National Fusion R&D Center
Korea Basic Science Institute

ITER Korea TFT

ITER Participation and Possible Fusion Energy Development Path of Korea

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Outlook

- Korean Energy Program
- Korean Fusion Research Program
- ITER Participation
- We Need Tritium
- Korean Fusion Energy Development Path

Korean Energy Program

- Energy Situation in Korea
- Nuclear Power Program

Energy Situation in Korea

- Energy Import in Korea
  - Lack of domestic natural resources : 97% of energy is imported.
  - 80% of energy import is crude oil from Middle East
  - Anticipated average annual growth rate of energy demand through 2035 is 2.3%

- Rapid Increase of Electricity Demand
  - About 7 times in 20 years from 1980 to 1999 with an average annual growth rate of 10.3%
  - Anticipated average annual growth rate of electricity demand through 2015 is 4.9%.

Energy Situation in Korea

- CO_2 Emission
  - Total emission amount ranks 10th in the world.
  - Emission per unit area is the highest in the world.
  - Export expected to lose price competitiveness due to CO_2 Tax.

- Need to Prepare Future Social Demand
  - Unification of Korea

Nuclear Power Program

- First commercial nuclear power plant Kori Unit 1 started operation in 1978.

- Currently there are 16 PWRs and 4 CANDUs in operation
  - 8 out of 16 PWRs are KSNP (Korea Standard Nuclear Plant)
  - 6 in preparation
  - Total of 28 units by 2015

Nuclear Power Program

- Nuclear Power Share (as of Dec. 2003)
  - 28% of total installed capacity (6th in the world)
  - 40% of total electricity generation

- KO has a substantial infrastructure on nuclear technology
  - Shares the key technologies with fusion reactor
  - Design of various fission reactors
  - Experiences with Tritium recovery and storage from CANDUs
  - Relatively young and experienced staff

Korean Fusion Research Program

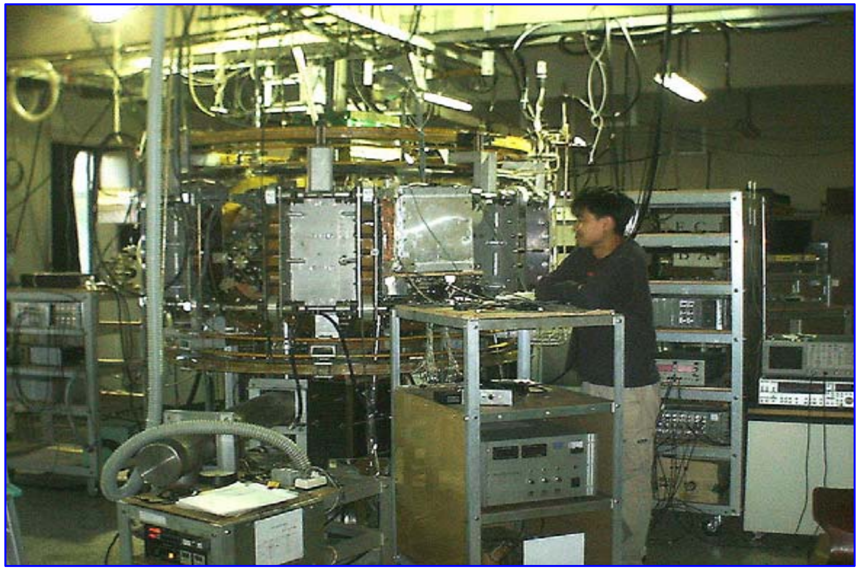
- SNUT-79 and KAIST Tokamaks
- KT-1 Tokamak and HANBIT Mirror
- KSTAR
- ITER Particiaption

SNUT-79 and KAIST Tokamaks

- Korea has been involved in plasma and fusion research in a modest way since the mid-1970s.
- Most activities were small in scale and housed within various universities.
- Based on basic plasma and fusion researches at Universities in 1970's, Seoul National University developed a small scale fusion research device named SNUT-79.
- And, KAIST (Korea Advanced Institute for Science and Technology) developed another device named KAIST Tokamak.
- These programs have valuable meanings to launch real tokamak projects in Korea, and to develop human resources in Korean fusion program up to now.

SNUT-79 and KAIST Tokamaks

SNUT-79 (Seoul National University)

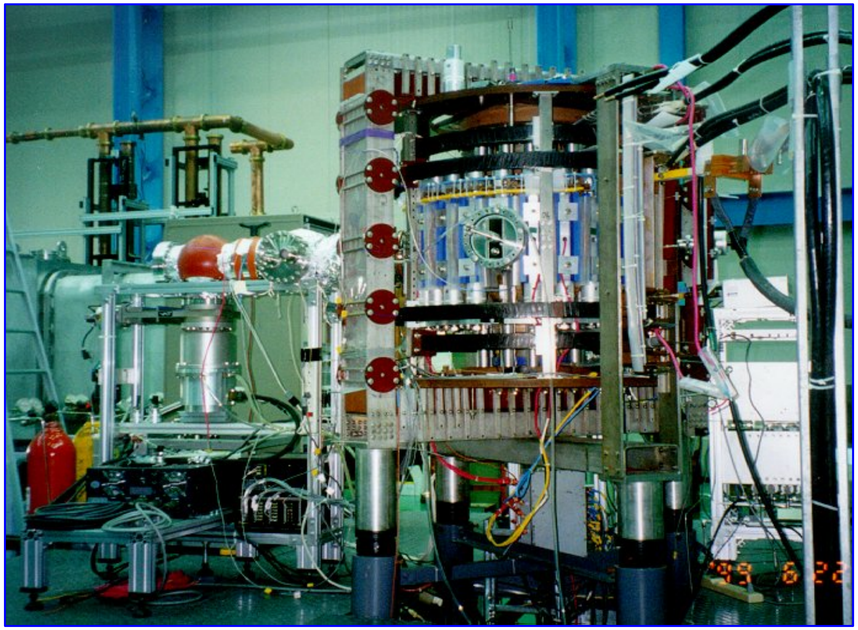


KAIST Tokamak

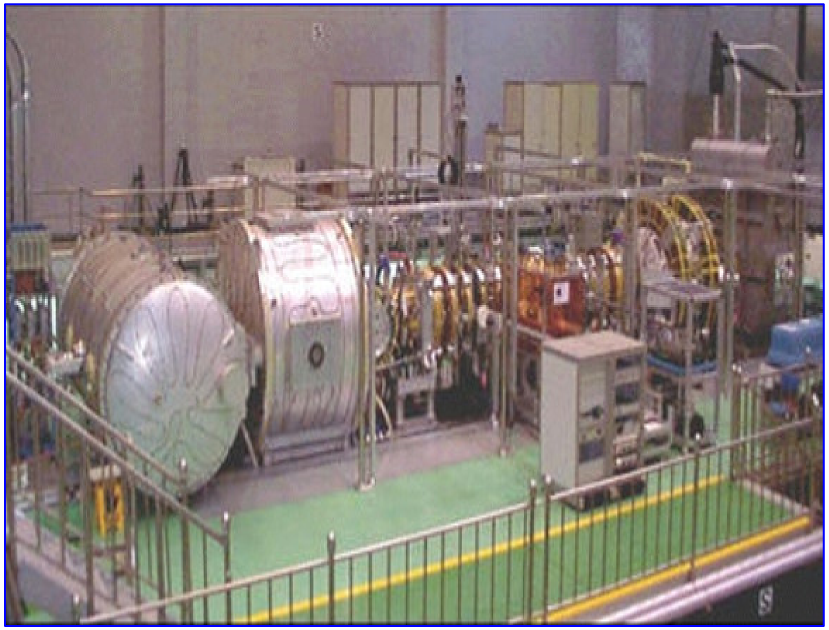
KT-1 Tokamak and HANBIT Mirror

- In the mean time, KAERI (Korea Atomic Energy Research Institute) developed KT-1 tokamak in a research institutional territory.
- In 1995, Korea Basic Science Institute installed a medium-sized device called HANBIT, which is now fully operational. HANBIT is devoted to basic plasma research such as basic plasma diagnostics and radio frequency/microwave heating method development.
- It is operating as a national-user facility and drawing more than 20 research work groups from universities and research institutes throughout the nation.

KT-1 Tokamak and HANBIT Mirror



KT-1 Tokamak (KAERI)



HANBIT Tandem Mirror (KBSI)

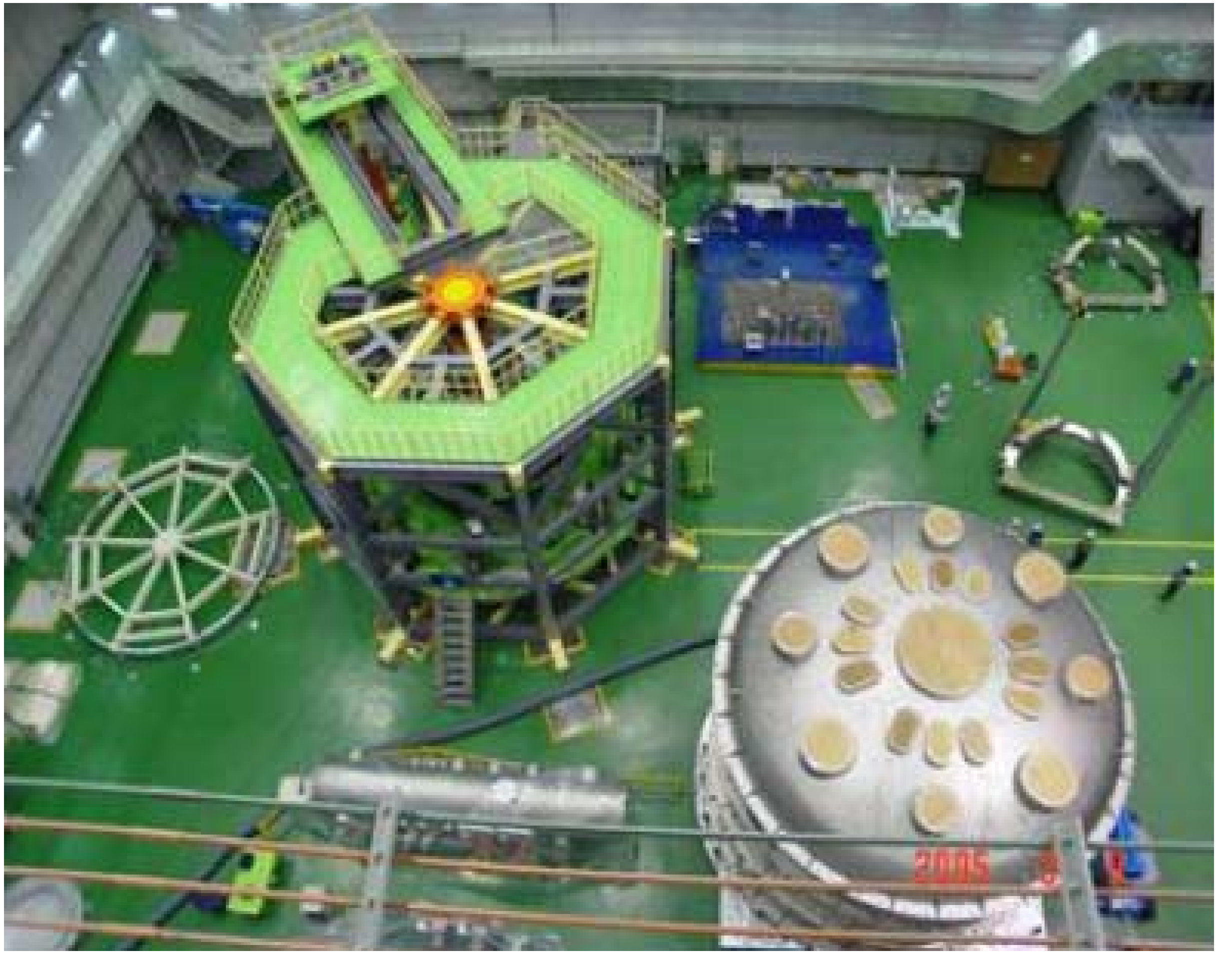
KSTAR (will be constructed by 2007)

- Korea Superconducting Tokamak Advanced Research

- Mission
  - To extend present stability and performance boundaries of tokamak operation through active control of profiles and transport
  - To explore methods to achieve steady state operation for tokamak fusion reactors using non-inductive current drive
  - To integrate optimized plasma performance and continuous operation as a step toward an attractive tokamak fusion reactor

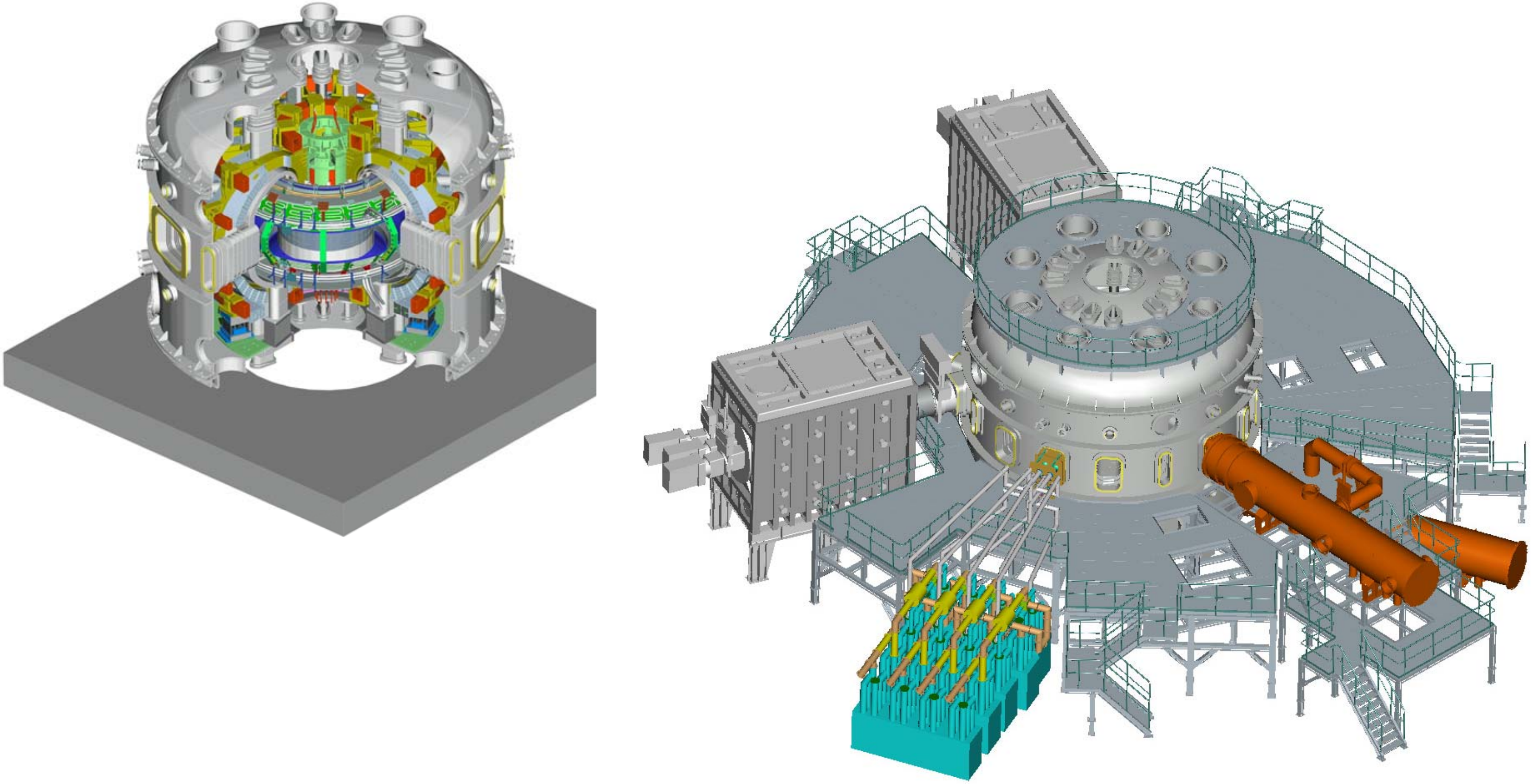
- Design Features
  - Fully superconducting magnets
  - Long pulse operation capability
  - Flexible pressure and current profile control
  - Flexible plasma shape and position control
  - Advanced profile and control diagnostics

KSTAR Main Hall (March 9, 2005)



Korean
Fusion
Energy

KSTAR Tokamak



Vacuum Vessel Fabrication

Cryostat Fabrication Highlights

Base Plate Assembly

BV Port Stub

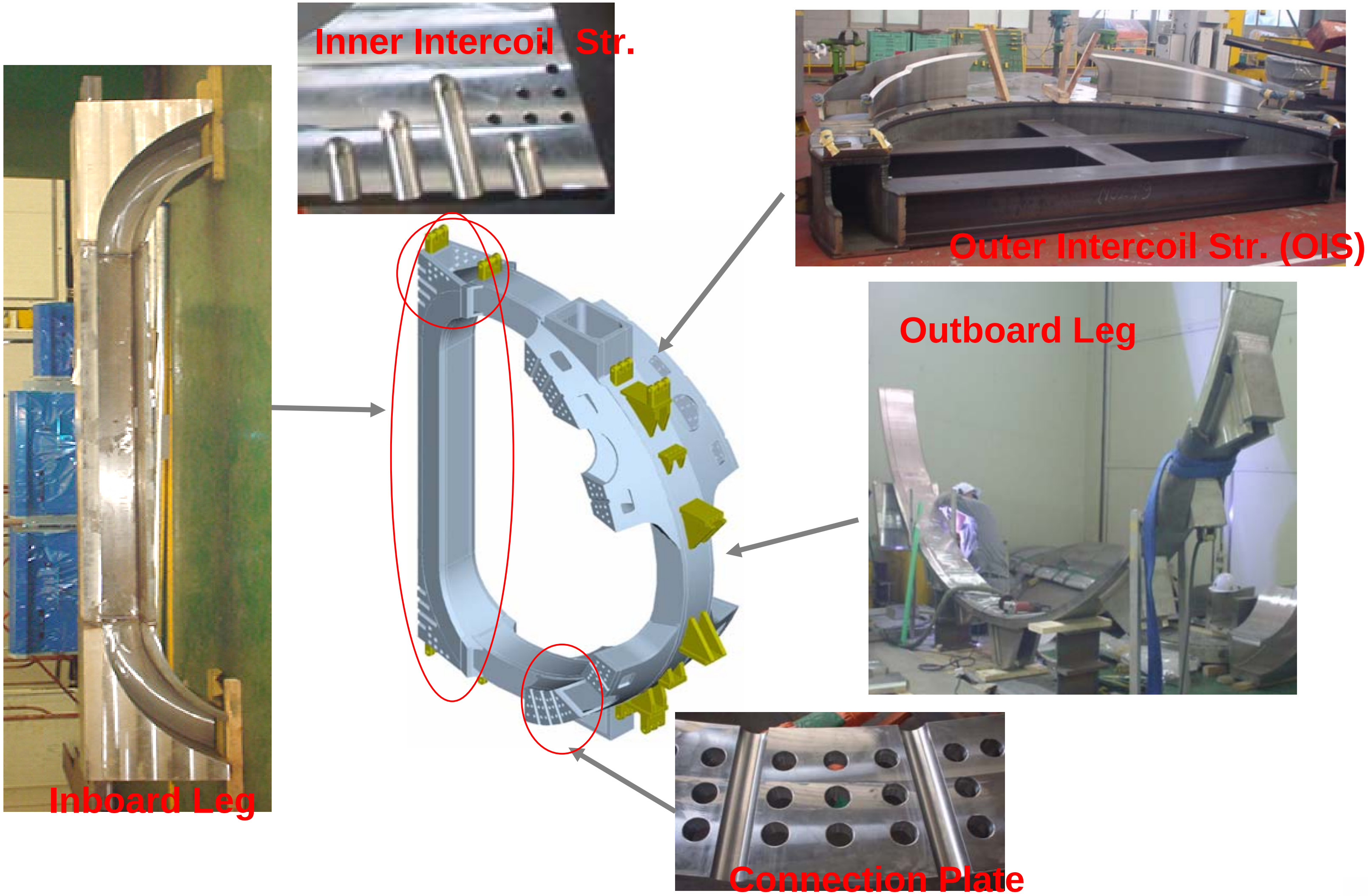
Connection Ring

Bearing Plate

Circular Port of Base

Korean
Fusion
Energy

KSTAR TF Magnet Structure Fabrication



TF Structure Fabrication Highlights

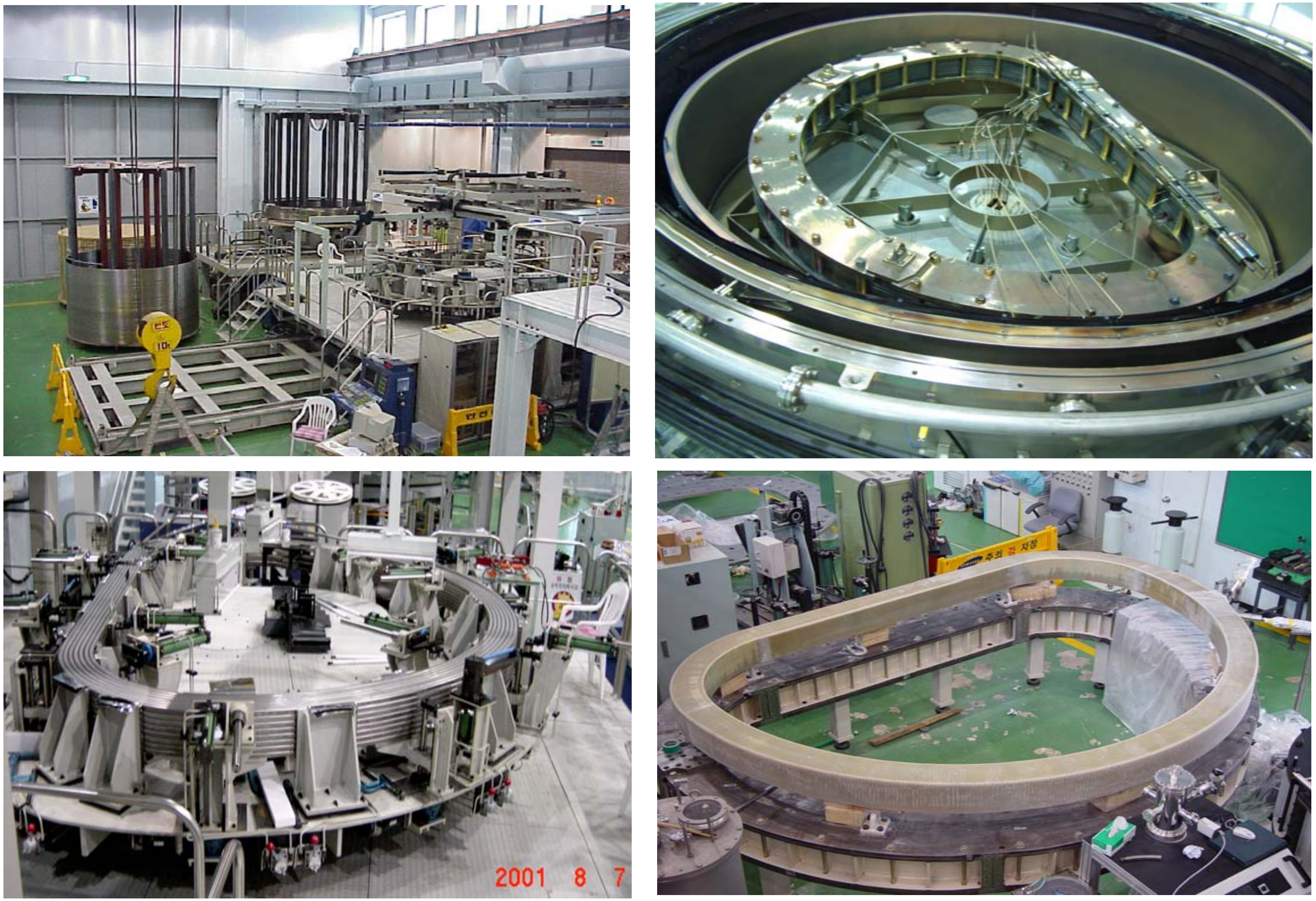
Formed Inter-coil Structure

Machined Inter-coil Structure

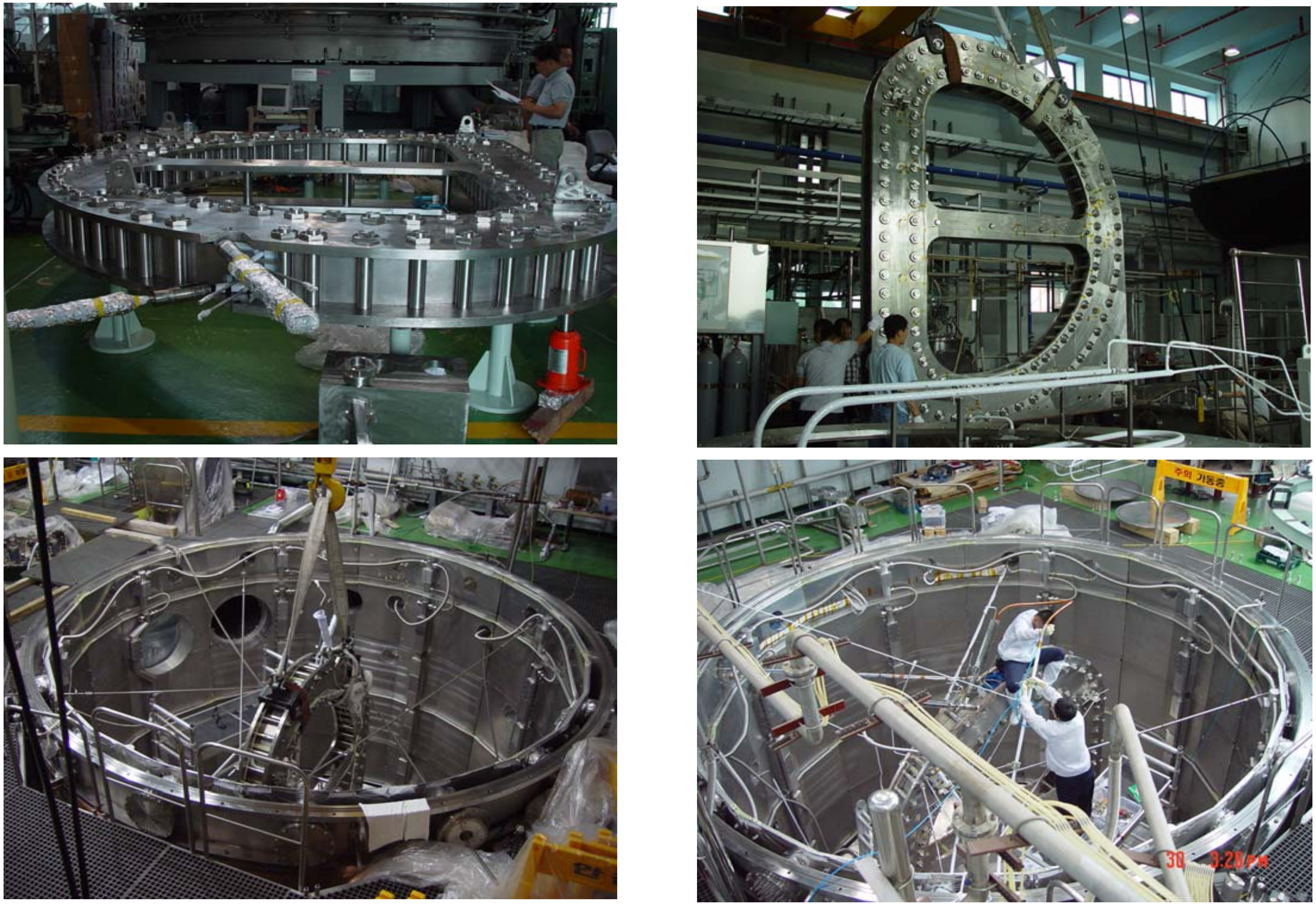
Welded with Connection Plate

Cover Structure

KSTAR SC TF Magnet Fabrication



Superconducting Magnet Test



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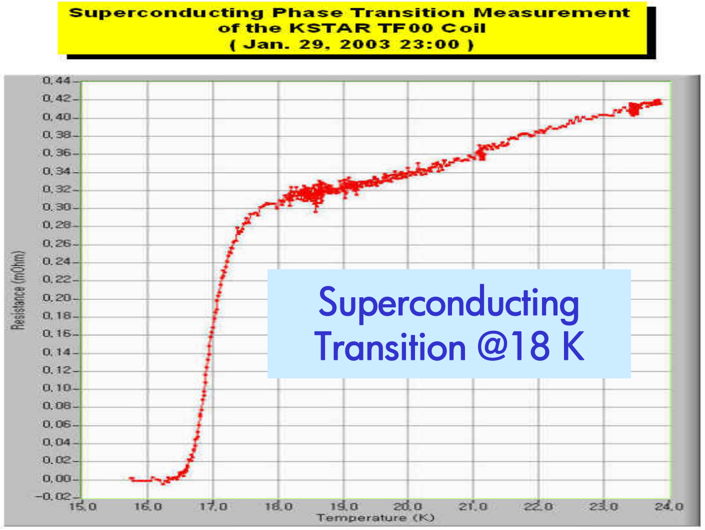
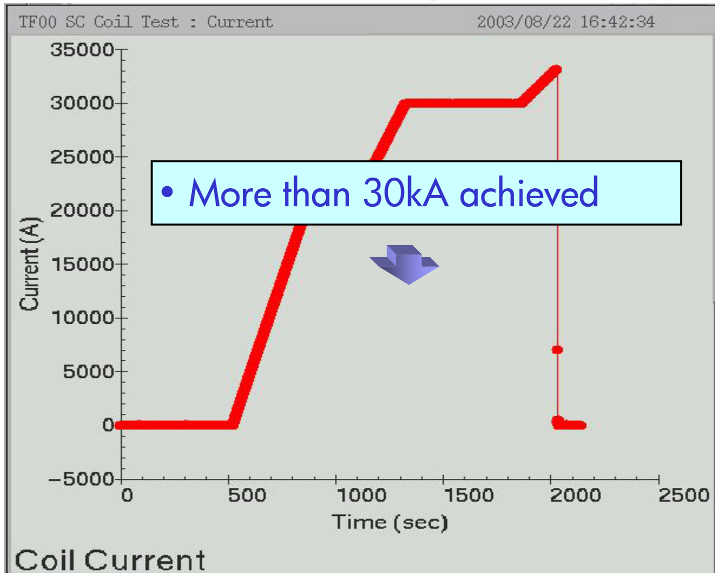
TF Superconducting Test



Superconducting Transition @18 K

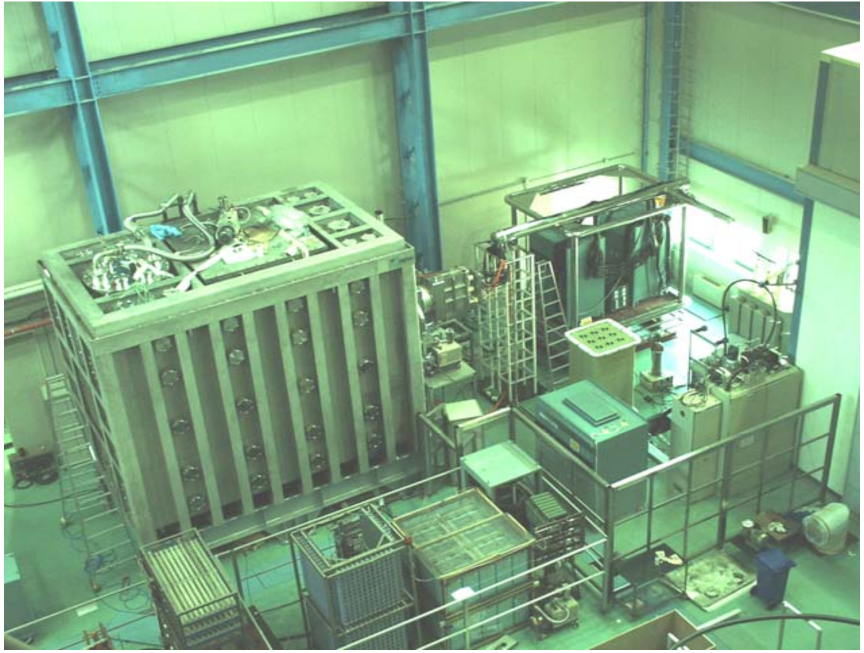
Coil Resistance vs. Temperature



- More than 30kA achieved

Heating System Development (KAERI)

NBI Heating System

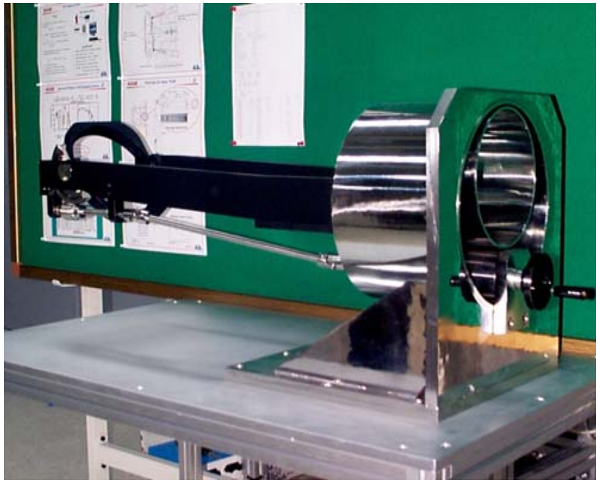


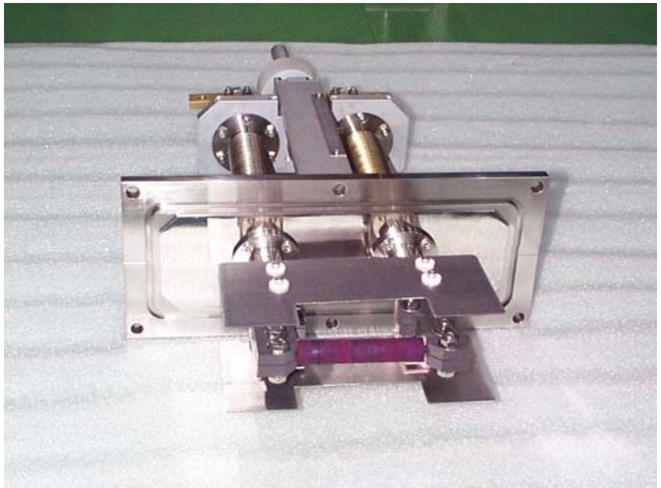
KAERI

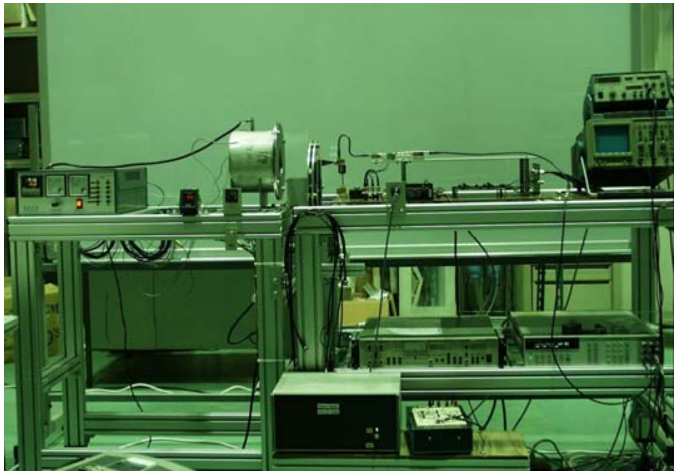
RF Heating System

MW Heating System

Diagnostics (KBSI, KAERI, KAIST, Univ.)







Power Supply Fabrication (POSCON, PAL)

POSCON

PAL 포항가속기연구소
POHANG ACCELERATOR LABORATORY

Industries Participating Fusion Program

PRISM

Wonshin

KO KOVA 韓國真空(株) KOREA VACUUM LIMITED

ESC

COMTECS

SAMSUNG

KISWIRE

SA SINCE 2000

HYUNDAI HEAVY INDUSTRIES CO.,LTD.

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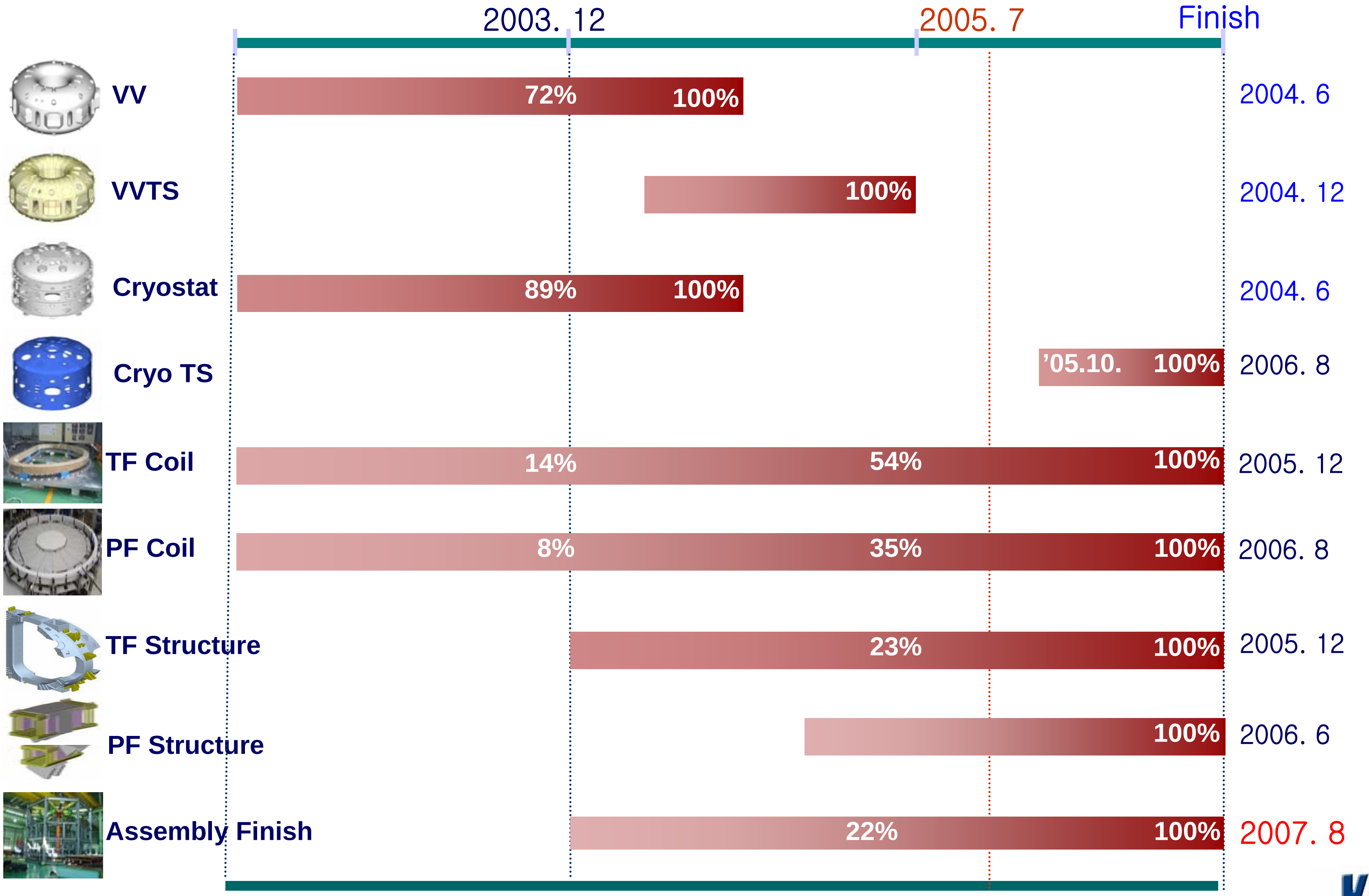
KSTAR Construction Progress



Fusion Research Activities in Korea

- Basic Plasma and Fusion Research at Universities : 1970's

- Construction of Small-scale Fusion Research Device : 1980-1990's
  - SNUT-79 Tokamak (SNU)
  - KT-1 Tokamak (KAERI)
  - KAIST Tokamak (KAIST)
  - HANBIT Tandem Mirror Device (KBSI)

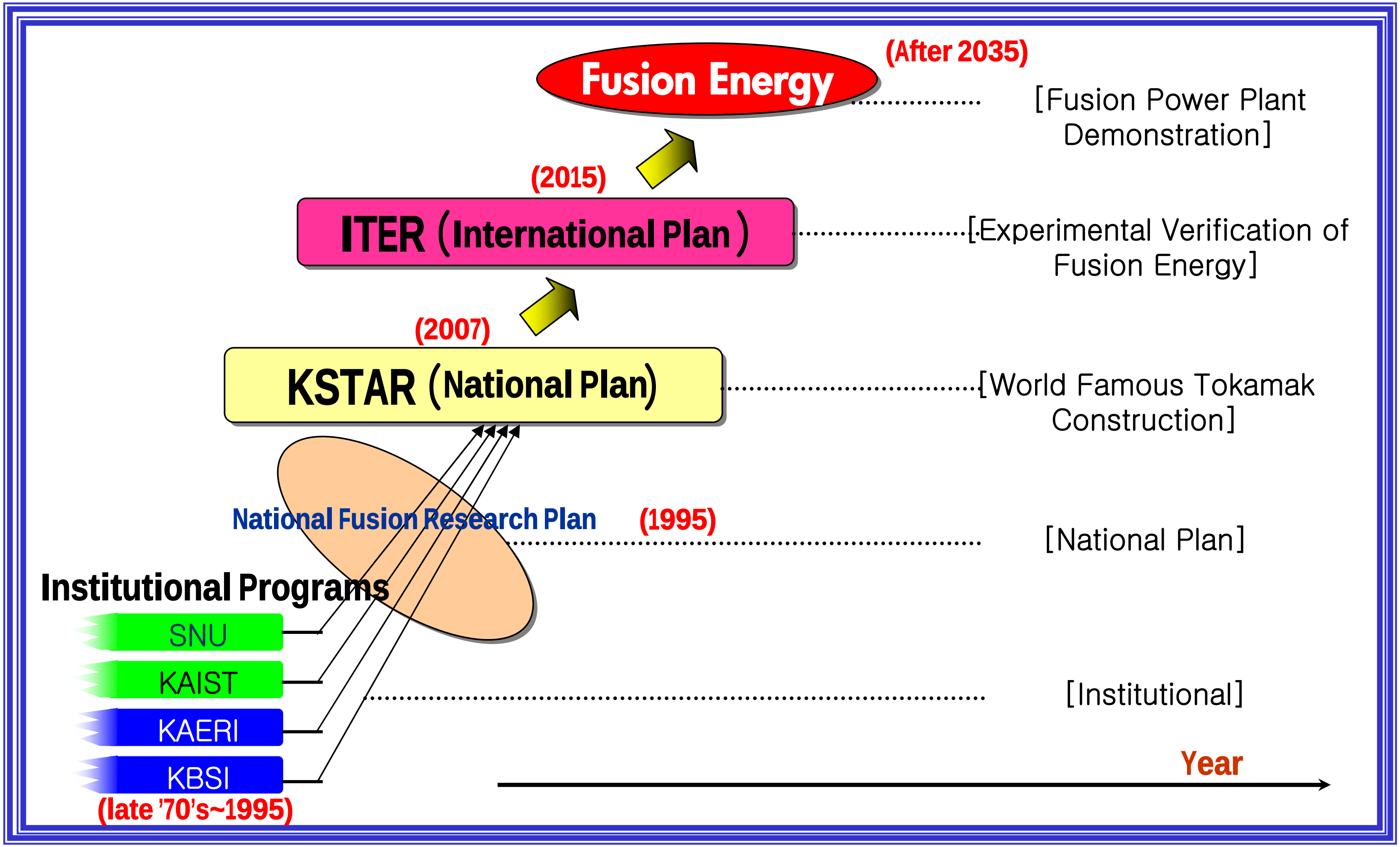
- KSTAR Tokamak Project (KBSI)
  - Will be constructed by 2007. 8
  - Operate as International Fusion Collaboratory

- ITER
  - KO Participation in June 2003

ITER Participation

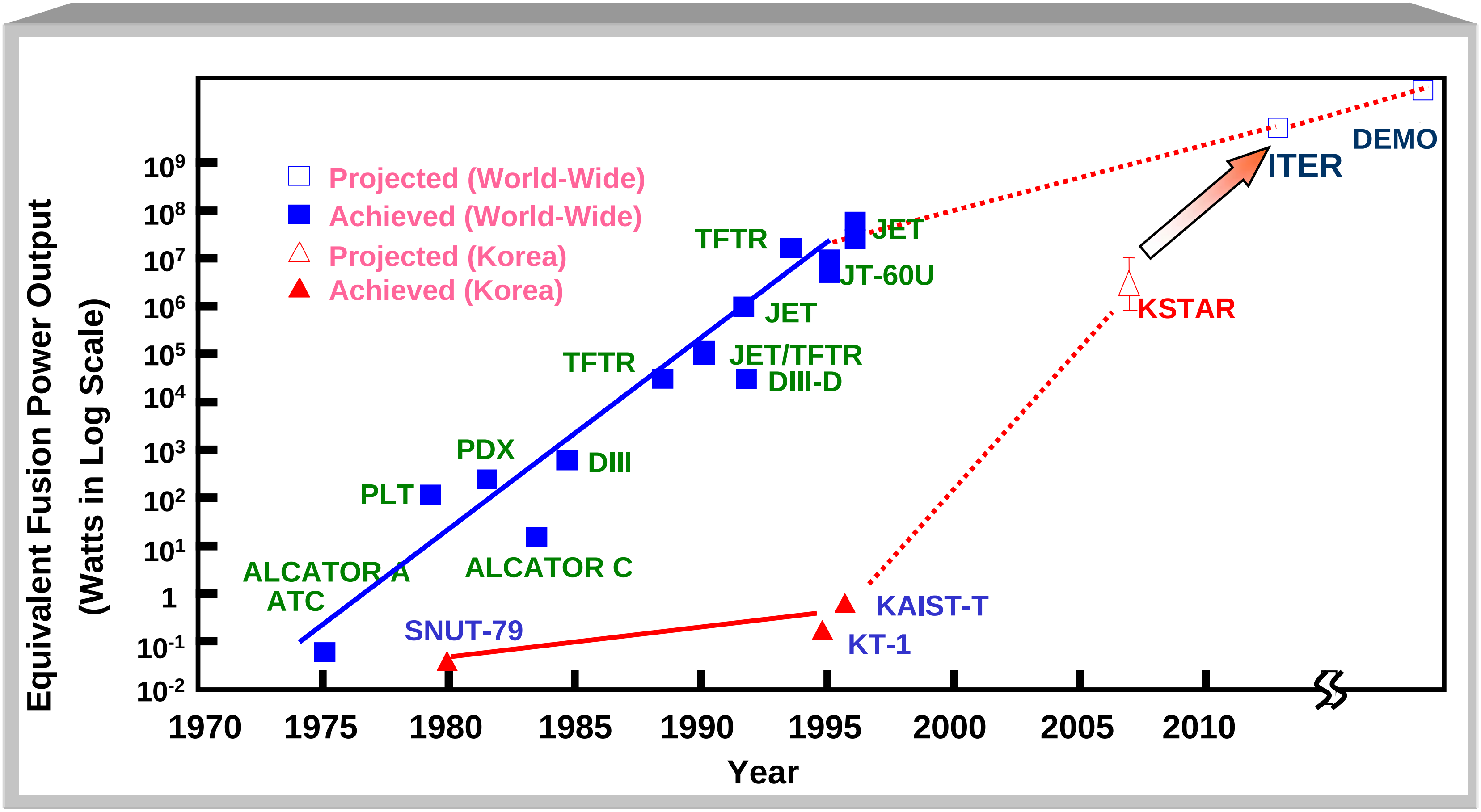
- KO’s Mid Entry
- Parameters
- The Site
- ITER’s Opportunity
- Korean Opportunity

KO's Fusion Research Strategy



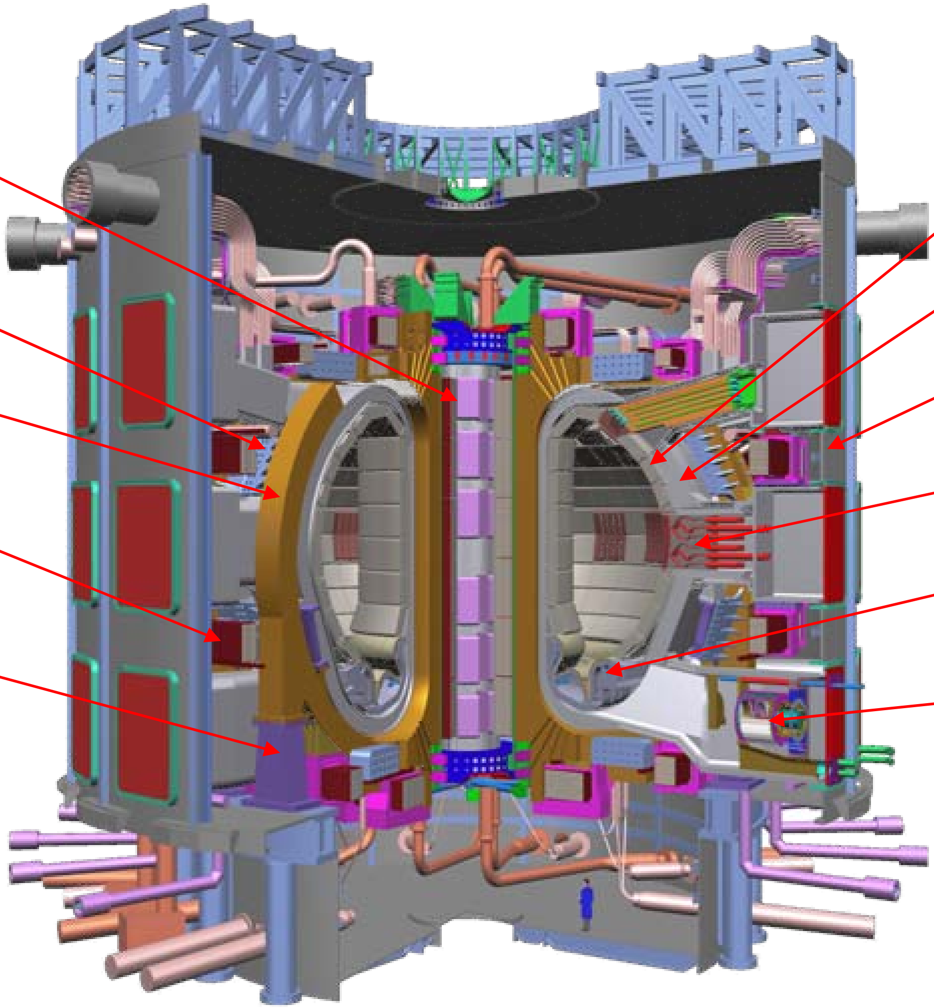
Korean Fusion Energy

KO's Mid Entry



Korean Fusion Energy

ITER Main Features



Central Solenoid

Outer Intercoil Structure

Toroidal Field Coil

Poloidal Field Coil

Machine Gravity Supports

Blanket Module

Vacuum Vessel

Cryostat

Port Plug

Divertor

Torus Cryopump

ITER Parameters

Total fusion power	500 MW (700MW)
Q = fusion power/auxiliary heating power	≥10
Average neutron wall loading	0.57 MW/m^2 (0.8 MW/m^2)
Plasma inductive burn time	≥ 300 s
Plasma major radius	6.2 m
Plasma minor radius	2.0 m
Plasma current (I_p)	15 MA (17.4 MA)
Vertical elongation @95% flux surface/separatrix	1.70/1.85
Triangularity @95% flux surface/separatrix	0.33/0.49
Safety factor @95% flux surface	3.0
Toroidal field @ 6.2 m radius	5.3 T
Plasma volume	837 m^3
Plasma surface	678 m^2
Installed auxiliary heating/current drive power	73 MW (100 MW)

ITER's Physics Opportunities

Capability to address the science of self-heated plasmas in reactor-relevant regimes and high β_N (plasma pressure), and with the capability of full non-inductive current drive sustained in near steady state conditions.

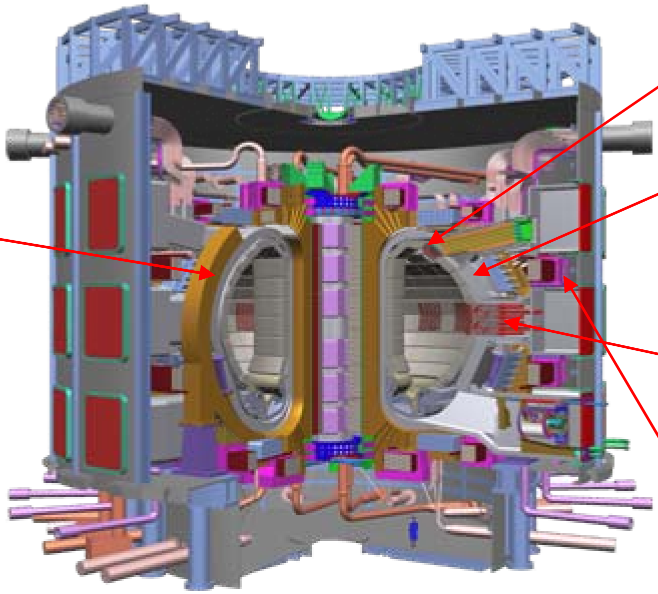
- Self-heated plasmas : Q ~ 5 (long pulse) to 10 (pulsed)
  - Exploration of alpha particle-driven instabilities in a reactor-relevant range of temperatures
- Exploration of high self-driven current regimes with a flexible array of heating, current drive, and rotational drive systems

ITER's Technology Opportunities

- Integration of steady-state reactor-relevant fusion technology
  - large-scale high-field superconducting magnets
  - long-pulse high-heat-load plasma-facing components
  - plasma control systems (heating, current drive, fueling, ...)
- Testing of blanket modules for breeding tritium

KO's Opportunity by ITER Participation

Tokamak



TF Conductor 20%

Assembly Tooling

About half of Whole Tools

Shield Blanket Modules 20%

Vacuum Vessel Main Body 20%

Vacuum Vessel Port 67%

Thermal Shield 100%

Auxiliary

Tritium Storage and Delivery 88% + Cash

Power Supply (AC/DC Converters) 65%

Diagnostics 4%

Other Contributions

- **ITER Organization Participation**
- **Cash Contribution, Test Blanket Modules (Tritium Breeding)**
- **Physics, Material, Safety, B/A (DEMO, Power Plant)**

We Need Tritium

- We Need Tritium
- Present Tritium Supply
- More Tritium Required for the Path to Fusion Energy

We Need Tritium

- Tritium used: 55.8 kg T/yr for 1000 MW_{fus} (includes alpha heat), 100% available

- Tritium bred : Fusion has never done this

- Tritium for next step :
  - ITER startup inventory estimated to be ~ 3 kg
  - DEMO startup inventory likely to be between 4-10 kg

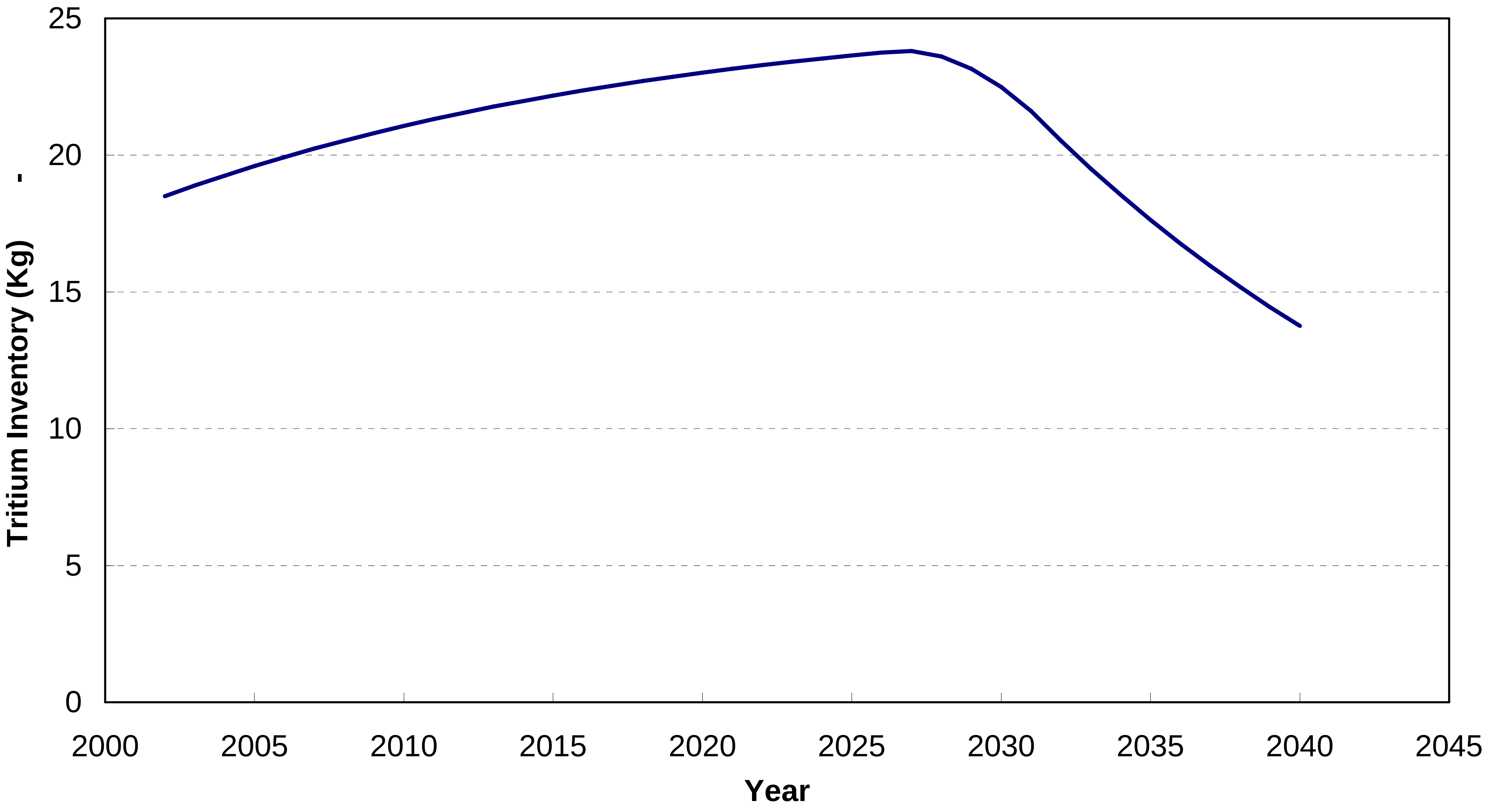
- Tritium available : 18.5 kg (2003)

- Tritium decays at a rate of 5.47% per year.

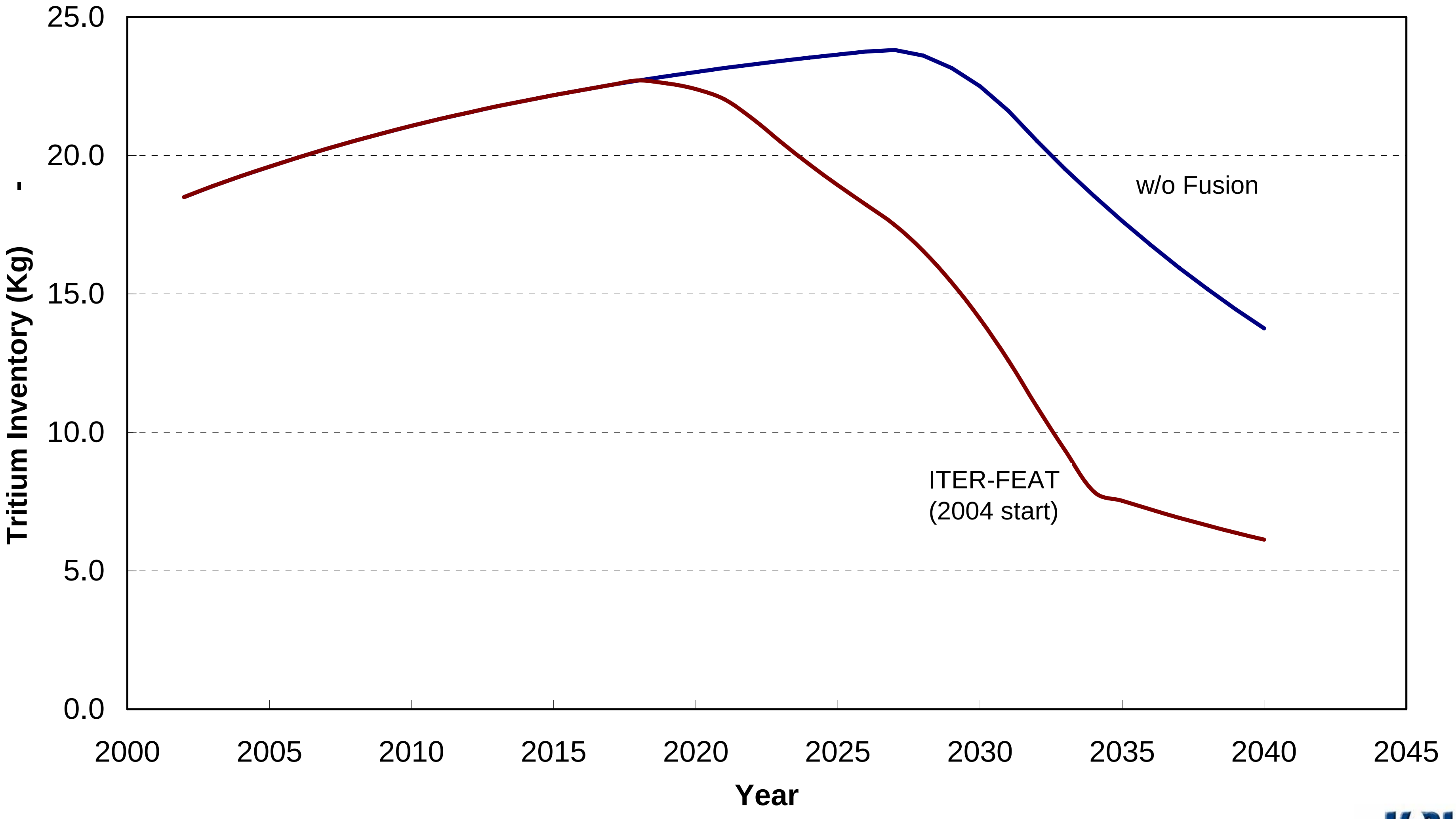
Generation Rate of Tritium in PHWR

Reaction	Generation Rate [Ci/MW yr]
^{6}Li(n, a) T ^{7}Li(n, na) T	1
^{10}B(n, 2a) T ^{10}B(n, a) ^{7}Li(n, na) T	0.0001
D(n, γ) T - Moderator - Coolant	2,340 60
Total	2,400

Projected Canadian tritium inventory without major impact from fusion



ITER will have a big impact on tritium supply



We Need More Tritium

- Tritium available for fusion development will likely begin to diminish rapidly during the next 35 years
- Fusion should be developed expeditiously to take advantage of this unique opportunity
- Development of D-T fusion must be carefully planned world-wide taking into account available tritium
  - Experiments without breeding must be low power and/or low availability (ITER-FEAT appears okay. . .but barely so)
  - Sufficient tritium must be left for next steps
  - Significant losses of tritium must be carefully avoided
- ITER-FEAT may change the operation level to require more tritium.

Additional Korean Tritium Supply

- Wolsong Tritium Removal Facility (WTRF) is now under construction to remove the tritium from heavy water at CANDU reactors in Korea.
- WTRF will start its operation at the end of this year.
- That means that more than 10 kg of tritium from Korea is available additionally.
- Additional Korean tritium supply can be a marginal source to the startup inventories and the consumption in ITER and DEMO.
- Korea is to deliver the tritium storage and delivery system to ITER and this can be very good opportunity to take advantage of Korean tritium supply.

Fusion Tritium Self-Sufficiency

- For the commercial fusion power plants, the achievable tritium breeding ratio should be somewhat larger than the required tritium breeding ratio for self-sufficiency.

- The achievable tritium breeding ratio is a function of technology, material and physics.

- Most of our works on Korean fusion energy development path should be focused on increasing the achievable tritium breeding ratio by the developments of technology, material and physics.

Korean Fusion Energy Development Path

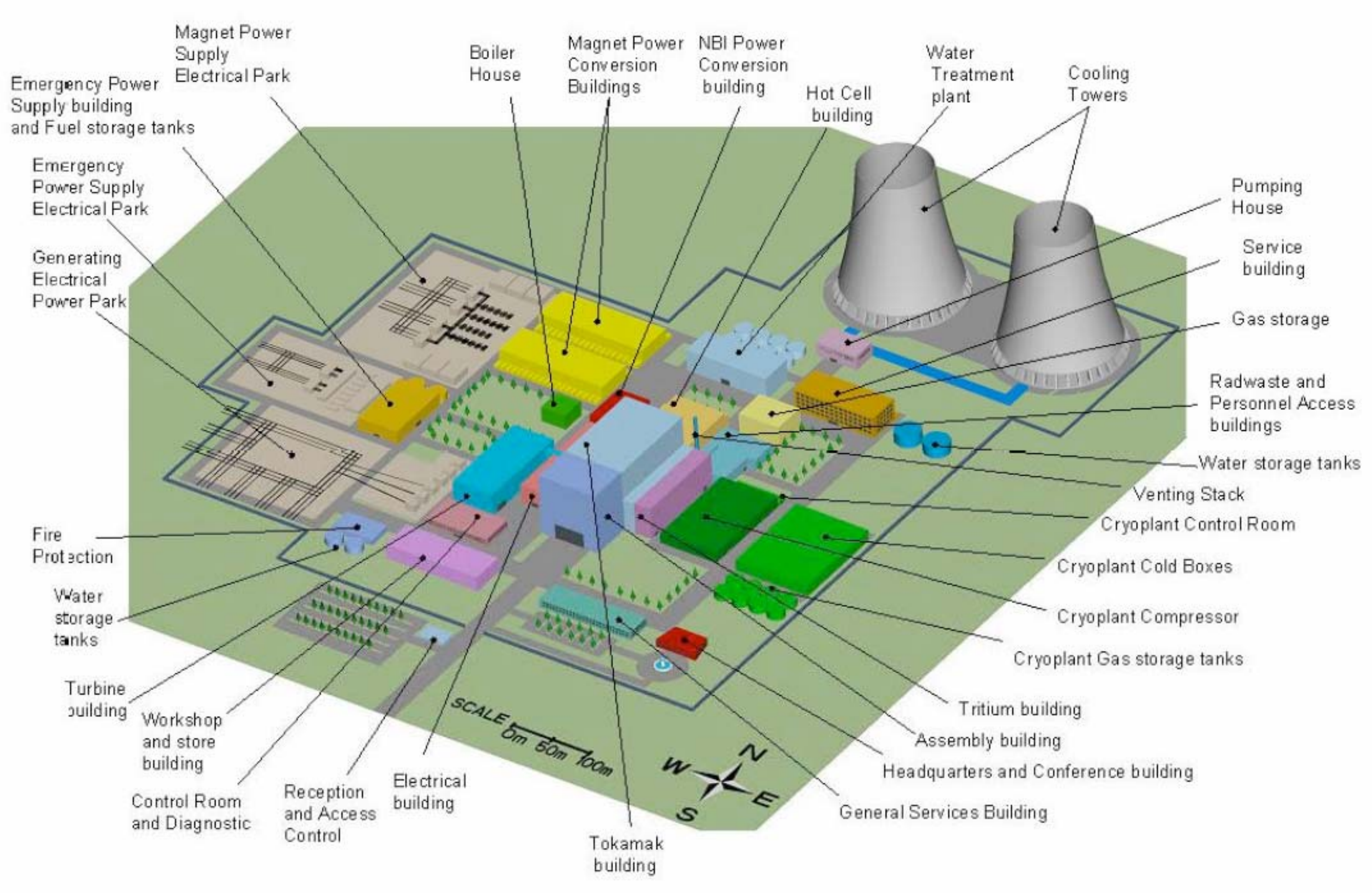
- Fusion Power Plant Study
- Korean Fusion Energy Development Path
- DEMO Concept
- ITER Test Blanket Module
- Korean Unification

Fusion Power

- Ultimate & Clean Energy
- Tritium can be recycled in Fusion Power Plants.
- Fusion is the only known technology capable in principle of producing a large fraction of world's electricity.
- We should burn our oil to develop Fusion Power Plants.

Korean
Fusion
Energy

Fusion Power Plant General Layout



From European PPCS Report

Korean Fusion Power Plant Study

- Should be launched soon.
  - KO has a substantial nuclear infrastructure which shares technologies with nuclear fusion.
  - KO would be serious about the development of the fusion energy.
- The information accumulated in and out of Korea is being investigated.
- Systems code varies the parameters of the possible designs, subject to assigned plasma physics and technology rules and limits, to produce economic optimum.

Korean Fusion Power Plant Study

- Plasma physics concerns
- Cost concerns
- Material concerns
- Maintenance concerns
- Safety concerns

- Outputs
  - Keep the cost of electricity lower
  - Keep safety and environmental features excellent (external costs [to health, environment] ~ wind power)
  - Economically acceptable fusion power stations, with major safety and environmental advantages, seem to be accessible on a fast- track through ITER + material testing by IFMIF (but without major material advances)

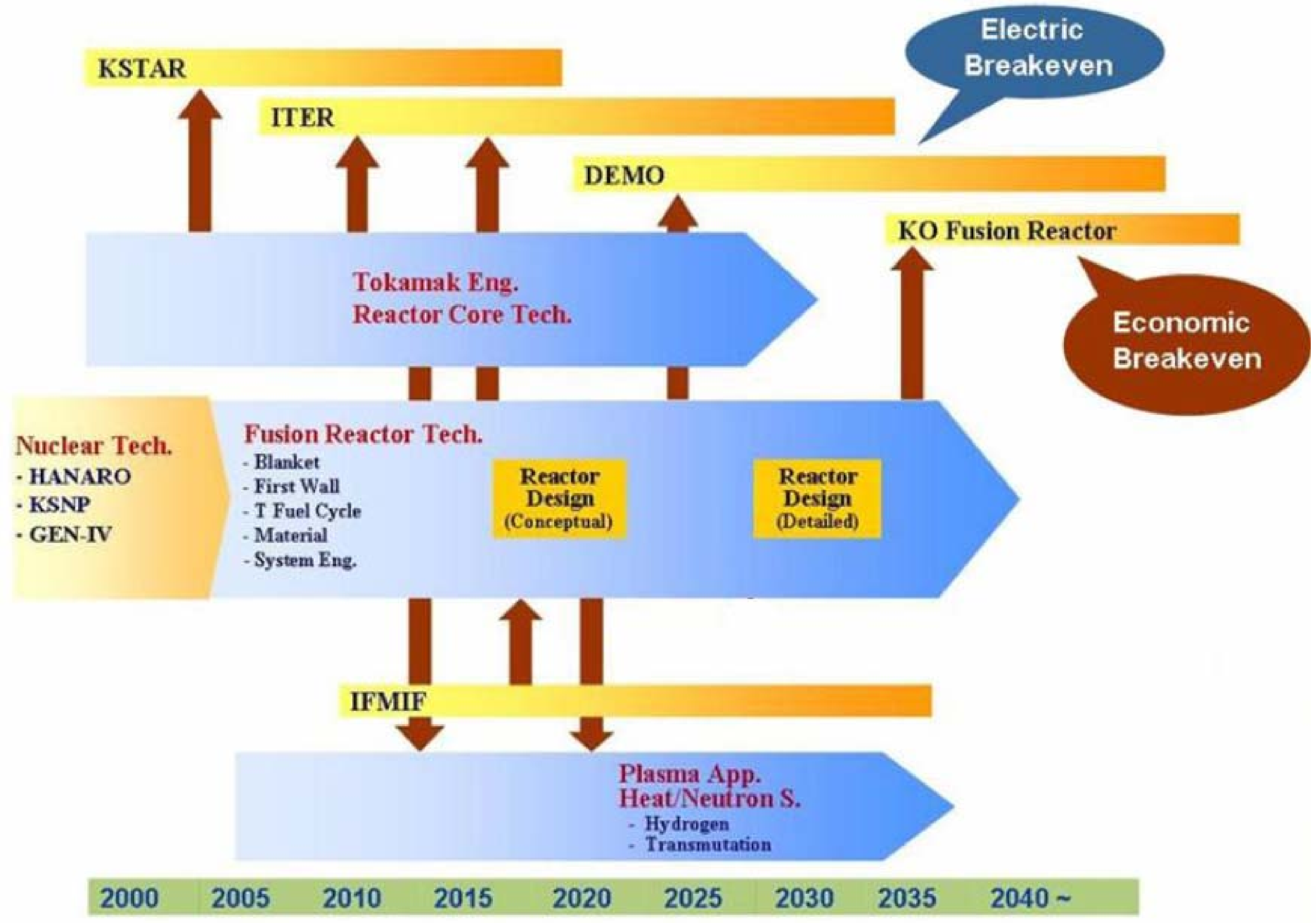
Current Strategy

- The world needs major sources of (environmentally responsible) energy.
- Fusion is one of very few options.
- Korean Fusion Power Plant Studies → time to move to a project oriented approach → fast track → DEMO → KFPP
  - This will require a change in mind set, organisation and funding.
  - First steps are
    - fusion community → agree an guiding fast track model
    - government → funding to turn aspirations to reality

Korean Fusion Energy

Korean Fusion Energy Development Path

- To be approved at National Science & Technology Council



KO DEMO

- DEMO is regarded as the last step before commercial fusion reactor.

- Requirements of DEMO
  - It should demonstrate a net electric power generation.
  - It should demonstrate a tritium self sufficiency.
  - Blanket system should have a reasonably high thermal efficiency to show an extraction of high-grade heat and positive evidence of a low COE.
  - It should demonstrate the safety aspect of a power plant and it should be licensable as a power plant.

KO DEMO

- With limited extension of the expected plasma physics and technology from the 2nd phase of the ITER operation, major technical parameters can be derived (System code analyses).
  - Fusion Power is about 2 GW for a net electricity generation
  - Neutron wall loading is above 2.0 MW/m^2
  - Maximum FW heat flux is less than 1.0 MW/m^2
  - Low-activation structural material is used
  - Thermal efficiency is above 30%

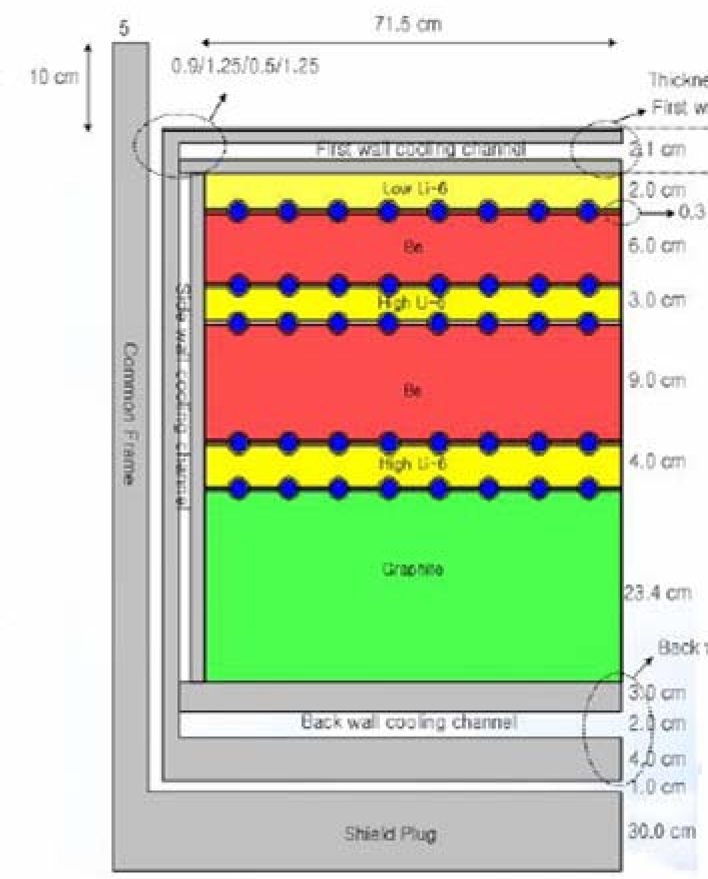
Korean ITER Test Blanket Module

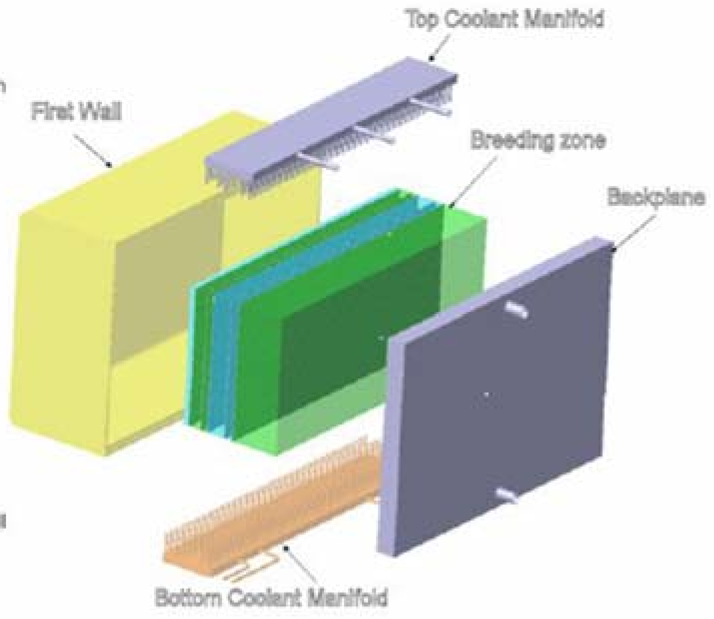
- Solid Breeder
  - Technically mature and all 6 parties have interests
  - Conceptual design of HCSB with graphic reflector is underway
  - Small size sub-module will be tested from a day-one operation of ITER and independent TBM will be tested from a later phase (D-T phase) of the ITER operation.
- Liquid Breeder
  - Conceptual design of He-cooled Li-breeder/FS (HCML) is underway
  - HCML TBM will be tested from a day-one operation of the ITER
- Also interests in the R&D progresses of other TBM families
  - Will contribute to the development of TBMs through collaboration
  - Blanket concept as well as the DEMO concept needs to be updated based on the R&D achievements

HCSB TBM

- Reduce Be multiplier by using graphite reflector
  - Optionally Pb multiplier
- Solid Breeders
  - Li_4SiO_4 (62% packing fraction)
  - Low Li-6 : 40% enrichment
- Be multiplier : 80% packing fraction
- Graphite reflectors
  - 85% packing fraction
  - Can be used as a heat sink
- Structural material : EUROFER

Design of HCSB TBM



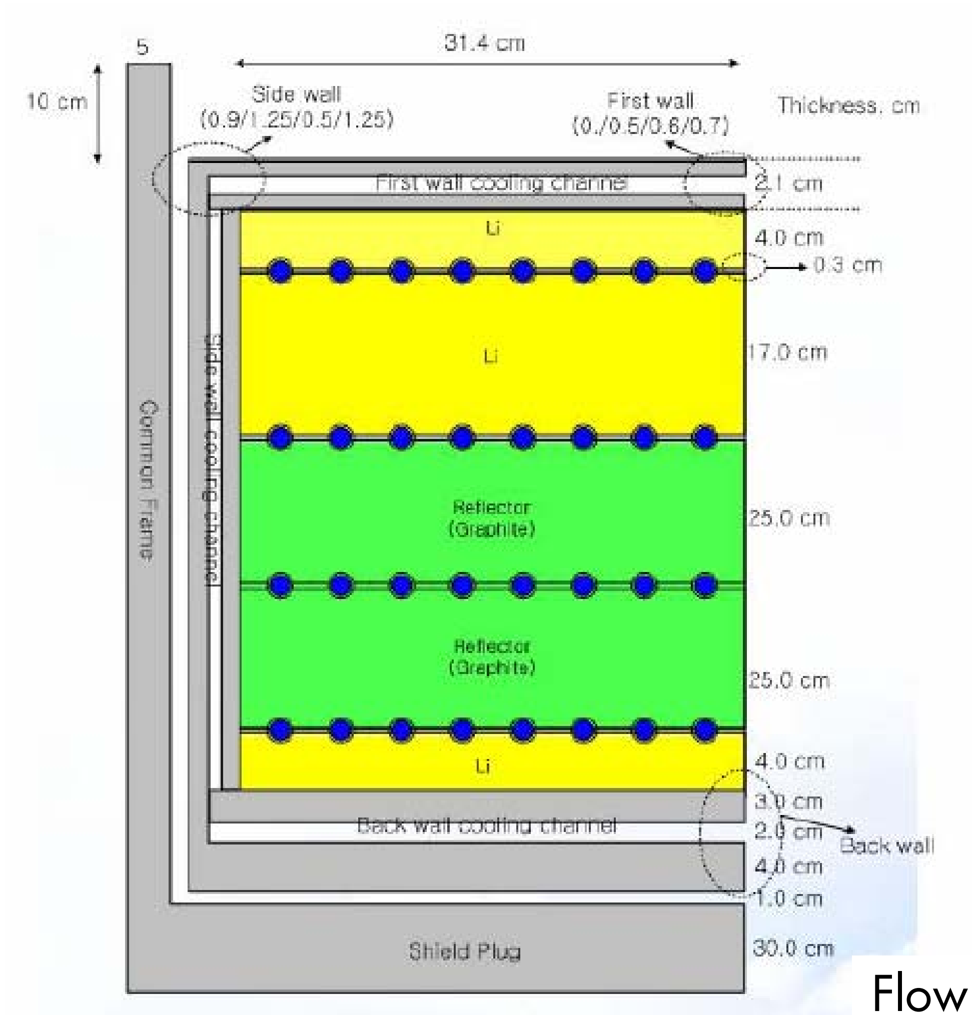


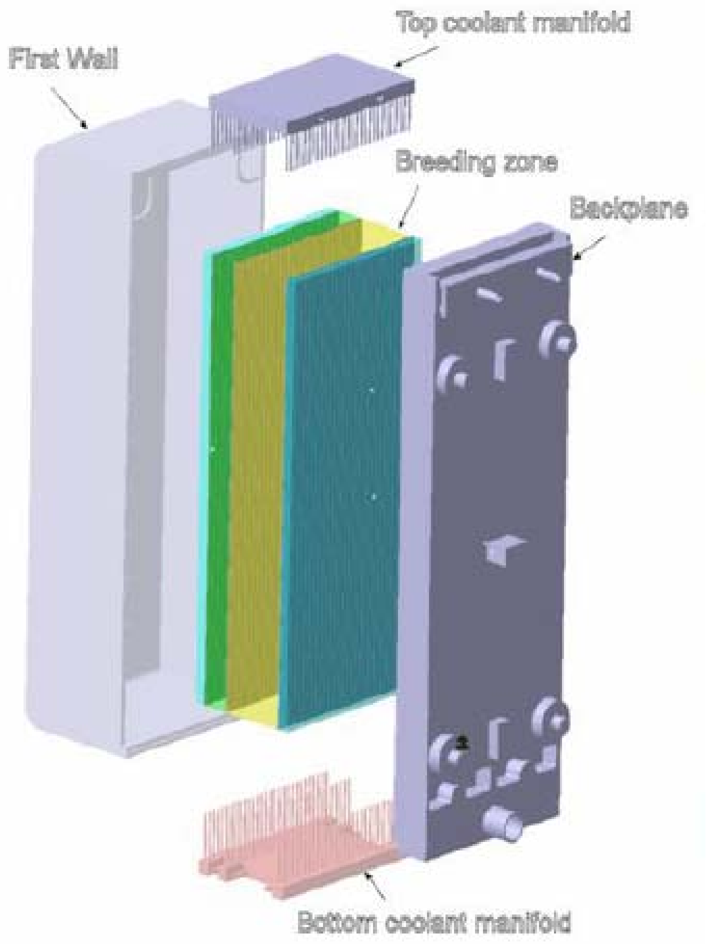
Flow path : FW → SW → Breeding zone

HCML TBM

- Cooled by He coolant
- Molten Li is breeder (Li speed < 1cm/sec)
  - No concern about MHD & material corrosions
  - Li-6 enrichment is 12 wt%
  - Li loop as a redundant cooling circuit in case of LOCA
- Pebble-bed type graphite reflector
  - No need for neutron multiplier
  - Reduced Li Volume (~28 Liters)
  - Maximizing TBR & minimizing neutron leakage
- Structural material : EUROFER
  - FS and Li is compatible up to 550°C

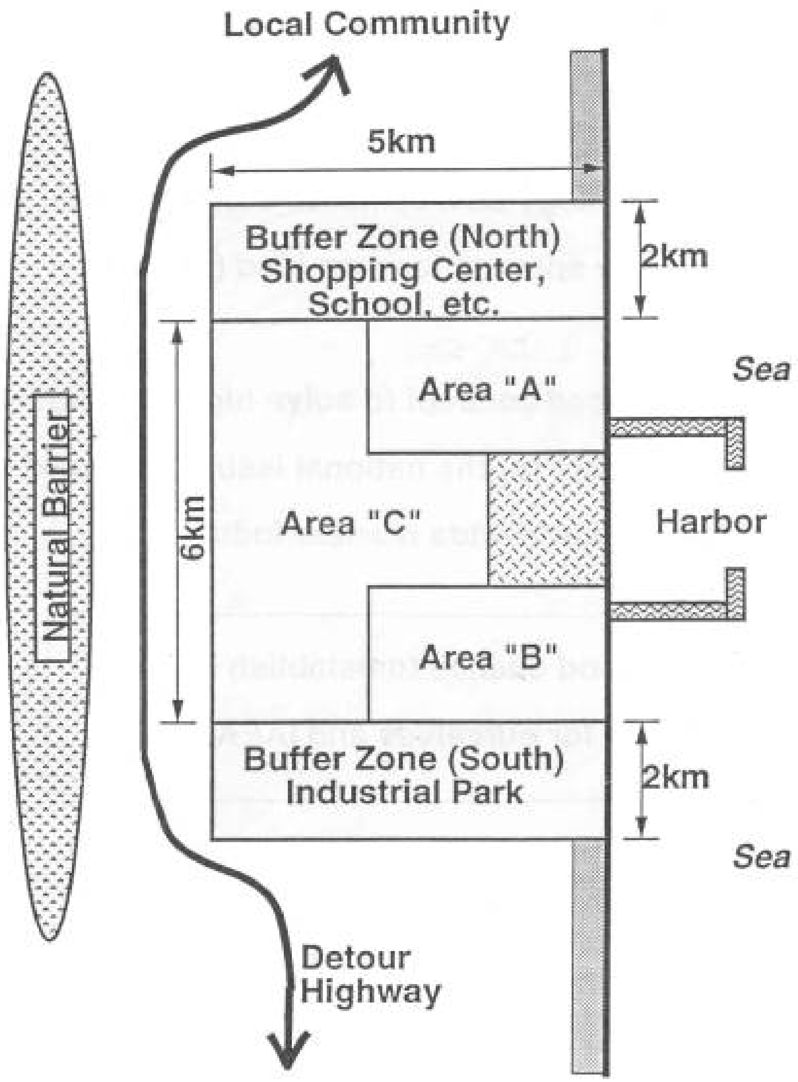
Design of HCML TBM





Flow path : FW → SW → Breeding zone

International Center for Energy Research



Proto/DEMO Fusion Reactor in "Unified Korea" !

Presented at

1992 KAPRA & KPS/DDP JOINT WORKSHOP

Proceedings on Accelerator and Plasma Research

Leading Nuclear Industry in the 21 C

July 14, 1992

Korea Atomic Energy Research Institute

Daejeon, KOREA