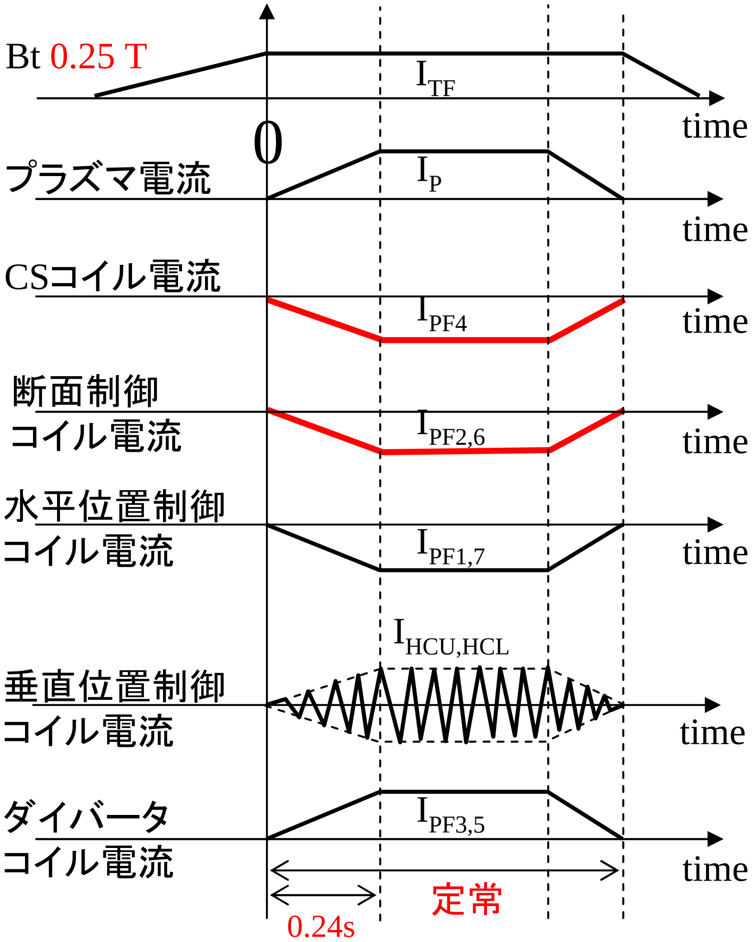
平成18年度:概念設計、高周波設計
平成18年度:低電力仕様での試作、動作確認
平成19年度:新規 CPD アンテナ 製作
平成19年度:QUEST アンテナの詳細設計
（熱設計を含む）
平成19~20年度:QUEST アンテナの製作

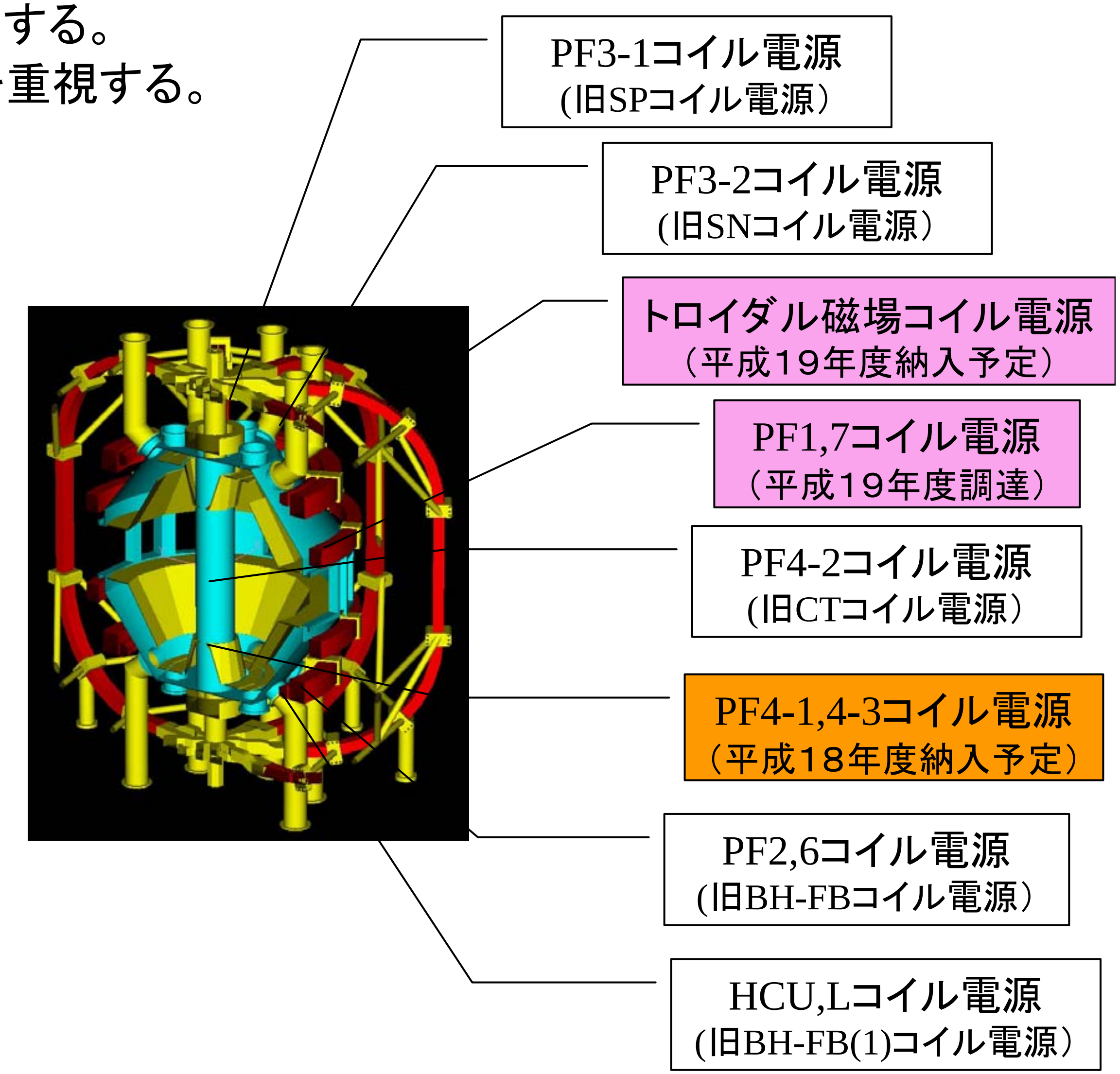


アンテナ概念図

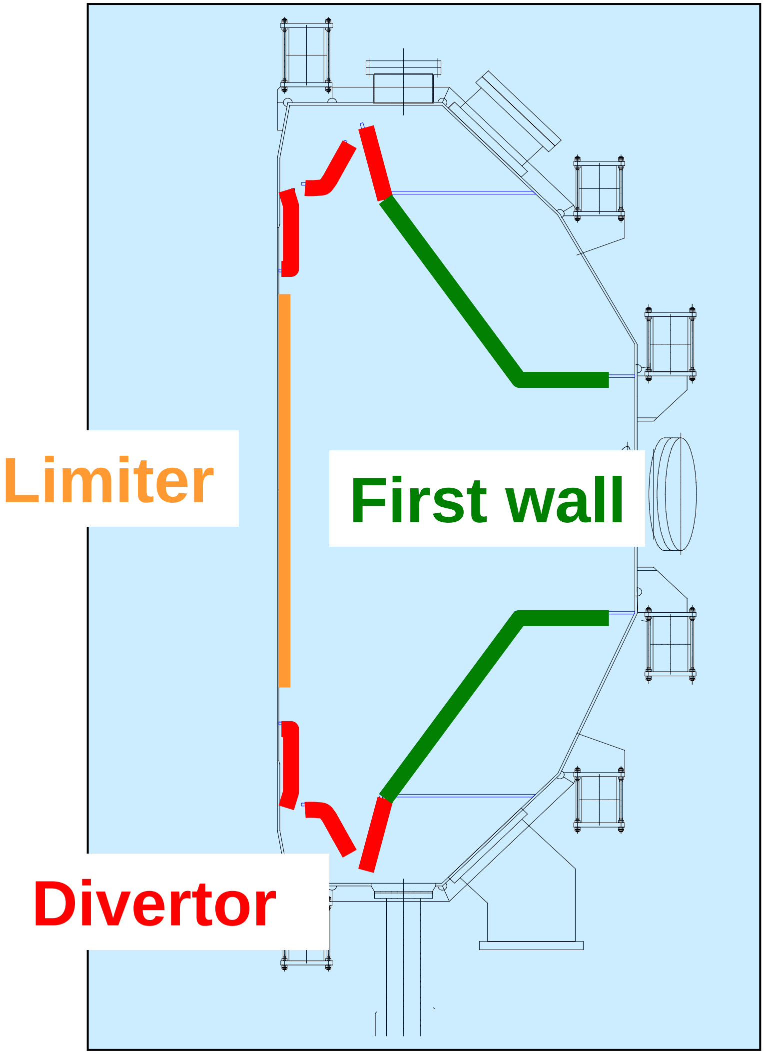
磁場コイル電源の活用（定常運転時）

TRIAM-1Mの磁場コイル電源を活用する。
新設の磁場コイル電源は定常運転を重視する。





Plan for high temp. wall and divertor



V.V. : SUS316L (~ 150℃)

First wall : W (300~500℃)

Divertor : W (400~500℃)

Limiter : SUS316L coated by W (300℃)

NBCD

- 40keV NB can be deposited at $3X10^{19}m^{-3}$.
- Plasma current of 100kA can be expected by 40keV 2MW NBI.
- There are no NBI in Kyushu University at present.
- Bootstrap current is not sufficient to maintain the plasma current in steady state.

Capability of Power supply

- Commercial power source

  7 MVA, 6.6 kV

  0.5MVA for Water cooling, vacuum pump and wall heating so on
- Motor generator

  Stored energy 125 MJ

  Available energy 60MJ in short pulse (1sec)

Short Pulse Operation in phase II

- 1 sec pulse (I_P=0.3MA)

  Toroidal field coil:

  Commercial power source : 1.9 MVA

  Poloidal field coil:

  MG : 29 MVA

  Motor:

  Commercial power source : 1MVA

  Heating

  10MW ((31+5.1-0.5)MWx0.3)

Steady State Operation

- SS (I_P=0.1MA)

  Toroidal field coil:

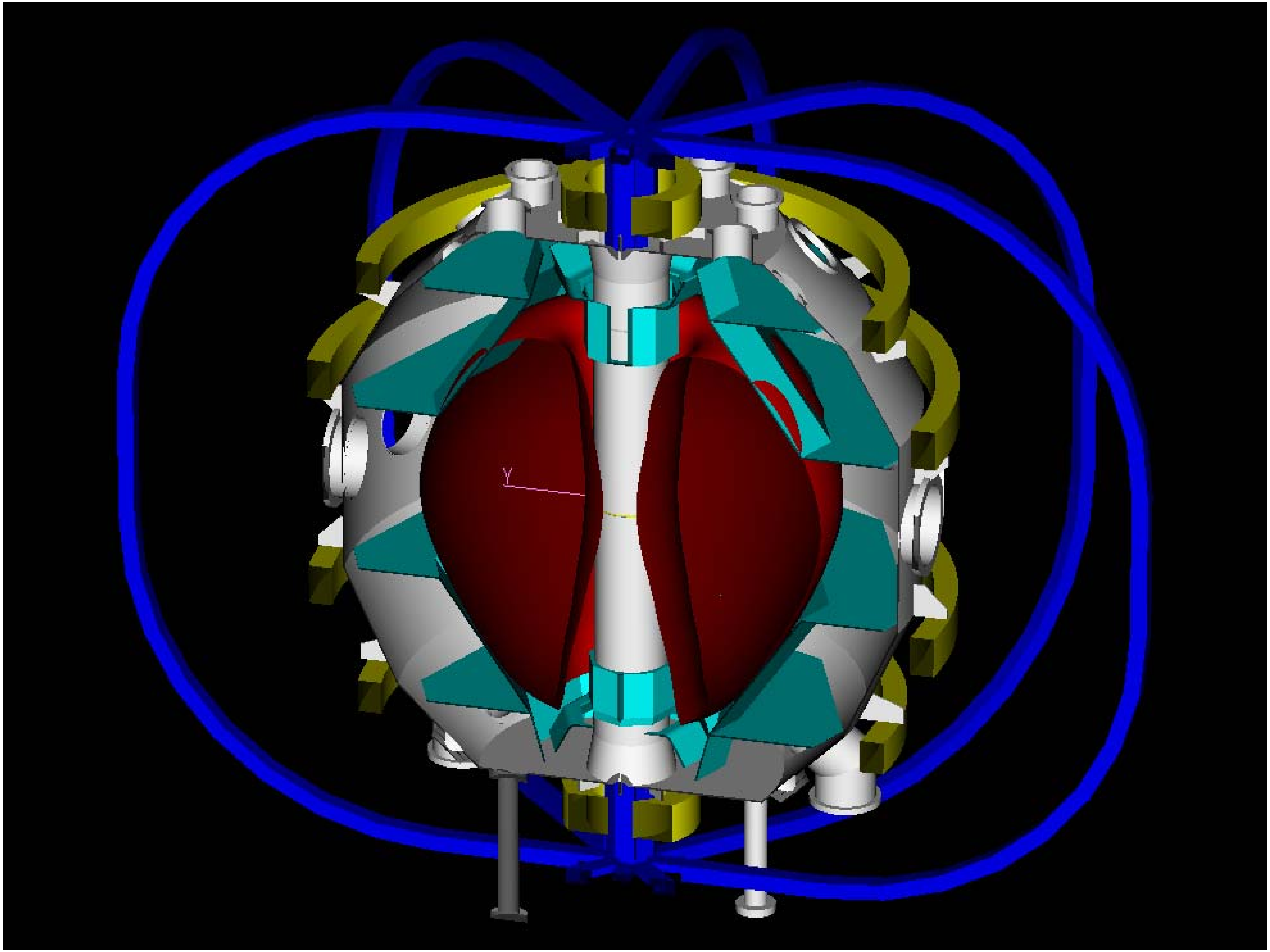
  Commercial power source : 1.9 MVA

  Poloidal field coil:

  Commercial power source : 1.2 MVA

  Heating

  1MW ((3.4)MWx0.3)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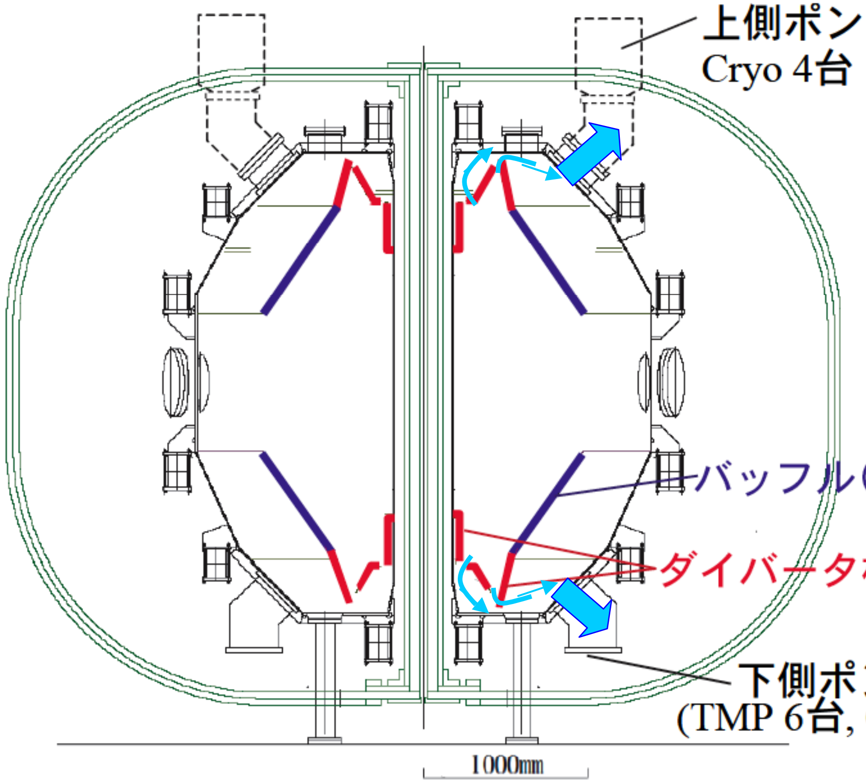
Particle exhaust （divertor pumping）



位置	ポンプ	単体排気速度 $m^3/s(H_2)$	台数	総排気速度 $m^3/s(H_2)$
下部	TMP	**~2.3**	**6**	**13.8**
下部	CRYO	**10**	**4**	**40**
上部	CRYO	**10**	**4**	**40**

（上部排気に関しては設置予定）

Outline of divertor (under consideration of best position of poloidal field coils)

Steady state operation
P=0.1 (Pa)
==> 9.4 (Pa m^3/s)

Pulse operation
P=1 (Pa)
==> 94 (Pa m3/s)

Thermal desorption of D from W

Twall = 300C

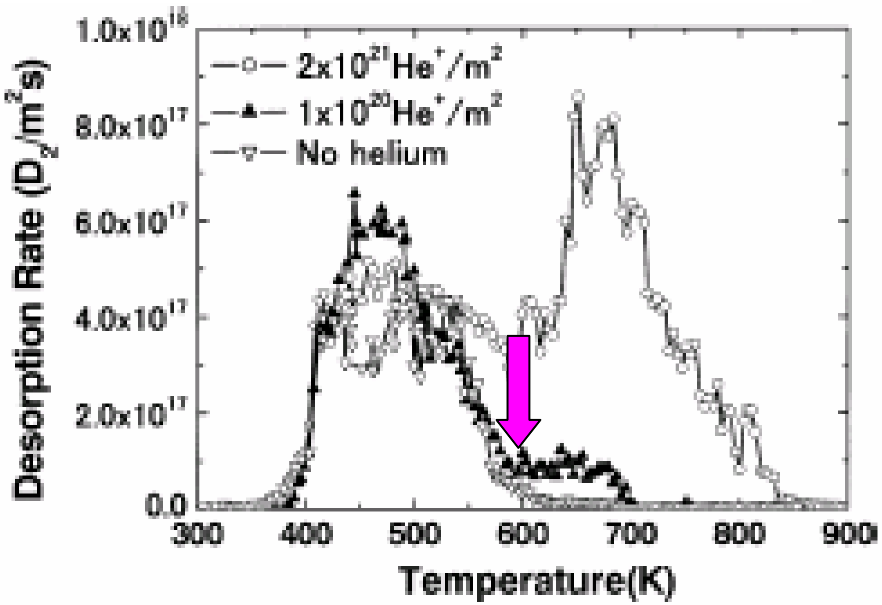
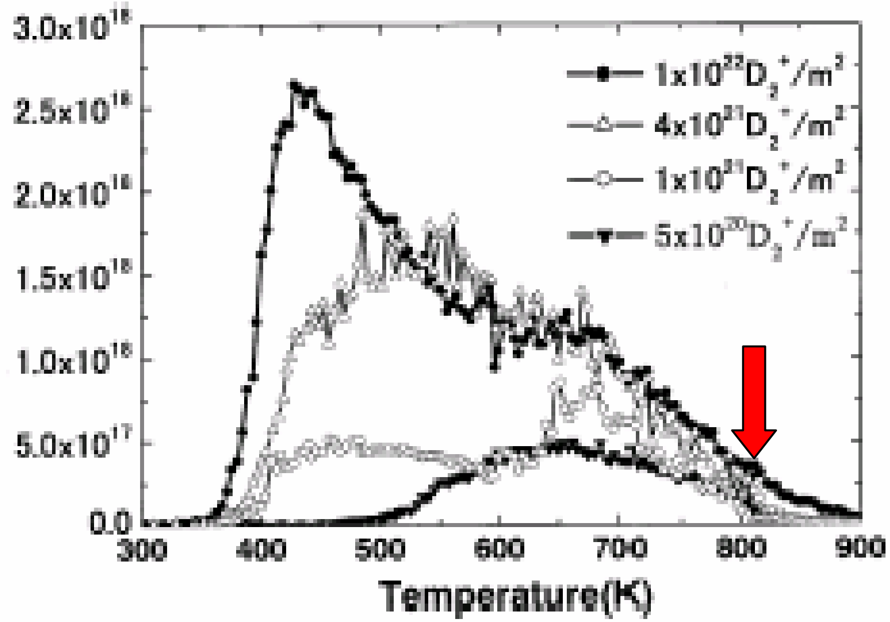


Fig. 1. Thermal desorption spectra of deuterium for samples without pre-irradiation and with pre-irradiation of 8 keV-He^+ to doses of 1.0×10^{20} and 2.0×10^{21} He^+/m^2 at room temperature.

Twall =600C



. 2. Thermal desorption spectra of deuterium for tungsten irradiated with 8 keV-He^+ to 2×10^{21} He^+/m^2 at room perature for deuterium doses ranging from 5×10^{20} to 10^{22} D_2^+/m^2 introduced at room temperature.

He – irradiation

D-Fluence

Iwakiri, Yoshida JNM (2000) 1134

Status of construction of QUEST

Red：in March 2006

PF coils

TF coil return

Blue：in March 2007

Vacuum Vessel w/o ports

Center Stack

Yellow：in March 2008

Vacuum Vessel with ports

Supports

Inside vessel components