FUSION, Future Vision of Green Energy

Fusion Energy Research and Development in “ITER Era”

- A Korean Perspective

Gyung-Su LEE
National Fusion Research Institute

NFRI 국가핵융합연구소 National Fusion Research Institute part

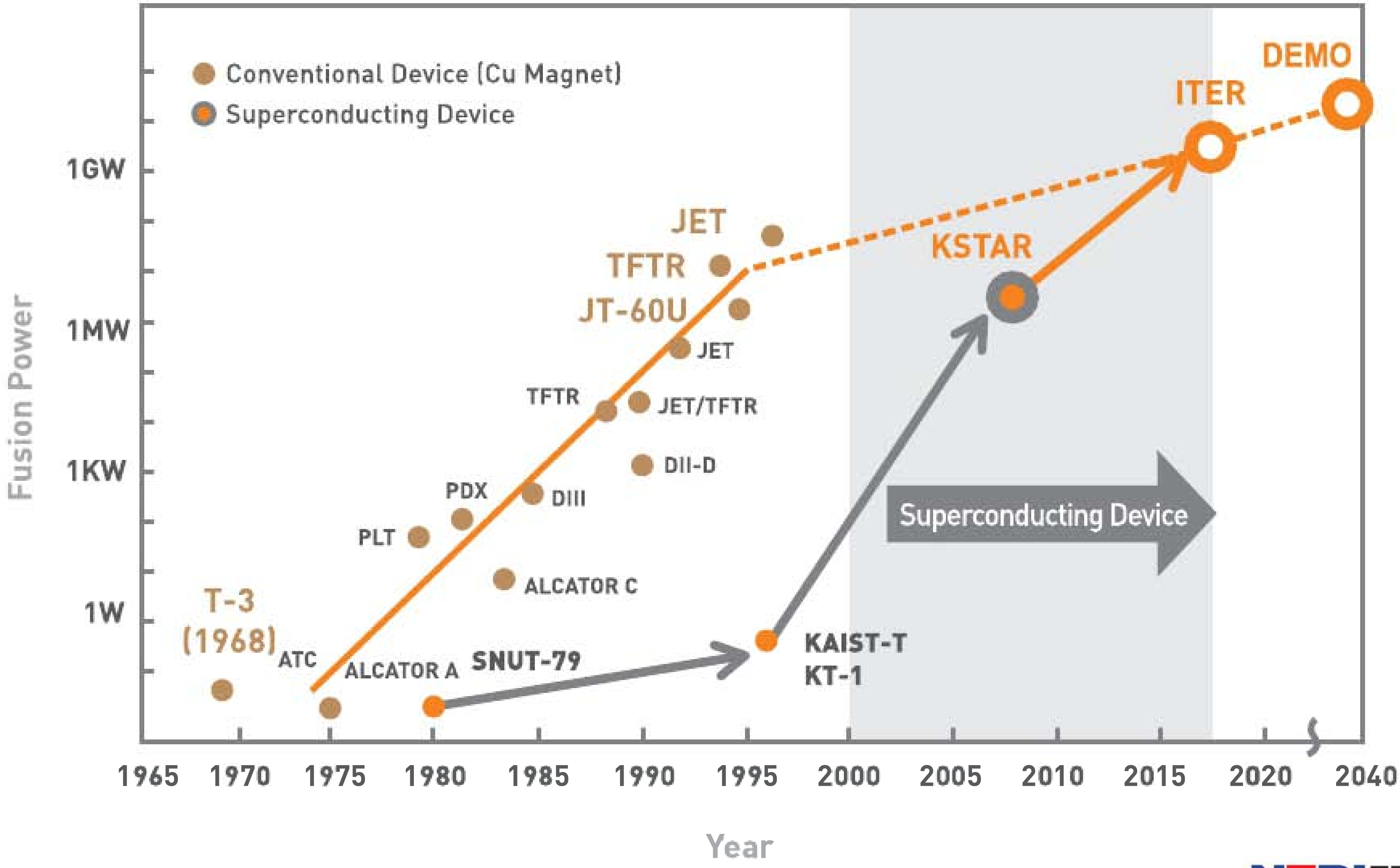
1

National Fusion Research Institute

Past and Present : KSTAR

국가핵융합연구소
National Fusion Research institute

Initiation of KSTAR Project based on "Mid-Entry Strategy"



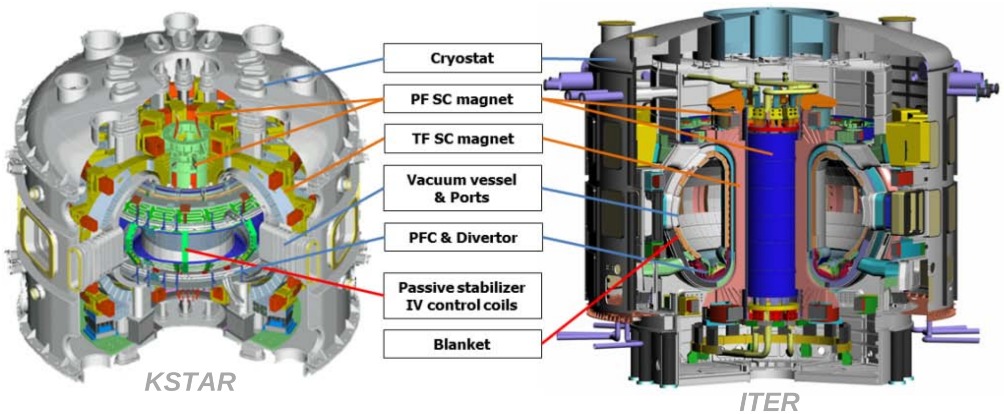
Establishment of National Fusion Research Center

Opening Ceremony of National Fusion Research Center in January 1996

KSTAR Project Mission and Parameters

❖ KSTAR Mission

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



PARAMETERS	Designed	2010 Op
Major radius, R_0	1.8 m	1.8 m
Minor radius, a	0.5 m	0.5 m
Elongation, κ	2.0	2.0
Triangularity, δ	0.8	0.8
Plasma volume	17.8 m^3	17.8 m^3
Bootstrap Current, f_{bs}	> 0.7	-
PFC Materials	C, CFC (W)	C
Plasma shape	DN, SN	DN, *SN*
Plasma current, I_P	2.0 MA	0.5 MA
Toroidal field, B_0	3.5 T	3.5 T
Pulse length	300 s	5 s
β_N	5.0	1.0
Plasma fuel	H, D	D
Superconductor	Nb_3Sn, NbTi	Nb_3Sn, NbTi
Auxiliary heating /CD	~ 28 MW	2.0 MW

Technology Development of entire process of KSTAR from Concept Design to Commissioning!

June 2008
First Plasma

2002 - 2007
Construction of KSTAR

1998 - 2001
Engineering Design and Facility Construction

1996 - 1997
Basic Design and R&D

1995
Launch of KSTAR Project

National Fusion Research Institute

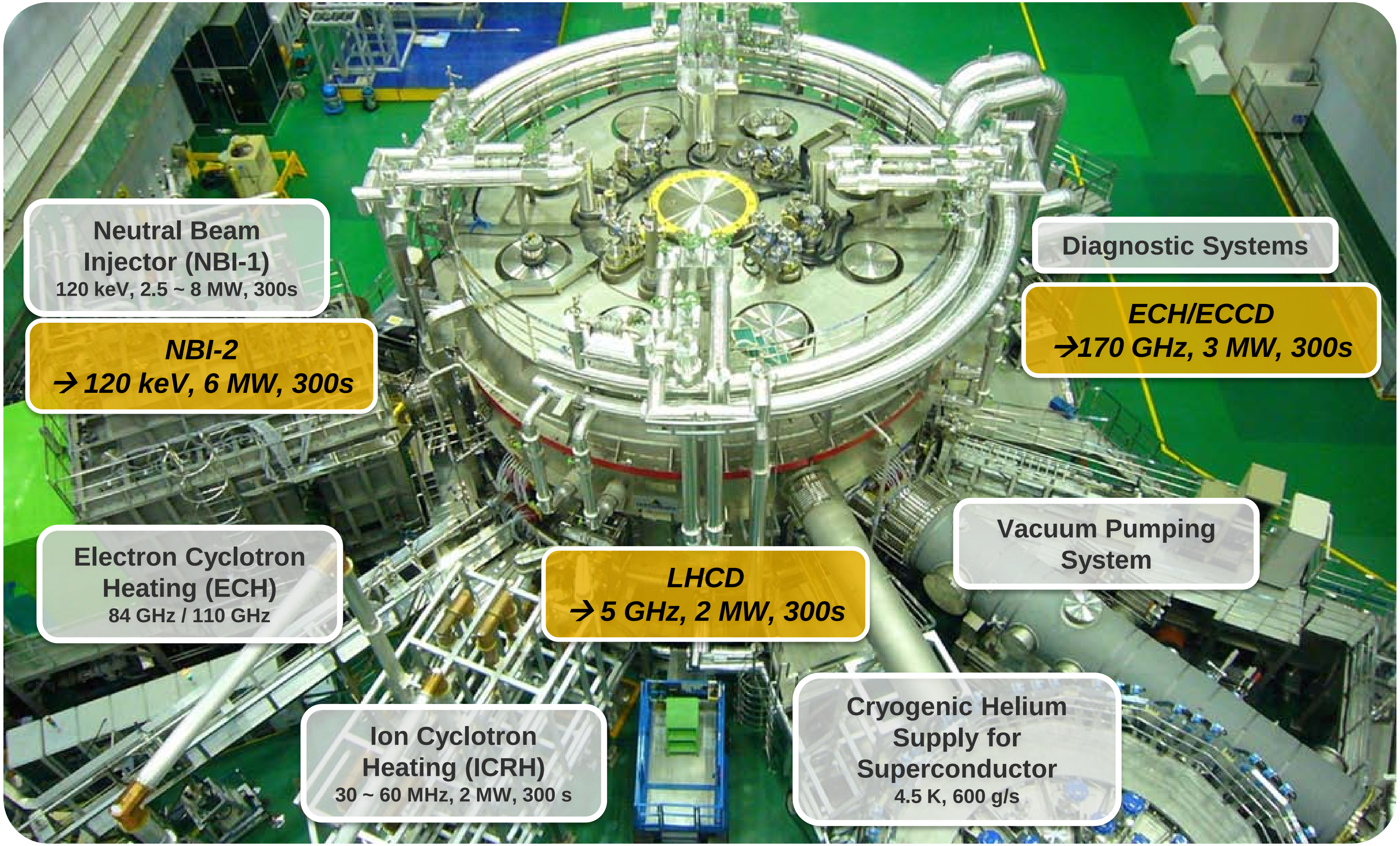
Success of KSTAR is based on dedication and Technological Advancements of Korean Industries!

HYUNDAI
SAMSUNG 삼성전자
DOOSAN 두산중공업
DAEWOO E&C CO., LTD.
poscon
GS 건설
KOPEC
대우건설
SONGWON EDWARDS LTD. BOC EDWARDS 성원에드워드주식회사
(주)성도 이엔지
PHILOSOPHIA
하늘엔지니어링
주식회사 한라이비텍
SeAH SeAH Steel Corp.
SFA SFA ENGINEERING CORP.
HANYANG ENG
Wonshin
금강기전
SAMSUNG 삼성중공업
SAMSUNG 삼성SDS
Kiswire
COMTECS
SAMYOUNG
KoSPI
GENESIS Technologies Inc.
3RLab
SA SINCE 2000

- **1,510 Participants from 69 Companies**

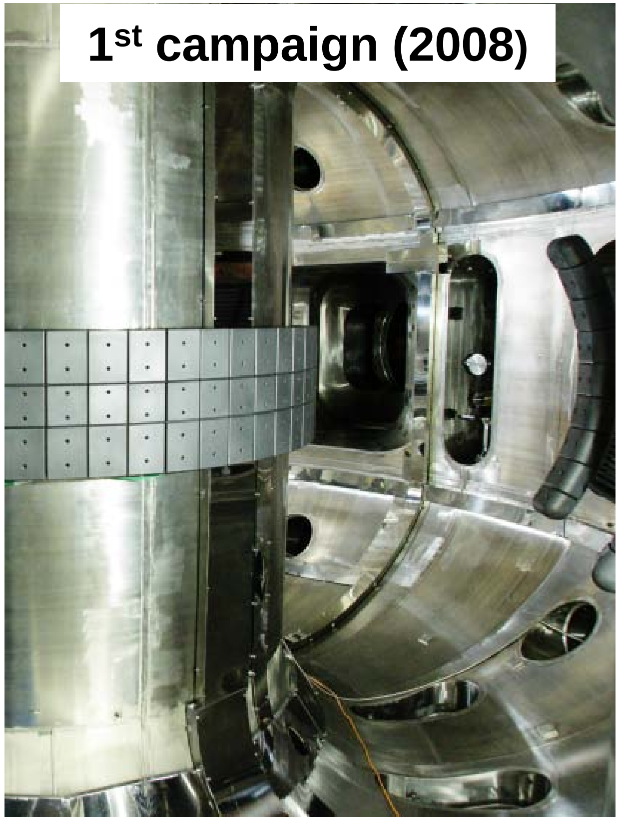
Panoramic View of KSTAR Experimental Hall

Ancillary Systems of KSTAR in 2010 & Upgrade

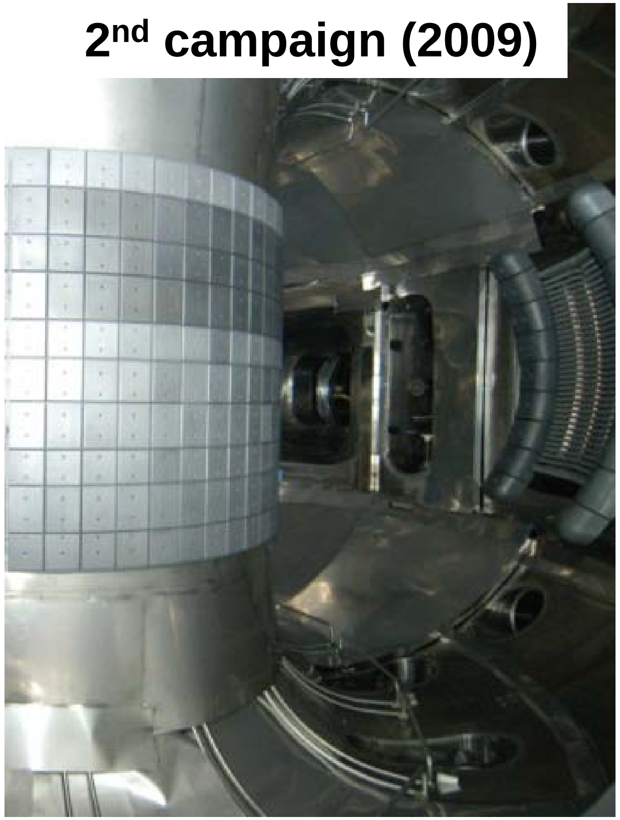


KSTAR In-Vessel System Upgrade

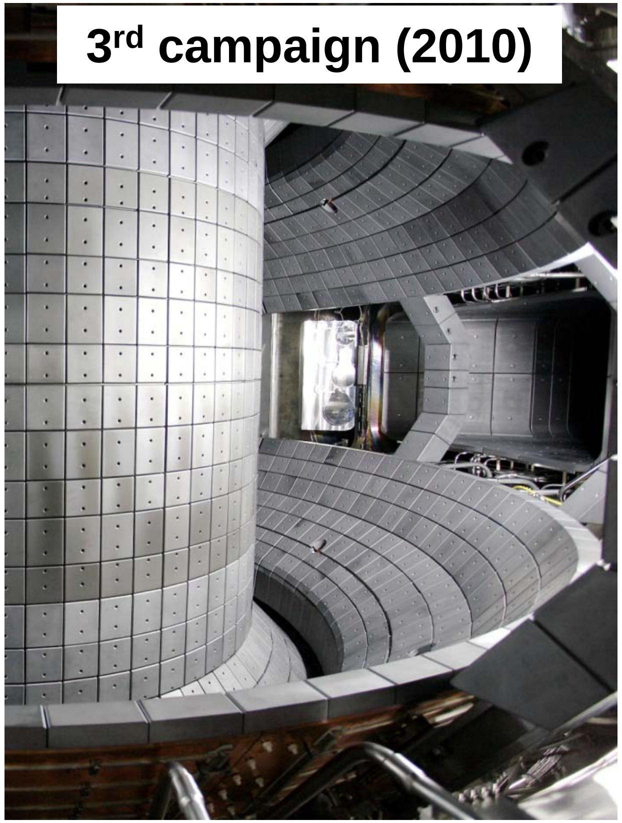
Whole in-vessel components were installed in 2010, including Divertors, In-vessel Coils, In-vessel Cryopumps, Passive Stabilizers, and In-board & Poloidal Limiters.



1^{st} campaign (2008)

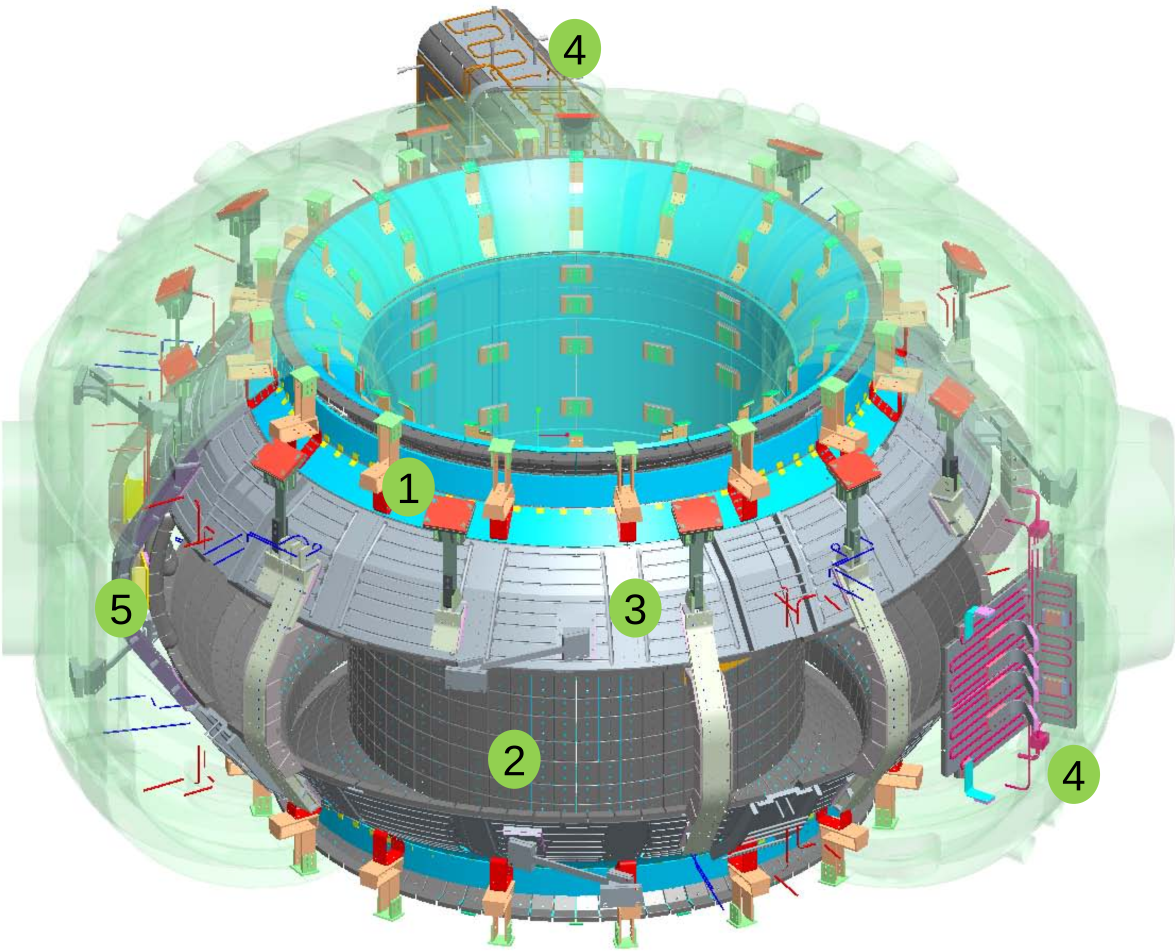


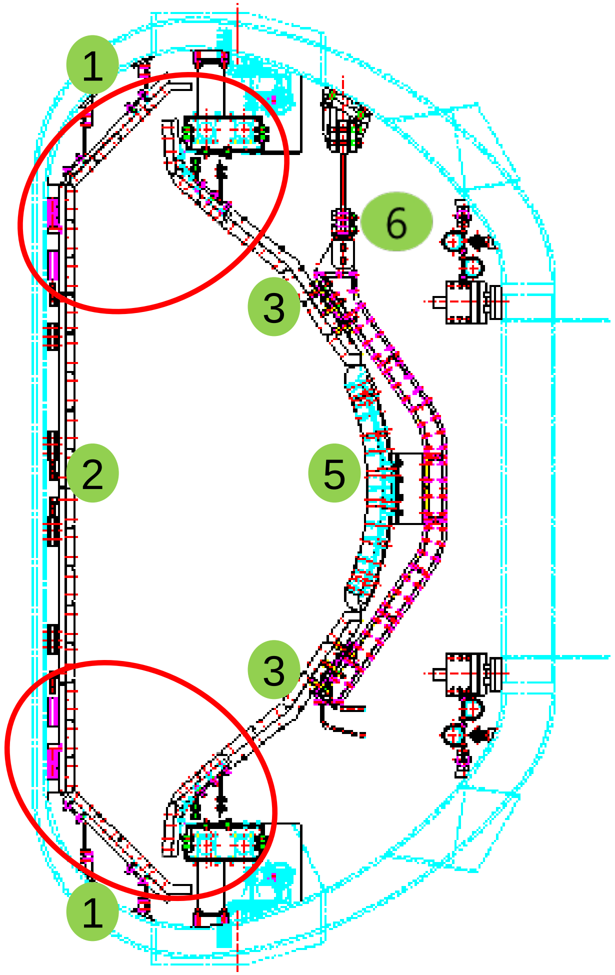
2^{nd} campaign (2009)



3^{rd} campaign (2010)

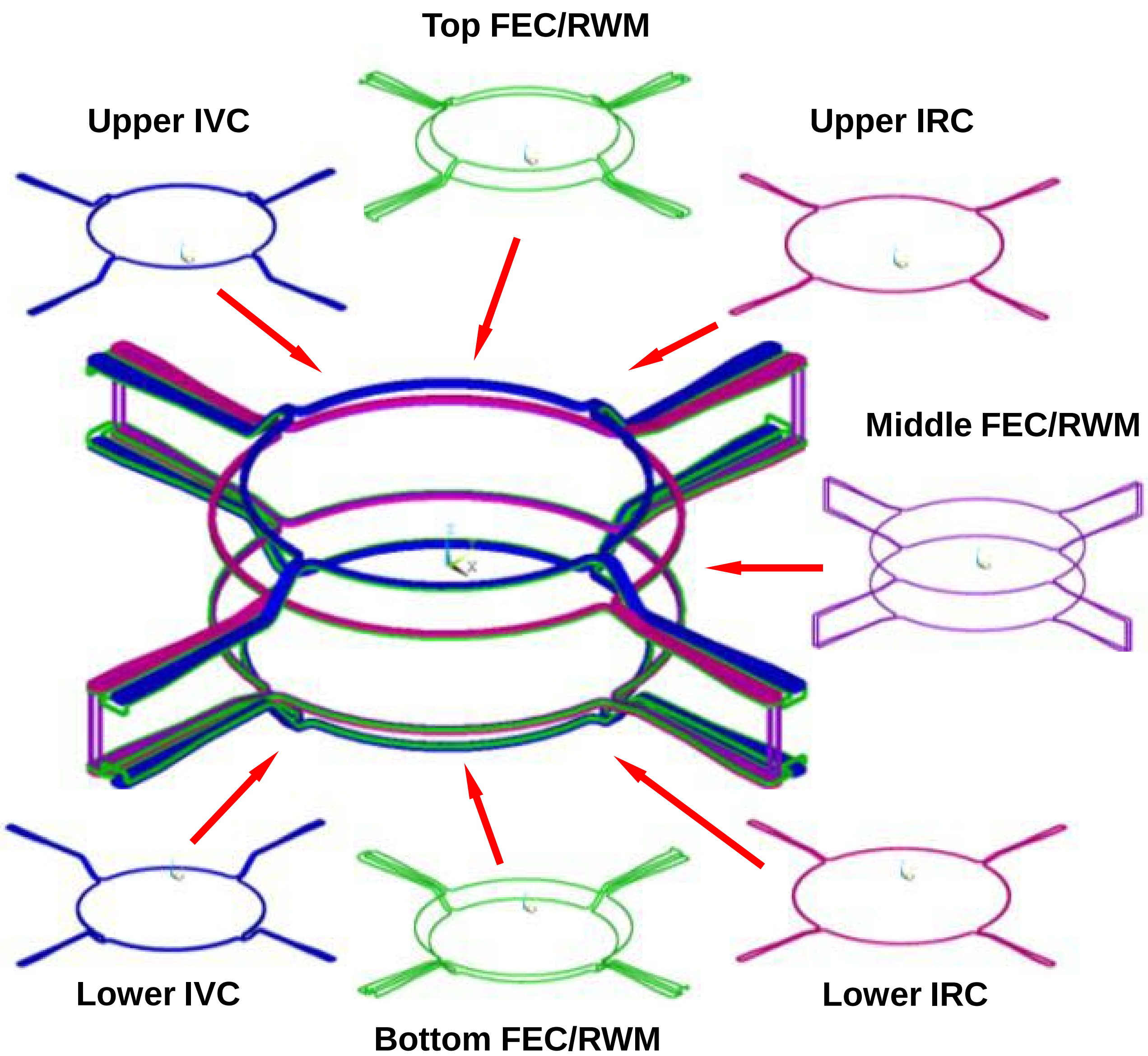
KSTAR In-Vessel System Design

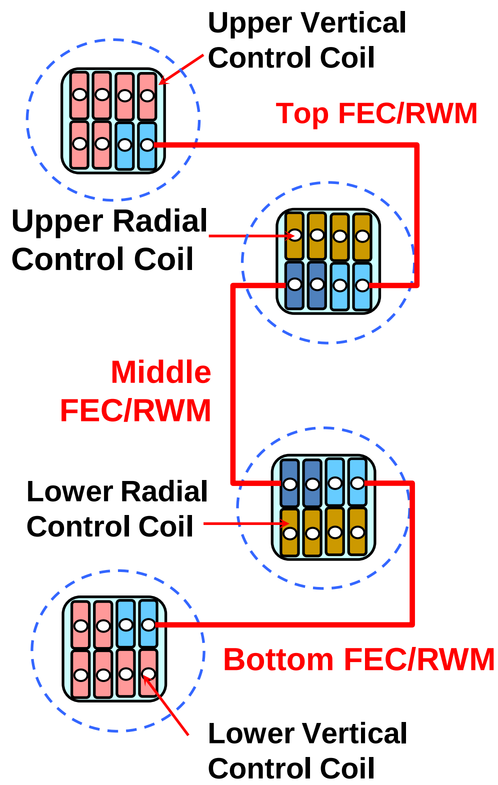




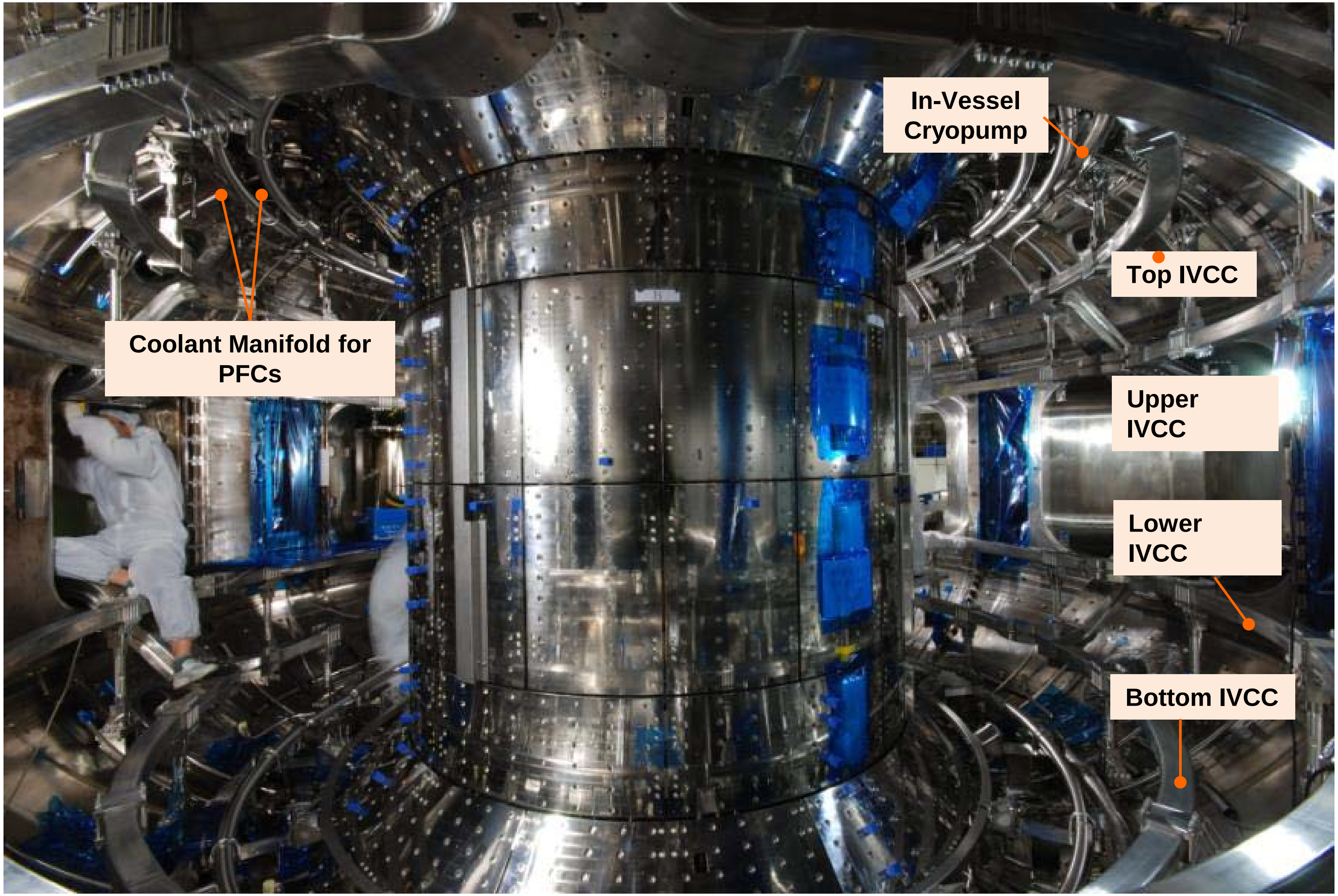
1 Divertor
2 Inboard Limiter
3 Passive Stabilizer
4 NB Armor
5 Poloidal Limiter
6 In-Vessel Control Coils

Segmented Coil Design of IVCC

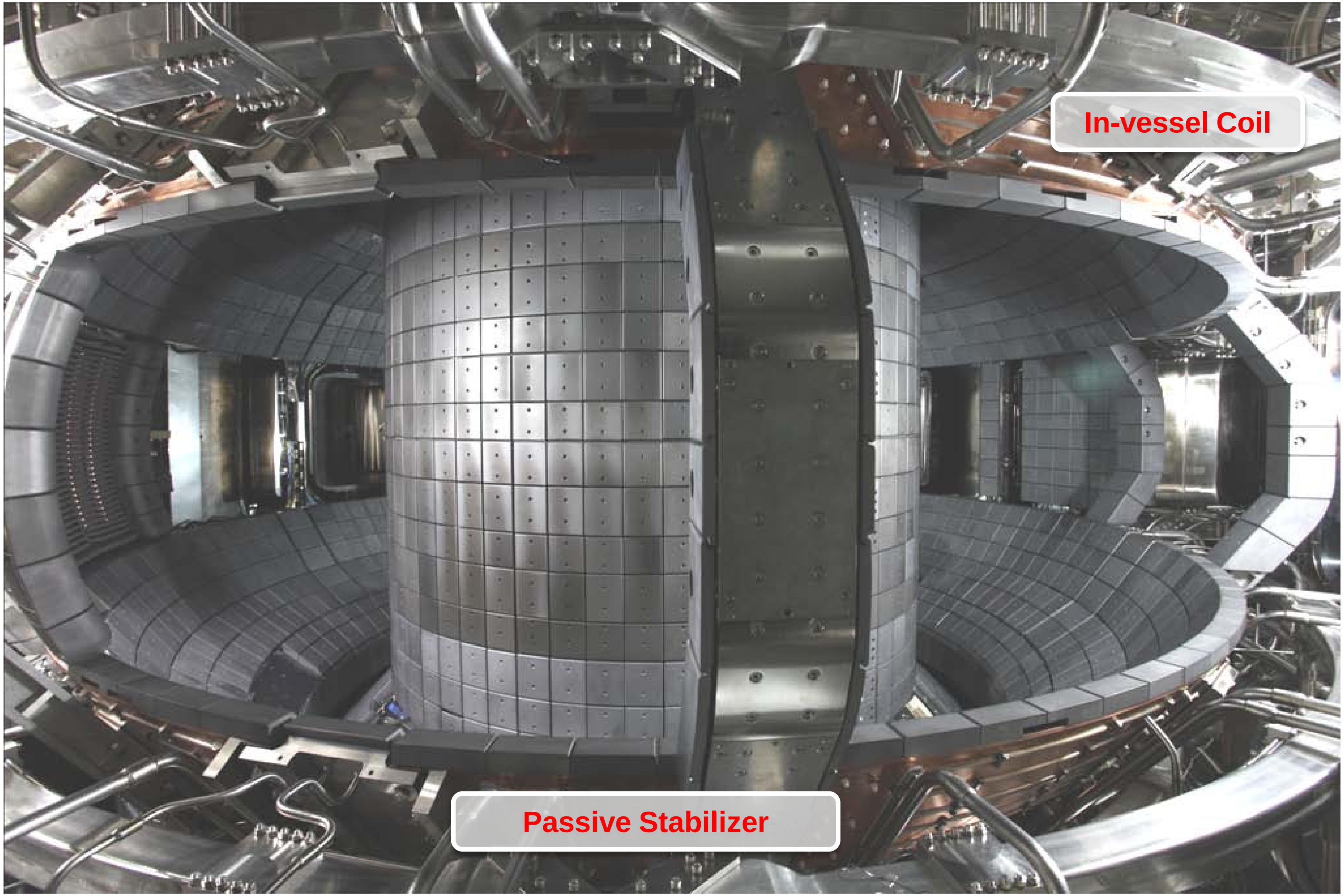




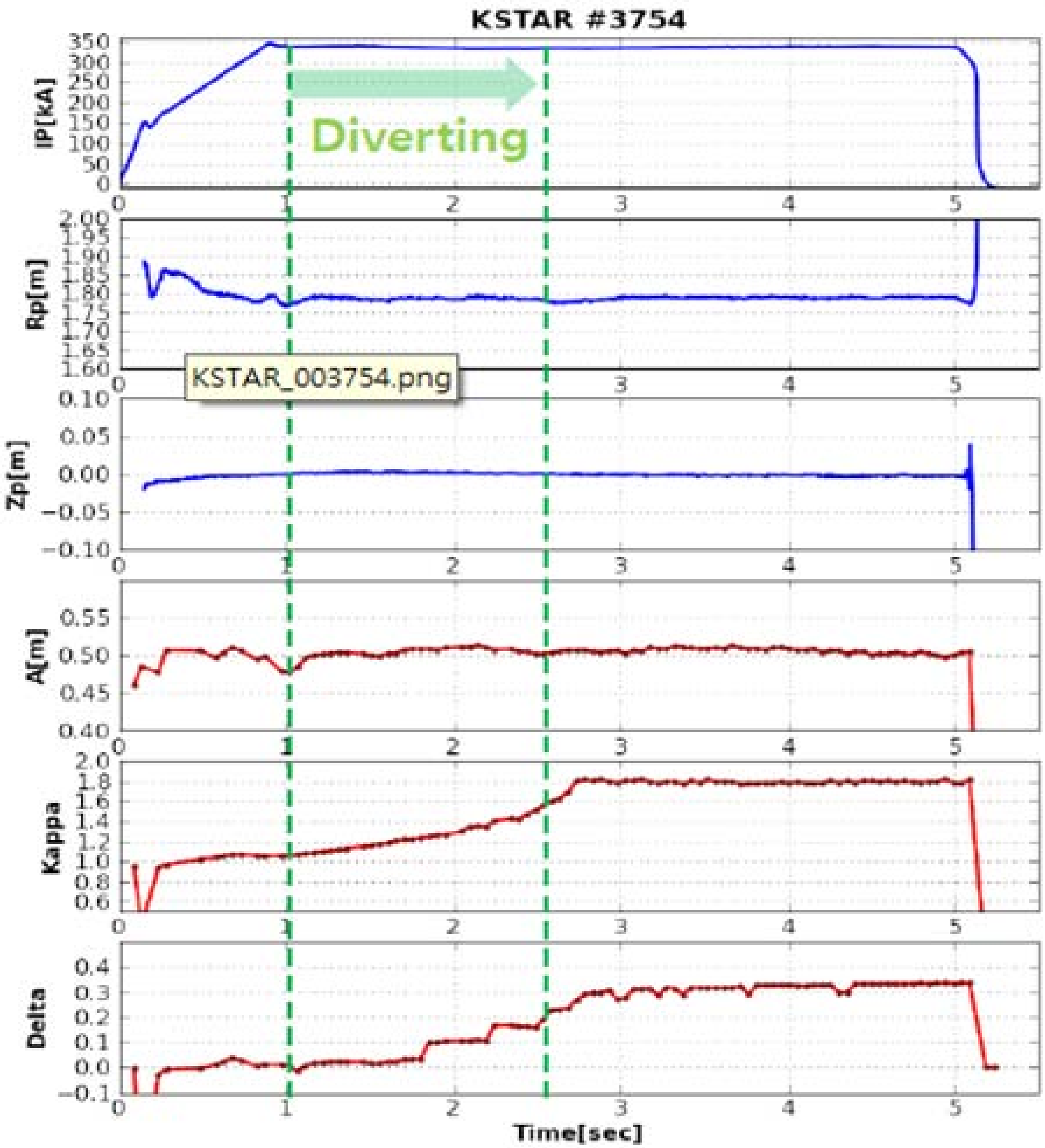
KSTAR In-Vessel System Installation



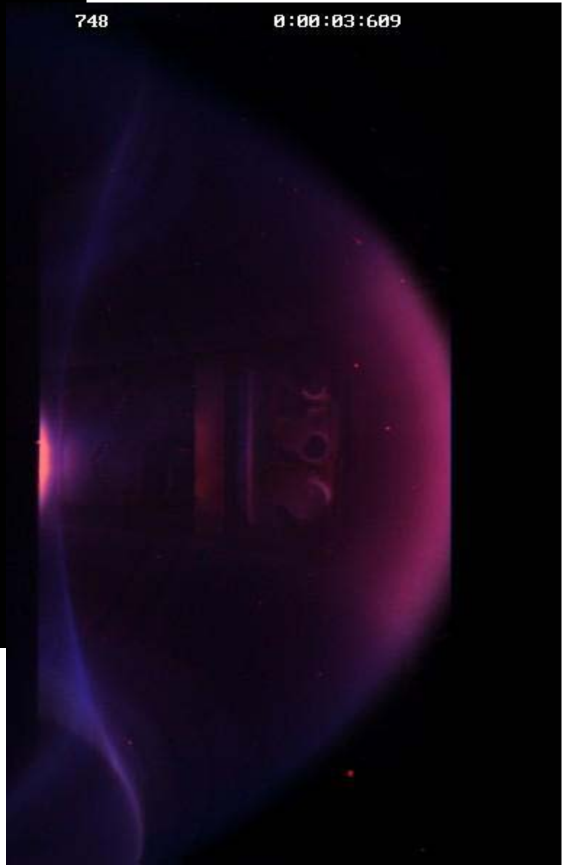
KSTAR In-Vessel Systems in 2010 Campaign



KSTAR D-shape Diverted Plasma



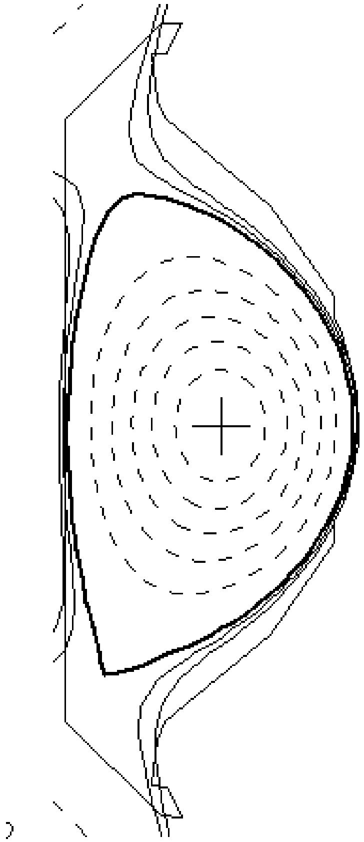
KSTAR #3766

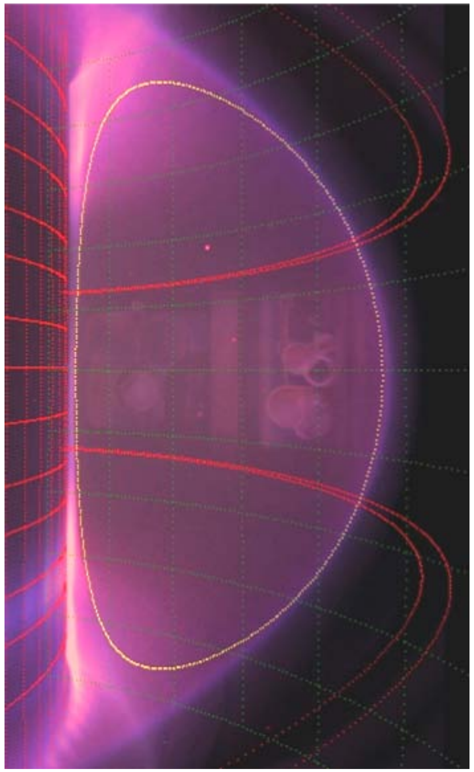


KSTAR Diverted H-mode Plasma

- Shaping Capability : Plasma Shaping with vertical instability control
- Heating : 1.2 MW NBI, 0.4 MW 110GHz ECH

- Wall Conditioning with full carbon PFC : Baking @ 200 C ,
- Intensive He Glow Discharge Cleaning, Boronization with Carborane

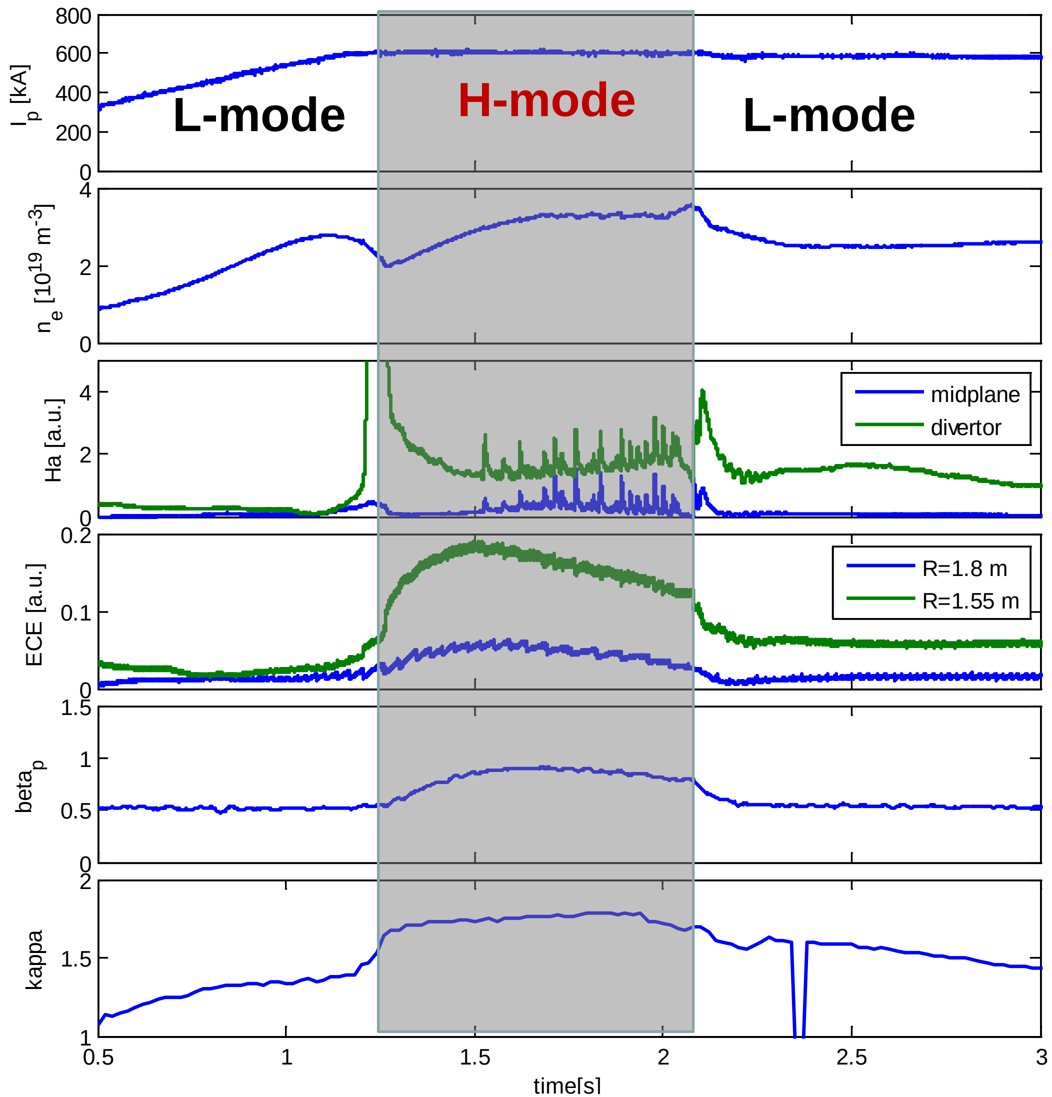




Shot #4333
kappa~1.7
delta~0.4
Rgap~3cm

- Slightly shifted to the lower divertor
- Ion ∇B is at lower divertor

Typical H-mode Discharge in KSTAR



Discharge #4333

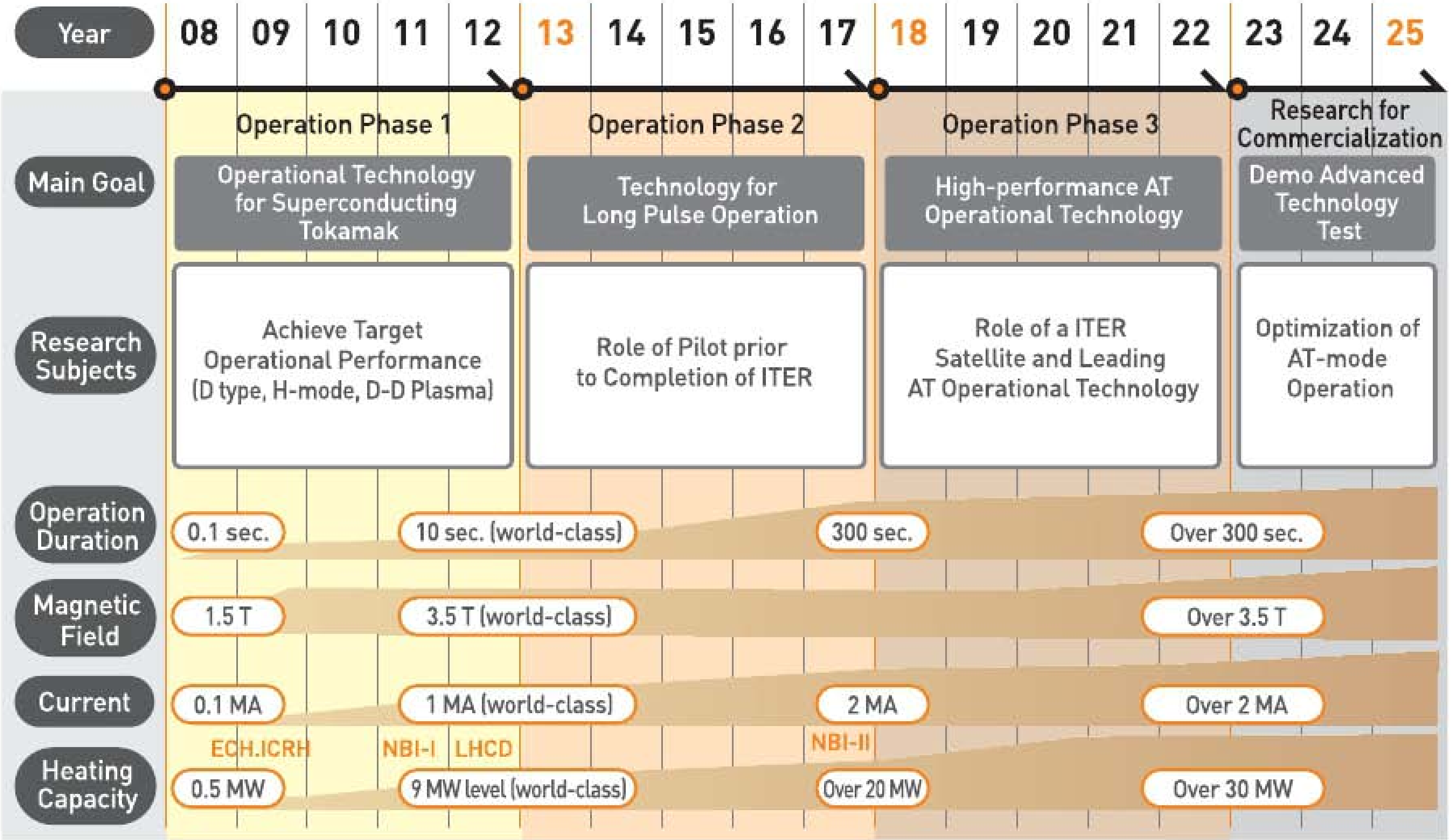
I_p~0.6 MA, N_e~2e19 m^{-3}
Double null, κ~1.8
B_T=2 T, R~1.8 m, a~0.5 m
Boronization with carborane

P_{NBI}~1 MW (80 keV, co-NBI)
P_{ECW}~0.25 MW (cntr - Ip)
P_{OH}~0.2 MW

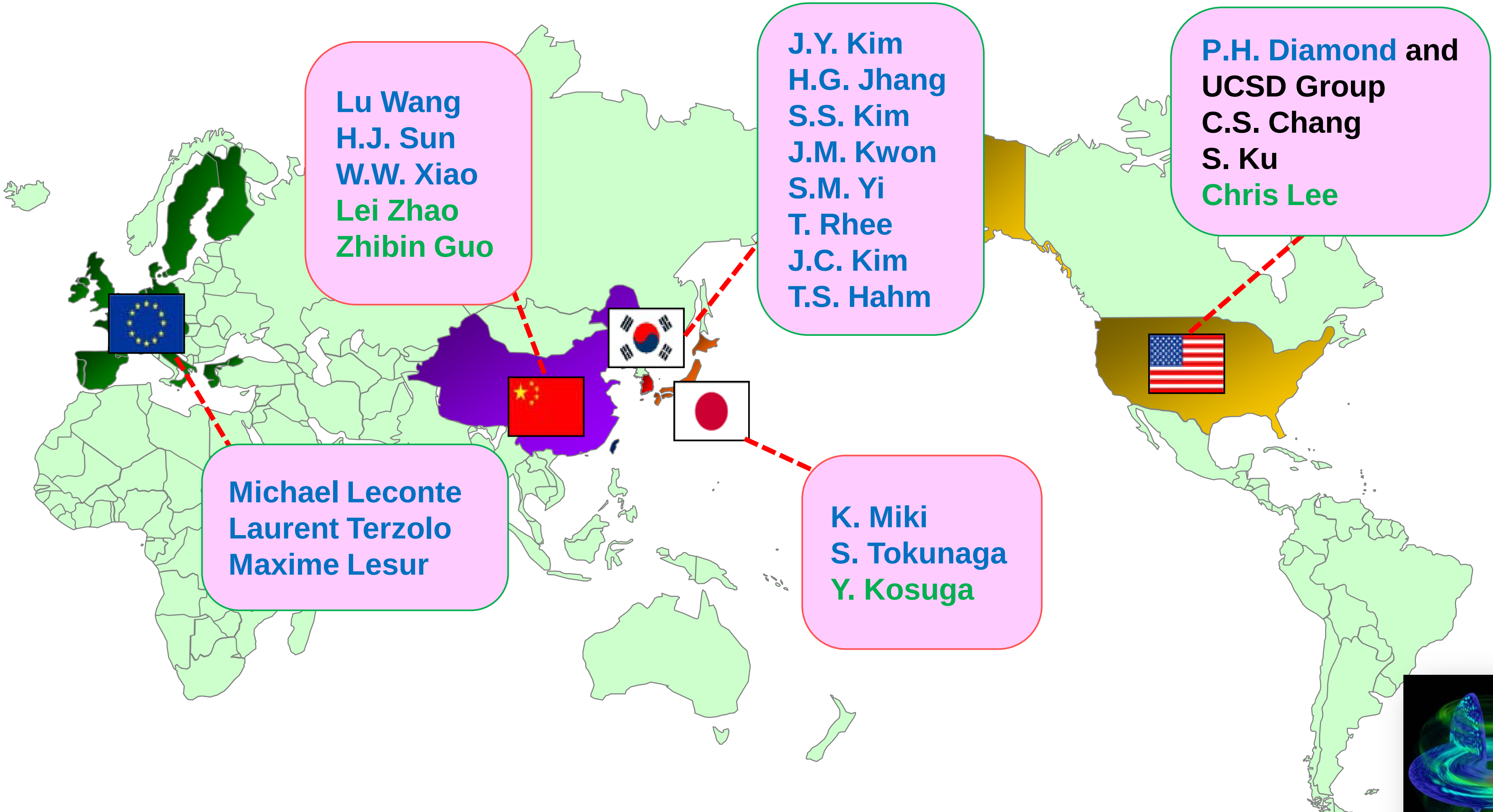
P_{thres} ~1.1 MW
(ITER Physics Basis, 1999)

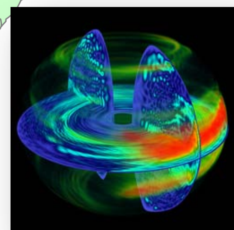
Type-I ELMs
sharp increase of edge ECE
80% increase of βp

Phased Operational and Experimental Plans for KSTAR



WCI Center for Fusion Theory and Simulation





* Goal : Large-scale Fusion Simulation and Fusion Informatics

part 2

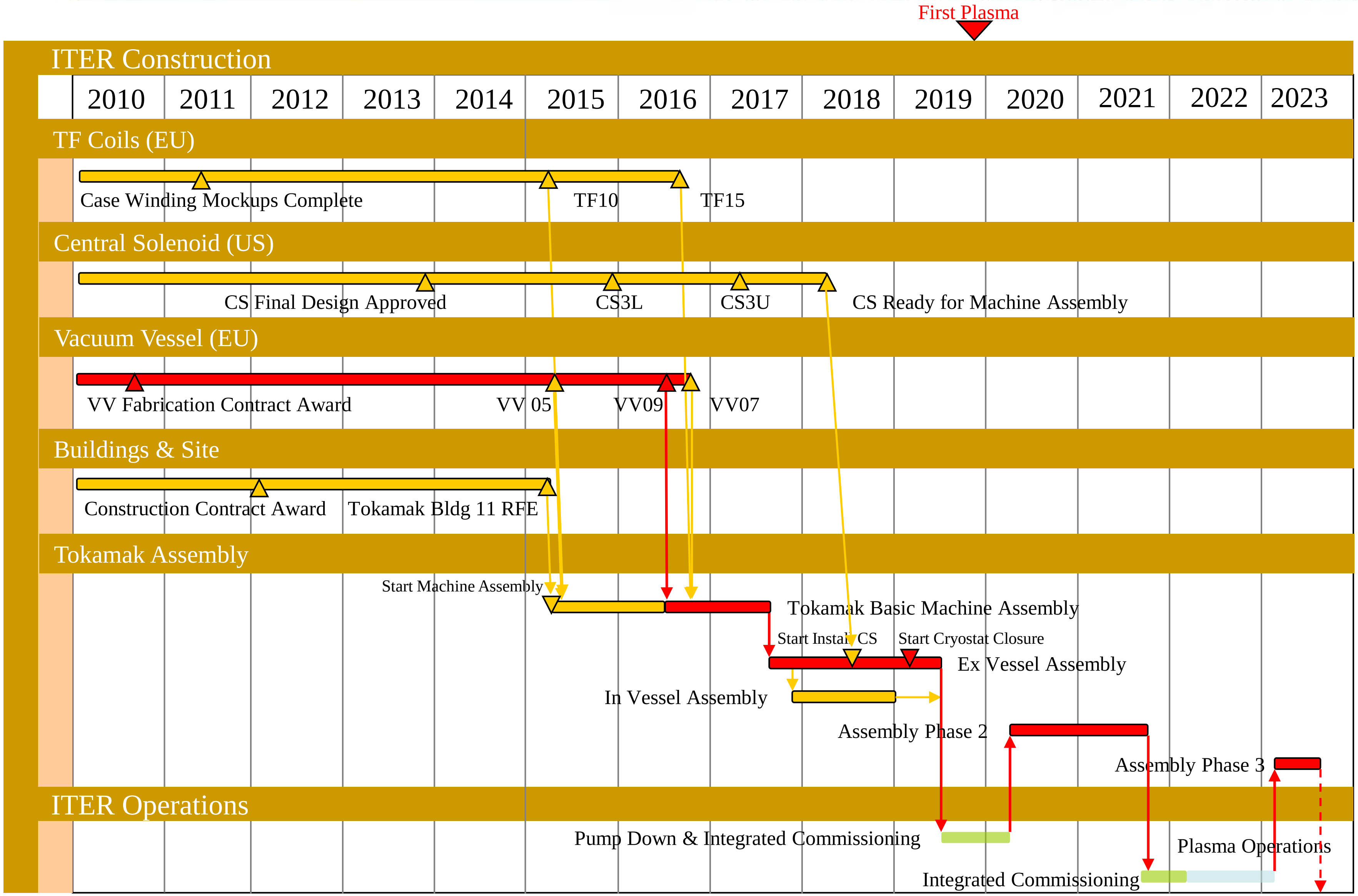
National Fusion Research Institute

Present and Future : ITER

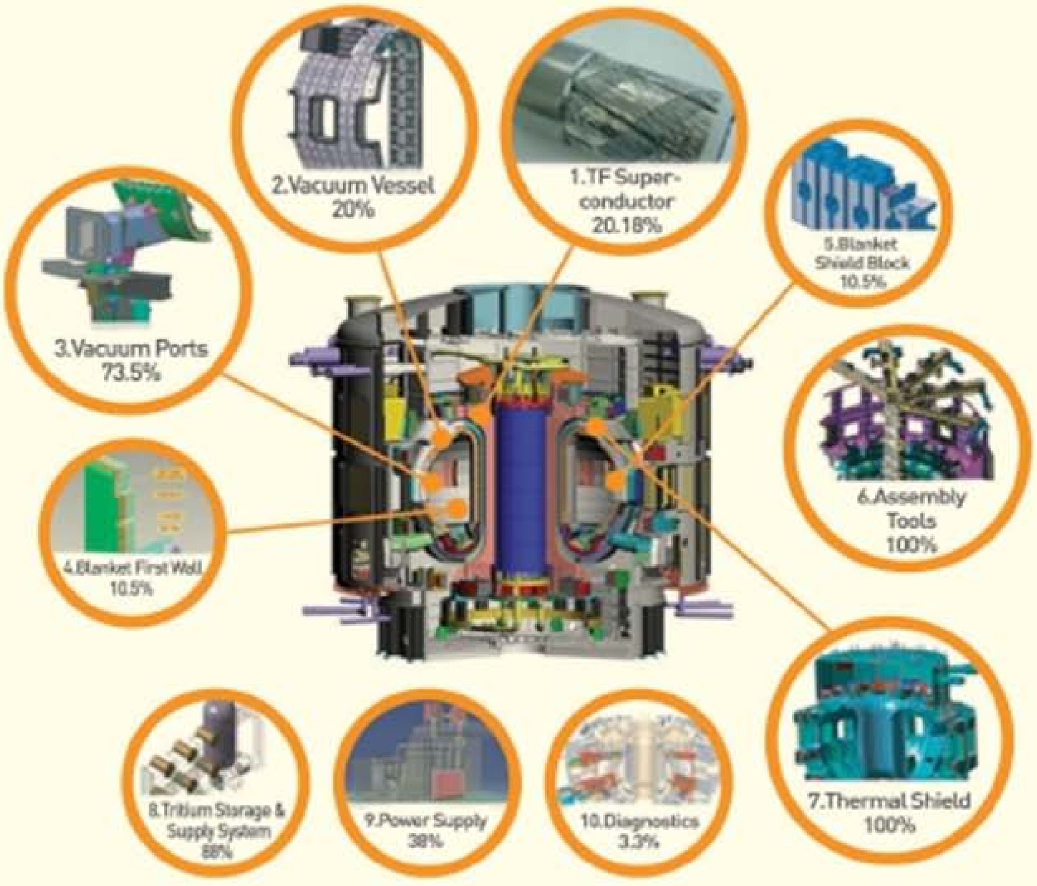
국가핵융합연구소
National Fusion Research institute

ITER Facility Design and Construction Site

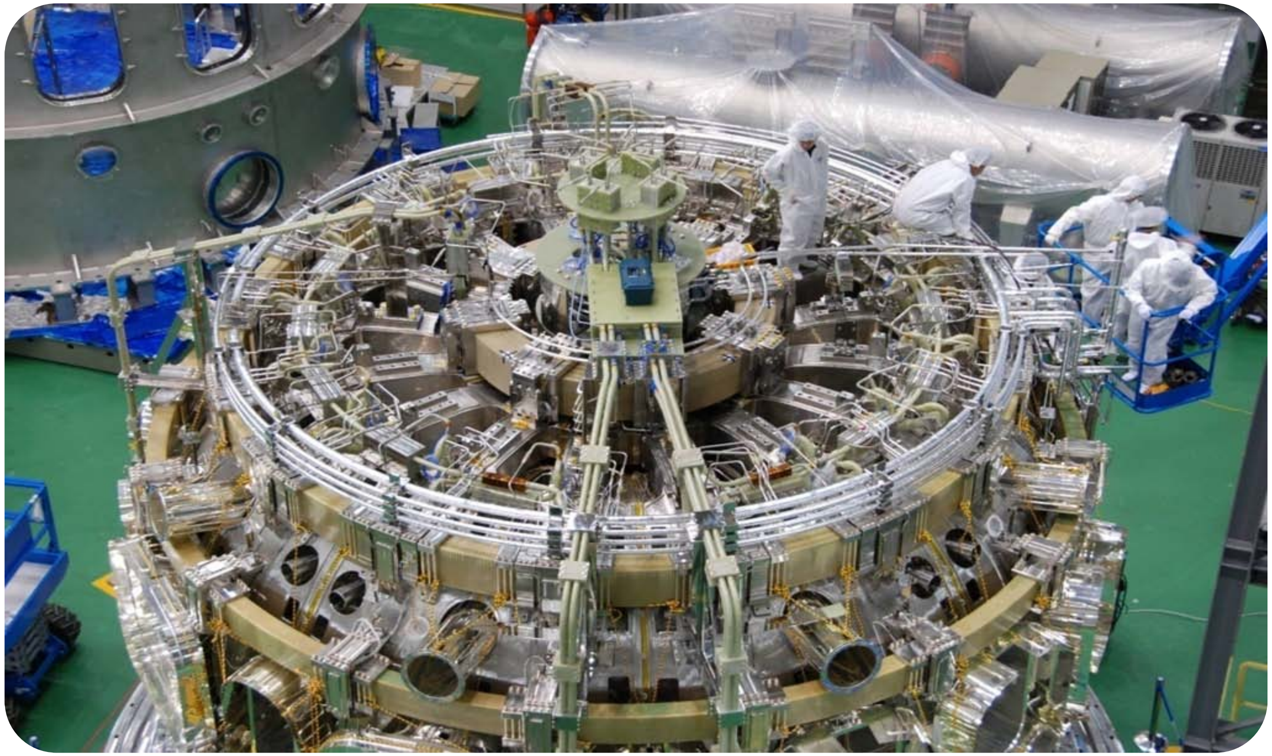
Overview of Construction Schedule



Participation of KSTAR Industrial Partners in ITER Procurement



Challenges and Risk Management thru KSTAR



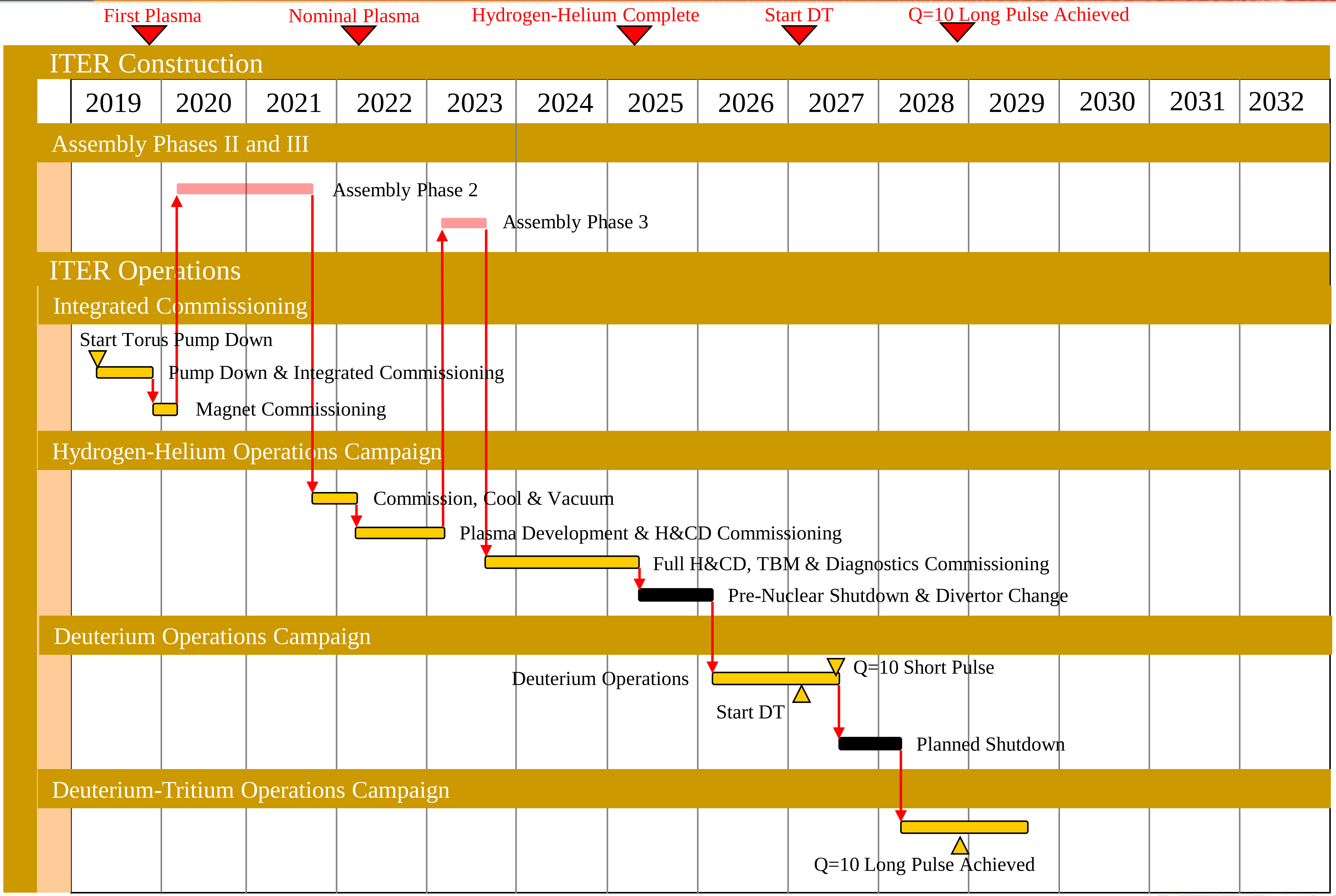
- In-cryostat welding of He lines > 8,500+ points
- In-situ joints of SC Magnets
- Composite material based Insulation Breakers to maintain
- He System Operation in AC System

- SC Installation Accuracy for reducing Magnetic Field Error
- CS Pre-load Assembly for anti-parallel Current Operation
- Thermal Shield Assembly for maximal Maintainability

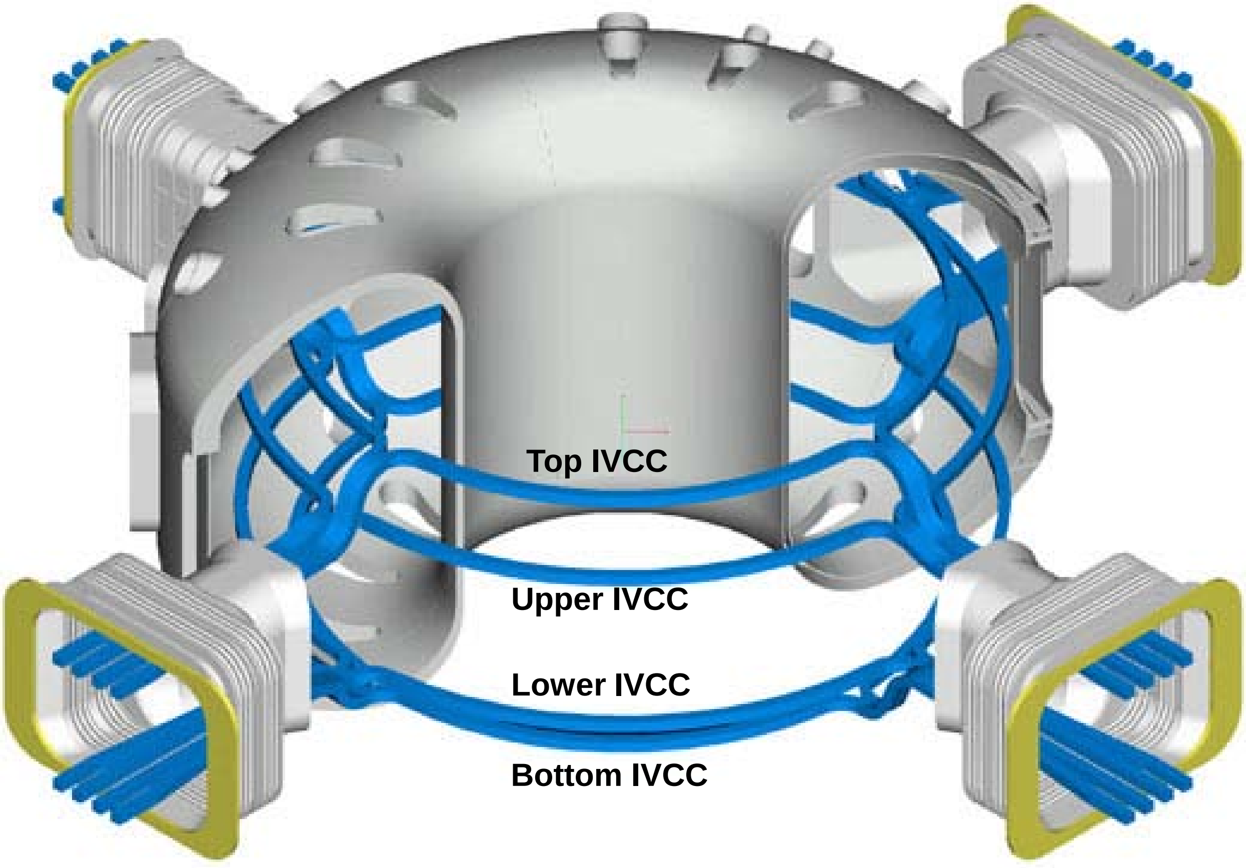
>>> Not by TEST, but by Quality Assurance! Engineering!

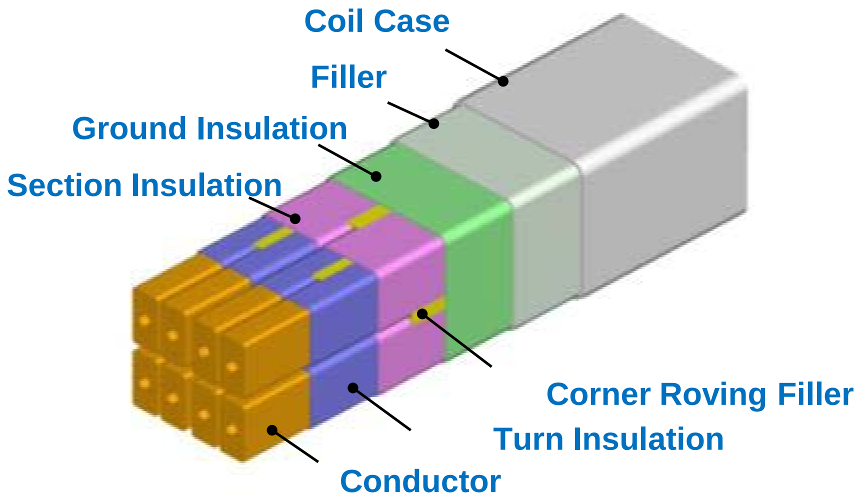
National Fusion Research Institute

Overview of Operation Schedule



In-Vessel Control Coil System (IVCC)



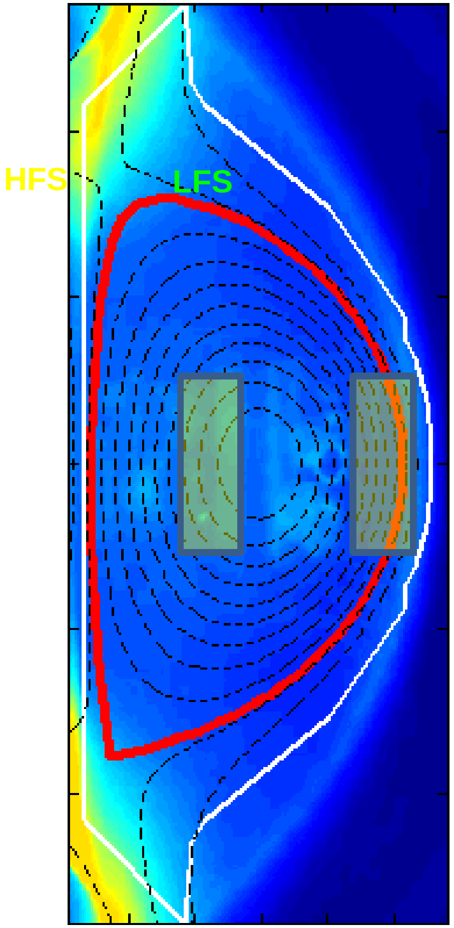


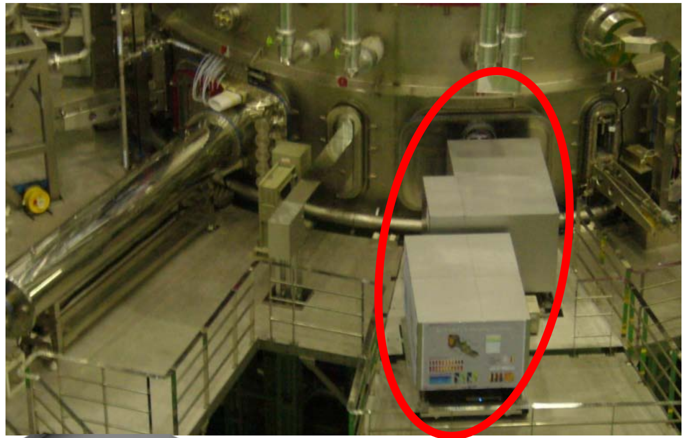
*** IVCC : Vertical & Radial Position Control, ELM & RWM Control**

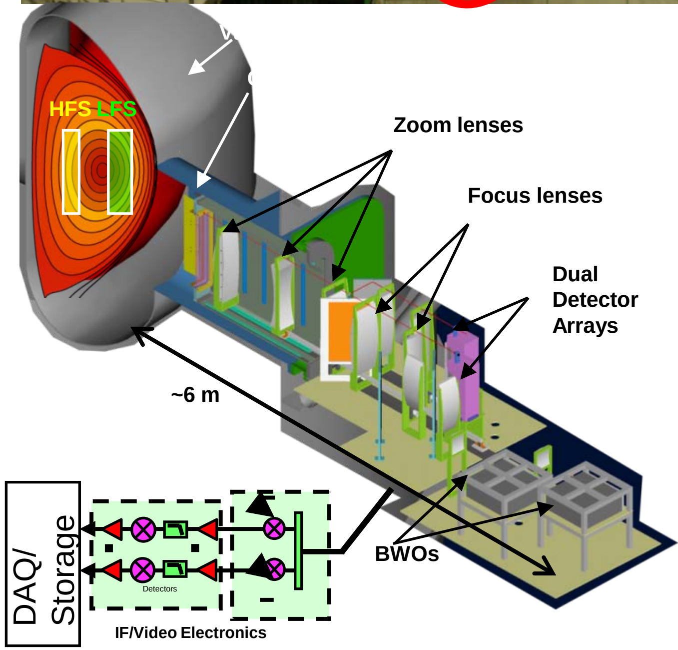
KSTAR ECE Imaging (ECEI) System

- Visualization of physics via 2-D real time imaging
  - Simultaneous imaging of the Edge and Core T_e fluctuations in KSTAR
  - Flexible zooming capability for high resolution and global image
- System Capability
  - Time resolution ~2 ms
  - Spatial resolution ~ 1 cm x 1 cm
  - Signal resolution ~ dT/<T> ~2%
  - Pixels ~ 400 channels

Plasma Coverage

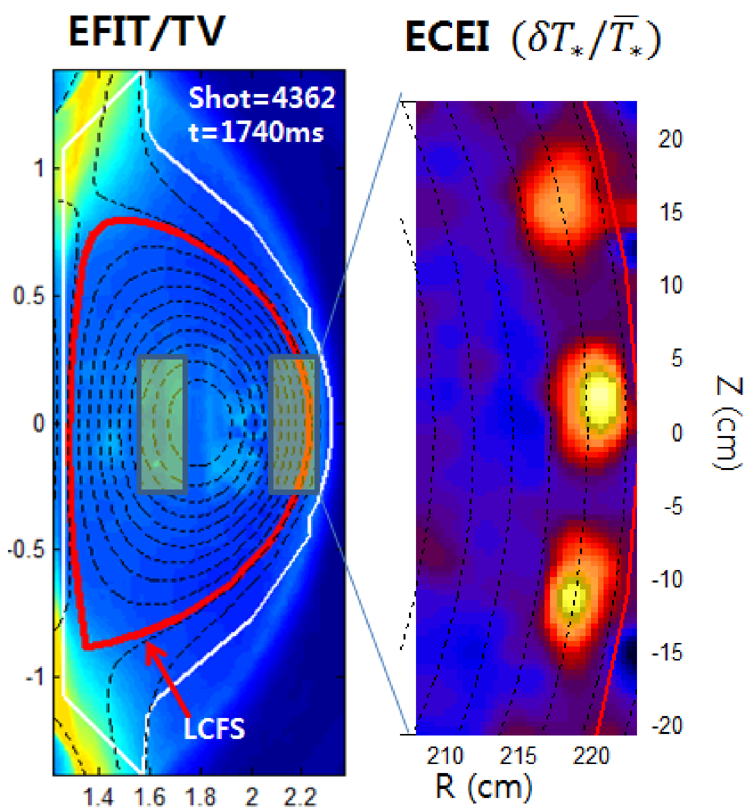




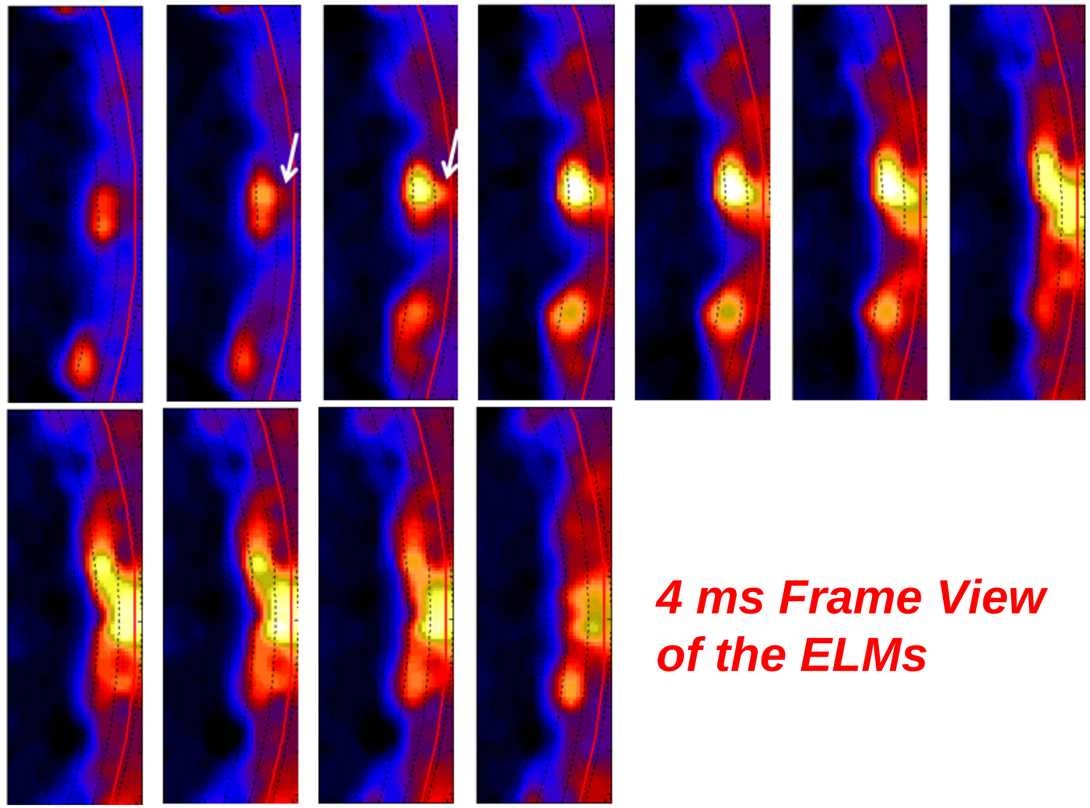


KSTAR ELM Study by ECE Imaging

Filamentary nature of the ELM

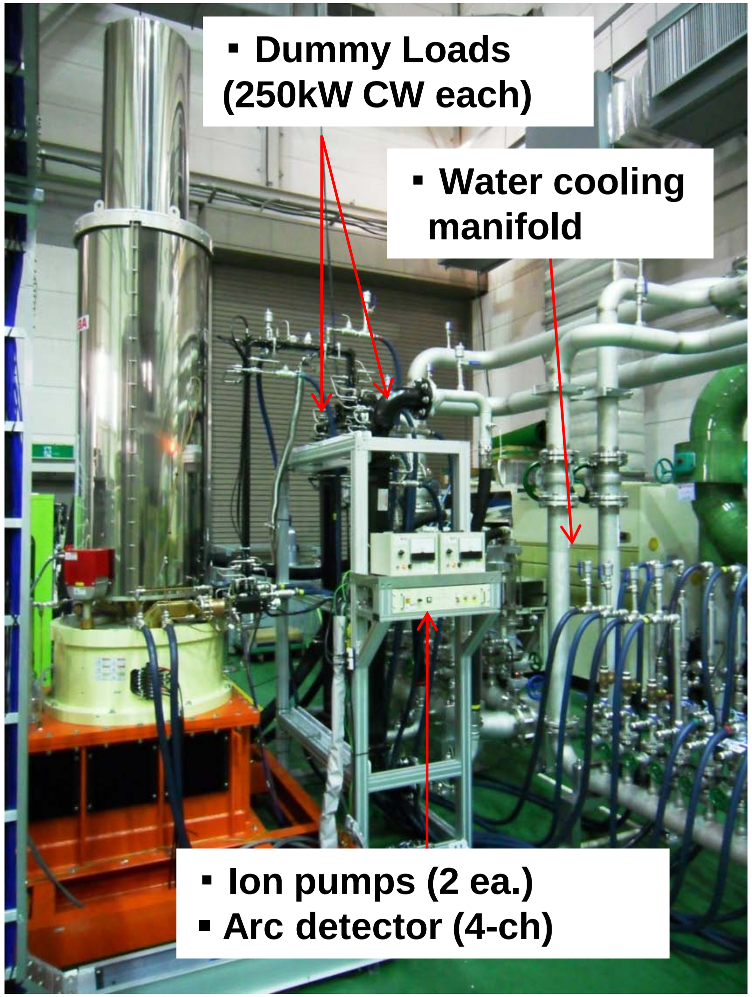


Nonlinear crash process of the ELM

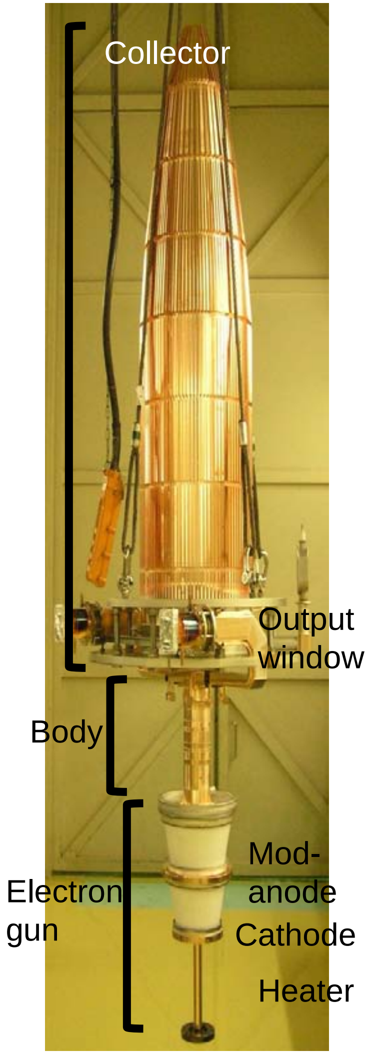


4 ms Frame View of the ELMs

KSTAR 5 GHz Klystron for LHCD (ITER Test-bed)



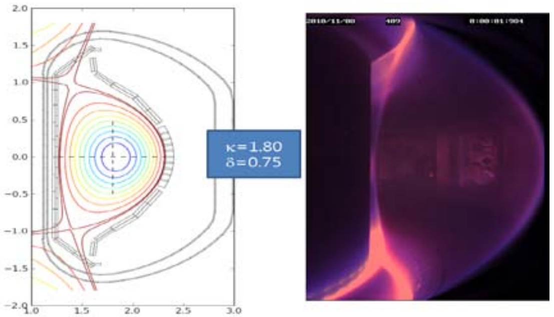
- Toshiba prototype Klystron (E3762 RD0)
- Output RF power (Toshiba factory test results
  - 510 kW, 0.5 s
  - 460 kW, 10 s
  - 300 kW, 10 min.
- Single beam 68 kV, 15 A
- Modulated anode (triode gun)
- Total 6 cavities: 3 input & 3 output cavities 48 dB gain
- 250 kW double windows (BeO) output on VSWR<1.4 any phase
- Collector dissipation: 800 kW
- Body loss < 5 kW
- Window loss < 3.2 kW



- Test at KSTAR: 20 s @460 kW, 800 s @300 kW
- Utilization for test-bed for ITER waveguide components development

ITER Operation Prep through KSTAR Collaboration

KO-US Collaboration in KSTAR

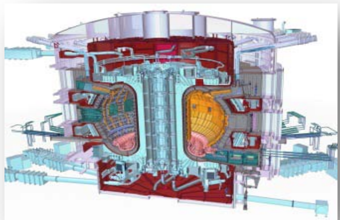


- **High Performance SS** Plasma Operation
- **Advanced Scenario** for ITER and beyond
- **Remote Collaboration** Prep for ITER

- Enhance Operational Readiness for ITER by **Joint Operation**
- Savings on Substantial Capital Investment for **DEMO R&D**

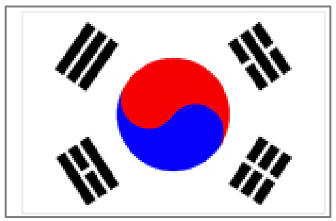
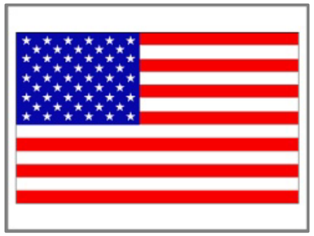
ITER TBM Collaboration

- Solid TBM R&D
- DCLL/DFLL TBM



Synergetic DEMO Consortium

- Open Innovation for DEMO R&D

 +  + ..

New ITER Korea Advanced Research Building

Plasma Application Research Facility

part 3

National Fusion Research Institute

Future : DEMO Design and R&D

NFRI National Fusion Research institute

Fusion Energy Development Promotion Law (FEDPL)

- To establish **a long-term and sustainable legal** framework for fusion energy development phases.
- To **promote industries and institutes** which participating the fusion energy development by supports and benefit.
- The **first country in the world** prepared a legal foundation in fusion energy development.

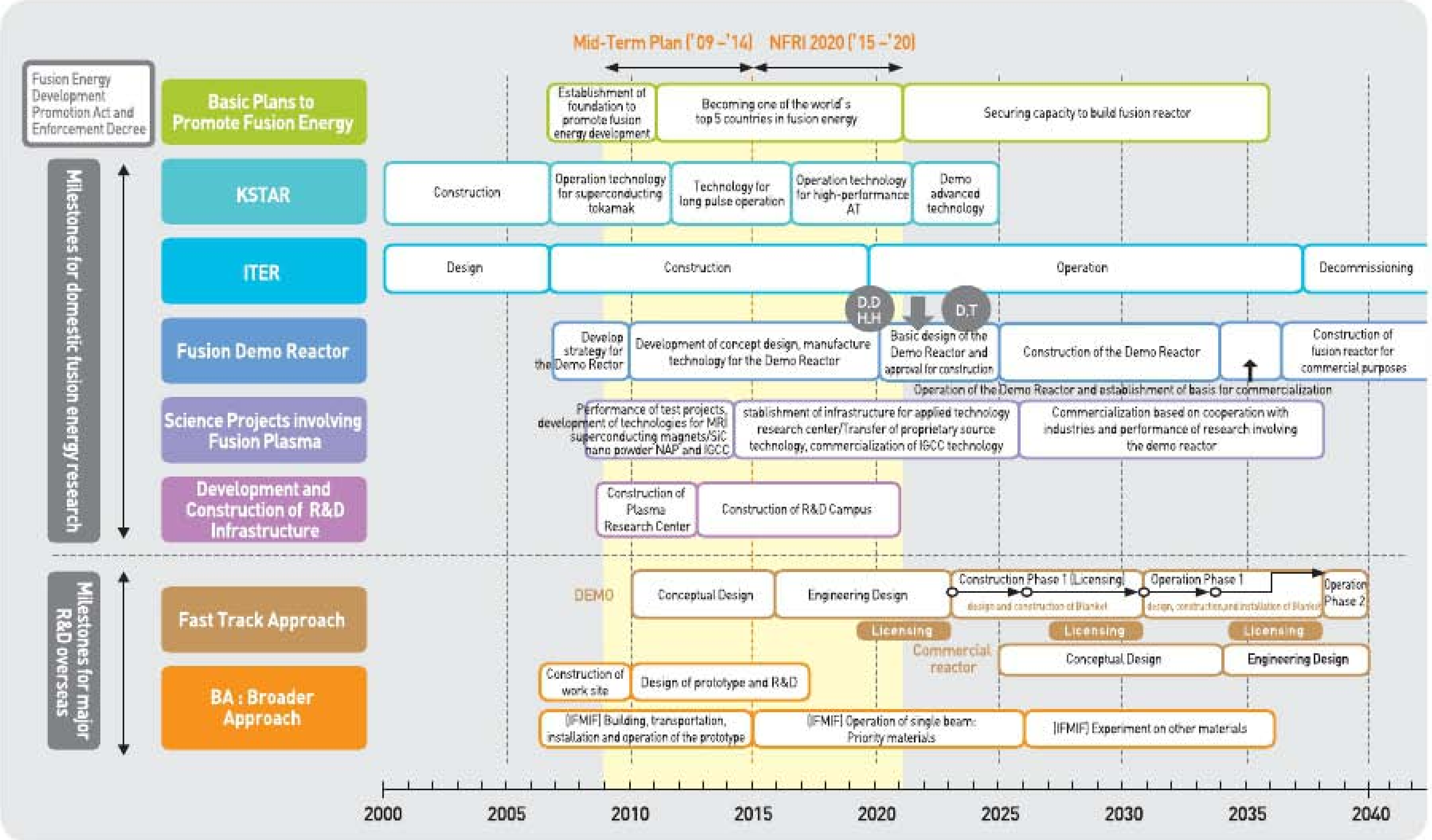
History of the FEDPL

- **1995. 12 :** National Fusion R&D Master Plan
- **2005. 12 :** National Fusion Energy Development Master Plan

- **2007. 3 :** Fusion Energy Development Promotion Law
- **2007. 4 :** Ratification of ITER Implementation Agreement
- **2007. 8 :** Framework Plan of Fusion Energy Development (The First 5-Year Plan)

National Fusion Research Institute

Strategy for Mid to Long-term R&D for Commercialization of Fusion Power



Plans for Headquarters Campus

Overview

- Development Duration: 2012-2026 (Construction in three Phases)

3 phases

• Phase 1 (12 - 16)	Construction of the Headquarters
• Phase 2 (17 - 21)	R&D on Fusion Technology
• Phase 3 (22 - 26)	Development of Fusion Reactor

- Planned Site: International Science Business Belt

Planned Site and Budget

- Site : 330,000m² (with total floor area of 86,800m²)
- Project Budget : about 489 Billion KRW
  - HQ Building, Test Facility Building, Basic Research Building, Development Research Building, Mega Science Infrastructures, etc.

Campus Plan for Headquarters

Phased Development Program for K-DEMO

- Preparatory Sub-Program (07~ 11)
- DEMO R&D Sub-Program (12~ 21)
- DEMO Design & Construction Sub-Program (22~ 36)
- Commercial FPP Construction Sub-Program (37~ 50)

Strategic Plan of the Program

- Program Definition / Gap Study
- Environmental Analysis for Licensing
- SWOT Analysis for Open Innovation
- Key Strategies & Strategic Initiatives
- Portfolio Management/Cross-Cutting Ideas

National Fusion Research Institute

Korean Demonstration Fusion Rector (K-DEMO) aimed for another Success following KSTAR and ITER

Perfect Location for DEMO

- Heavy water reactor producing a large supply of tritium
- Low to intermediate-level radioactive waste repository site nearby
- Equipped with large-capacity power transmission facilities for test

Conceptual Layout Study of K-DEMO Plant

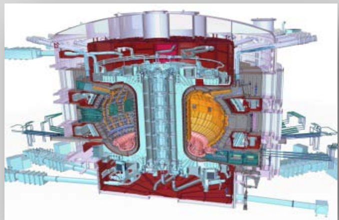
R&D Plan toward DEMO (Proposal)

Fusion DEMO R&D

GAP Study

Present Fusion R&D

<KSTAR>



<ITER>

DEMO R&D Plan

Open Innovation

KO-US, … Collaboration and Post-ITER Coordination

Broader Approach JA-EU

Other collaboration scheme

part
4

National Fusion Research Institute

Epilogue

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National Fusion Research institute

Start of Korean Nuclear Power Program

Dr. Syngman Rhee, the founding president of Korea, at the groundbreaking ceremony of the first nuclear research reactor in 1959. (TRIGA)

Exportation of Korean Nuclear Power Plant

- **KEPCO UAE Task Force Team is rejoicing for wining Nuclear Power Plant contract on constructing 4 APR-1400 units in Abu Dhabi, UAE (December 2009)**