Ministry of Science, ICT and Future Planning

FUSION, Future Vision of Green Energy

参考資料5

Attachment 7

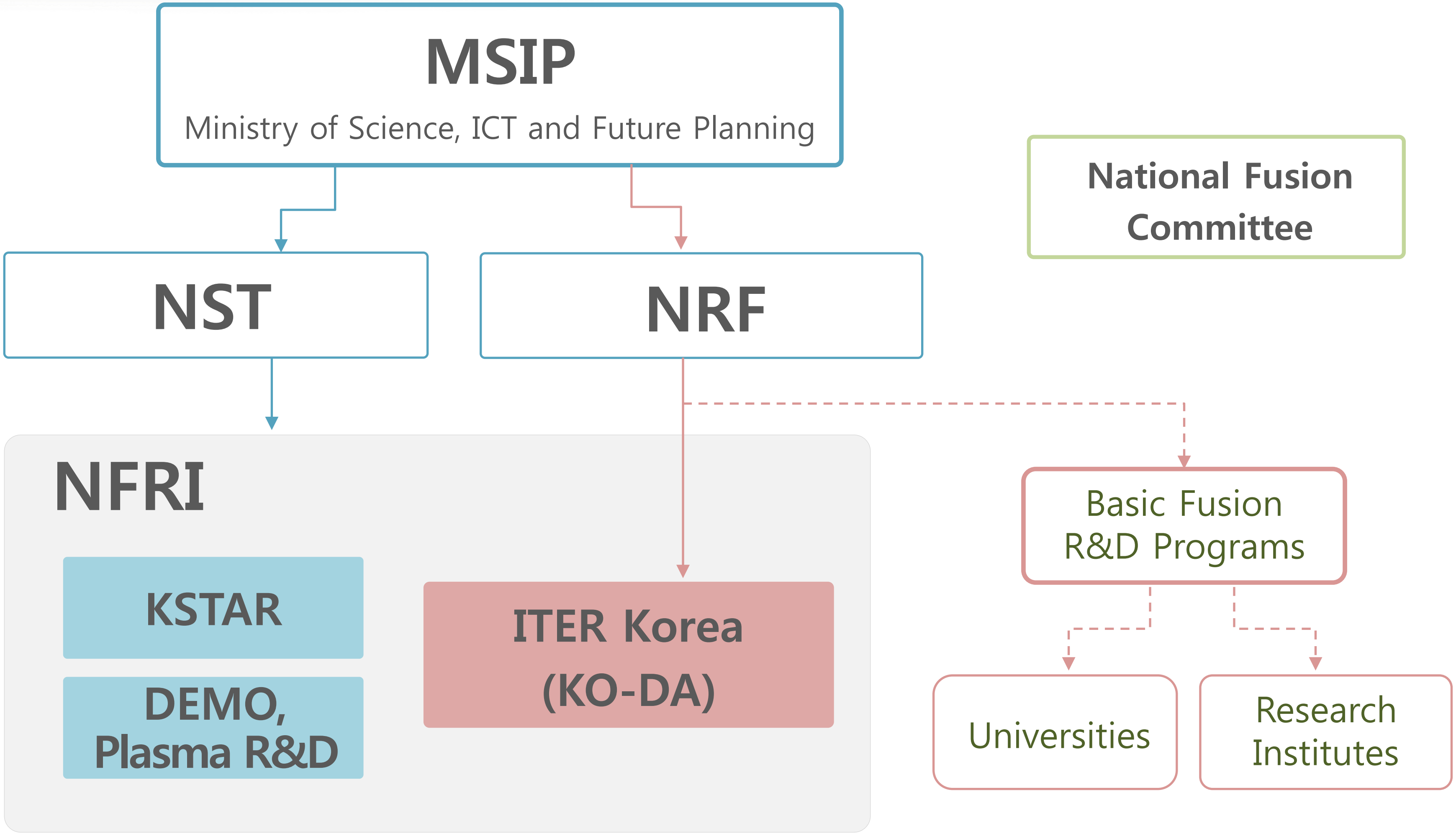
13th Korea-Japan Joint Coordinators' Meeting

Korean Status Report on Fusion R&D

July 6, 2017 / Naka, Japan

NFRI 국가핵융합연구소 National Fusion Research Institute

Governance Framework of Fusion R&D



***NST: National Research Council of Science & Technology**

***NRF: National Research Foundation of Korea**

Korea Fusion Energy Development Plan

Vision: Secure sustainable new energy source by technological development and the commercialization of fusion energy

Phase	Phase 1 ('07~'11)	Phase 2 ('12~'26)			Phase 3 ('27~'41)		
Policy Goal	Establishment of a foundation for fusion energy development	Development of Core Technology for DEMO			Construction of DEMO by acquiring construction capability of fusion power plants		
Basic Directions	▪ Acquisition of operating technology for the KSTAR ▪ Participation in the international joint construction of ITER ▪ Establishment of a system for the development of fusion reactor engineering technology	▪ High-performance plasma operation in KSTAR for preparations for the ITER Operation ▪ Completion of ITER and acquisition of core technology ▪ Development of core technology for the design of DEMO			▪ DEMO design, construction, and demonstration of electricity production ▪ Undertaking of a key role in ITER operations ▪ Completion of reactor core and system design of the fusion power reactor ▪ Commercialization of fusion technology		
Basic Promotion Plan	Basic Promotion Plan 1 ('07~'11)	Basic promotion plan 2 ('12~'16)	Basic promotion plan 3 ('17~'21)	Basic promotion plan 4 ('22~'26)	Basic promotion plan 5 ('27~'31)	Basic promotion plan 6 ('32~'36)	Basic promotion plan 7 ('37~'41)

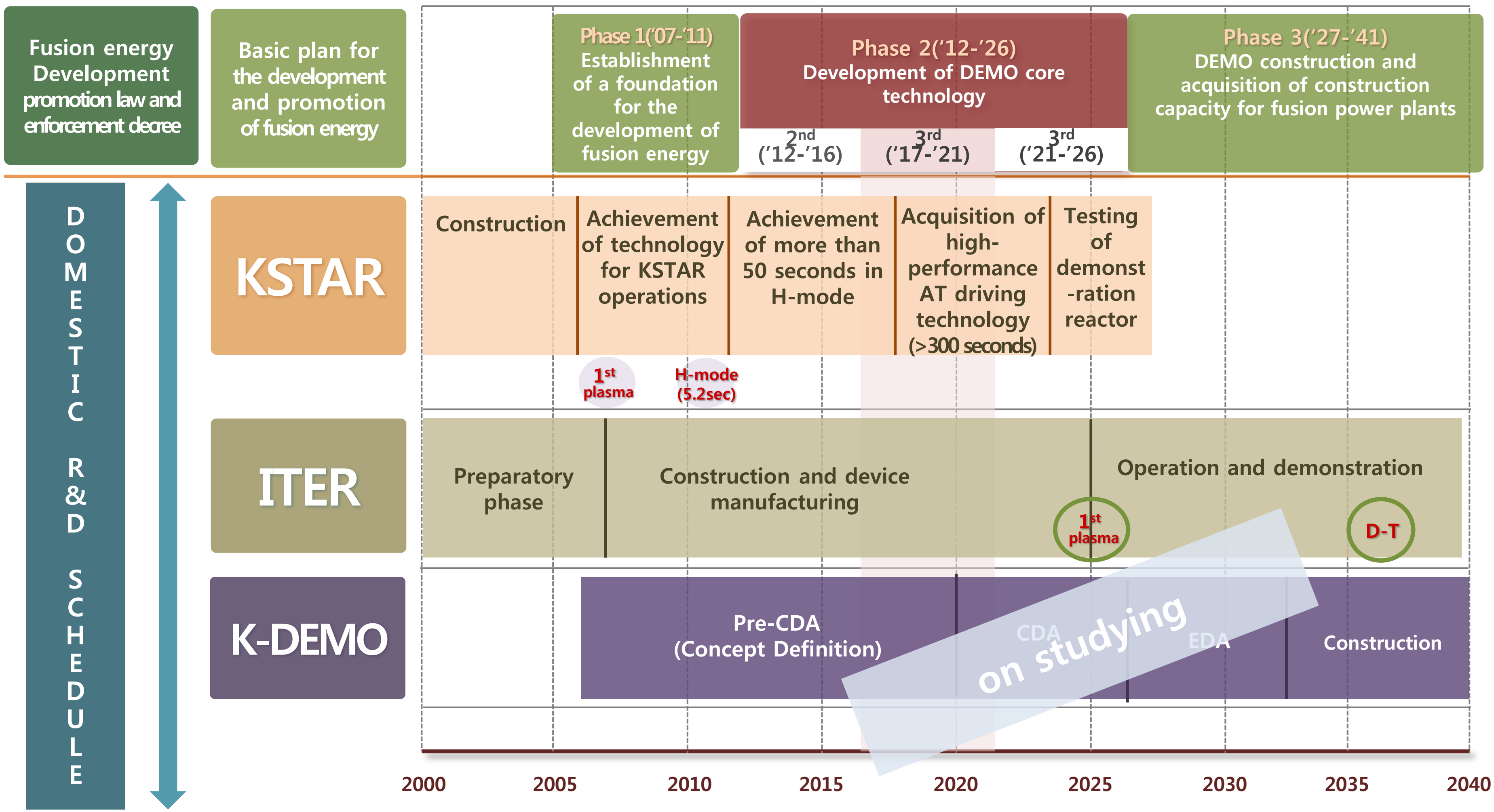
Policy Goal for Plan 3: Establishment of foundation for fusion engineering technology development for demonstrating electricity production

Primary Strategy for Plan 3:

❖ Acceleration for development of DEMO core technology
❖ Strengthening of basic research in fusion and manpower fostering system
❖ Broadening the base of support for fusion energy development

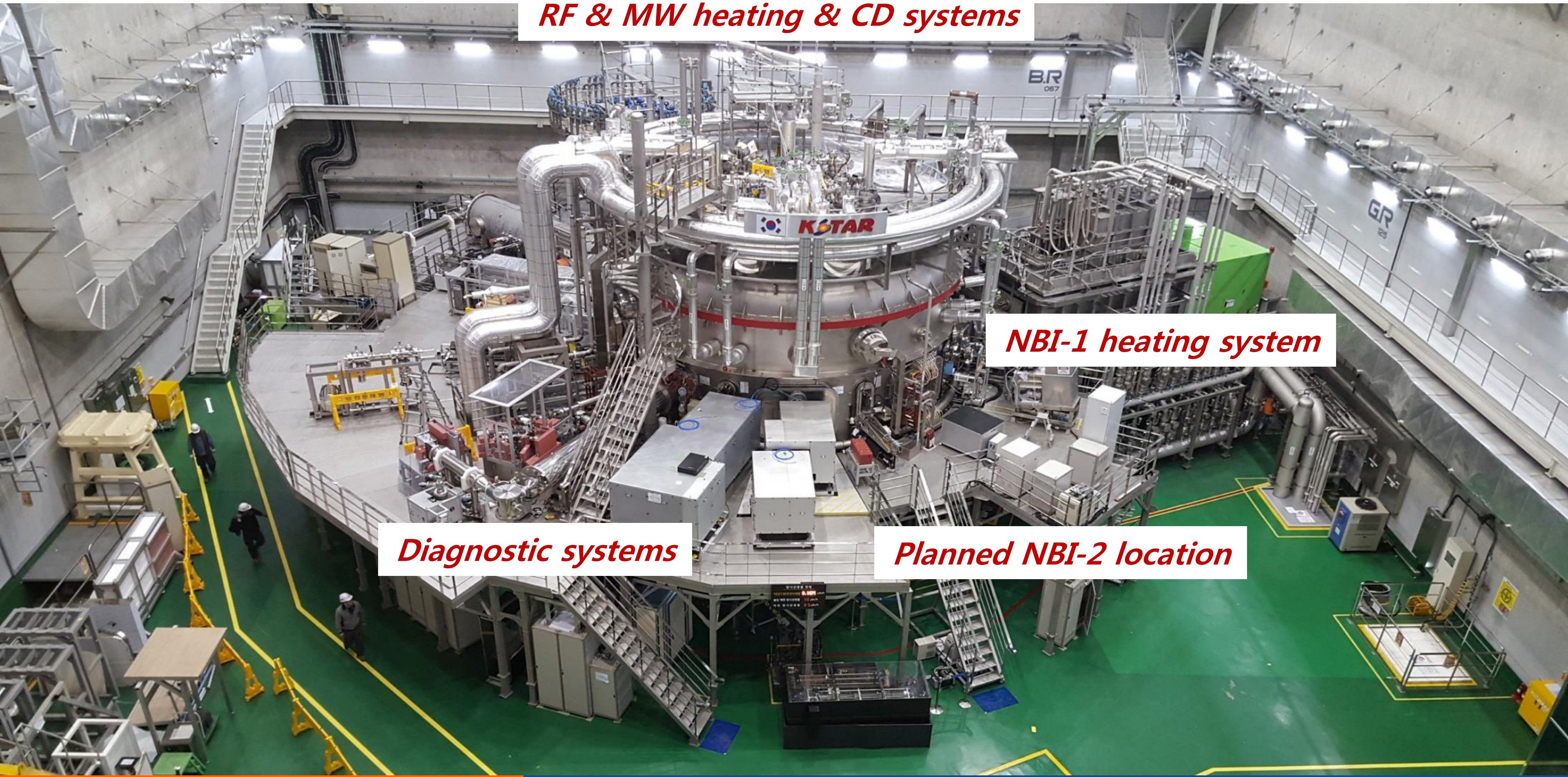
Korea, Fusion Energy Development Roadmap

Work in Progress



KSTAR Project

Mission is exploring the physics and technologies of **high performance and steady-state operation** that are essential scientific and technological basis for ITER and fusion reactor

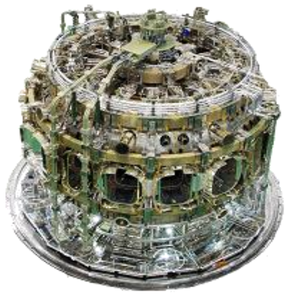


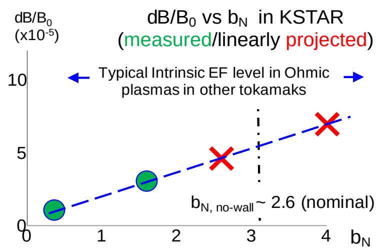
KSTAR Project

Unique tools of KSTAR foradvanced plasma research capabilities

▶ SC magnet technology

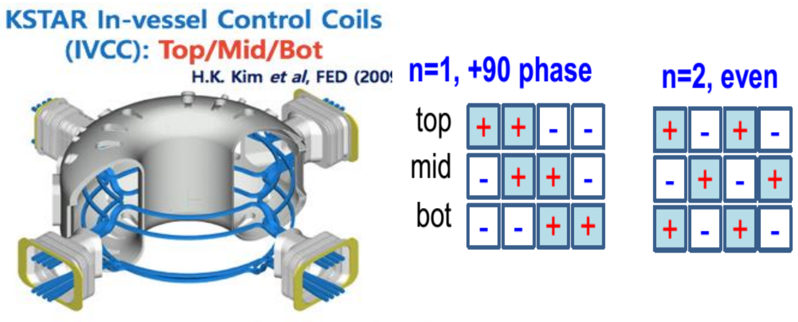
- Lowest error field ($\delta B/B_0 \sim 1 \times 10^{-5}$)
- Lowest toroidal ripple (~0.05 %)





▶ ITER relevant In-vessel coils

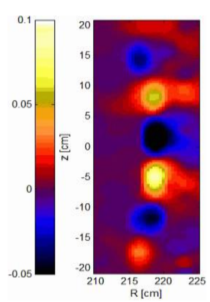
- Uniquely top/middle/bottom coils
- Reliable ELM-crash suppression



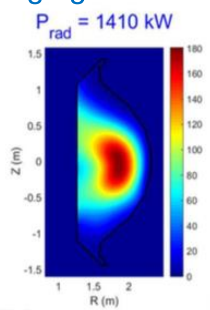
▶ Advanced diagnostic systems

- Profile and 2D imaging diagnostics
- Domestic and int'l collaboration

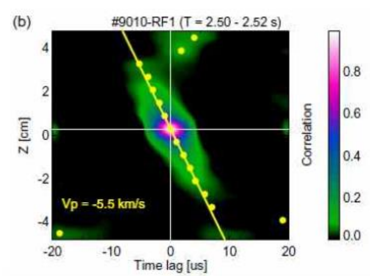
3D/2D ECEI



Imaging bolometer

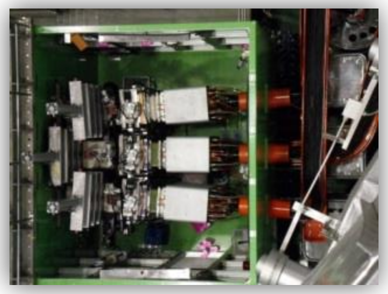


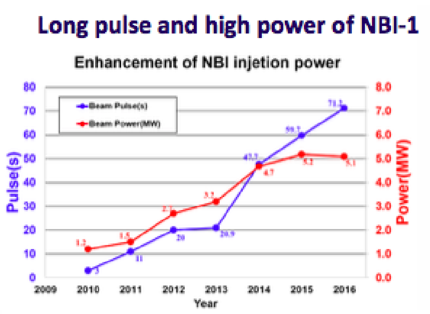
MIR



▶ Long-pulse capable beams

- Long pulse NBI and ECCD
- 2^{nd} NBI system is under construction

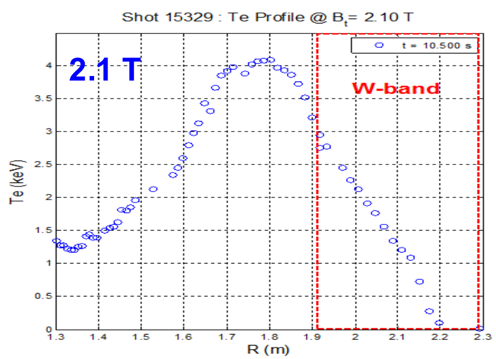




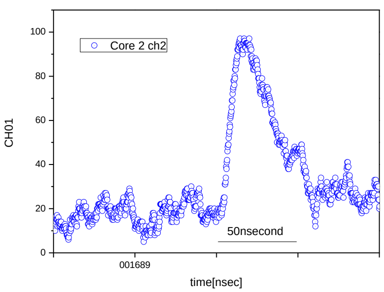
KSTAR Project

Japan collaboration and contribution in KSTAR research

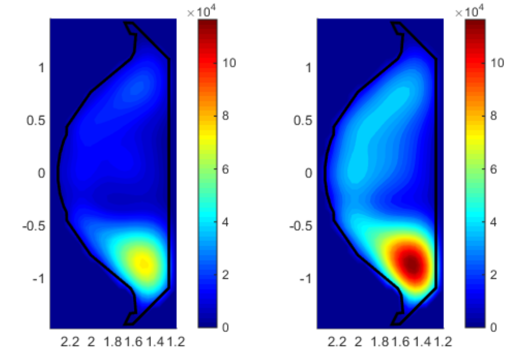
ECE Radiometer : channel extension for low field operation



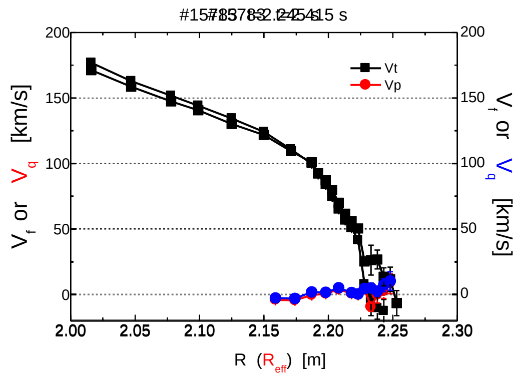
Thomson scattering : Giga sampling digitizer



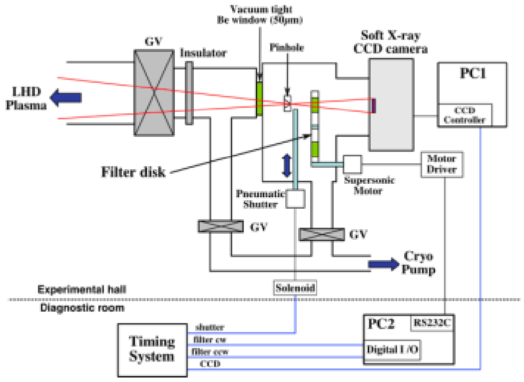
Imaging bolometer(IRVB) : IRTV replacement



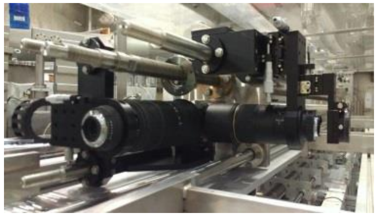
CES diagnostics : Additional poloidal rotation



Soft X-ray imaging VUV camera



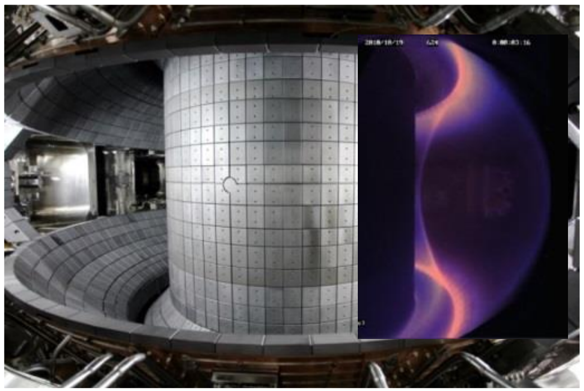
- **Fast ion Loss Detector (FILD)**

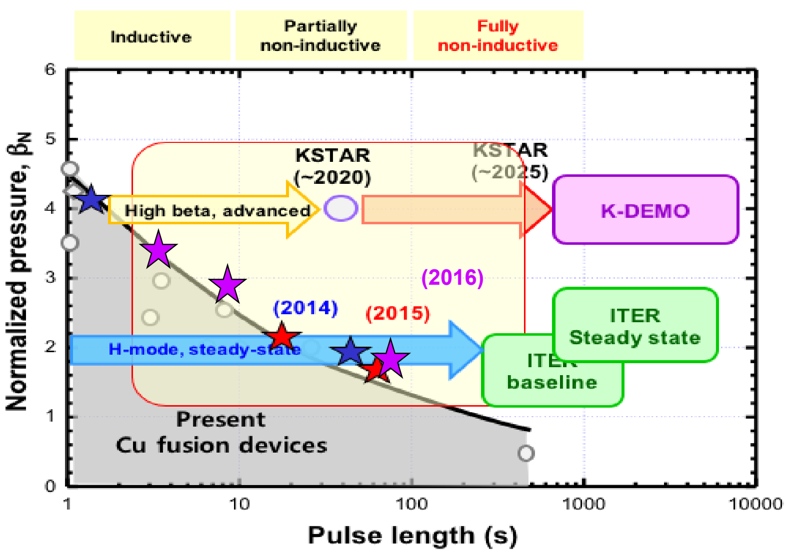


KSTAR Project

Outstanding progress in achievement the steady-state H-modes and advanced operation modes

▶ Progress in plasma performance





▶ Achieved key parameters

Parameters	Designed	Achieved (~2016)
Major radius, R_0	1.8 m	1.8 m
Minor radius, a	0.5 m	0.5 m
Elongation, κ	2.0	2.15
Triangularity, δ	0.8	0.8
Plasma shape	DN, SN	DN, SN
Plasma current, I_P	2.0 MA	1.0 MA
Toroidal field, B_0	3.5 T	3.5 T
H-mode duration	300 s	70 s
β_N	5.0	4.3
Superconductor	Nb_3Sn, NbTi	Nb_3Sn, NbTi
Heating /CD	~ 28 MW	~ 10 MW
PFC	C, W	C, W(sample)

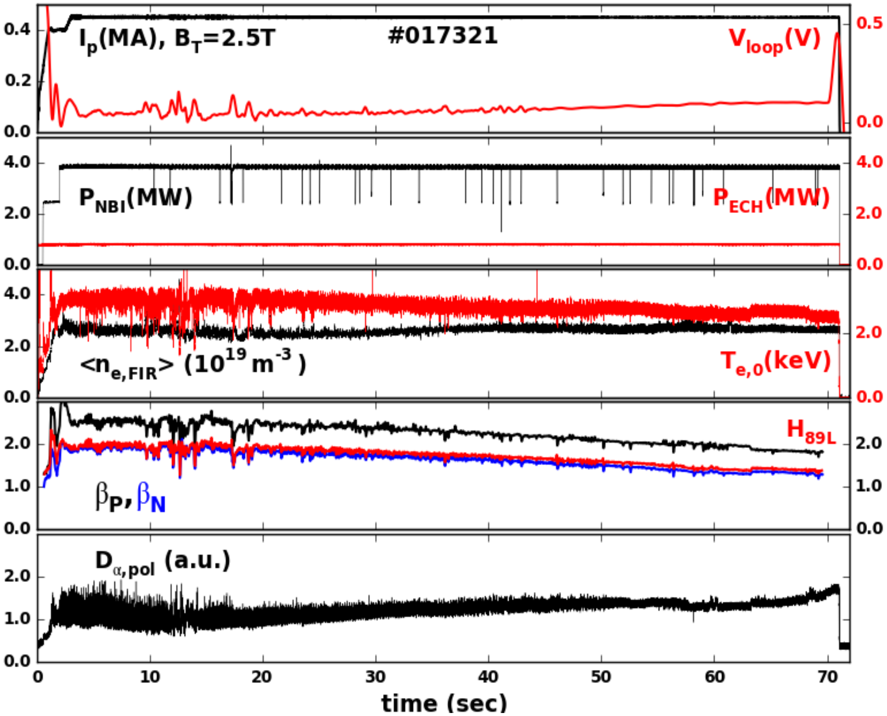
KSTAR Project

Long pulse H-mode operation and alternative operation mode development

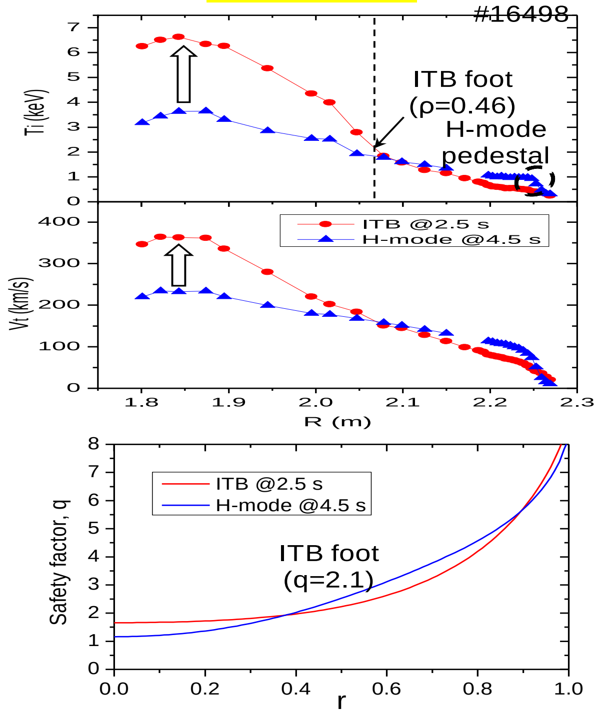
Longest H-mode discharge
- H-mode discharge : **70 s** (0.45 MA)
- Nearly non-inductive discharge

Alternative operation mode development
- Internal transport barrier (**ITB**) > 13s
- High beta operation (**β_N > 3.0, β_P > 3.0**) : > 3s

0.45 MA, 70s



ITB mode



KSTAR Project

Reliable and robust operation of the Edge Localized Mode (ELM) crash suppression using the in-vessel control coils

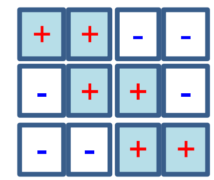
▶ **Robust suppression of the ELM-crash**

- LM-crash free for **> 30s**
- n=1, q95 = 4.0, 5.0, 6.4
- n=2, q95 = 3.4 (ITER compatible), 3.8

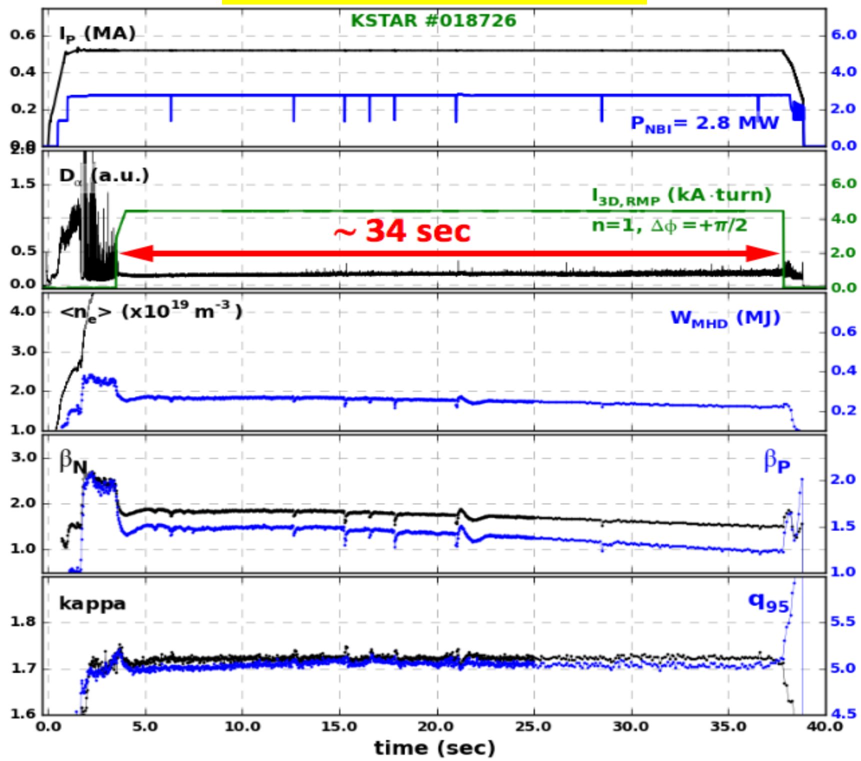
▶ **Validation of sustaining ELM-crash suppression under 360^0 rotated at n=1 RMP**

- ITER required rotated RMP ~ 1 Hz)

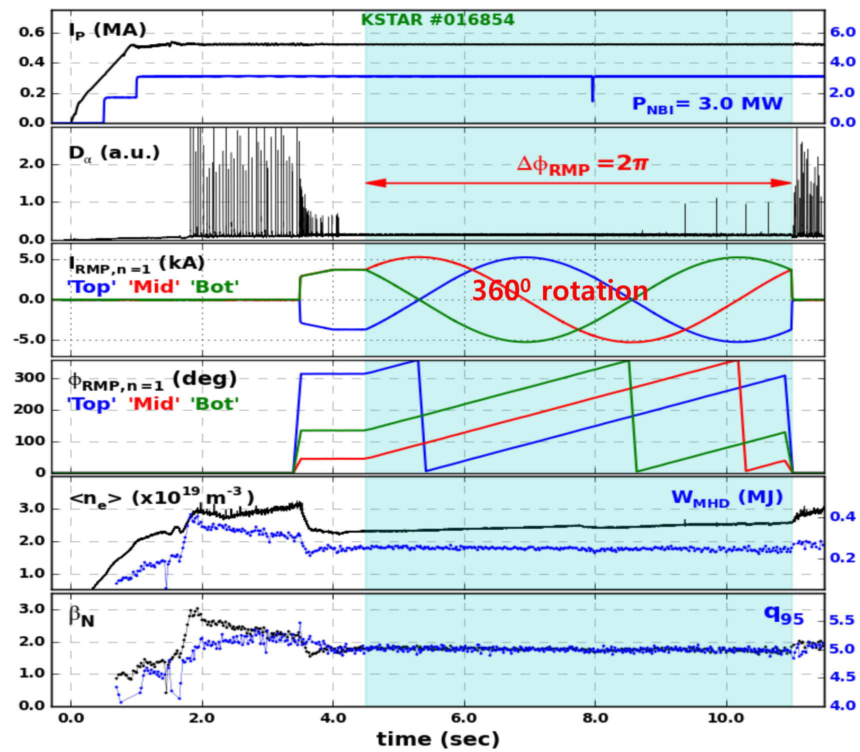
n=1, +90 phase



34s ELM suppression



n=1 full RMP under 360 degree rotation

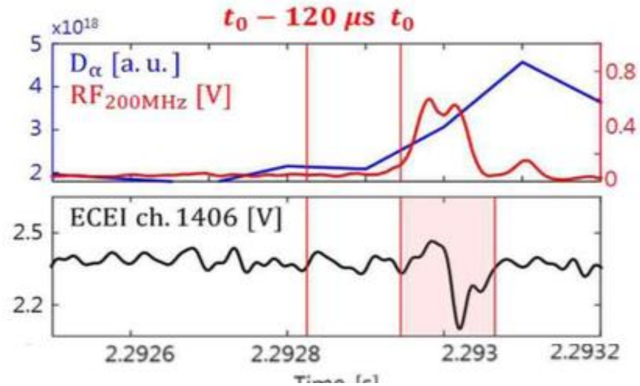


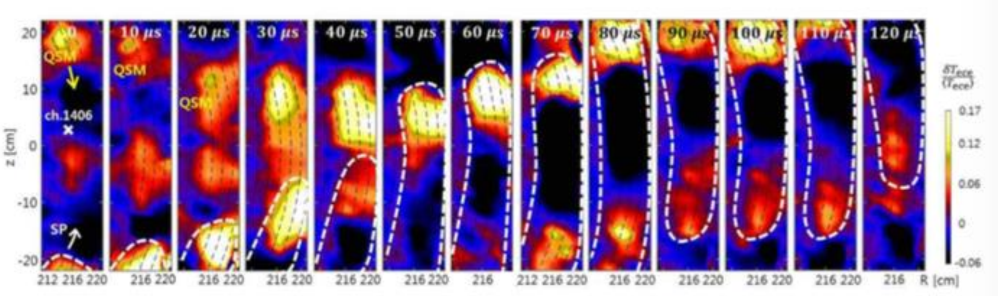
KSTAR Project

Role of RMP in ELM-crash suppression and dynamics of the ELM-crash

▶ **Interaction of the ELMs and Solitary Perturbation (SP: partial n=1 mode)**

- SP appears ~100μs prior the crash
- Opposite rotation due to E_r X B drift



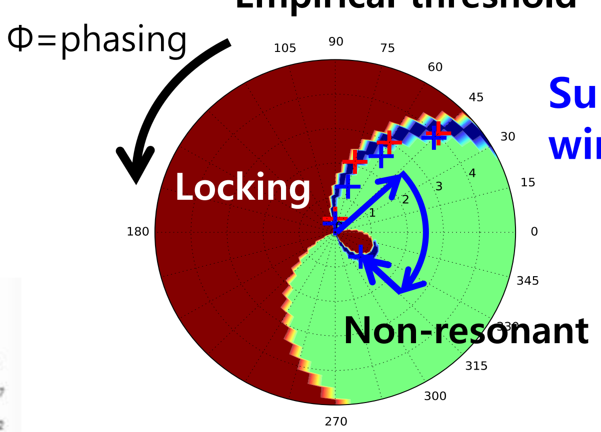


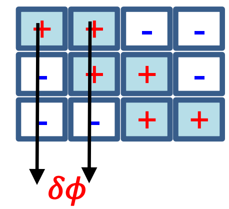
JE Lee (UNIST), Scientific Report 7, 2017

▶ **ELM-crash suppression experiments based on predictive modeling**

- Prediction based on Ideal plasma response

Polar plot of (I_{MID}, ϕ)
with I_U=I_L=5kA and ϕ=ϕ_{UM}=ϕ_{ML}





(Locking "+", ELM suppression "+")

KSTAR Project

Upgrade plan for higher beta and steady-state operation

2008 → **2017**

First plasma
(ECH 84 GHz)

Long-pulse H-mode
(NBI~5.5 MW)
(ECH~1 MW)

2017 → **2021**

Heating upgrade
(NBI~12 MW)
(ECH~6 MW)

2021 → **2025**

Divertor upgrade
(Tungsten divertor)
(Detached divertor)
(Diagnostics)

Advanced current drive
(LHCD~4 MW)
(Helicon CD~4 MW)

Long-pulse H-mode research

- *First plasma (0.1s)*
- *Long pulse H-mode (>70s)*
- *ELM research & control (>30s)*

Advanced scenario & MHD research

- *Stable high beta operation (betaN>3.0, Ti ~10 keV)*
- *Advanced mode develop. (ITB, low q, hybrid)*
- *MHD & disruption control*

Steady-state & reactor mode research

- *Tungsten divertor & active cooling*
- *Advanced current drive under test (HFS LHCD & Helicon CD)*
- *Steady-state operation (~300s)*

ITER Project

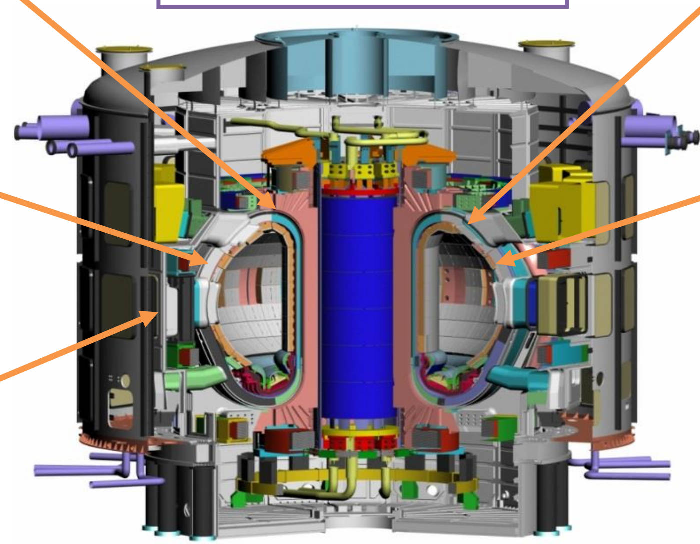
In-kind Contribution of Korea

1. TF Conductor (Completed)
- Total Value (kIUA) : 215.01
- KO Allocation : 20.2%
- KO Contribution (kIUA) : 43.39

2. Vacuum Vessel Main Body
- Total Value(kIUA) : 123.04
- KO Allocation : 21.3%
- KO Contribution (kIUA) : 26.20

3. Vacuum Vessel Port
- Total Value(kIUA) : 76.96
- KO Allocation : 72.7%
- KO Contribution (kIUA) : 55.98

11. Test Blanket Module*
- KO Contribution :
- HCCR TBS (TBM System)
- kIUA Value : N/A



4. Thermal Shield
- Total Value(kIUA) : 26.88
- KO Allocation : 100%
- KO Contribution(kIUA) : 26.88

5. Blanket Shield Block
- Total Value(kIUA) : 56.34
- KO Allocation : 49.8%
- KO Contribution(kIUA): 28.07

6. Assembly Tooling
- Total Value(kIUA) : 23.01
- KO Allocation : 100%
- KO Contribution(kIUA): 23.01

7. Tritium SDS
- Total Value(kIUA) : 15.21
- KO Allocation : 82.1%
- KO Contribution(kIUA) : 12.48

8. AC/DC Converters
- Total Value(kIUA) : 123.58
- KO Allocation : 37.3%
- KO Contribution(kIUA): 46.06

9. IVC Bus bars
- Total Value(kIUA) : 3.98
- KO Allocation : 100%
- KO Contribution(kIUA) : 3.98

10. Diagnostics
- Total Value(kIUA) : 142.09
- KO Allocation : 3.2%
- KO Contribution (kIUA) : 4.49

* TBMA (TBM Agreement) was signed in 2014
Total Value : 270.54 kIUA

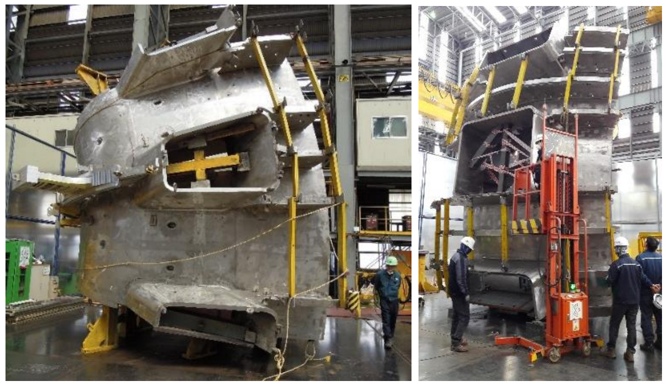
Leading Items | Tokamak Main | Ancillary

ITER Project

Progress of the ITER Procurement Activities of Korea

❖ **<u>VV Main Sectors</u>: Manufacturing progress of the first Sector 6 is about 67% (as of June).**

PS1: IWS SR assembly



PS2, PS3: T-rib assembly

PS4: Inner Shell and TrS assembly

❖ VV Ports

T-rib to Inner Shell ass'y of LPSE

Outer Shell assembly of LPSE

T-rib to Inner Shell of LPE

❖ Thermal Shield

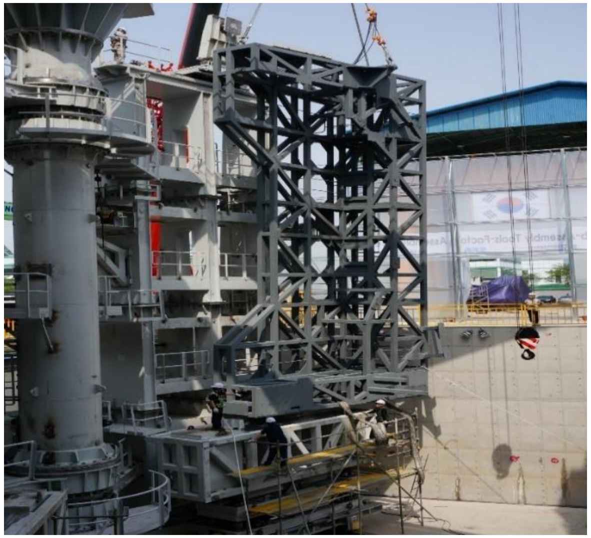
Thermal Shield factory shop

ITER Project

Progress of the ITER Procurement Activities of Korea

❖ Sector Sub-Assembly Tools:

- Factory Acceptance Test of SSAT was completed at the end of April.
- The 1st delivery package departed on 15th May 2017 at Busan harbor.
- It arrived at Fos-Sur-Mer harbor in France on 19th June 2017 and the ITER site on 23rd June 2017.
- So, its IC milestone (Q2 2016: receiving the SSAT by the IO) was met.



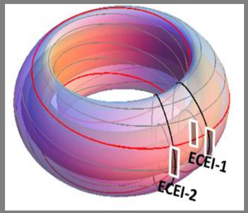
FAT with a load of the VVTS OB Sector Frame

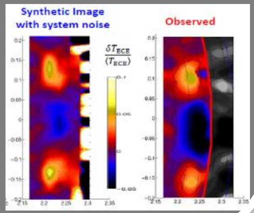
1st delivery package arrived at Fos-Sur-Mer harbor on 19th June

1st delivery package arrived at IO Site on 23rd June

Domestic Fusion R&D collaboration network

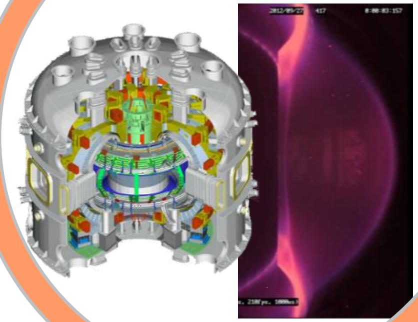
Fusion Plasma Stability and confinement Research Center
UNIST (POSTECH, PU)



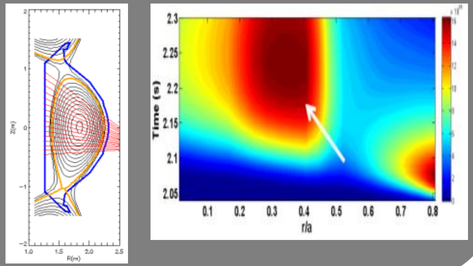


Three core research centers and universities supporting the basic fusion research and HR development

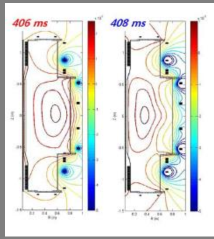
KSTAR



Impurity and Edge Research Center
KAIST (HYU, SNU)



Center for Advanced Tokamak Study
SNU (KAERI)



Universities & Research Institutes

Hanyang U.	Yonsei U.
Daegu U.	Dankook U.
Ajou U.	Chonbuk Nat'l U.
Jeju Nat'l U.	Kyungpook Nat'l U.
KAERI, UST	Chungnam Nat'l U.

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DEMO R&D Program

K-DEMO Mission

❖ To demonstrate the sustainable generation of electricity from fusion power

K-DEMO Strategy

❖ Natural Path : KSTAR ➡ ITER ➡ DEMO (Tokamak)

❖ To mitigate risks in the course of DEMO development ➡ Two-Phased Operation strategy

❖ The operation Stage I ➡ not considered as a final DEMO

- At least one port will be designated for the CTF including blanket test facility.
- To demonstrate the net electricity generation (Q_{eng} > 1) and the self-sufficient Tritium cycle (TBR > 1.05)

❖ The operation Stage II

- Major upgrade of In-Vessel-Components
- To demonstrate the net electricity generation > 400 MWe
- To demonstrate the competitiveness in COE