Korean Fusion Energy Development Strategy*

February 26, 2018

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Committee on a Strategic Plan for US Burning Plasma Research,
February 26-28, 2018

General Atomics, San Diego, USA

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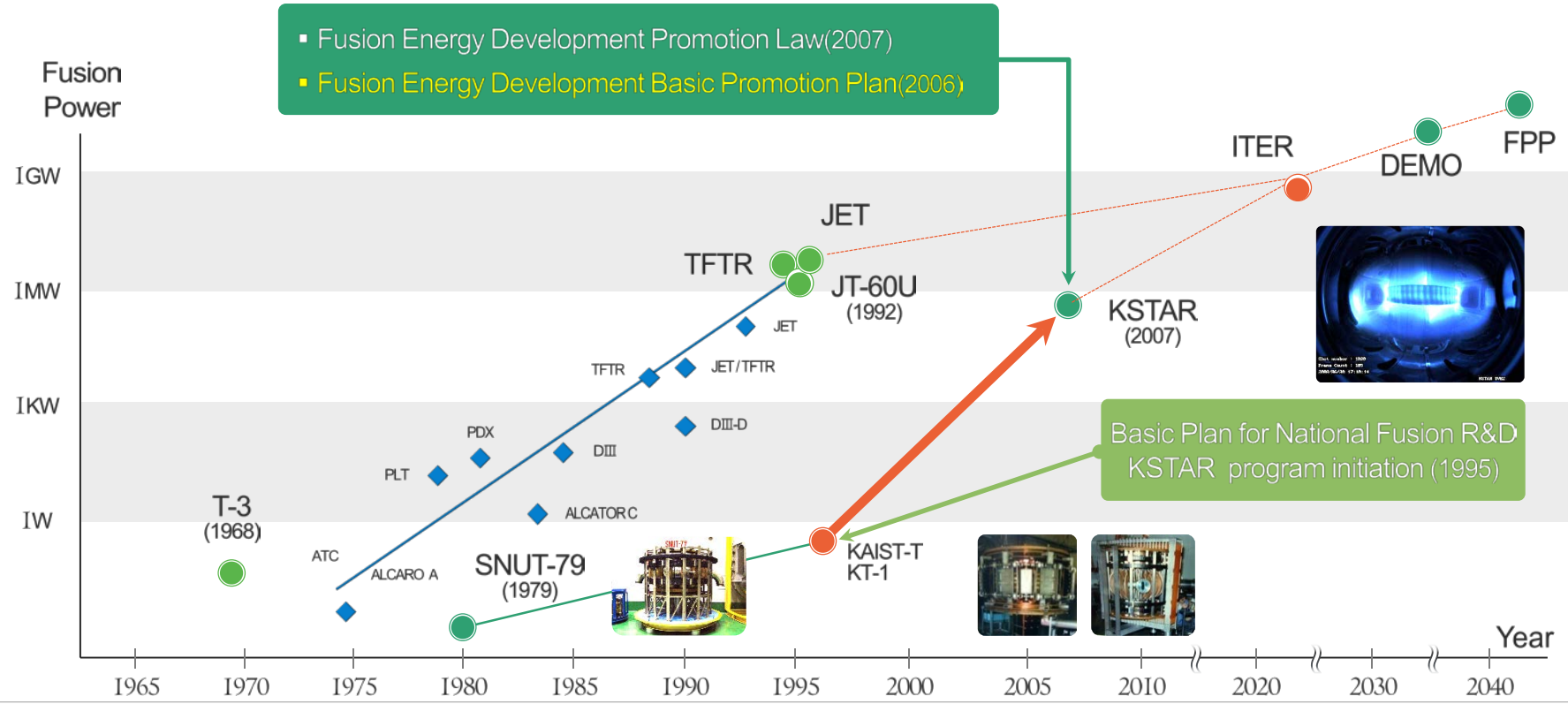
* This presentation represents Y.S. Hwang's personal view.

Outline

- Korean Fusion Energy Development via Mid-Entry Strategy
- Revision of Korean Fusion Energy Development Basic Promotion Plan
- On-going Discussion on DEMO Technology Development Strategy

Korean Fusion Energy Development via Mid-Entry Strategy



KSTAR program(1995), ITER join(2003), Fusion Energy Development Promotion Law(2007), KSTAR construction(2007) leads to major role in ITER construction!

Successful Fast Follower: KSTAR construction (2007) → ITER

◆ **KSTAR : Strong domestic industry with global fusion network**

총 69개 기업,
연인원 1,510명 참여

◆ **Fostering Korean industry and human resources via KSTAR**
⇨ ITER Construction

VV Port Fabrication

TF Conductor Delivery

AC/DC Converter

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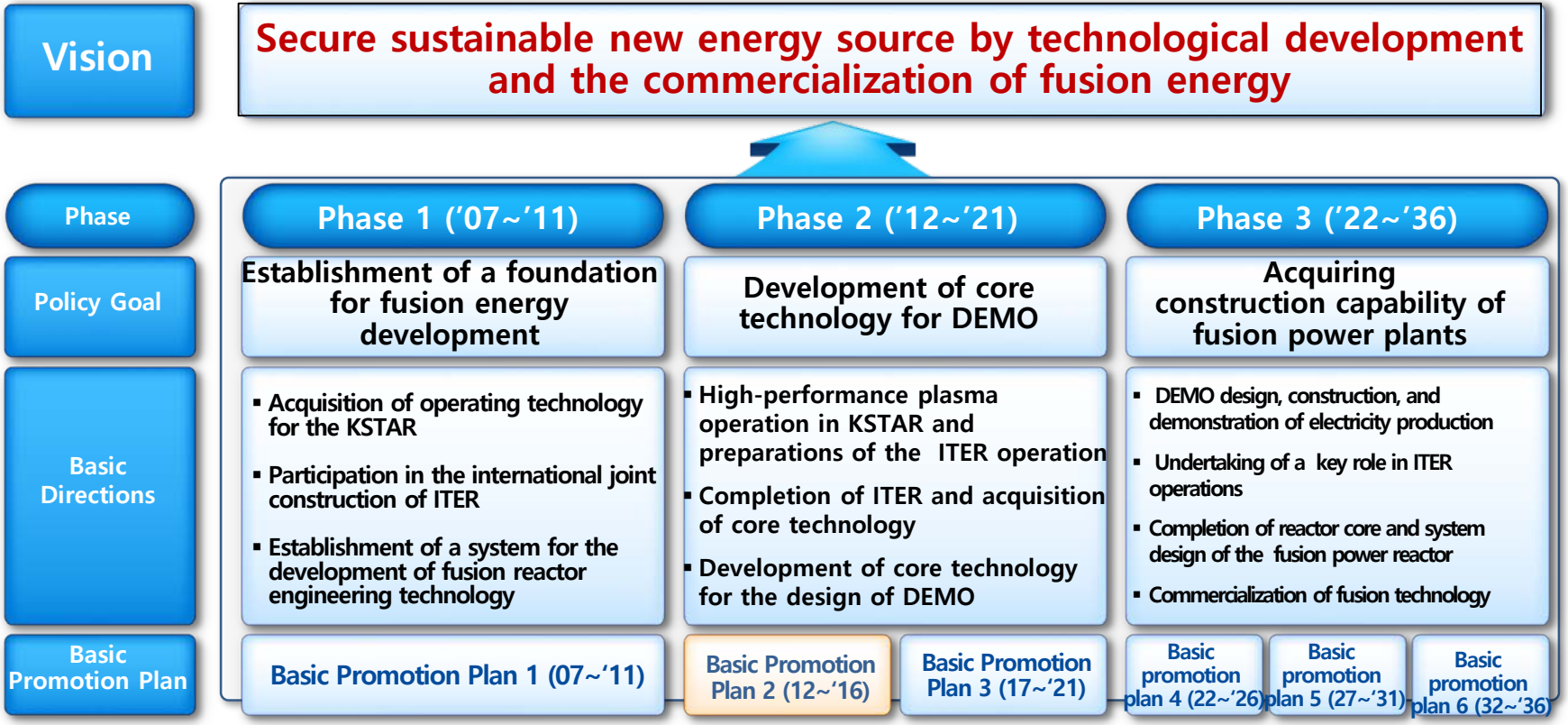
Korean Fusion Energy Development Basic Promotion Plan(2006)



Fusion Energy Development Promotion Law (2007)

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

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

- 2007. 3 : Fusion Energy Development Promotion Law
- 2007. 4 : Ratification of ITER Implementation Agreement
- 2007. 8 : Framework Plan of Fusion Energy Development (First 5-Year National Plan)
- 2012. 1 : The 2nd 5-year National Plan was established.
- 2017. 4 : The 3rd 5-year National Plan has been revised.

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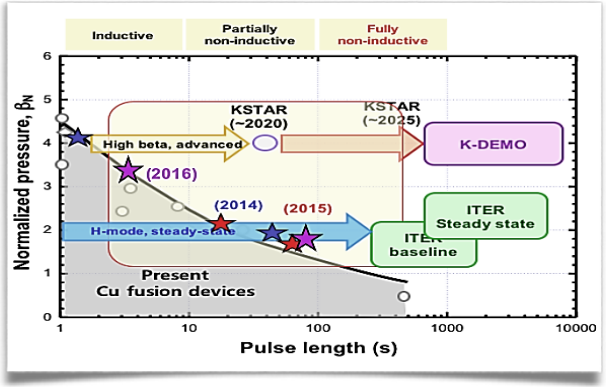
Successful 2nd Stage of Fusion Energy Development Plan

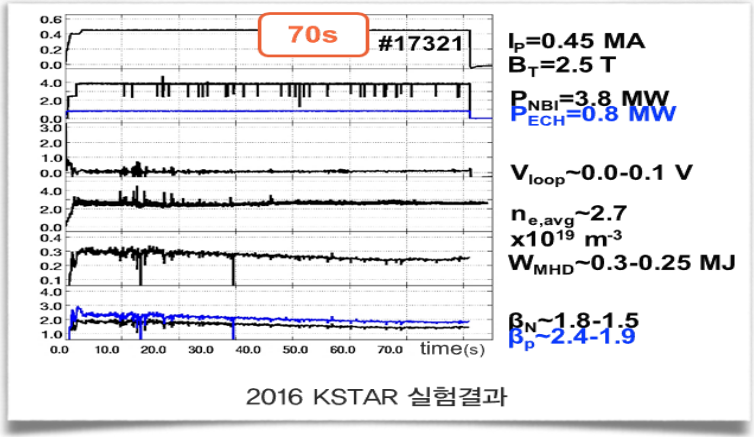
◆ Fostering Korean industry and human resources via KSTAR

➡ ITER Construction

TF Conductor Delivery

◆ Successful KSTAR operation





2016 KSTAR 실험결과

Korean Fusion Energy Development Plan and ITER Delay

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	Acquiring construction capability of fusion power plants
Basic Directions	▪ Acquisition of operating technology for the KSTA ▪ 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 and preparations of 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)

ITER council confirms new first plasma date: December 2025

New schedule for ITER leading to first Plasma in 2025

Staged approach to lead to new ITER Baseline

will further delay the first D-T operation until at least 2035.

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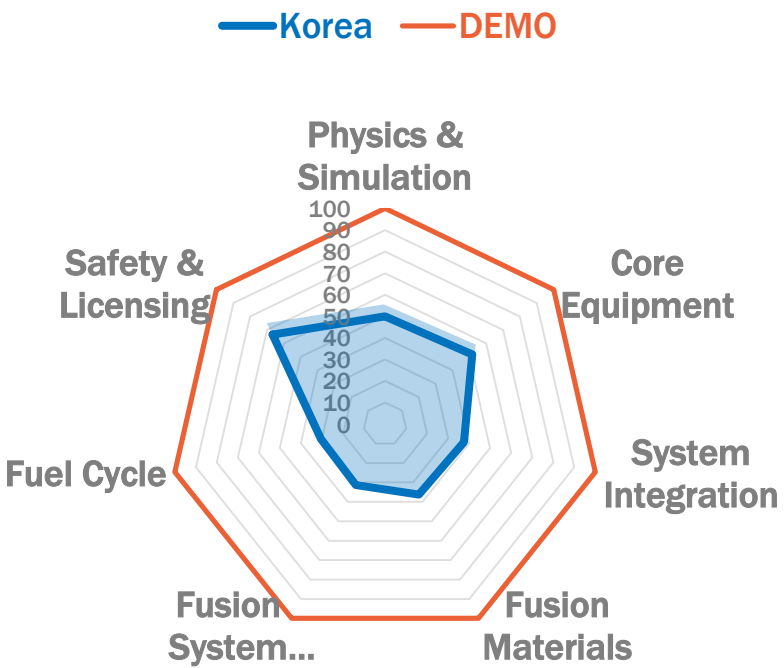
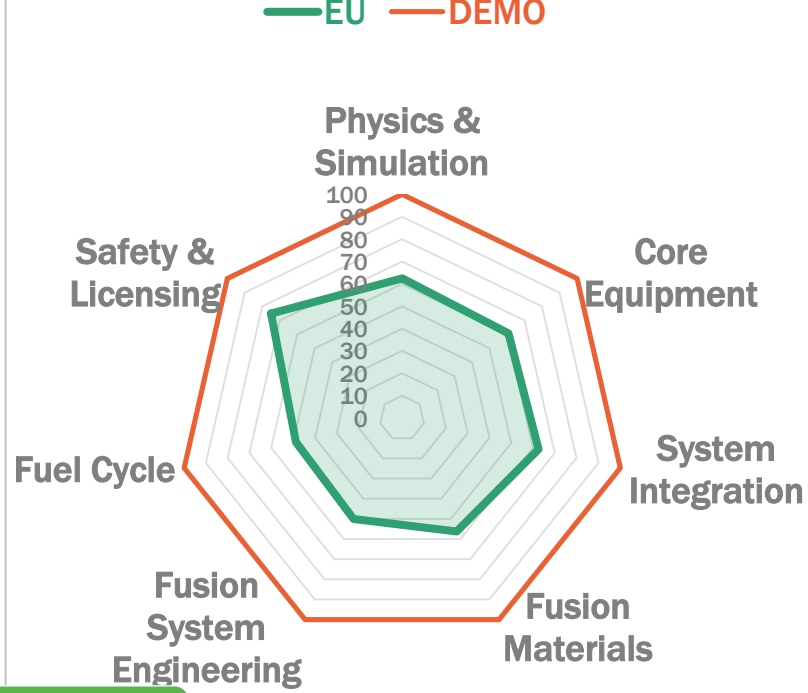
Technical Readiness for DEMO

Korean Fusion Technology level



EU Fusion Technology level



Are we going to be ready for DEMO after Phase 2 ?

No! Korea is very weak in the fields of Fusion materials, Fuel cycle and Energy conversion systems !

Revised Fusion Energy Development Basic Promotion Plan (2017)

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	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 and preparations of 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)

Phse 1('07~'11)	Phase 2 '12~'26)			Phase 3('27~'41)		
1st Promotion Plan ('07~'11)	2nd Promotion Plan ('12~'16)	3rd Promotion Plan ('17~'21)	4th Promotion Plan ('22~'26)	5th Promotion Plan ('27~'31)	6th Promotion Plan ('32~'36)	7th Promotion Plan ('37~'41)

Five more years for the Phase 2 reflecting delayed ITER schedule
3rd Promotion Plan ('17 ~ '21) : "Preparation of Basis for Fusion Reactor Technology Development",
4th Promotion Plan ('22 ~ '26) : "DEMO Conceptual Design and Fusion Reactor Technology Development"

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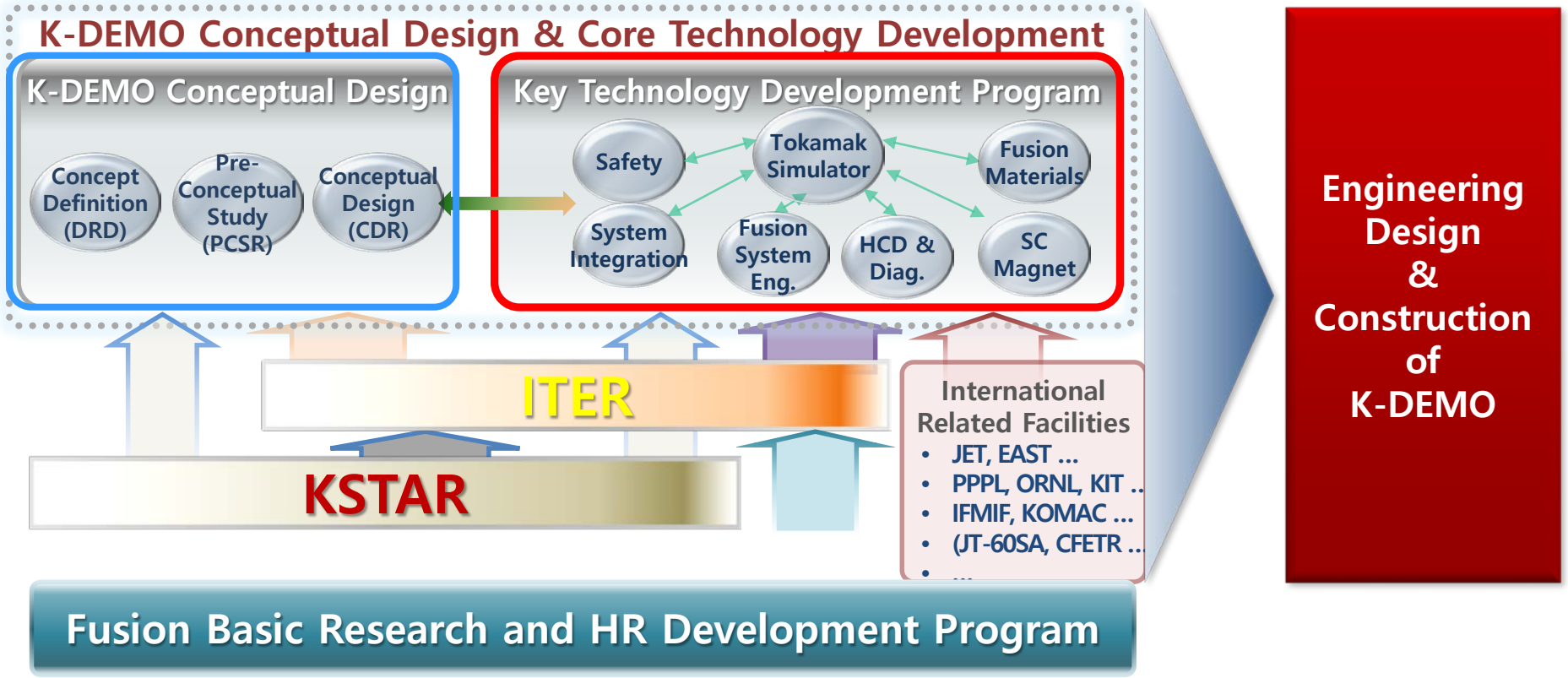
K-DEMO Design & Core Technology Development (2013)



DEMO Core Technology Development Plan (2013)

Development of Core Technology

- Total budget of ~ 500 MUSD including major facility cost of ~150 MUSD for 7 years
- 3 Major Technology Bases, 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 engineering fields such as nuclear, computing, mechanical, material, electrical and electronic engineering as well as fusion science.

3 Major Technology Bases	7 Core Technologies	Major Research Facilities
Design Basis Technology	Tokamak Core Plasma Technology	• (KSTAR, ITER) • 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	
Device and System Engineering Basis Technology	H&CD and Diagnostics Technology	• (KSTAR) • Blanket Test Facility • PMI Test Facility
	Power Conversion System Technology	

Nation-wide DEMO R&D Center Planning

Chonbuk Province

Daegu Province

Busan Province

Extreme Environment Material R&D Hub
- Fusion Reactor Materials R&D

Advanced Magnetic Field Center
- Superconductor Magnet Test Facility

High Enthalpy Plasma Application R&D Center
- Plasma-Material Interaction Test Facility etc.

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Modified Plan for DEMO Core Technology (2015)

Preparatory R&D Program for DEMO Core Technology Development

- Modified plan with reduced budget

✓ Prioritize core technologies with leading groups

✓ Link with existing and planned R&D program

✓ Utilize existing facilities and global fusion R&D network

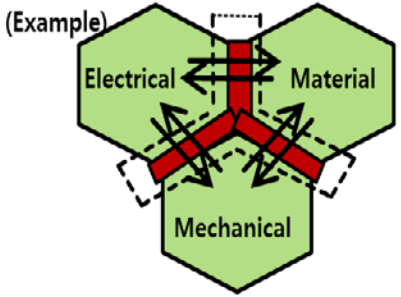
Technical bases
Human resources

Two-Step Approach

Program of Fusion DEMO Core Technology Development

Inter-disciplinary (Engineering) · Open-innovation (Domestic & International)

Interdisciplinary R&D



Industrial Resources

Global Fusion R&D Network

Major Research Facilities

Advances in Fusion DEMO Core Technologies

↓

Fast Realization of Fusion Energy

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Current Structure of Korean Fusion R&D Programs

- Basic Fusion Research ~ 5M
- ITER Core Technology ~ 6M

Basic Fusion Research

ITER non-procurement

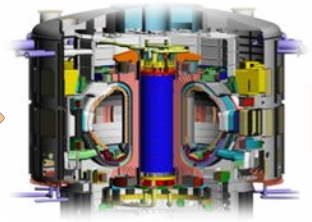
University and other institutes

ITER TBM

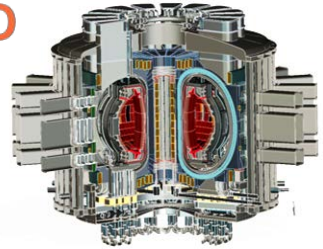
ITER TBM Operation

KSTAR

ITER



DEMO



- KSTAR R&D ~50M
  - Construction
  - SC Tokamak operation
  - >50 sec H-mode Operation, etc.
  - AT operation
  - DEMO R&D
- ITER Procurement ~80M
  - Preparation
  - Construction
  - Operation
  - Dec.
- DEMO ~1M
  - Concept definition
  - Conceptual Design
  - Engineering Design
  - Construction

2000 2005 2010 2015 2020 2025 2030 2035 2040

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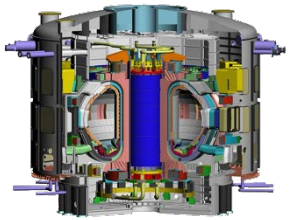
DEMO Preparation in the Revised Basic Promotion Plan (2017)

Securing DEMO preparation via KSTAR and ITER projects

- KSTAR R&D (Next-generation operation mode)
- ITER operation (Burning plasma)

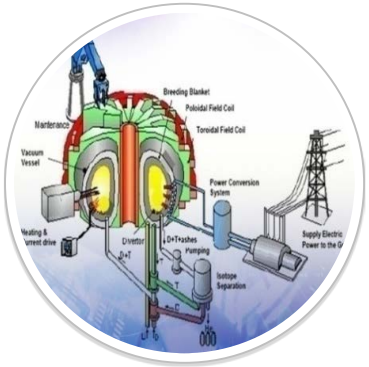
▶ DEMO reactor operation technology



- ITER construction and core technology
  - ITER construction : Technology for design, manufacturing and integration
  - ITER non-procurement: Divertor and sub-system technology
  - ITER TBM : Material and blanket technology

▶ Fusion reactor technology development

Perform
Conceptual DEMO Design

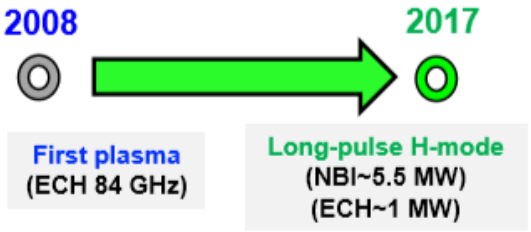


Secure
DEMO Base Technology

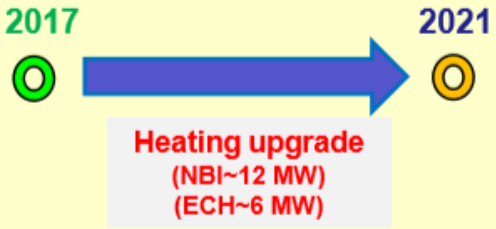
KSTAR R&D Plan for DEMO

Near-term Upgrade and Research Plan in KSTAR

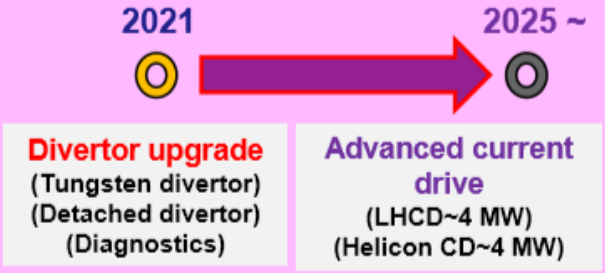
Y.K. Oh



Long-pulse H-mode research
- *Long pulse H-mode (>70s)*
- *ELM research & control (>30s)*
- *Alternative operation modes (ITB, low q, ..)*



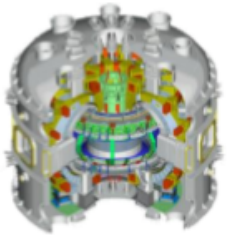
Advanced scenario & MHD research
- *Stable high beta operation*
  (β_N>3.0, T_{ion} ~ 10 keV)
- *Advanced mode develop.*
  (hybrid, ITB, low q)
- *MHD & disruption control*



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

KSTAR contribution to ITER and K-DEMO :

medium beta & steady-state (ITER) and high beta (K-DEMO)

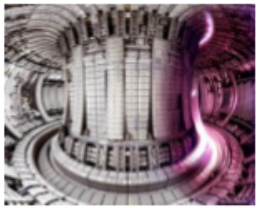


KSTAR
(β_N~2, steady-state)
(β_N~4, stationary)
($f_{bootstrap}$ > 50%)

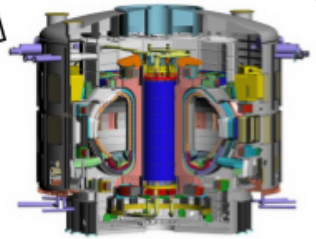
(high β_N~4, stationary) (high $f_{bootstrap}$)

(β_N~2) (steady-state)

(β_N~2) (D-T operation)

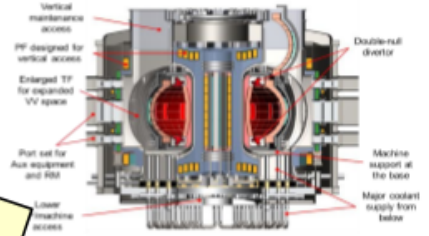


TFTR, JET, JT60U
(Large plasma volume)
(β_N~2 & D-T fusion)



ITER
(Reactor-scale plasma volume)
(β_N~2 & D-T fusion)
(steady-state, external CD)
(alpha heating)

(α-heating) (TBM)



K-DEMO
(Reactor-scale plasma volume)
(β_N~4 & D-T fusion)
(steady-state, by bootstrap)
(alpha heating)
(Blanket, T-breeding)

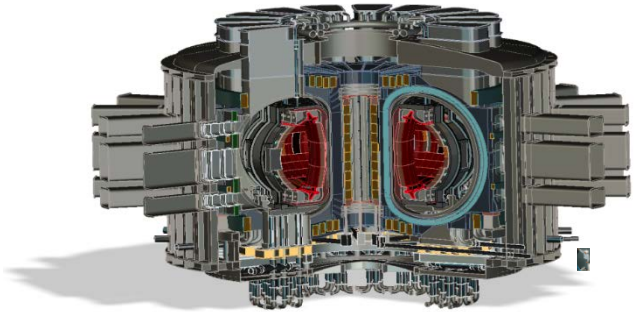
Fusion Technology R&D / others
- Material R&D
- System Eng. (Tritium, remote)
- Engineering optimization
- License & Codes
- Human resource
- Etc

Y.K. Oh

DEMO Technology Development Strategy and Roadmap (2018)

◆ **Secure DEMO concept and generate approximate overall project cost**

Main Parameters
R = 6.8 m, a = 2.1 m
B-center = 7.4 T (peak 16T)



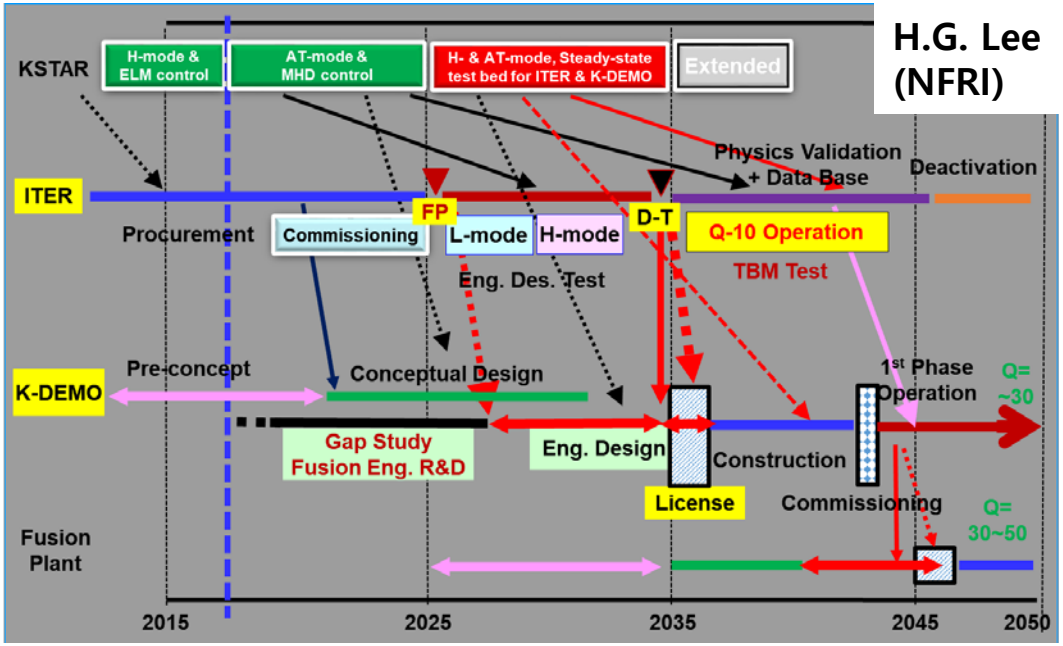
◆ **Establish DEMO roadmap with its technology development strategy**

- **Present ITER cost may tell order of magnitude for the DEMO plant cost.**
- **ITER schedule is not any more ticking clock for DEMO.**
- **Linkage of human and industrial resources from KSTAR to ITER tells that there is a critical transition time to DEMO.**

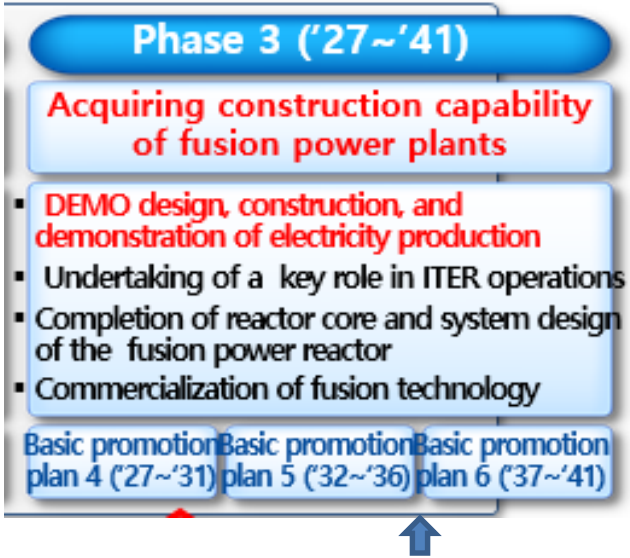
We may need some kind of Mid-Entry strategy for DEMO!

Lessons Learned from ITER for Fast-Track DEMO Roadmap

- **ITER 1st plasma and DT operation schedule becomes difficult to get along with the DEMO roadmap in the Korean fusion energy development plan.**



H.G. Lee (NFRI)



DEMO construction?

- **Risks related to TBM are still remain severe in this plan.**

- **Linkage of human and industrial resources from KSTAR to ITER tells a critical transition time to DEMO.**
  → We cannot delay DEMO schedule by following ticking clock of ITER schedule.

Update DEMO Technology Development Strategy (under Discussion)

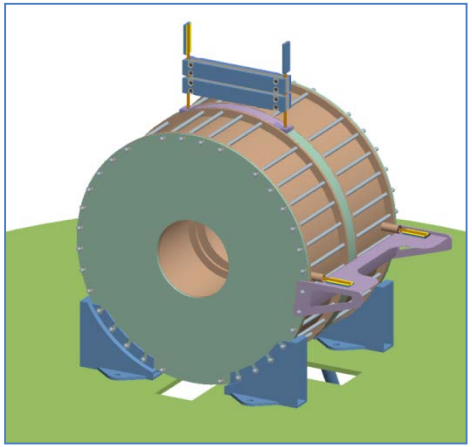
- Full power plant demonstration may be in the form of international consortium while developed core technologies are integrated into a simulator-based demonstration as a back-up option.
- Core technology development plan will be pursued by concentrating on selected critical items with relevant facilities. Global fusion network and industrial infra via ITER need to be utilized.

Critical Facilities	Important Tasks
KSTAR	. Operation Scenario + advanced divertor
Full Tokamak Simulator	. Full power plant validation, design and license tools
Superconducting Magnet	. High temperature superconducting magnets
Fusion Neutron Sources + MSR	. Component test facility, tritium production
IFMIF (+ POSCO)	. Material development with irradiation facility

Updated DEMO Core Technology Development Strategy

Superconducting Conductor Test (SUCCEX) Facility

- **SUCCEX (SUperConducting Conductor EXperiment)**
  - **Background field : 16 Tesla**
  - Split-pair Solenoid Magnet System
  - Inner-bore Size : ~ 1 m
  - Two Test Modes :
    - ✓ Sultan-like sample test mode
    - ✓ Semi-circle type conductor sample test mode



→ **High-Temperature Superconducting Magnet Development**

Joint development with SMES energy storage system

Thank you for your attention !

K-DEMO Plant by 2040 ?

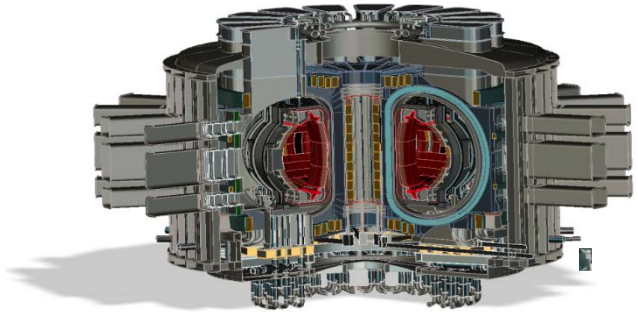
Requests from the Committee

- **Current view of Korean strategy toward developing fusion power plant**
- **Any lessons learned from the formulation of the 2005 national roadmap for fusion, the value of legislation to support fusion energy research and development, and how the Korean strategic plan has evolved over time**
- **Views of role of international partnership in fusion energy research, including participation in the ITER project and research plans for KSTAR**
- **Any strategic approaches that might further strengthen or accelerate fusion energy development as an economical energy source of electricity**

DEMO Technology Development Strategy and Roadmap (2018)

◆ Secure DEMO concept

Main Parameters
R = 6.8 m, a = 2.1 m
B-center = 7.4 T (peak 16T)



Reference design of DEMO will be continuously evolving according to the progress of fusion-related R&D while its design guides the R&D.

◆ Implications from ITER for DEMO roadmap

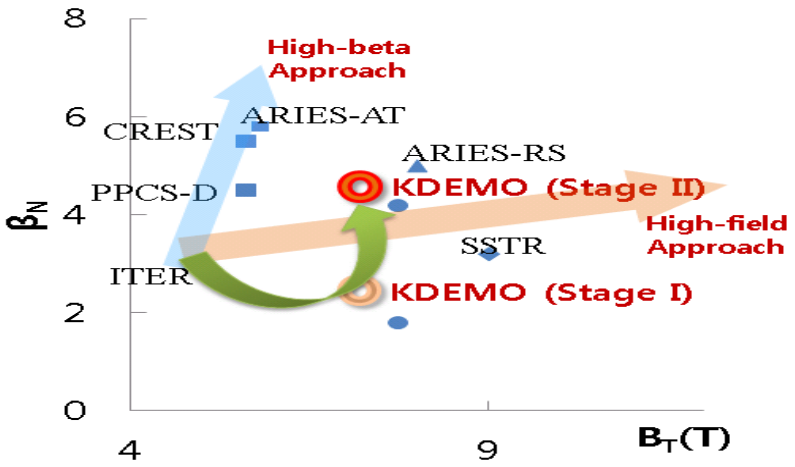
- **ITER 1st plasma and DT operation schedule becomes difficult to get along with the DEMO roadmap in the Korean fusion energy development plan.**
- **More realistic plans for DEMO become feasible. Many risks and possibilities have been identified.**
- **Linkage of human and industrial resources from KSTAR to ITER tells a critical transition time to DEMO.**

◆ Update DEMO technology development strategy

- **Full power plant demonstration may be in the form of international consortium while developed core technologies are integrated into a simulator-based demonstration as a back-up option.**
- **Core technology development plan will be pursued by concentrating on selected critical items. Global fusion network and industrial infra via ITER are important.**

K-DEMO Concept Definition

Demonstrate electricity generation, tritium self-sufficiency with cost data



- Similar Size of ITER (engineering approach)
- High field approach
- Two stages : 2200 MW_{th} → 3000MW_{th}
- Extrapolation from KSTAR and ITER operation

Reference design of DEMO will be continuously evolving according to the progress of fusion-related R&D while its design guides the R&D.

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 (κ)		2.0	
Magnetic Field (B_o)		7.4 Tesla	
Peak Field		~16 Tesla	
Divertor Type		Double Null (or Single Null)	
Plasma Current	> 10 MA	> 12 MA	> 13 MA
Total Fusion Power	1500~2000 MW	2200~3000 MW	2700~3500 MW
Net Electric Power	130~200 MWe	400~700 MWe	550~900 MWe

ITER Roles for DEMO

- Burning plasma physics and control
- Fusion reactor technology
  - Test Blanket Module (TBM) for breeding blanket
  - Tritium fuel cycle
- License technology
  - Licensing and environmental safety, etc
  - Code and standard
- System integration and project management technology