Considerations for KSTAR 2010 Campaign

- Objectives
  - Initial key physics results: IAEA 2010 and ITPA/ITER focus (?)
  - Balance of systems commissioning and physics experiments?
- Constraints
  - Three months operation in 2010, two months run before IAEA 2010
  - Must maximize input from 2 month 2009 campaign to support this!
- Needs
  - Analysis:
    - Equilibrium reconstruction key input for most subsequent analyses
    - Determine other analysis capabilities to support objectives
  - Diagnostics: identify key diagnostics to support objectives (priority)
    - E.g. toroidal Mirnov array, SXR arrays, are locked mode sensors needed?
  - System capabilities:
    - aggressive schedule – what are priority needs to support objectives?

Available operation time in 2009-2010

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2009 Operation

2009	1	2	3	4	5	6	7	8	9	10	11	12
H/W upgrade												
Vacuum & wall conditioning												
Cool-down & warmup												
SC magnet operation												
Plasma exp.												

2010 Operation

2010	1	2	3	4	5	6	7	8	9	10	11	12
H/W upgrade												
Vacuum & wall conditioning												
Cool-down & warmup												
SC magnet operation												
Plasma exp.												

IAEA FEC
In Korea

Research topics in 2009-2010

Magnetic control

- Power supply control
  - TF magnet operation and protection test up to 35 kA
  - PF magnet & power supply control for zero-crossing
  - Vertical & radial stability control using IVCC ('10)
- Plasma control
  - Plasma current and position control (Ip, Rp)
  - Plasma shape control (Rp, Zp, kappa, delta) ('10)
- Magnetic probes & analysis
  - Refined characterization of the magnetics with additional sensors and electron beam system. (quantifying field errors, calibration of magnetic probes)
  - Understanding the material (Incoloy908) and geometry effects on plasma

Research topics in 2009-2010

Heating researches

- ECH pre-ionization
  - Full exploitation of 84 GHz & 110 GHz Gryotron
  - Further Investigation of ECH assisted pre-ionization
  - Dependence on 1st & 2nd harmonics, injection directions
- ICRH heating and RF discharge cleaning
  - Exploitation of ICRH heating
  - Exploit RF discharge cleaning between shots
- Commissioning of additional heating hevices
  - NBI (1 MW), LHCD (0.5 MW) ('10)

Research topics in 2009-2010

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Other researches

- Wall conditioning & wall interaction
  - Quantitative approach on wall conditioning & wall recycling
  - Hydrogen recycling/retention under different wall condition(Boronization, RFGDC, ICRH DC)
  - Characterization of the dust behavior
- Experiments
  - Disruption studies
  - Possible MHD Studies ; sawtooth manipulation, locked mode
  - Experiments based on the collected proposals (domestic /international)
- Data access and collaboration
  - Data access, analysis, logging
  - Remote experiments participation & operation

Collaboration items

- Plasma control system (GA)
    - PCS upgrades for the higher performance plasma controls
    - Development on control modeling & scenarios
- Analysis code
    - Utilizing EFIT for daily KSTAR experiments, EFIT training
    - Review on magnetic validation tools development
    - Transfer and consulting on analysis codes
- Consulting and simulation of In-vessel control coil system
    - Position and shape control using IVC & IRC coil system
    - Consults on IVCC hardware engineering
    - *Benchmark on error field analysis*
    - *Preparation for other MHD instability control*
- Remote operation tools development
    - *Collaboration on experimental logbook, remote visualization, remote access, etc.*

Collaboration items (System development)

- Heating & current drive
  - ECH operation support on 84 GHz, 110 GHz
  - ECH/CD study and launcher development
  - LHCD study and launcher development
- Diagnostics
  - Diagnostic system developments
- Others
  - Consulting on boronization system
  - Consulting on In-vessel cryo-pump system
  - Consulting on e-beam measurement system
  - Others

System availability for 2009-2010 operation

	2008	2009	2010
SC Magnetic system			
• TF coils • PF coils & leads	• 15 kA • 4 kA unipolar • Up/Low series	• 35 kA • 4 kA bipolar • Up/Low series	• 35 kA • 20 kA bipolar • Up/Low separate (4 more PF PS)
In-vessel system			
• In-vessel coil • PFC • Wall conditioning	• Inboard limiter • Glow DC, RF DC	• Inboard limiters • + boronization	• Vertical control • Divertor / limiters • Passive stabilizer • + PFC baking
Heating system			
• ECH • ICRH • NBI • LHCD	• 0.5 MW (84 GHz) • 0.03 MW (30 MHz)	• 0.5 MW (84 GHz) • 0.3 MW (45 MHz)	• 0.5 MW (84 GHz) • 0.5 MW (110 GHz) • 1 MW • 1 MW
Infra system			
• Electricity	• 50 MVA (154 kV)	• 50 MVA (154 kV)	• 100 MVA (154 kV)

Operational parameters in 2009-2010

	2008	2009	2010
Experimental parameters			
• Peak TF field • Operation TF field • Flux • Ip • Plasma shape • Gas	• 1.5 T • 1.5 T • ~ 1 Wb • < 133 kA • Circular • H_2 (He for DC)	• 3.5 T • 1.5 T, 3.0 T • ~ 2 Wb • ~ 300 kA • Circular • H_2 (He for DC), *D_2*	• 3.5 T • 1.5 T, 2.0 T, 3.0 T • ~ 4 Wb • < 1 MA • Double null • H_2, D_2
Control			
• Plasma control	• PF blip & start up • Ip, Rp , ne	• PF zero-crossing • Ip, Rp, ne	• IVC control • Ip, Rp, Zp, shape
Diagnostics			
• Diagnostic systems	• MD/ MMWI/ ECE / Hα/ filterscope/ ViS . TV	• MD/ MMWI / ECE / Hα/ filterscope/ Vis. TV • PD / XCS / Soft X-ray / Reflect.	• MD / MMWI / ECE/ Hα/ filterscope/ Vis. TV • PD / XCS / Soft X-ray / Reflect. • TS/ Hard X-ray / Fast neutral / ECEI/ IRTV

Near-term experiment plan

	FY 2008	FY 2009	FY 2010	FY 2011	FY 2012
Operation (Vac,CD & WU)	**'08. 3 ~ '08. 8 (6 mon.)**	**'09. 8 ~ '09.12 (5 mon.)**	**'10.6 ~ '10. 11 (6 mon.)**	**'11. 4~ '11. 9 (6 mon.)**	**'12. 2 ~ '12. 7 (6 mon.)**
Experimental Goals	• First plasma startup • 2nd Harmonic ECH pre-ionization	• 1st Harmonic ECH Pre-ionization • Startup stabilization	• Shaping control & vertical stabilization • Heating	• Confinement (L-H) • Stabilization • Heating	• Plasma–Wall Interaction • Profile control • RWM, ELM control • Off-axis current drive
Target Operation Parameters	• B_T ~ 1.5 T • I_P > 0.1 MA • t_P > 0.1 s • Te > 0.3 keV • Ti ~ 0 keV • Flux ~ 1 Wb • Shape ~ Circular • Gas : H_2	• B_T ~ 3 T • I_P > 0.3 MA • t_P > 2 s • Te > 0.3 keV • Ti ~ 0.3 keV • Flux ~ 2 Wb • Shape ~ Circular • Gas : H_2, *D_2*	• B_T ~ 3 T • I_P < 1 MA • t_P ~ 10 s • Te ~ 1 keV • Ti ~ 1 keV • Flux ~ 4 Wb • Shape ~ DN(double null) • Gas : H_2, D_2	• B_T ~ 3 T • I_P < 1.5 MA • t_P ~ 10 s • Te ~ 1 keV • Ti ~ 3 keV • Flux ~ 6 Wb • Shape ~ DN & SN • Gas : D_2	• B_T ~ 3 T • I_P < 2 MA • t_P > 100 s (0.5 MA) • Te ~ 1 keV • Ti ~ 5 keV • Flux ~ 8 Wb • Shape ~ DN & SN • Gas : D_2
PFC & Wall conditioning	• Inboard limiter (belt) • Gas puff	• Inboard limiter (w/o cooling) • Boronization	• Divertor / Passive plate • PFC baking • In-vessel coil	• Cryopump operation • PFC cooling	• PFC cooling • *Pellet*
Magnetic control	• TF : 1.5 T • PF : 4 kA unipolar	• TF : up to 3.5 T • PF : +/-4 kA	• TF : up to 3.5 T • PF : +/-10 kA • IVCC : VS, RS	• TF : up to 3.5 T • PF : +/-15 kA • IVCC : FEC. RMP	• TF : up to 3.5 T • PF : +/-20 kA • IVCC : RMP, RWM
Heating operation	• ECH(84G): 0.5MW, 0.4s	• ECH(84GHz): 0.5MW, 2s • ICRH(45MHz): 0.3MW, 10 s	• ECH(84/110GHz): 0.5MW • ICRH(45MHz): 1MW, 10 s • NBI: 1.0MW, 10s • LHCD: 0.5MW, 2s	• ECH(84/110GHz): 0.5MW • ICRH(45MHz): 2MW, 10 s • NBI: 2.5MW, 10s • LHCD: 0.5MW, 2s • ECCD(170GHz): 1MW, 10s	• ECH(84/110GHz): 0.5MW • ICRH(45MHz): 2MW, 300 s • NBI :5MW, 300s • LHCD : 1MW, 2s • ECCD(170GHz): 1MW, 300s
Diagnostics	• MD (77 Ch)/ MMWI / ECE / Hα / filterscope / VS / TV	• MD/ MMWI / ECE / Hα / filterscope / VS / TV • PD / XCS (1 set) / Bolometer (resistive) / Reflect. / Soft X-ray	• MD / MMWI / ECE / Hα / filterscope / VS / TV • PD / XCS / Bolometer / Reflect. / Soft X-ray • Thomson Scattering / Hard X-ray / Fast neutral / IR TV / ECEI	• MD / MMWI / ECE / Hα / filterscope / VS / TV • PD / XCS / Bolometer / Reflect. / Soft X-ray • TS / Hard X-ray / Fast neutral / IR TV / ECEI • MSE / FIR / CES / neutron	• MD / MMWI / ECE / Hα / filterscope / VS / TV • PD / XCS / Bolometer / Reflect. / Soft X-ray • TS / Hard X-ray / Fast neutral / IR TV / ECEI • MSE / FIR / CES / neutron / VUV • MIR / BES / CI /

Key Milestones of the H&CD Upgrade

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Device	2008	2009	2010	2011	2012
ECH/CD					
- 84 GHz	0.5MW/0.4s	0.5MW/2s	0.5MW/2s	0.5MW/2s	0.5MW/2s
- 110 GHz (under collaboration)			0.5MW/2s	0.5MW/2s	0.5MW/2s
- 170 GHz				1MW/10s	1MW/300s
LHCD				0.5MW/2s	1MW/2s
ICRF	30MHz 50kW/10s	45MHz 300kW/10s	45MHz 1MW/10s	45MHz 1MW/10s	45MHz 2MW/300s
NBI			100keV D0 1.5MW/10s	120keV D0 2.5MW/10s	120keV D0 5MW/300s

Development Plan of NBI System

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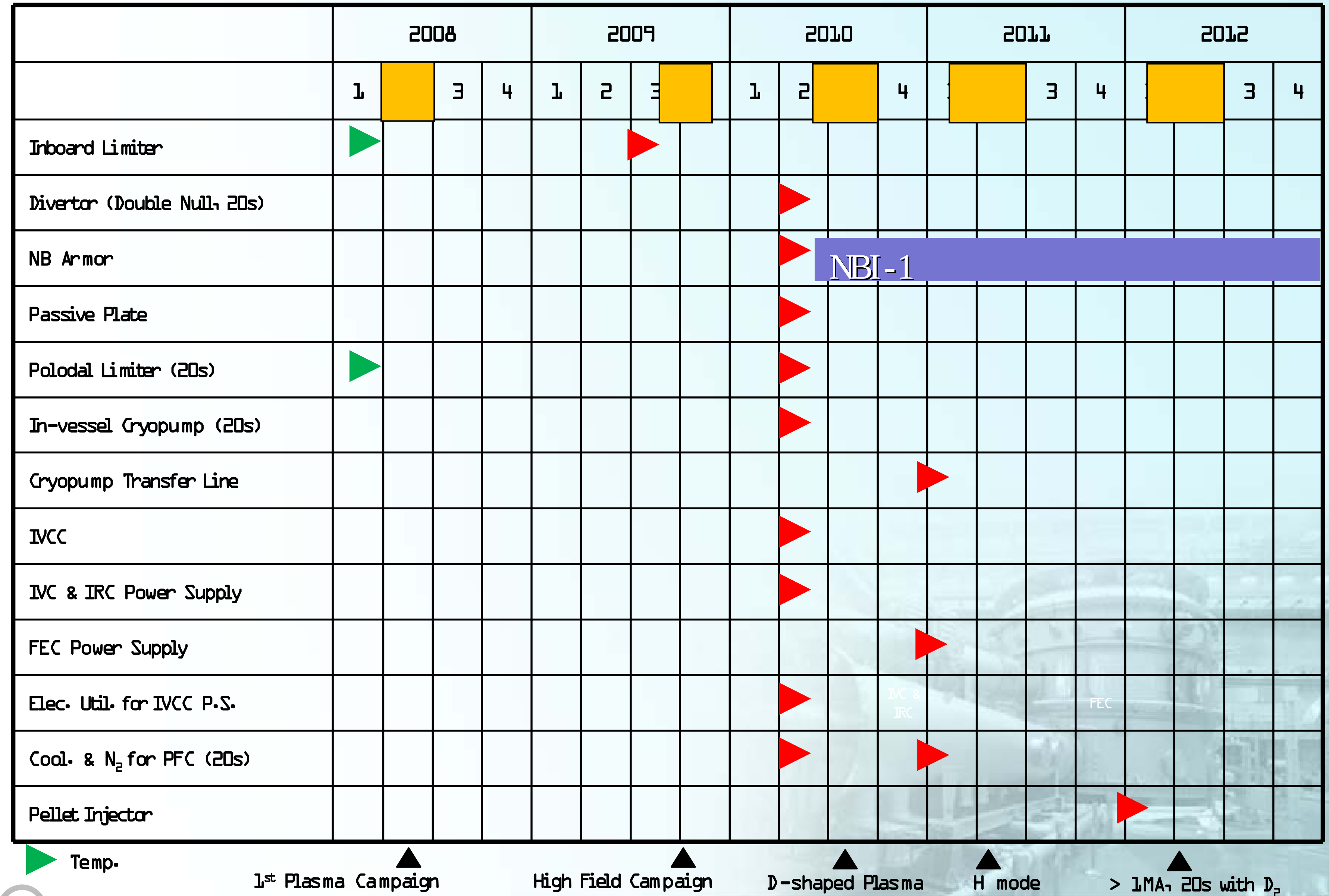
- We are aiming at the injection of 1-1.5 MW deuterium neutral beam power for the 2010 KSTAR campaign with a maximum pulse length of 10 seconds.
- For this, the first NBI beam line is presently under design and the fabrication will begin very soon.
- The design and capability of the ion source is based on those of prototype ion sources developed by the Korea Atomic Energy Research Institute (KAERI).
- A 1-MW, 300-s long hydrogen neutral beam has been recently extracted with a beam energy of 90 keV in the KAERI test-stand. For the higher beam energy of 100 keV, only 2-s long neutral beam extraction was possible.
- The ion source is under development in collaboration with KAERI and JAEA
  - A source chamber (plasma generator) of 120 kV, 65 A, 300 s has been developed by JAEA and it was delivered to KAERI. Now it is being tested.

In-Vessel Components for Next Campaign



Status and Plan KSTAR Diagnostics

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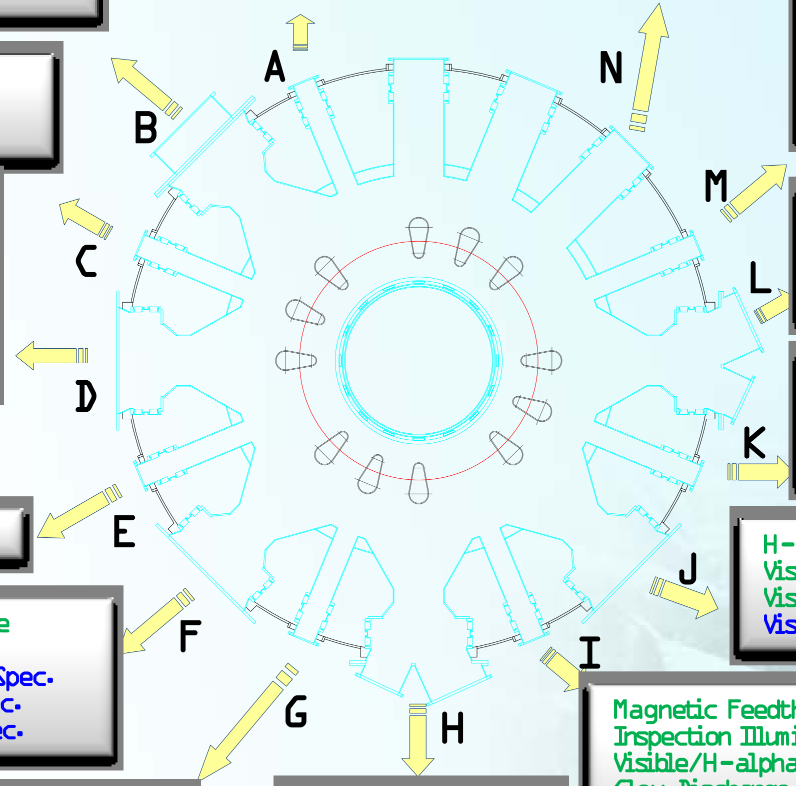
Basic Diagnostics (2008)
2009 New Diagnostics
Next Diagnostics



A
- Magnetic Feedthrough
- Inspection Illuminator
- Visible/H-alpha TV
- Glow Discharge Probe
- Survey IR TV
- CES (Background)

B
- Torus Ion Gauge
- RGA
- X-ray Crystal Spec.
- Fast Neutral Pressure Gauge
- Thomson S.(Beam Dump)

C
- Reciprocating Langmuir Probe
- Bolometer Array
- X-ray Pinhole Camera

D
- Soft X-ray Array
- Survey IR TV
- Visible/H-alpha TV
- X-ray PHA
- Multichord Vis. Spec.
- X-ray Pulse Height Anal.
- Impurity Pellet Injector

E
- Magnetic Feedthrough

F
- Torus Ion Gauge
- RGA
- X-ray Crystal Spec.
- Soft X-ray Spec.
- VUV Survey Spec.

G
- mm-Wave Interferometer
- Reflectometer
- MIR
- ECEI

H
- Fast Neutral Pressure Gauge
- Tan. FIR Int. (Laser Input)

I
- Magnetic Feedthrough
- Inspection Illuminator
- Visible/H-alpha TV
- Glow Discharge Probe
- Survey IR TV
- MSE(D)

J
- H-alpha Monitor
- Visible Survey Spec.
- Visible Filterscope
- Visible Brems. Array

K
- ECE Radiometer(110~162GHz)
- ECE GPC
- Diagnostic Neutral Beam
- LIF (Optics)

L
- Bolometer Array
- Fast Neutral Pressure Gauge
- Thomson S. (Laser Input)
- CX-NPA

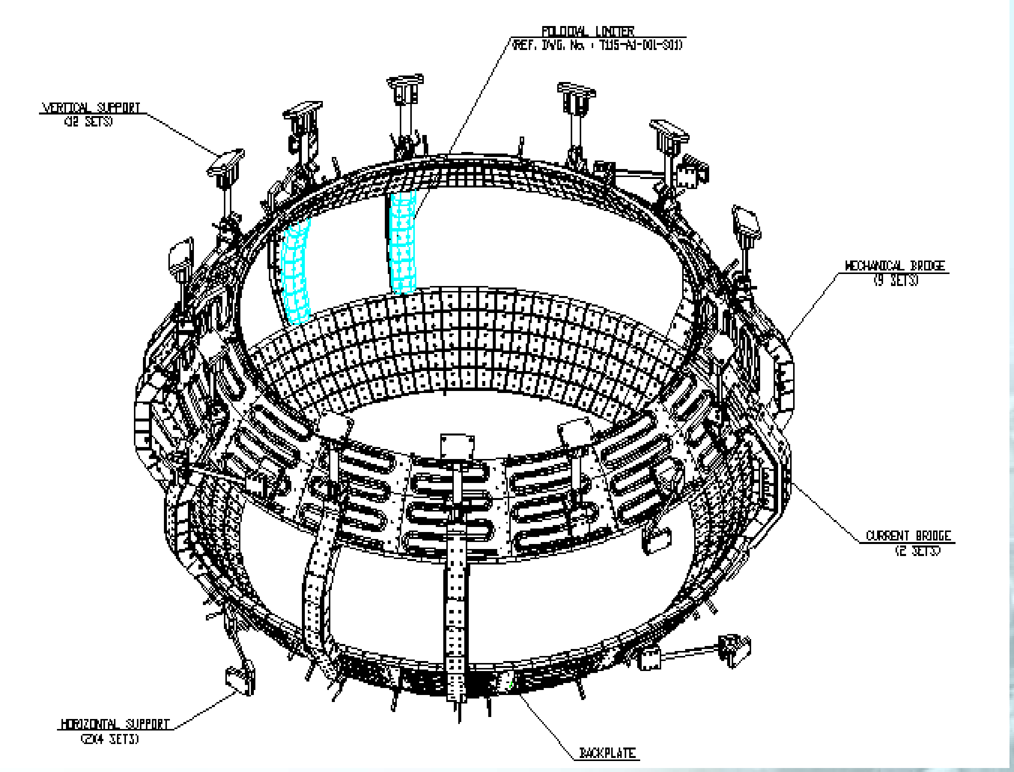
M
- Magnetic Feedthrough
- Inspection Illuminator
- MSE
- CES
- BES

N
- Thomson Optics
- Div. Thomson Optics

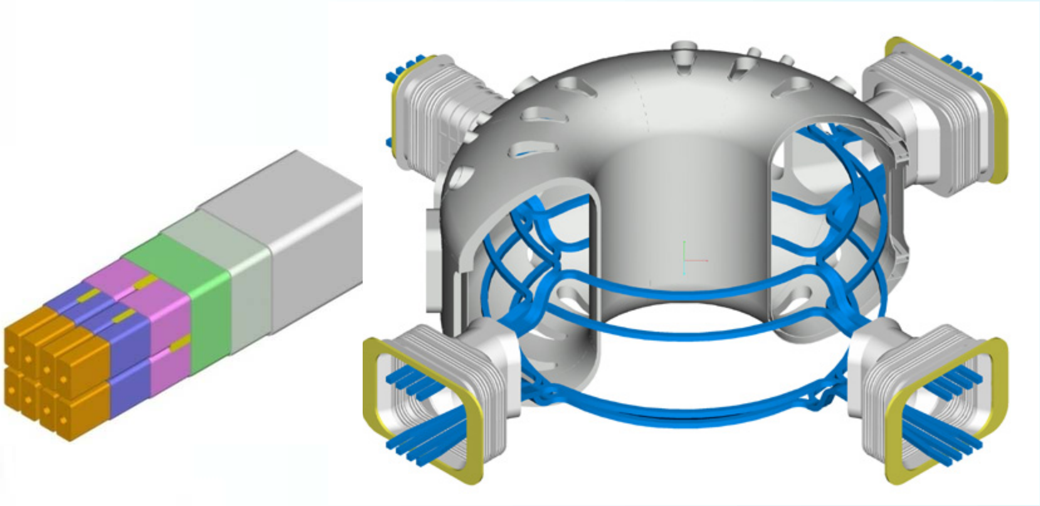
Revised Version: Dec. 2008

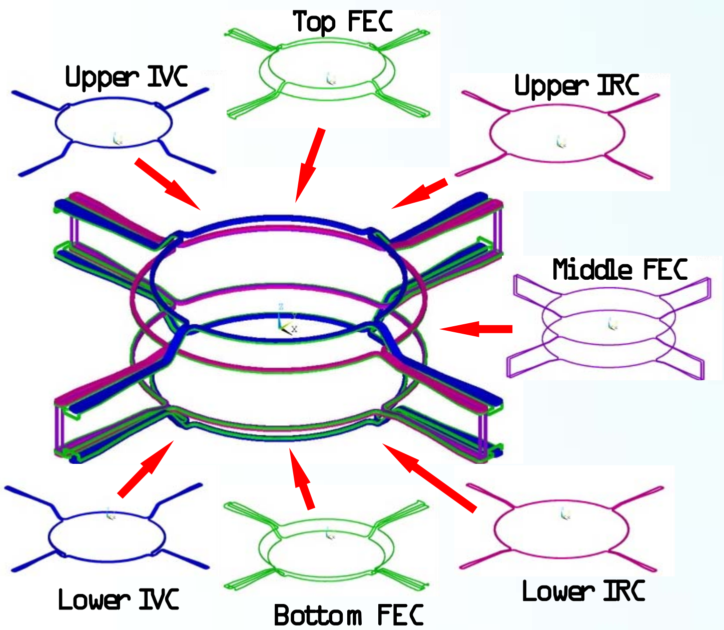
In-Vessel Component – Passive Stabilizer

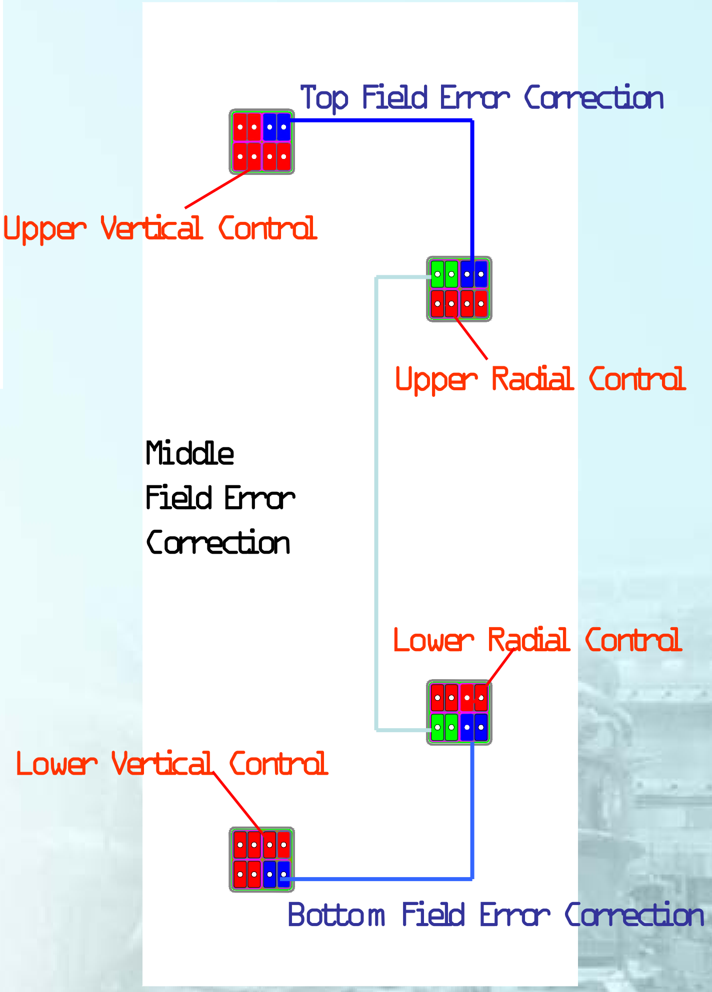
- Design
  - Two toroidal rings shape, 9 Mechanical bridges , 2 Current bridges (under consideration)
  - Total 32 sectors (16 x 2)
  - 12 vertical supports(at upper TR), 4 horizontal supports(at upper/lower TR)
  - Upper parts support lower parts with 9 mechanical bridges
  - Graphite tile (impurity < 10ppm)
  - Back plate : CuCrZrMg, Water cooling tube



In-Vessel Component - IVCC







Backup Slides

Overview of the 2008 campaign

Objectives of 2008 Campaign

- Completion of the integrated commissioning to demonstrate the performance of the device and facilities meet the design specification.
  - classified the commissioning processes into 4 steps
  - vacuum, cool-down, SC magnet, and plasma discharge
- Generation of the first plasma to verify the device capability for the fusion plasma experiments.
  - Target values : 100 kA, 100 ms
  - Limited circular plasma

Limitations on the first plasma campaign

- Limited power supply capacity : 15 kA TF, 4 kA PF
- Uncertainty in 2nd harmonic ECH pre-ionization
- Limited baking temperature for wall conditioning
- Limited experience in tokamak and superconducting magnet operation
- Limited experience in plasma startup and control

2008 operation and device commissioning

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Four steps commissioning due to superconducting device

Vacuum

- To evacuate vacuum vessel & cryostat without leak
- VV base pressure < 5 x 10^{-7} mbar
- Cryostat base pressure < 1 x 10^{-4} mbar

Vacuum vessel pumping
Cryostat pumping
Leak detection
Baking
Gas puffing
Discharge cleaning

Cool-down

- To cool magnet system down to operating temperature
- TF/PF coil temperature < 5 K
- T. Shield temperature < 80 K

Refrigerator cool-down
Distribution cool-down
SC magnet purging
Step 1 (300 K → 80 K)
Step 2 (80 K → 20 K)
Step 3 (20 K → 4.5 K)
SC phase transition

SC magnet

- To charge all SC magnet system without quench
- Joint resistance < 5 nΩ
- TF current : 15 kA
- PF current : 4kA

MPS dummy load test
Joint resistance check
Insulation test
TF power test (15 kA)
PF power test (4 kA)
Field measurement
AC loss measurement

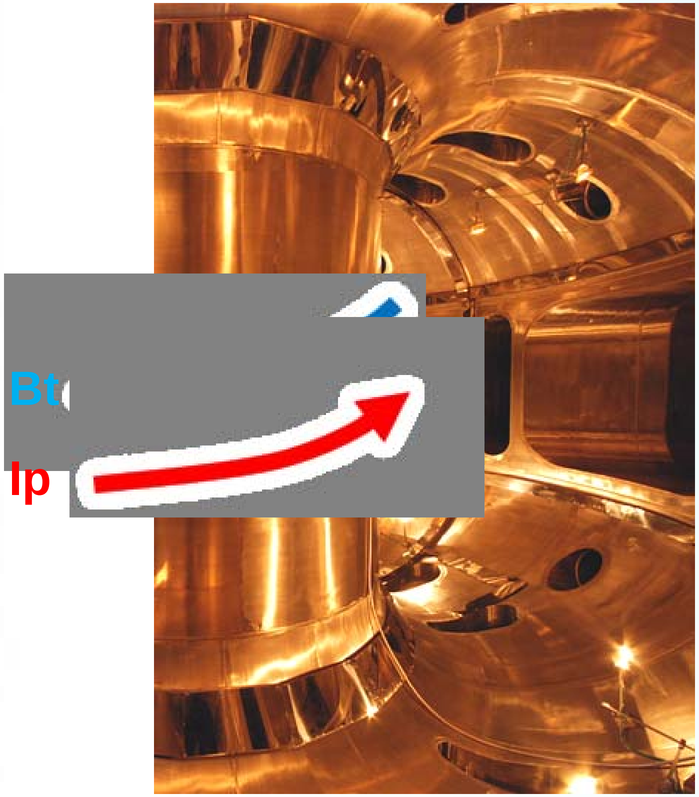
Plasma

- To make tokamak plasma discharge reliable
- ECH pre-ionization 2nd harmonic @84GHz
- Ip > 100 kA
- Pulse > 100 ms

Field null formation
Blip operation
ECH pre-ionization
Gas control
Discharge cleaning
Feedback control

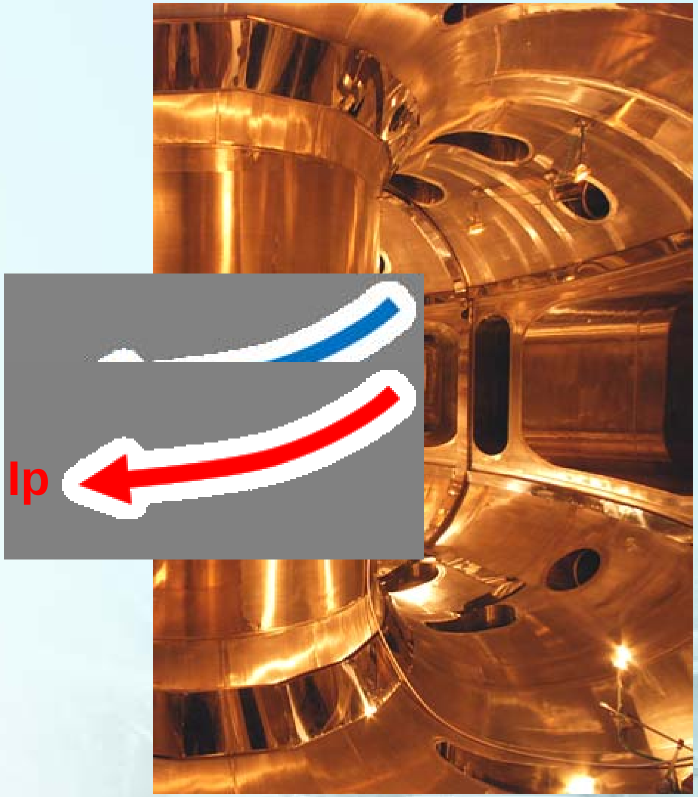
Directions of plasma current & B_T

2008 ~ 2009 campaigns



Change from 2010 campaign

From 2010 campaign ~



- depends on direction of new installed NBI Injection
- PF initial magnetization in negative direction

Results of the 2008 campaign

Most of the targeted values of the 1st campaign were achieved.

Classifications	Target	Achieved	Remarks	Final Spec.
·VV base pressure	≤5.0x10^{-7} mbar	3.0x10^{-8} mbar	OK	←
·Cryostat base pressure	≤1.0x10^{-4} mbar	3.0x10^{-8} mbar	OK	←
·Total leak rate	≤1.0x10^{-4} mbar·l/s	1.7x10^{-7} mbar·l/s	OK	←
·SC coil temperature	≤TF & PF : 5 K	TF & PF : 4.48 K	OK	←
·Thermal shield temperature (In/out)	≤55 / 70 K	51 / 72 K	OK	←
·Temperature distribution	≤50 K	48 K	OK	←
·SC transition temp.	Nb_3Sn : 18.3 K	Nb_3Sn : 18±0.2 K	OK	←
	NbTi : 9.2 K	NbTi : 9.9±0.1 K	OK	←
·Joint resistance	≤5 nΩ	0.5 ~ 2 nΩ	OK	←
·Coil insulation	> 100 MΩ	> 3,000 MΩ	OK	←
·TF current	≥15 kA	15 kA	OK	35 kA
·TF field at major radius	≥1.5 T	1.5 T	OK	3.5 T
·PF coil current	4 kA	4 kA	OK	25 kA
·PF Blip period	≥100 ms	50□150 ms	OK	←
·ECH for pre-ionization	≥400 kW (0.2 s)	480 kW (0.4 s)	OK	←
·Plasma current	≥100 kA	133 kA	OK	2,000 kA
·Plasma duration	≥0.1 s	0.86 s	OK	300 s
·Plasma duration≥100 kA		0.33 s	OK	300 s