FUSION, Future Vision of Green Energy

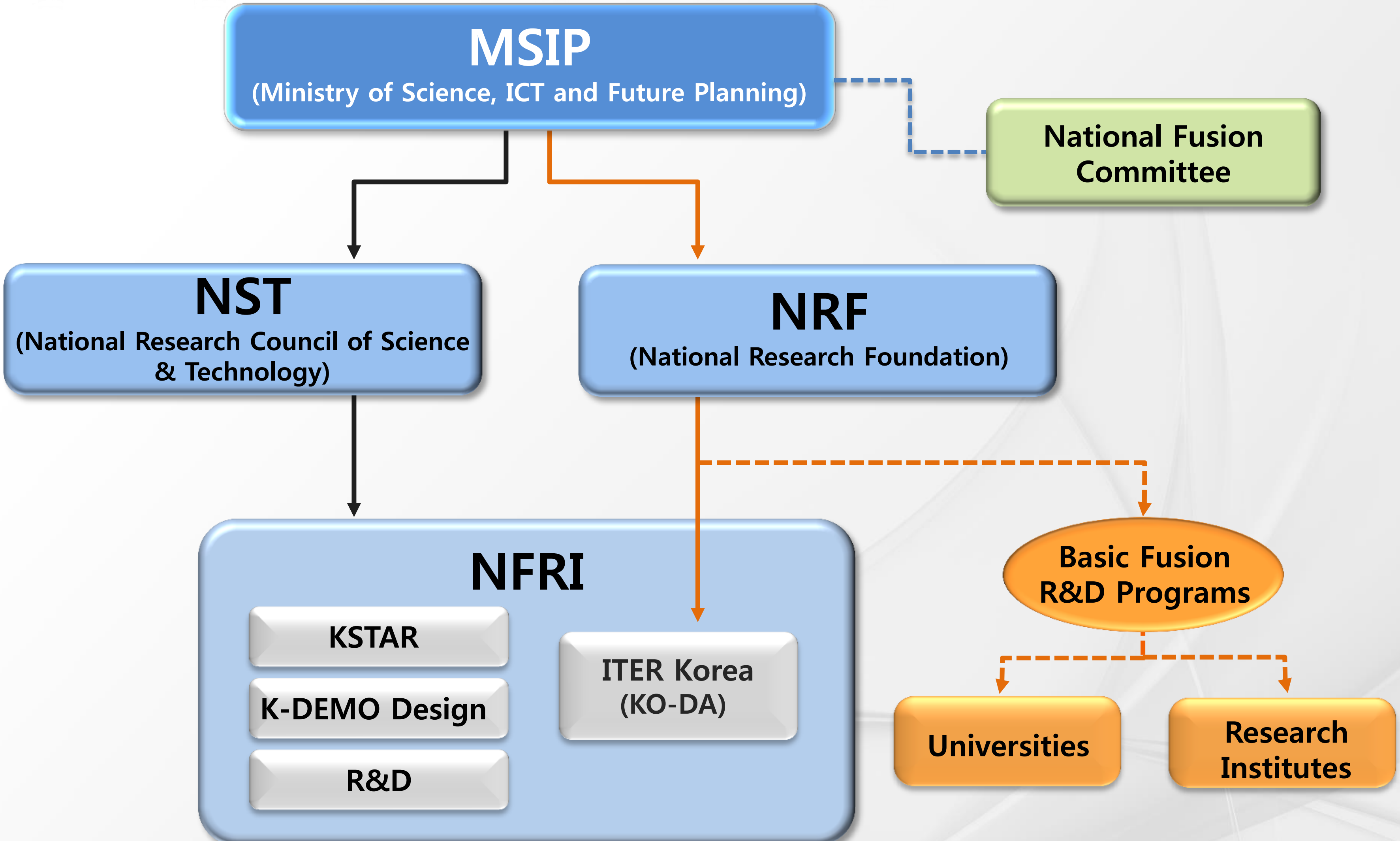
Fusion Energy Development in Korea

Current Activities and Development

Fusion Power Associates
35th Annual Meeting and Symposium
December 16, 2014 / Washington D.C. USA

NFRI 국가핵융합연구소
National Fusion Research Institute

Governance Framework of KO Fusion R&D



* Fusion Energy Development Promotion Law (FEDPL, 2007)

Korean 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~'21)	Phase 3 ('22~'36)
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)

Goal for Plan 2	R&D for DEMO Core Technology based on KSTAR and ITER
Strategy for Plan 2	✦ Attainment of KSTAR high-performance plasma and development of DEMO basic technology ✦ Basic research in fusion and cultivation of man power ✦ International cooperation and improvement of status in ITER operations ✦ Commercialization of fusion/plasma technology and promotion of social acceptance

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KSTAR Program & Basic Fusion R&D

R&D Facility in NFRI

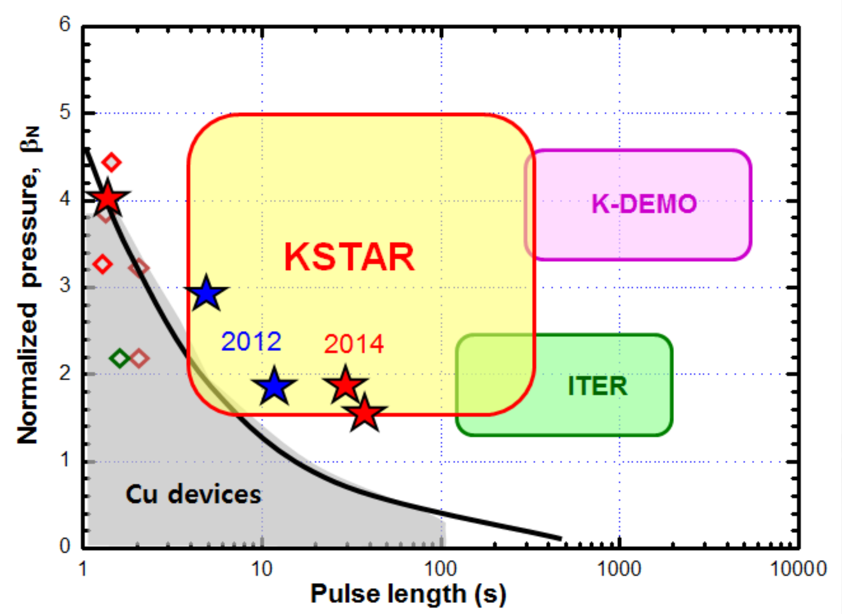
- ***KSTAR Experiment Building***

- ***NFRI HQ (including ITER Korea)***
- ***Home for K-DEMO Design***

KSTAR Project Mission and Parameters

KSTAR Missions

- To achieve the **superconducting tokamak construction and operation experiences**
- To explore the **physics and technologies of high performance steady-state operation** that are essential for ITER and fusion reactor



Achieved Parameters

Parameters	Designed	Achieved
Major radius, R_0	1.8 m	1.8 m
Minor radius, a	0.5 m	0.5 m
Elongation, κ	2.0	1.8
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 length	300 s	40 s
Normalized beta, β_N	5.0	4.0
Superconductor	Nb_3Sn, NbTi	Nb_3Sn, NbTi
Heating /CD	~ 28 MW	~ 7 MW
PFC	C, CFC or W	C

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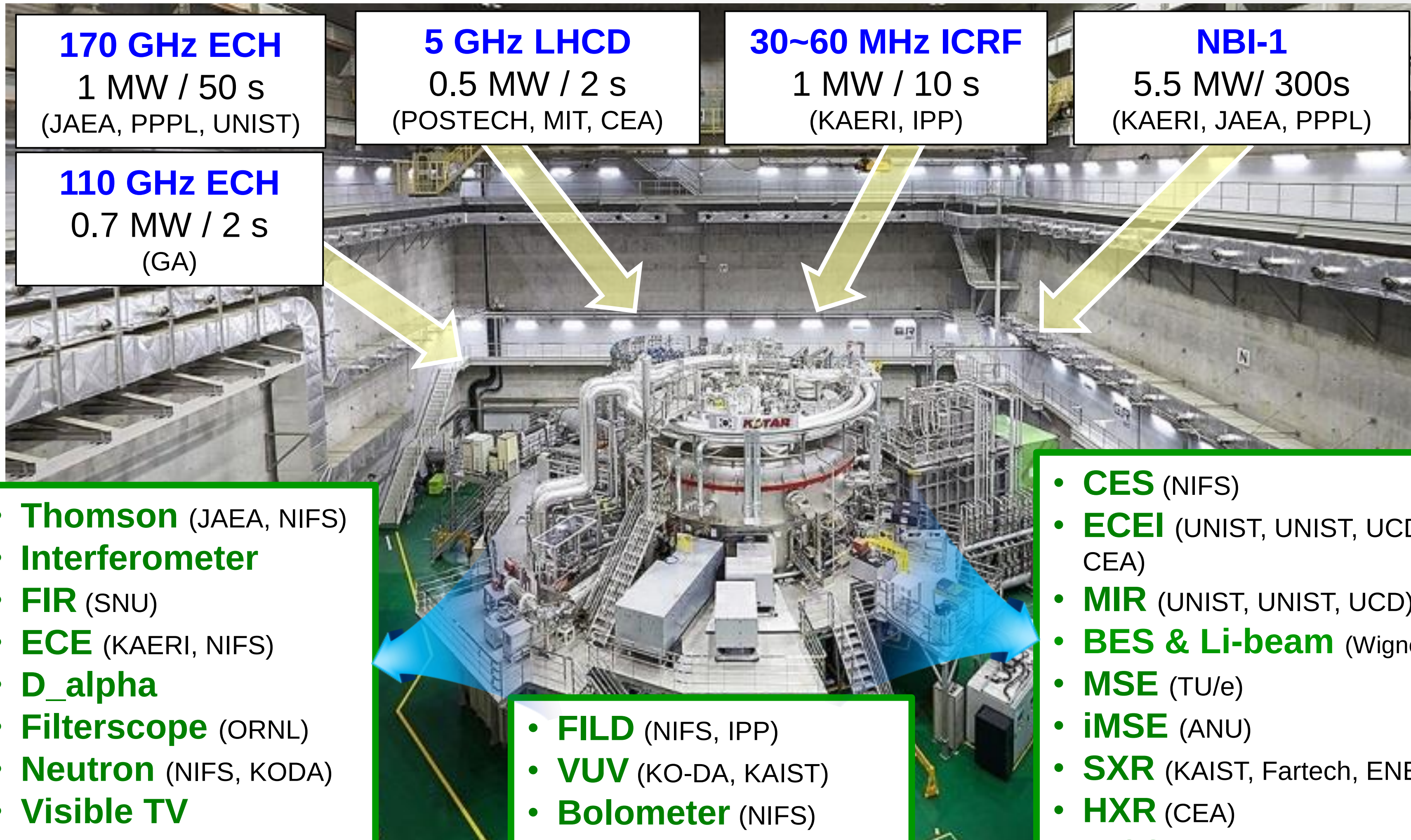
KSTAR Device Status (2014 Campaign) : Heating/CD and Diagnostic Systems



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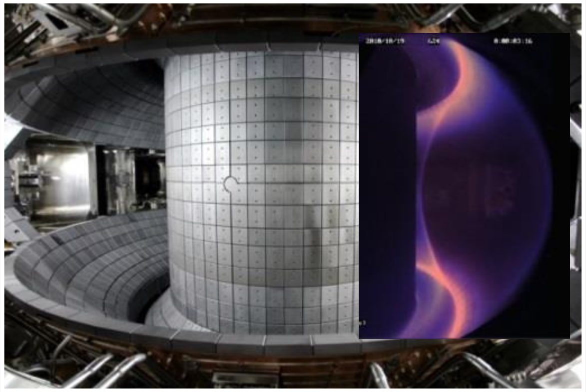
KSTAR Operation Window is expanding to the steady-state and high-performance areas

- **Extension of H-mode Discharges for the steady-state physics research :**
  - **t_H~ 30s, Ip=0.4 MA**, B_T=2T, β_N~ 2.0, f_{NI}~ 0.5 (#10123)
  - **t_H~ 40s, Ip=0.5 MA**, B_T=3T, β_N~ 1.4, f_{NI}~ 0.5 (#10512)
  - **Planned System Upgrade for > 50s @ 1 MA**

  → Motor-generator, ICWC between shots & PFC active cooling, In-vessel Cryopump & Pellet Injection



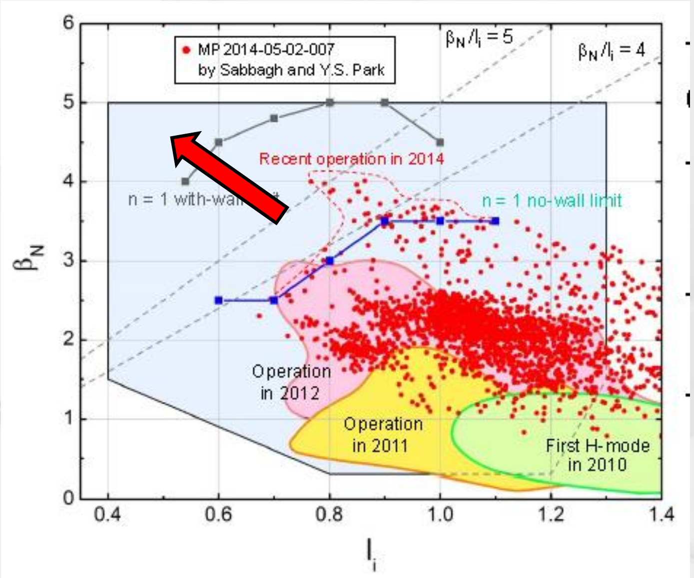
KSTAR PFC & Plasma Discharge

- **Reach extreme operation range without external error field correction**
  - **High β_N > 4.0, li ~ 0.8,** B_T=0.9 T, Ip=0.4 MA (#10313)
  - **Low q_{95} < 2.1, li ~ 0.6**, Ip=0.6 MA (#10549)
  - **Planned System Upgrade for Advanced Research**

  → Off-axis Neutral Beam Injection (NBI-2)

  → Real-time Profile & Stability Control (NTM, RWM)

  → Advanced Diagnostics (ECEI, CES, BES, MIR, MSE, Li-Zeeman, …)



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KSTAR is an unique device for the advanced research under low intrinsic error-field

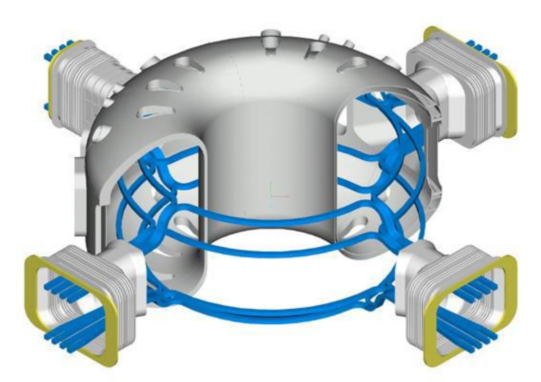
- **Lowest intrinsic error-field and TF-ripple compared to present-day tokamaks**
  - **$\delta B_{m/n=2/1} / B_0 \leq 10^{-5}$** (#9940, 10010, 10087, 10112)
  - **TF ripple at edge ~ 5 x 10^{-4}**
  - **How to get the low intrinsic error field**

  → Analyze and control the CS/PF coil terminals allocation to minimize n=1 & 2 error (∠PF1L /1U ~ 90^0)

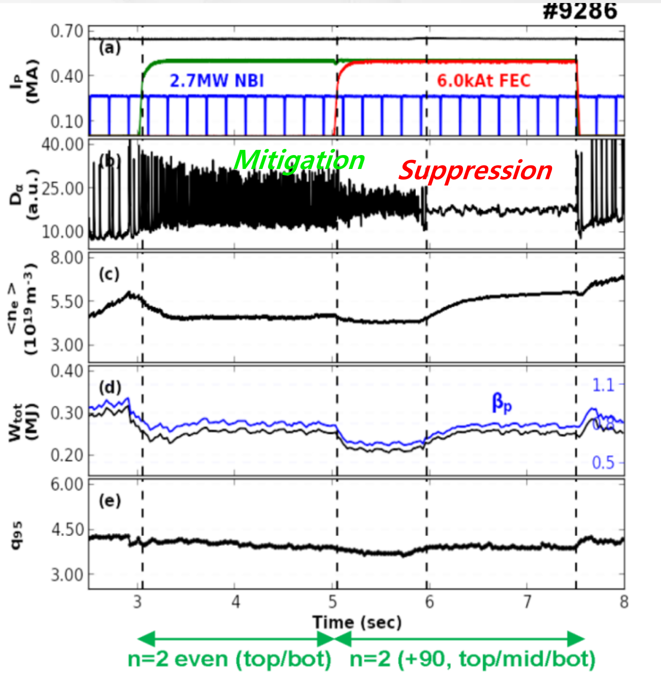
  → Accurate dimension control in magnet assembly

  → Control magnetic permeability in VV welding

- **Outstanding 3D-field research capability using in-vessel control coils & low error-field**
  - **Coils for error-field source instead of correction**
  - ELM suppression at n=1, n=2, and mixed
  - Mixed error field perturbation (3 poloidal row)
  - Dynamic error field correction (DEFC)
  - NTV rotation control
  - RWM stabilization



KSTAR In-vessel Coil System



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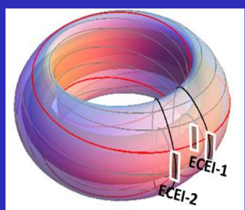
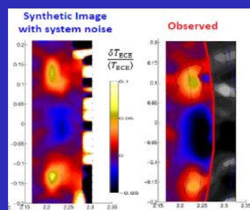
Korean Basic Fusion R&D Programs

Fusion Plasma Stability and Confinement Research Center

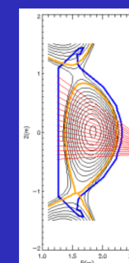
UNIST (POSTECH, PU)

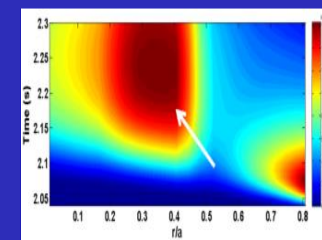




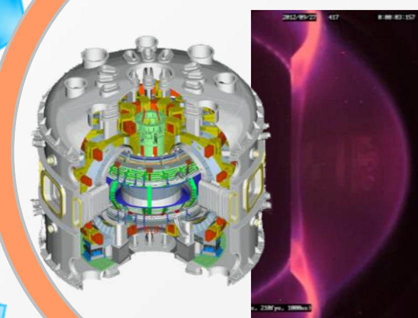
Impurity and Edge Research Center

KAIST (HYU, SNU)



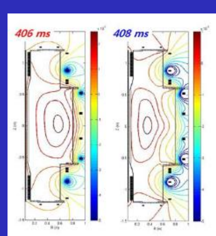


KSTAR



Center for Advanced Tokamak Study

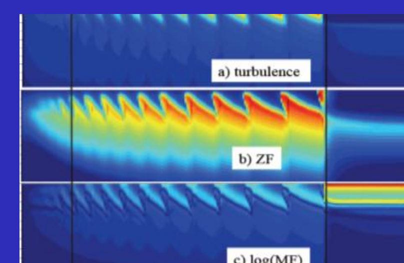
SNU (KAERI)



Universities & Research Institutes

Center for Fusion Theory

WCI (NFRI)



UNIST POSTECH POHANG UNIVERSITY OF SCIENCE AND TECHNOLOGY SEOUL NATIONAL UNIVERSITY KAIST KAERI UST WCI

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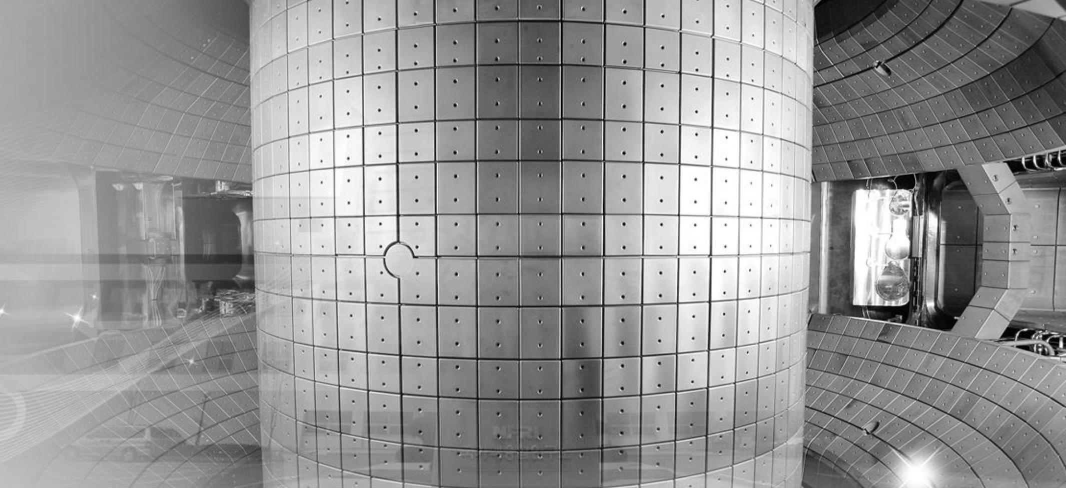


ITER KO-DA Project

KO In-kind Contribution to ITER Project

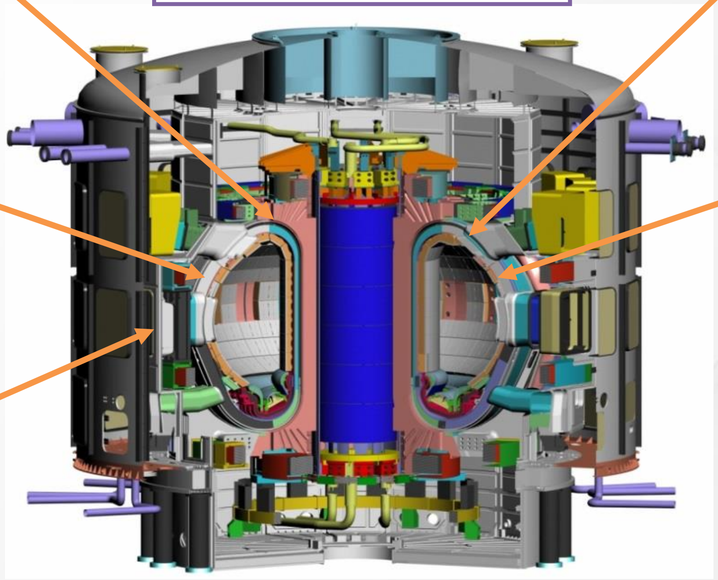
1. TF Conductor
Total Value (kIUA) : 215.01
KO Allocation : 20.18%
KO Contribution (kIUA) : 43.39

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

2. Vacuum Vessel Main Body
Total Value(kIUA) : 123.04
KO Allocation : 21.29%
KO Contribution (kIUA) : 26.20

5. Blanket Shield Block
Total Value(kIUA) : 58.00
KO Allocation : 49.82%
KO Contribution(kIUA): 28.07



3. Vacuum Vessel Port
Total Value(kIUA) : 76.96
KO Allocation : 72.74%
KO Contribution (kIUA) : 55.98

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

7. Tritium SDS
Total Value(kIUA) : 15.36
KO Allocation : 81.25%
KO Contribution(kIUA) : 12.48

8. AC/DC Converters
Total Value(kIUA) : 123.58
KO Allocation : 37.27%
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) : 143.74
KO Allocation : 3.13%
KO Contribution (kIUA) : 4.49

* TBMA (TBM Agreement) was signed in 2014
Total Value : 270.55 kIUA

Leading Items | Tokamak Main | Ancillary

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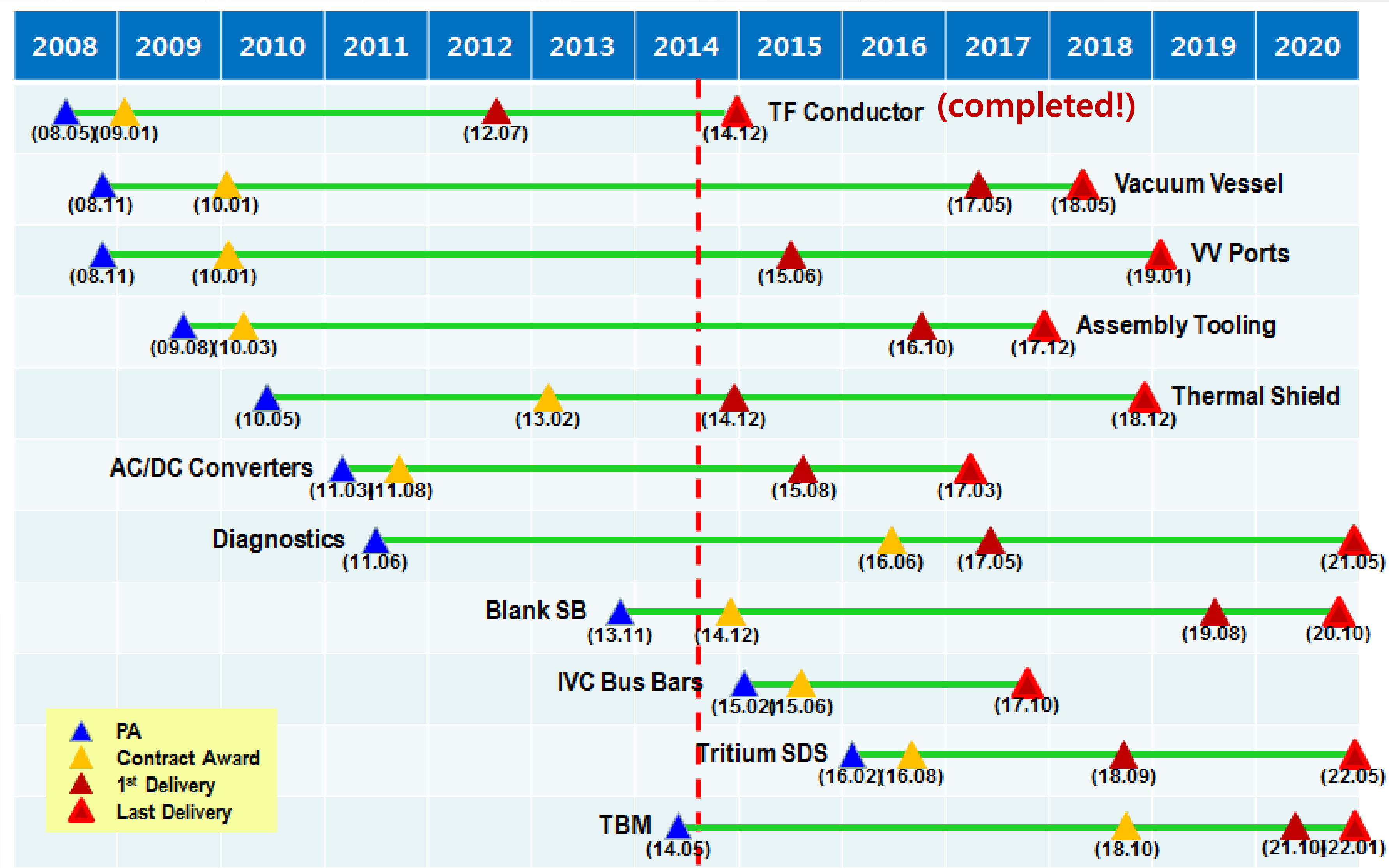
Progress of KO In-kind Contribution



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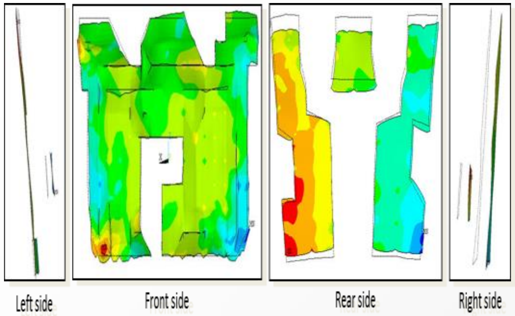
ITER Procurement Activities of Korea

TF-conductor Delivery

VVMV Fabrication

VV Port Fabrication

Blanket Shield Block



TS Prototype

AT Mock-up Test

Tritium DU Bed

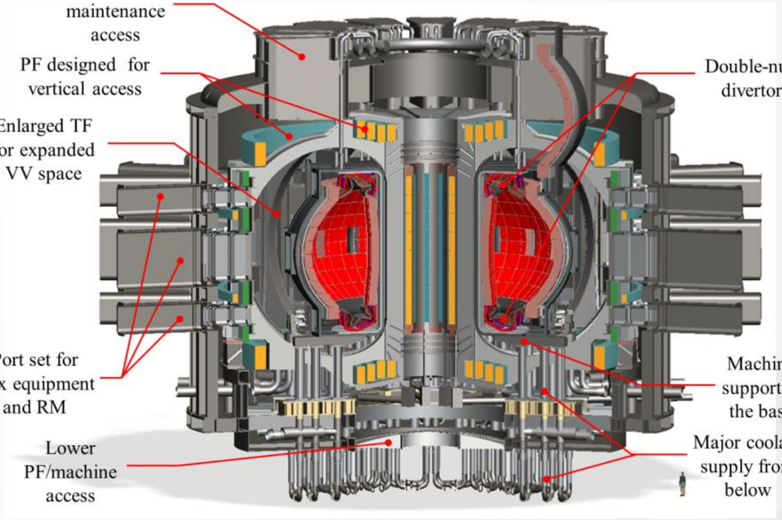
AC/DC Converter

VUV Prototype Test

K-DEMO Program

K-DEMO Program Outline

- **Based on the Fusion Energy Development Promotion Law (FEDPL, 2007).**
- **Pre-conceptual Design Study for the K-DEMO was initiated in 2012.**
- **Pre-conceptual Design based on Option-II of K-DEMO (main parameters)**
- **Operation of K-DEMO in two-phases.**
  - Phase-1 is for facility for components & material test and operation
  - Phase-2 is to demonstrate the competitiveness in Cost of Electricity (COE)



Basic Parameter	Option I	**Option II**	Option III
Major Radius	6.0 m	**6.8 m**	7.3 m
Minor Radius	1.8 m	**2.1 m**	2.2 m
Elongation (k)		**2.0**	
Magnetic Field (B_o)		**7.4 Tesla**	
Peak Field		**~16 Tesla**	
Divertor Type		**Double Null**	
Plasma Current	> 10 MA	**> 12 MA**	> 13 MA
Fusion Power (MW)	1500~2000	**2200~3000**	2700~3500
Net Elec. Power (MWe)	130~200	**400~700**	550~900

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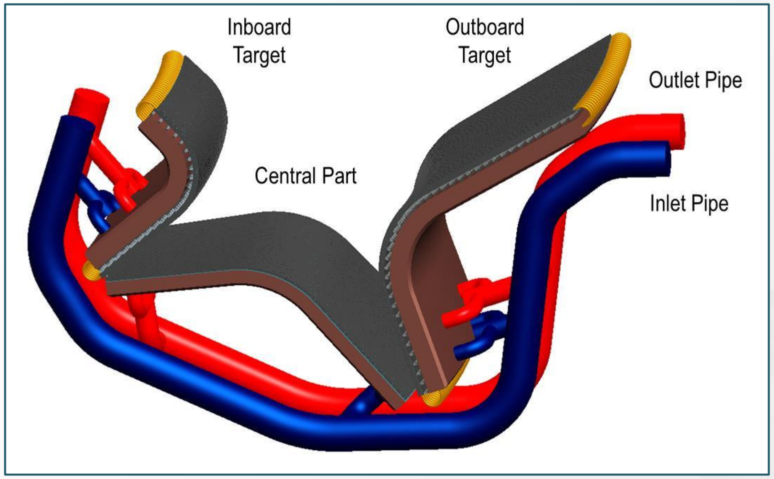
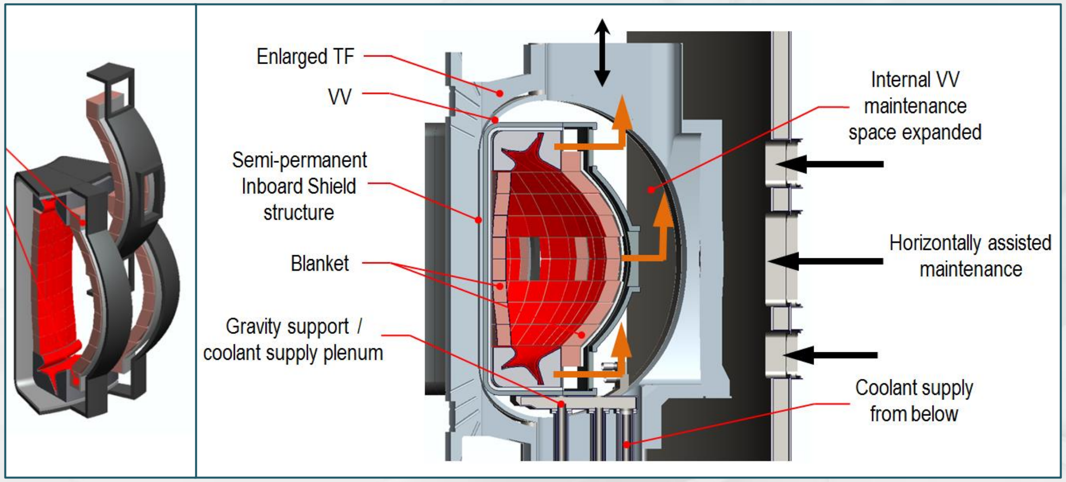
Pre-conceptual Design of In-vessel Components of K-DEMO

- **Divertor Design**
  - Analysis on nuclear heating and thermo-hydraulics using MCMP neutronics analysis (“Tokamak” 45 degree)
  - Confirmation of pressurized water reactor (PWR)-like coolant compatibility Tungsten Monoblock (~ 10.4 MW/m^3) RAFM Back-plate (~ 0.78 MW/m^3).
- **Blanket Design**
  - Global TBR of ~1.0 has been achieved using the mixed pebble type Li_4SiO_4 and $Be_{12}Ti$ (Design Value)
- **Maintenance of In-vessel Components**
  - Horizontally assisted Vertical maintenance through enlarged VV top vertical port





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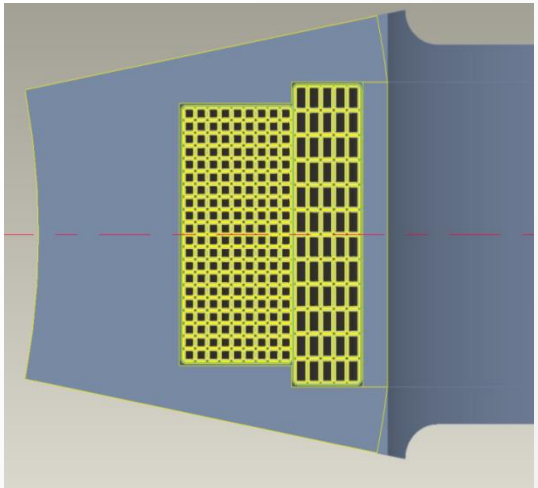
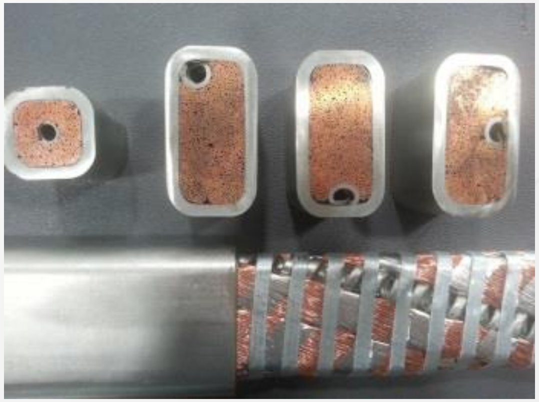
Design and Sample Conductor R&D of K-DEMO Superconducting Magnets

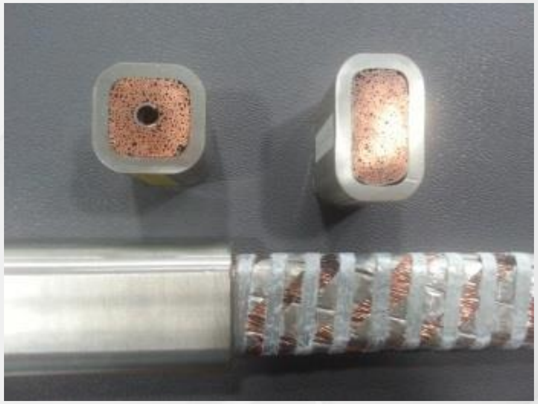
- **TF Winding Design :**
  - Two types of cable-in-conduit (CIC) conductor : small & large TF CICCs.
  - I_{TF} ~ 65.5 kA, B_T ~ 7.4 T, B_{peak} ~ 16 T, T_{margin} > 1 K
- **Sample Conductor for TF, CS, and PF Magnets were fabricated.**
  - Small TF, large TF, CS and PF 1-4 (Nb3Sn), PF5-6 (NbTi)



TF-winding with two kinds of CICC cross sections



Small & Large TF CICC
Small CICC : Central Channel
Large CICC : Helical Channel



PF & CS CICC
PF CICC : Central Channel
CS CICC : Corner Channel

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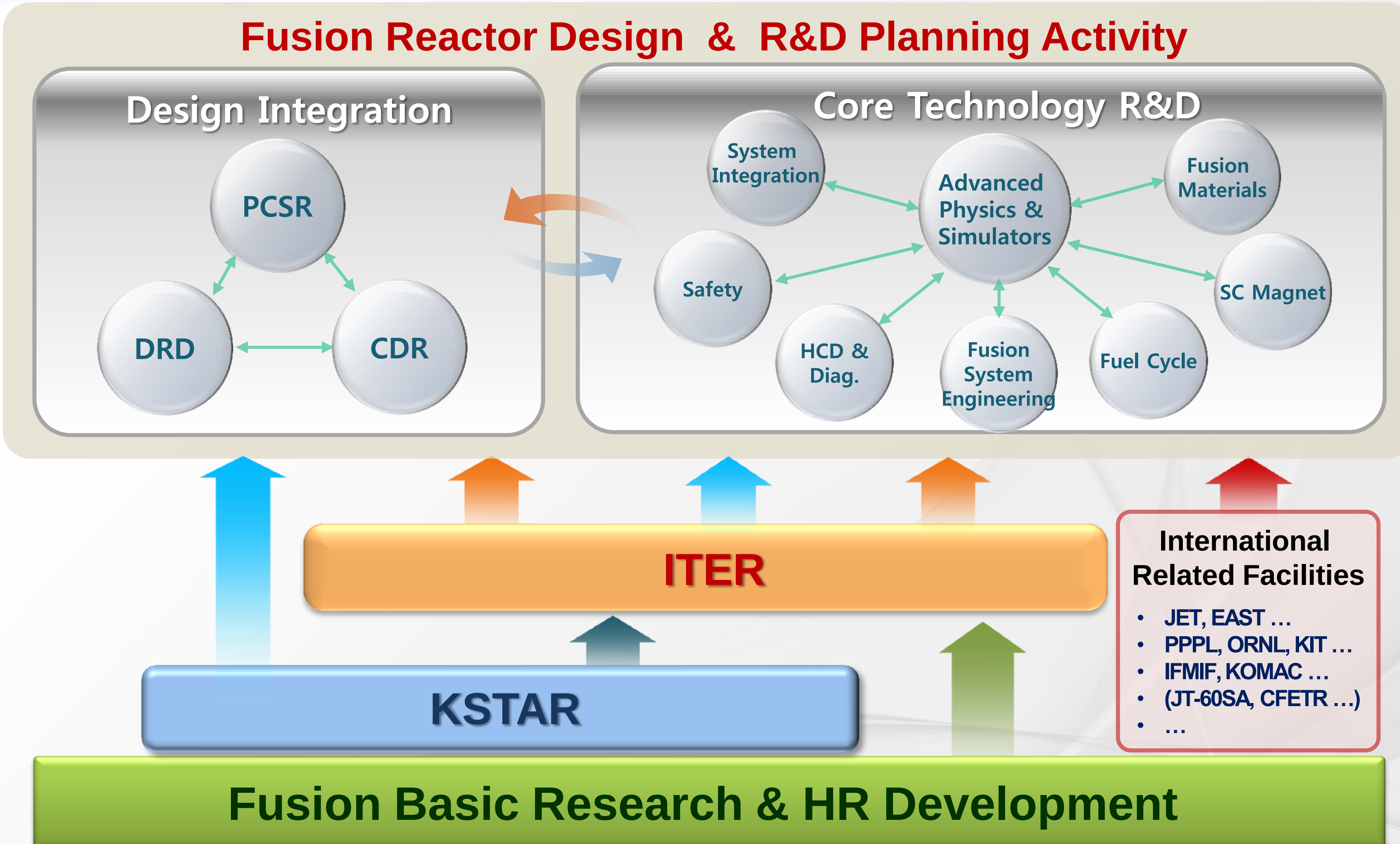
R&D for K-DEMO Reactor Technology



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K-DEMO Core Technology Development Plan

Development of Core Technology

- 3 Major Research Fields, 7 Core Technologies, 18 Detail Technologies and 6 Major Research Facilities
- Through the complete technical planning process with the full participation of experts from all fields covering fusion, fission, physics, computing, mechanics, material, electrics, electronics, and so on.

K-DEMO 3 Major Research Fields	K-DEMO 7 Core Technologies	Major Research Facilities
Design Basis Technology	Tokamak Core Plasma Technology	• Extreme Scale Simulation Center
	Reactor System Integration Technology	
	Safety and Licensing Technology	
Material Basis Technology	Fusion Materials Technology	• Fusion Materials Development Center • Fusion Neutron Irradiation Test Facility • SC Conductor Test Facility
	SC Magnet Technology	
Machine and System Engineering Basis Technology	H&CD and Diagnostics Technology	• Blanket Test Facility • PMI Test Facility
	Heat Retrieval System Technology	

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The 12th International Symposium on Fusion Nuclear Technology

September 14 (Mon) - 18 (Fri), 2015
Jeju Island, KOREA

★ **Website : www.isfnt-12.org**