Ministry of Science and ICT

FUSION, Future Vision of Green Energy

A Pathway to Fusion Power in Korea

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KFE 한국핵융합에너지연구원
KOREA INSTITUTE OF FUSION ENERGY

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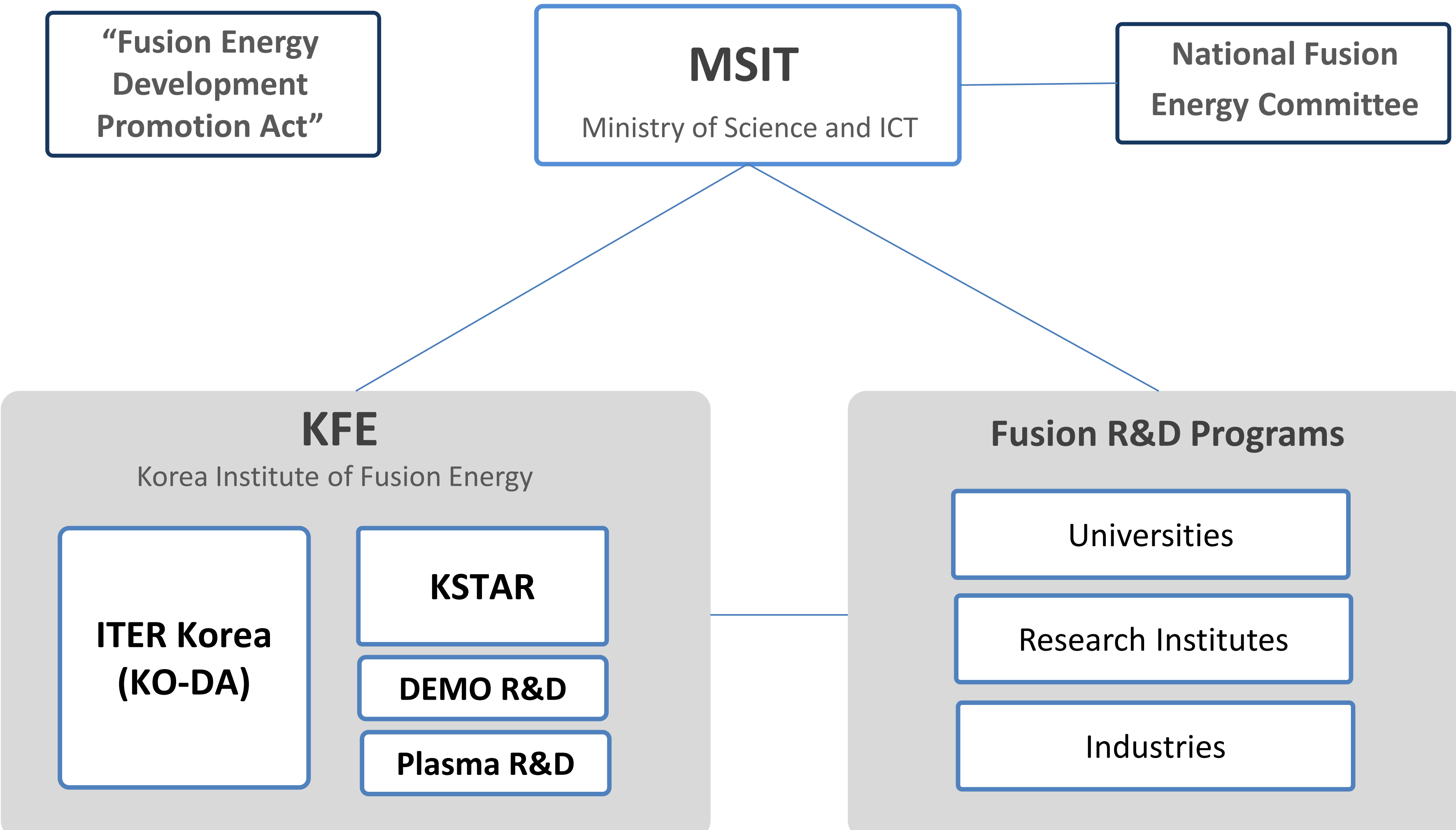
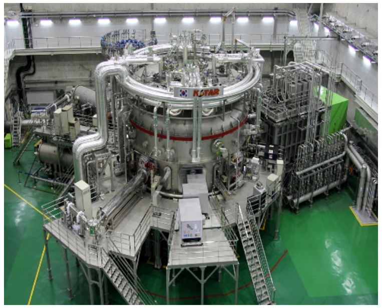
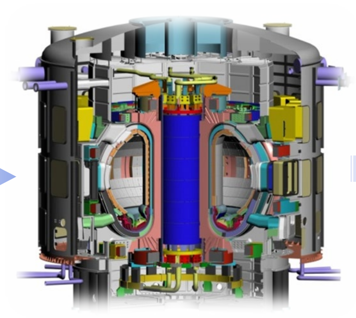
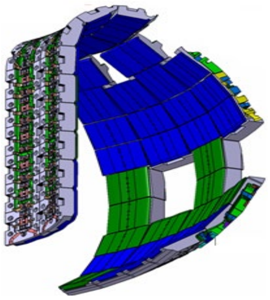
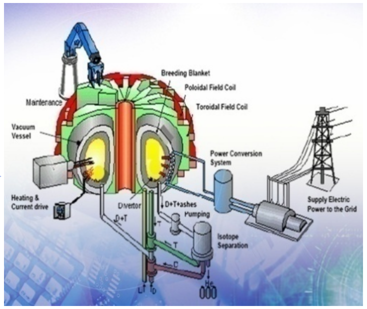
Governance Framework of Fusion R&D in Korea

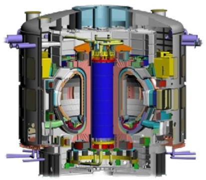


The Most Important Gap Technology

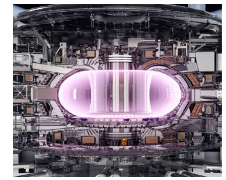
KSTAR	ITER	Breeding Blanket	DEMO
			
High Performance Plasma Control	Burning Plamsa Construction/ Engineering	**Tritium self-Sufficiency** Energy Extraction	Electricity Generation Commercial Feasibility

Gap Technology

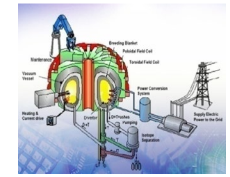
Roadmap based on ITER project



ITER
First Plasma



ITER
Burning Plasma



Electricity Demonstration

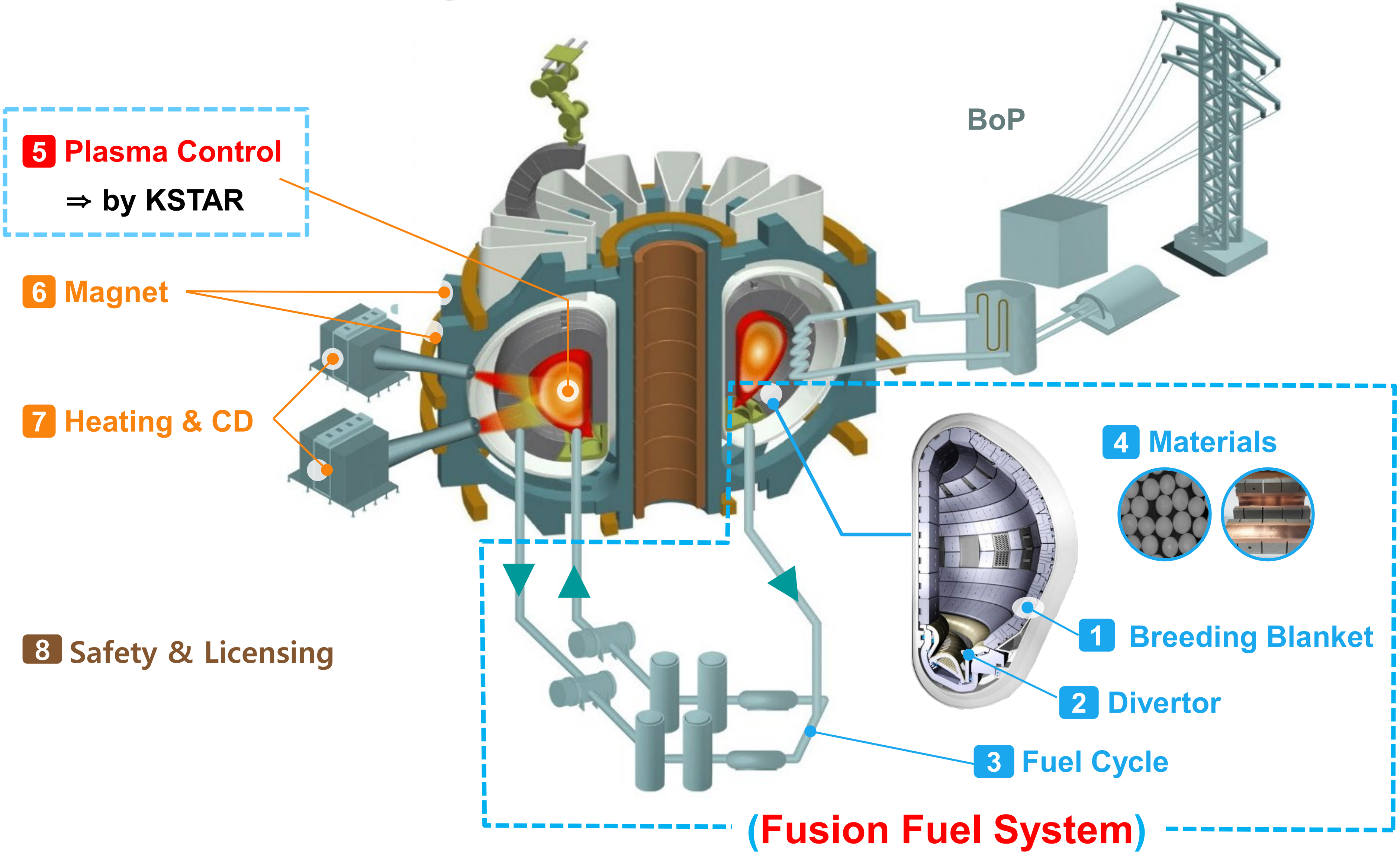
2020 — 2025 — 2030 — **2035** — 2038 — 2040 — ≈ — 2050

Decision/ Construction of DEMO

Secure Gap Technologies btw. ITER and DEMO

Turning point
of Fusion Energy Development

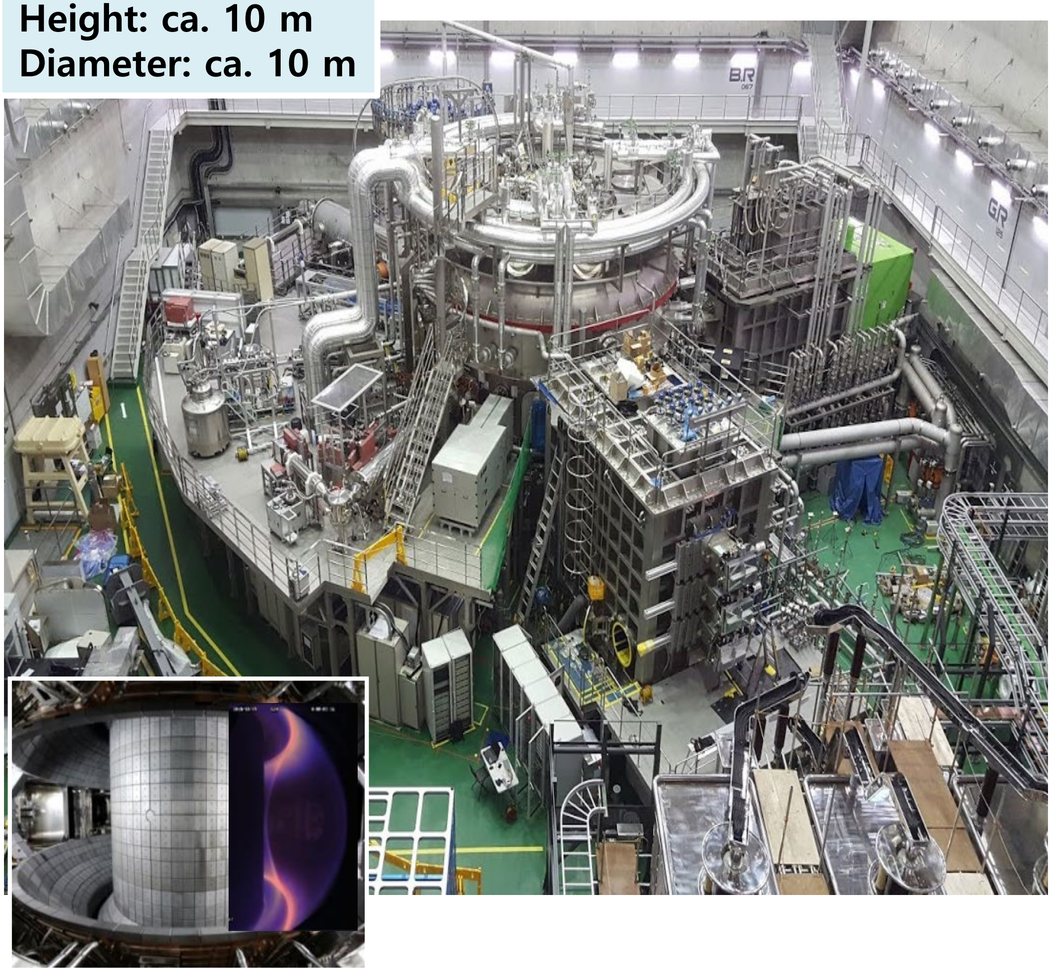
Core Technologies selected for DEMO R&D



⇒ Need to find a new campus for Fusion Fuel System R&D

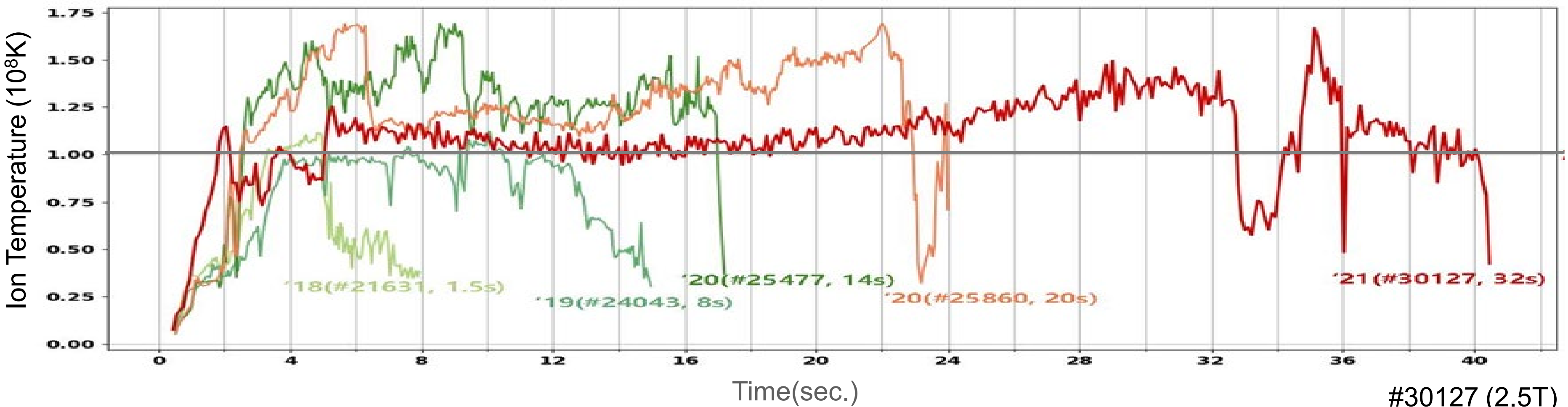
KSTAR Korea superconducting Tokamak Advanced Research

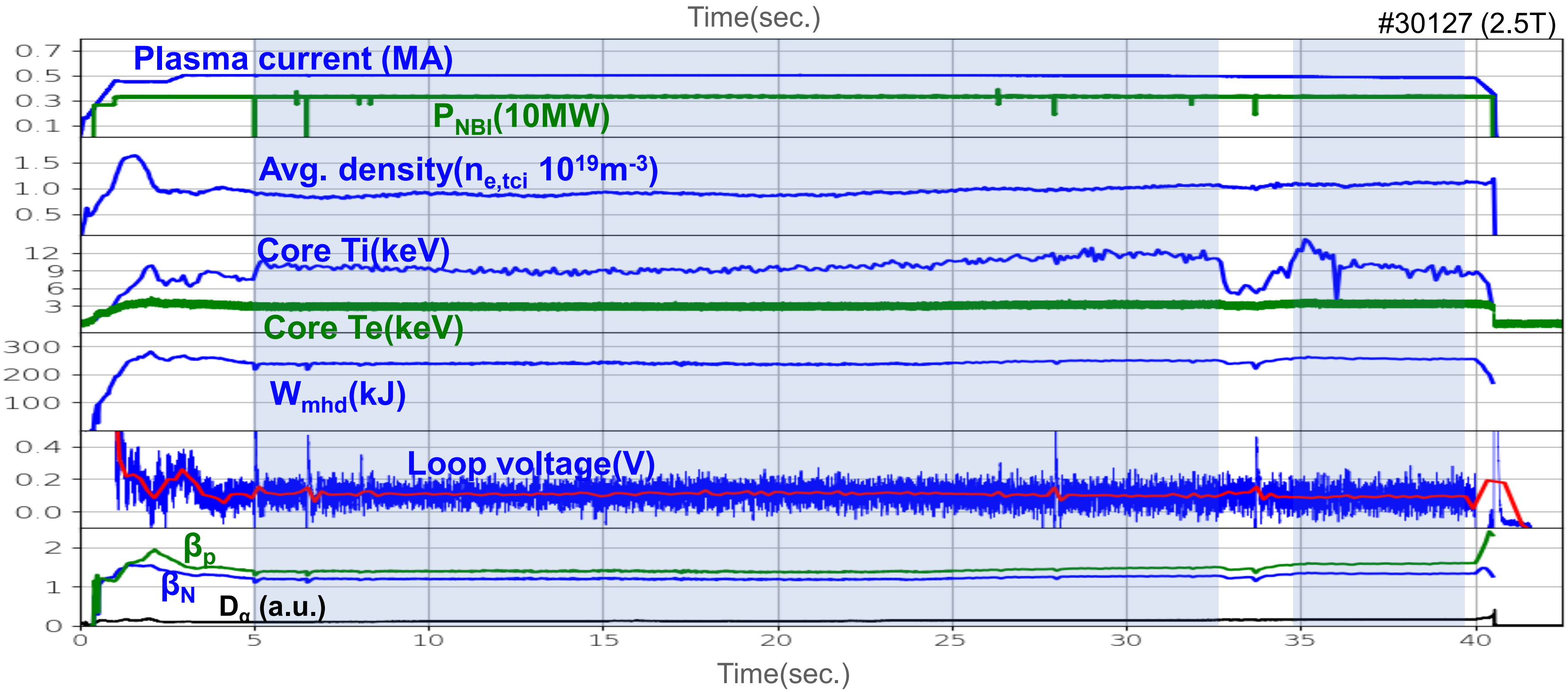
Main body
Height: ca. 10 m
Diameter: ca. 10 m



Parameters	Designed	Achieved (~2021)
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	1.2 MA
Toroidal field, B_0	3.5 T	3.5 T
H-mode duration	300 s	~ 90 s
β_N	5.0	4.3 (~ 0.1 s)
		3.4 (~ 4 s)
		3.0 (~ 10 s)
Superconductor	Nb_3Sn, NbTi	Nb_3Sn, NbTi(Pol.#6,7)
Heating /CD	~ 28 MW	~ 15 MW
PFC	C, W	C, (W)

Achievements (1): High T_i (> 100 MK) for 30 s

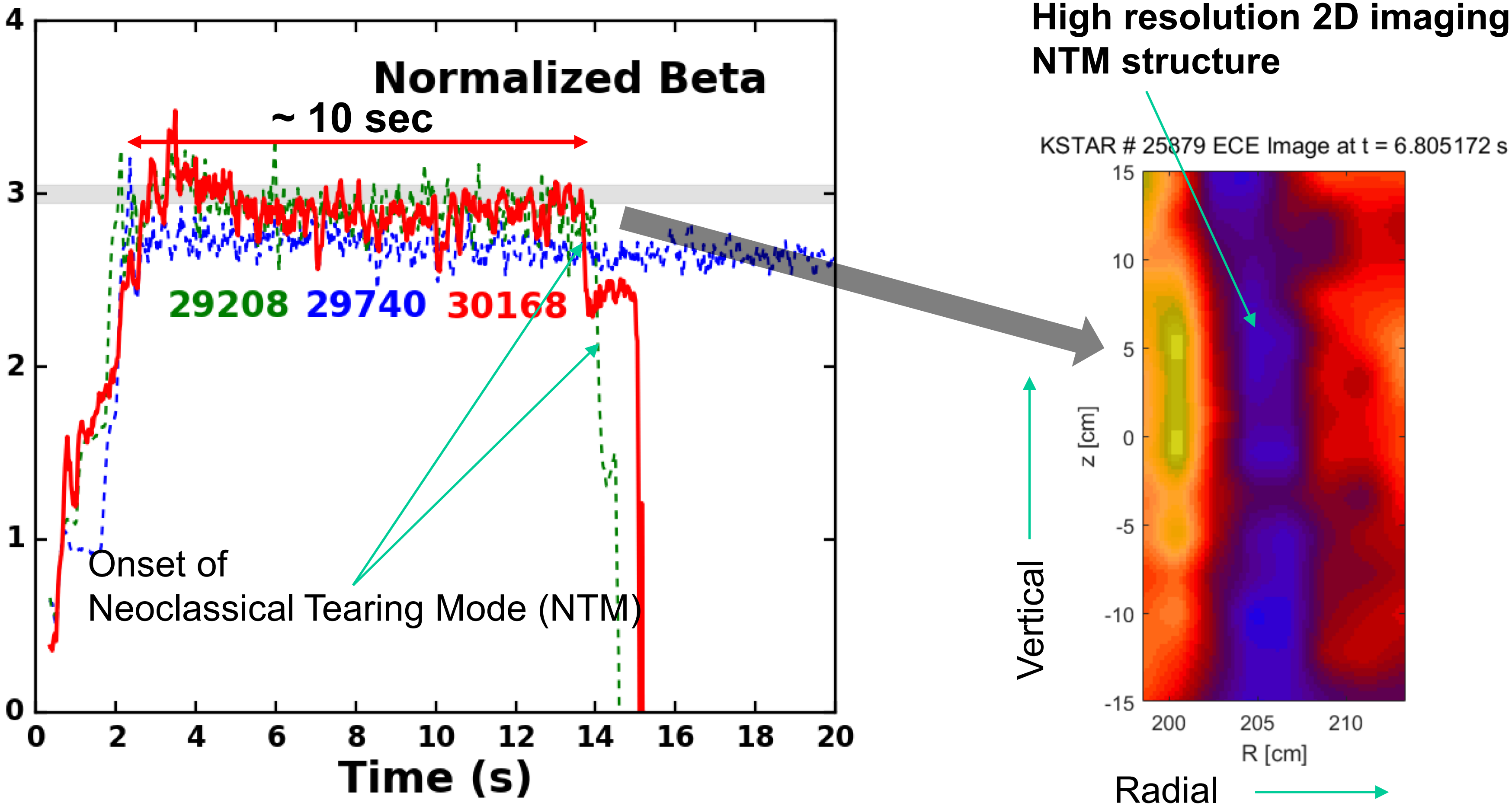




Achievements (2): High β_N (~ 3) for 10 s

NTM is the biggest obstacle to achieve β_N over 3

High resolution 2D imaging of NTM structure



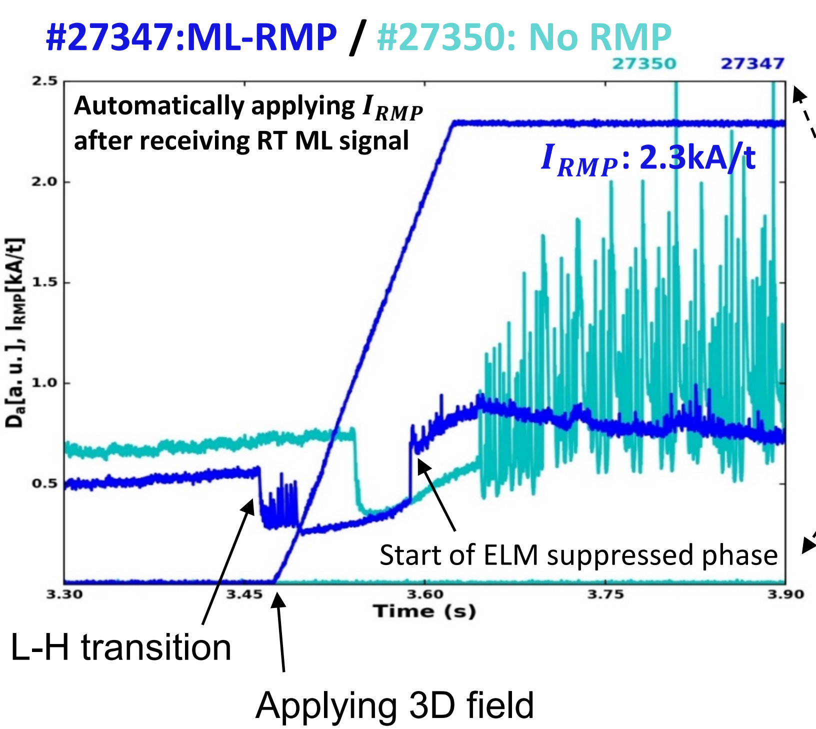
- NTM occurs when it knocks the β_N ~ 3 and performance drops significantly.
- Need to avoid the NTM or increase NTM threshold to get the β_N ~ 3 longer time.

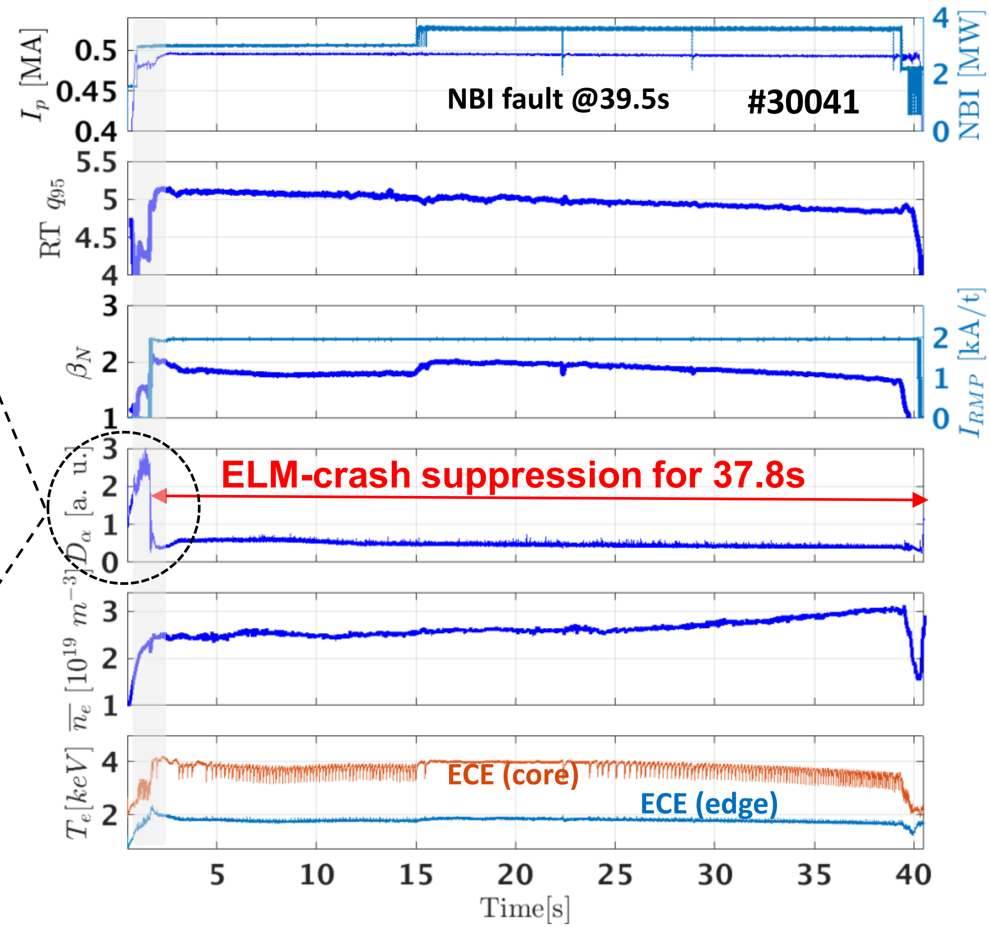
Achievements (3): ELM Crash Control by RMP based on ML

Our approach is to apply the preemptive RMP in pedestal build-up period right after the H-mode transition based on a real-time machine learning (ML) algorithm → prevent any ELM-crash event during H-mode (highly favorable to ITER)

Successful suppression of the first giant ELM : Detection of L-H transition based on ML techniques

~37.8 s long-pulse ELM-crash suppression: ELM crashes completely suppressed during H-mode phase

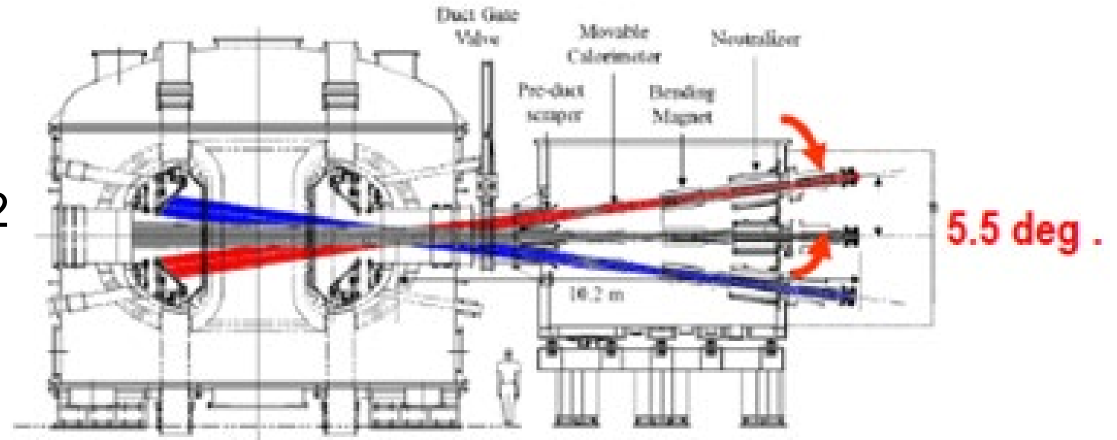




Hardware Upgrade Plans

✓ Commissioning of off-axis NBI-2

- 6 MW in 2022

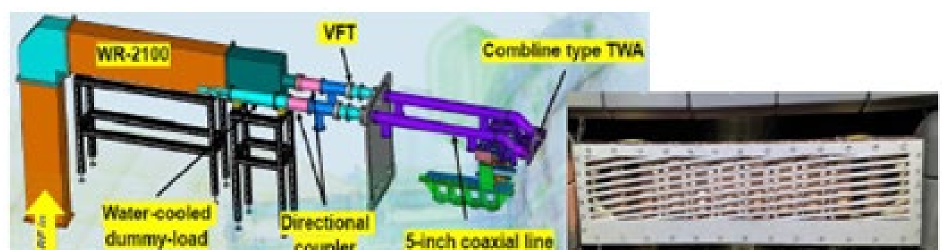


✓ Upgrade to W divertor by 2023

- Successful test of the prototype in 2021
- Assembly will be completed in 2023

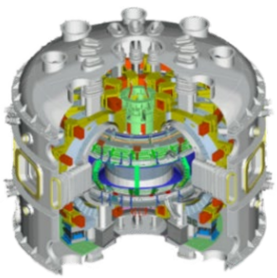
✓ Helicon Current Drive

- ! MW in 2022



Virtual DEMO: Bridges the present (KSTAR, ITER) and the future (K-DEMO)

- Validated simulations with data provided by KSTAR, ITER and Blanket facilities
- Integrated simulations of engineering components (Blanket, BOP, licensing etc)
- Optimization of K-DEMO design (simulations), Reduced risks and construction costs

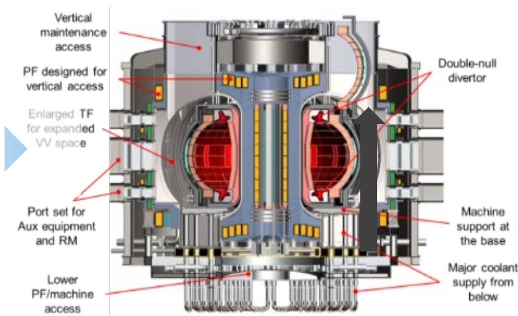


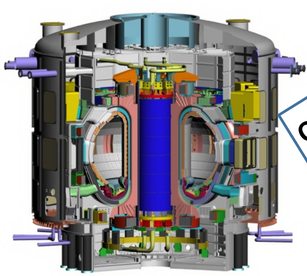
KSTAR

High Performance Plasma **Data**

Optimization
Reduced costs

K-DEMO

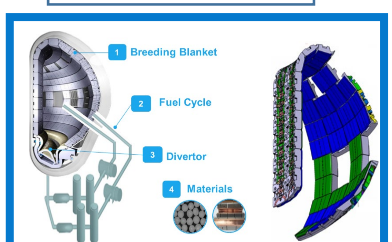




ITER

Construction Engineering
Burning Plasma **Data**

Fueling System
Materials **Data**



Fueling System R&D Facility

Basic Fusion R&D Program

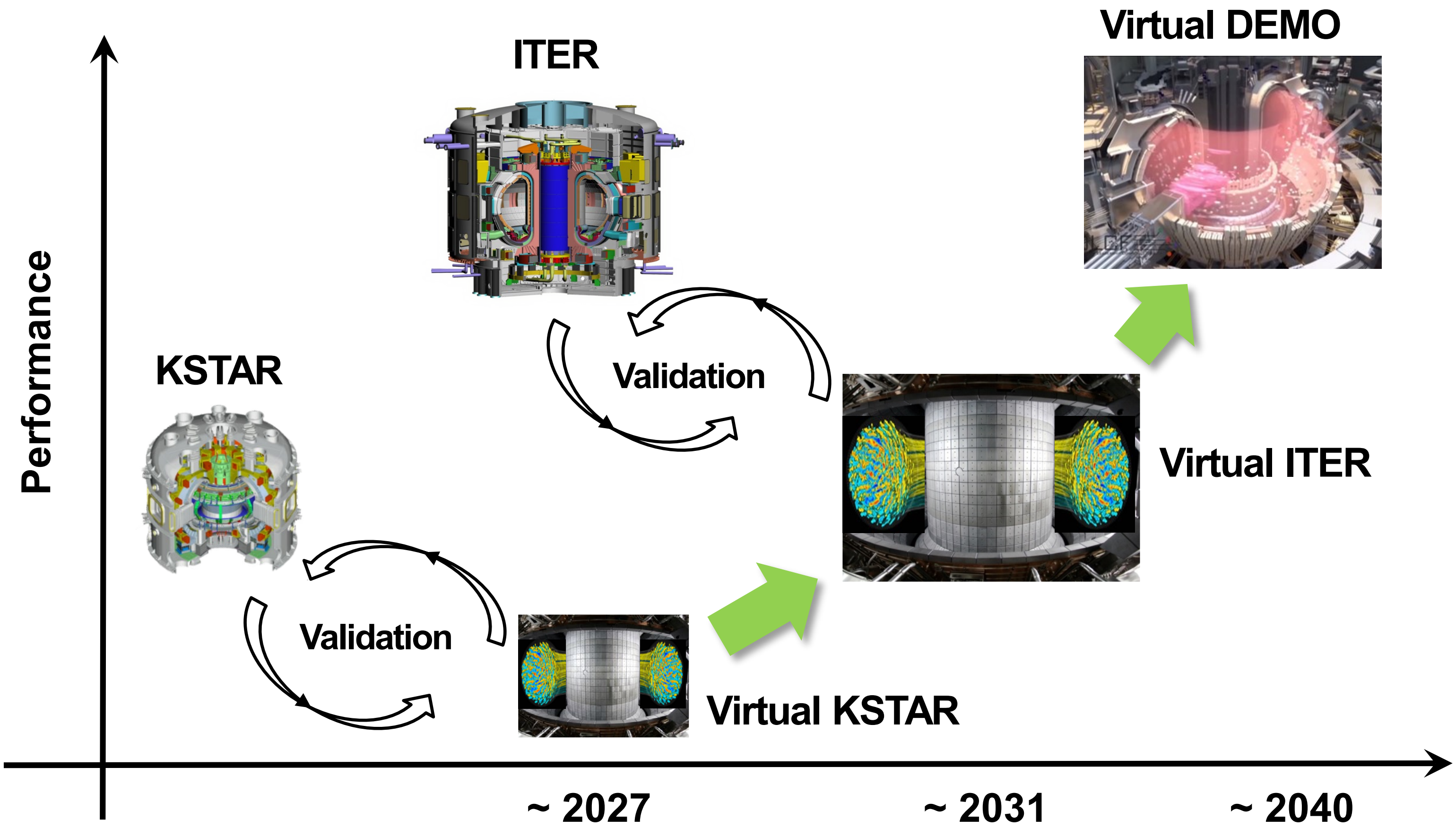
Real machines is inevitable for establishing virtual machines

– Virtual DEMO validation can be made well based on KSTAR, ITER data

☞ Simulations validated with KSTAR, ITER experiments

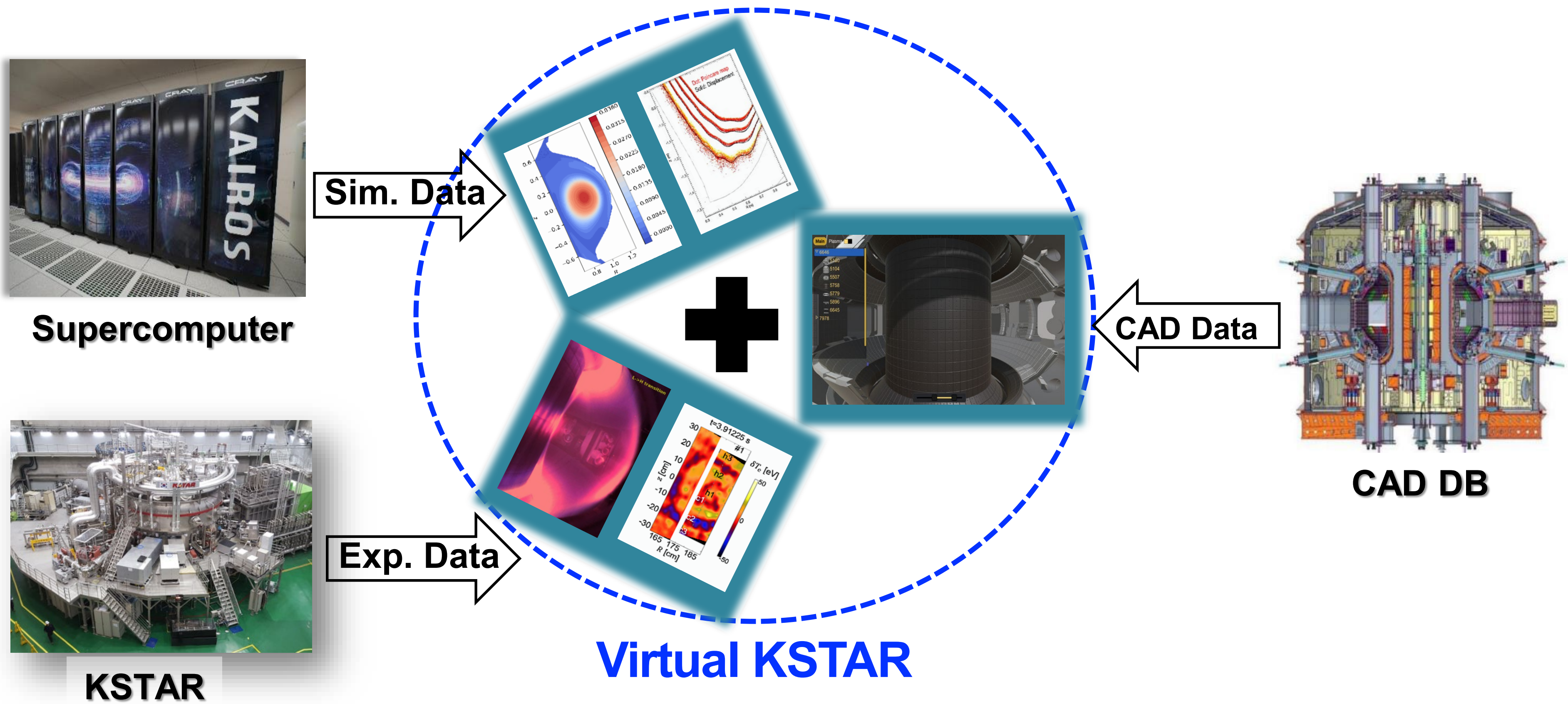
– Decreased uncertainties with high fidelity and accuracy of simulations

☞ Reduced risks and construction costs by validated simulations



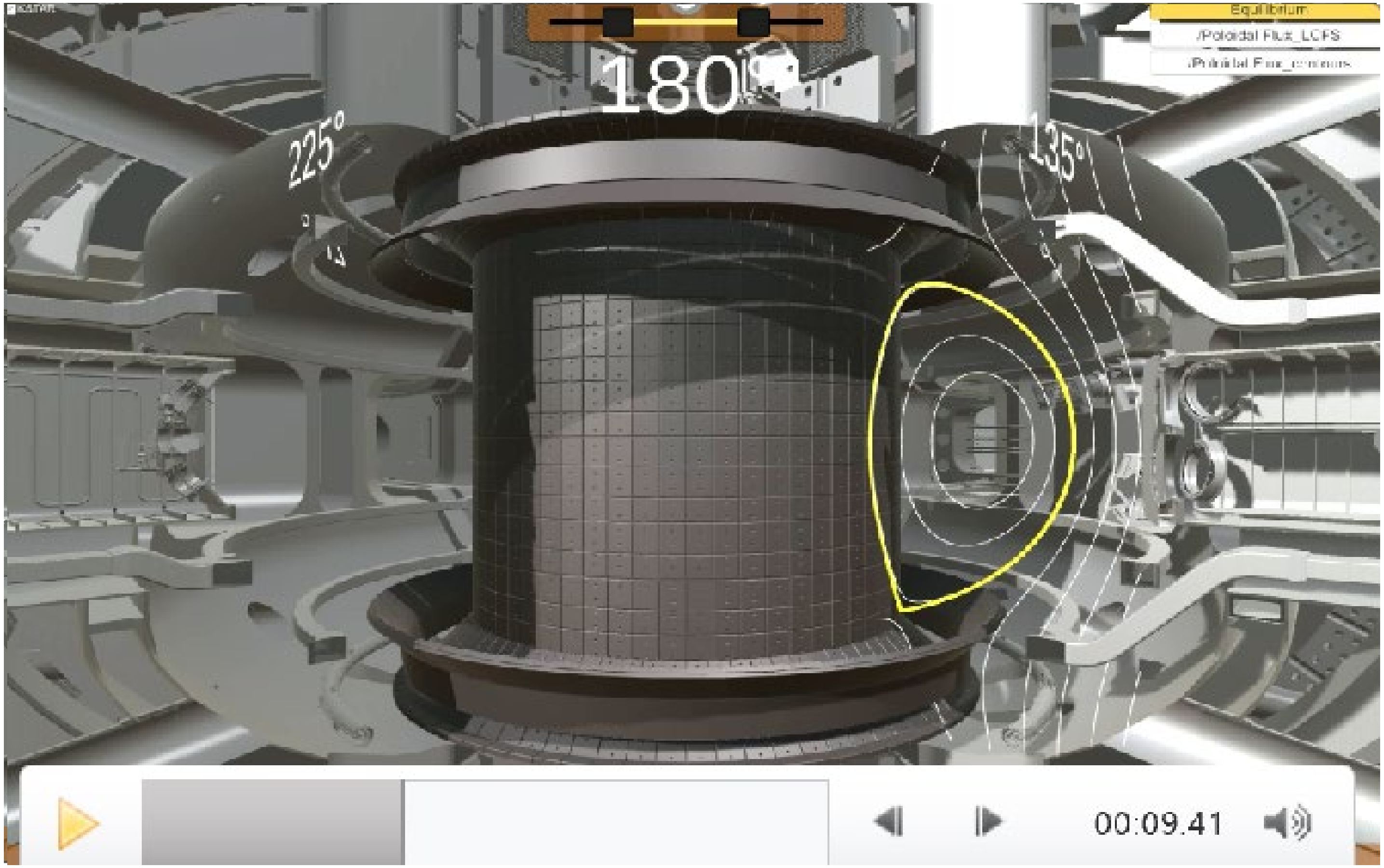
Virtual KSTAR

- ❖ **Quantitative validation owing to reliable data of the real KSTAR**
- ❖ **Precision simulation for quantitative predictive capabilities with KAIROS**
- ❖ **Fast virtualization/visualization based on game graphic technology**
  - Based on Unity game engine, the client is fast enough to be running on PC
  - Easily customizable according to user's work scope

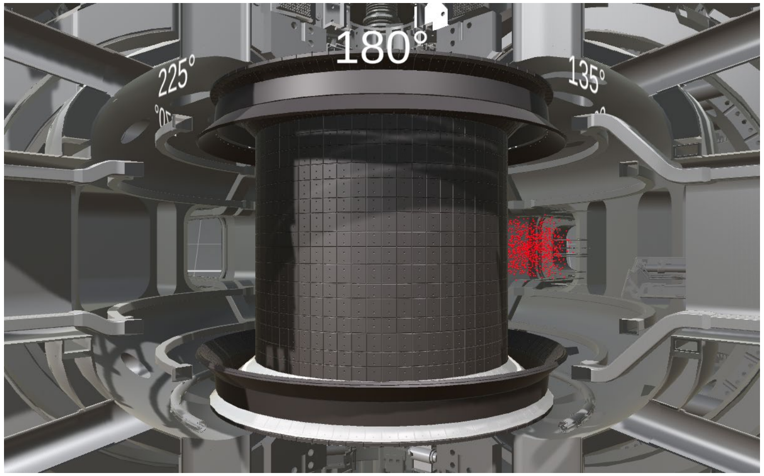


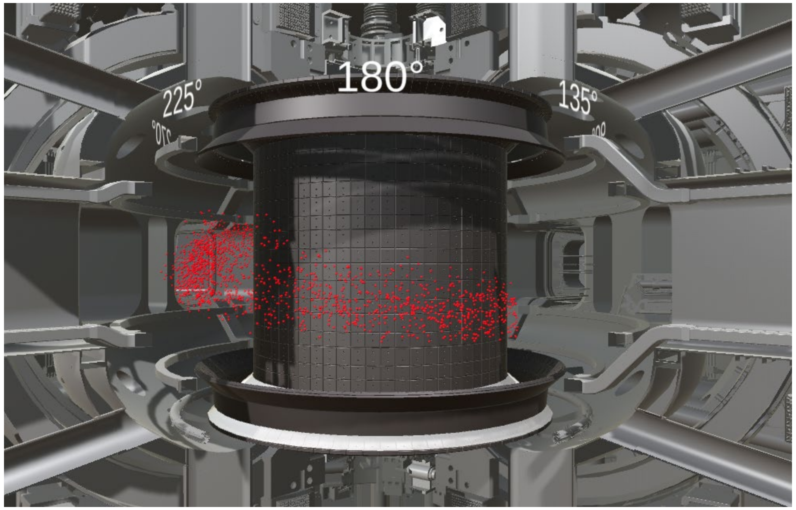
Virtual KSTAR: Real Time Monitoring

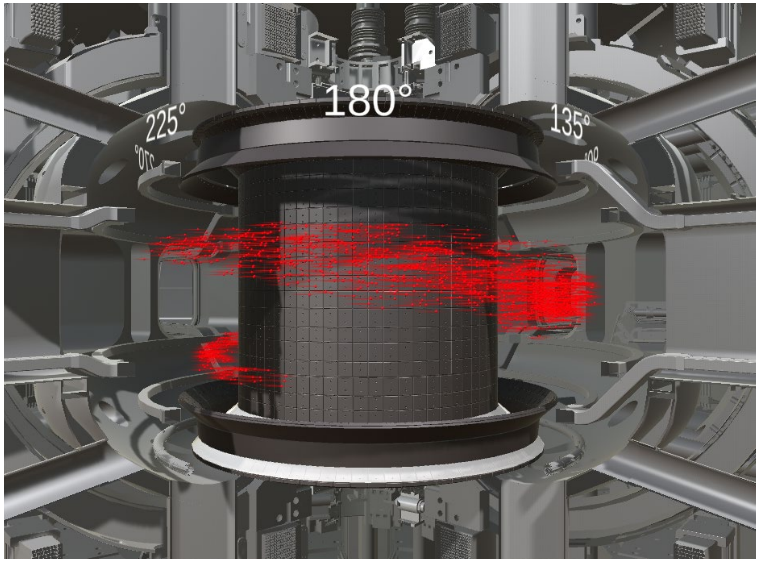
- Real time visualization of equilibrium magnetic field reconstruction
- Plan to add more monitoring capabilities in coming years

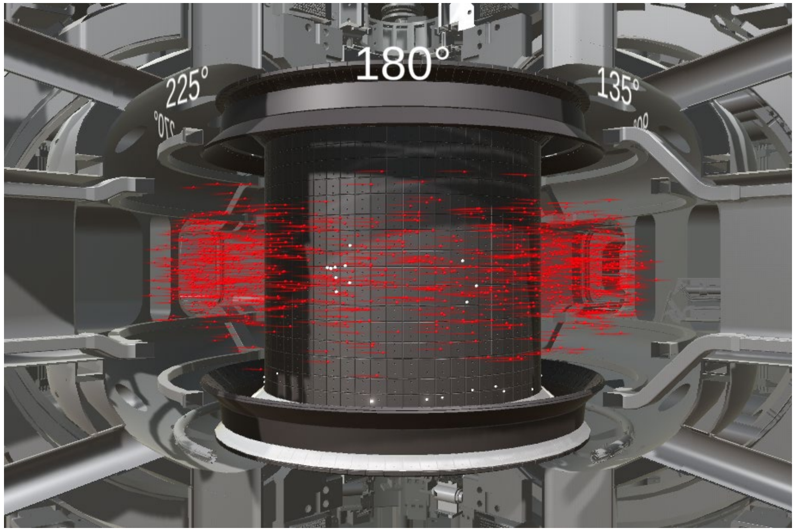


Virtual KSTAR: NBI particles' Motion









Government Policies

Master Plans for Fusion Energy Development

Fusion Energy Development Promotion Act

Article 4 (Establishment of Master Plans to Promote Development of Fusion Energy)

(1) In order to facilitate research and development of fusion energy, the Government shall establish a master plan…

(2) The Minister of Science and ICT shall prepare a master plan every five years in consultation with the heads of relevant central administrative agencies and shall confirm such plan following the deliberation of the National Fusion Energy Committee under Article 6 (1).

Master Plans for Fusion Energy Development

1st Master Plan ('07~'11)	▪ ***Establish the foundation for fusion energy development***
2nd Master Plan ('12~'16)	▪ ***Research and Development on fundamental fusion technologies utilizing KSTAR and ITER***
3rd Master Plan ('17~'21)	▪ ***Establish foundation for fusion engineering technology development for demonstration of electricity production*** ❖ Accelerate development of DEMO core technologies ❖ Strengthen basic research and HR training ❖ Promote social & industry support for fusion energy development

Draft 4th Master Plan ('22-'26)

- Discussion/Preparation ongoing to formulate the 4th Master Plan.
- Fresh analysis on global environment for fusion energy development efforts.
- Emphasis on acceleration of fusion R&D and fusion policy efforts.

Government Policy for Fusion Energy R&D

⇒ Fusion was selected as one of 10 key areas for strategic R&D investment for carbon neutrality

Renewable energy	Solar energy	Wind energy	Ocean energy	New renewable
Hydrogen economy	Production	Storage & transport	Fuel cell	Utilization
Power grid	Smart grid	Energy storage		
Eco-friendly cars	Electric cars	Hydrogen cars		
Demand Control and high efficiency	Digital demand management	Increasing industry efficiency	Increasing transport efficiency	Increasing building efficiency
Industry process innovation	Steel	Cement	Petro/Chemical	Semiconductor /Display
CCUS	Capture	Storage	Utilization	
Clean fuel and Resource circulation	Bio-energy	Resource circulation	H-combined generation	
Fusion	Fusion			
Adaptation and absorption	Climate prediction & monitoring	Water management	Sink reinforcement	

Summary

- **The gap core technologies for DEMO are being discussed among Government, KFE, and fusion R&D groups.**
  - There are 8 candidate gap core technologies that are Breeding Blanket, Fuel cycle, Divertor, Fusion Materials, Heating and CD, Superconducting Magnets, Plasma control, and Safety and licensing

- **KFE will mainly focus on three important items for DEMO**
  - The R&D of '**fusion fuel system**' that includes Breeding Blanket, Fuel cycle, Divertor, and Fusion Materials
  - The achievement of '**high performance plasma control**' by using **KSTAR**
  - The development of **virtual DEMO** based on the **virtual KSTAR** that has been well under development

- **Highlight Achievements 2021 of KSTAR**
  - Ion temperature of 100 mil. K with an operation duration longer than 30 s
  - High beta (β_N <~ 3) operation for longer than 10 sec
  - Effective suppression of ELM by 3D field for ca. 40 s

- **The fusion R&D will have more opportunity owing to new government policies**
  - The 4th master plan of promoting fusion energy R&D in Korea will be officially confirmed by the Government within 2021
  - Fusion was selected as one of 10 key areas for strategic R&D investment for carbon neutrality

Thank you for your attention !

Around 2035, owing to the success of the ITER burning, I hope the **recovery of the honor of fusion energy** that has been teased with "the Boy Who Cried Wolf" of Aesop's Fables

http://pesstevensone.blogspot.com/2013/08/the-boy-who-cried-wolf.html

KAIROs, Supercomputing System

KAIROS

(**K**orea **A**dvanced **I**nstrument for **R**ealizing the **O**peration of the **S**ustainable Fusion Reaction)

Model	Cray XC50
CPU	Intel Xeon Cascade Lake 2.4 GHz 424 x 2x 24 = 20,352 computing cores 1.56 PF (Rpeak, theoretical Max) 1.02 PF (Rmax, measured)
GPU	NVIDA Volta 6 x 5,120 = 30,720 cores 0.78 PF*
Memory	8 GB per core, Total 162 TB