8th IAEA DEMO Workshop
August 30-September 2, 2022
Vienna International Center, Vienna, Austria

KO facilities anticipated for DEMO preparation

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On behalf of KO TBM Teams and Fusion Engineering Research Facility TFT

한국핵융합에너지연구원
KOREA INSTITUTE OF FUSION ENERGY

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Introduction

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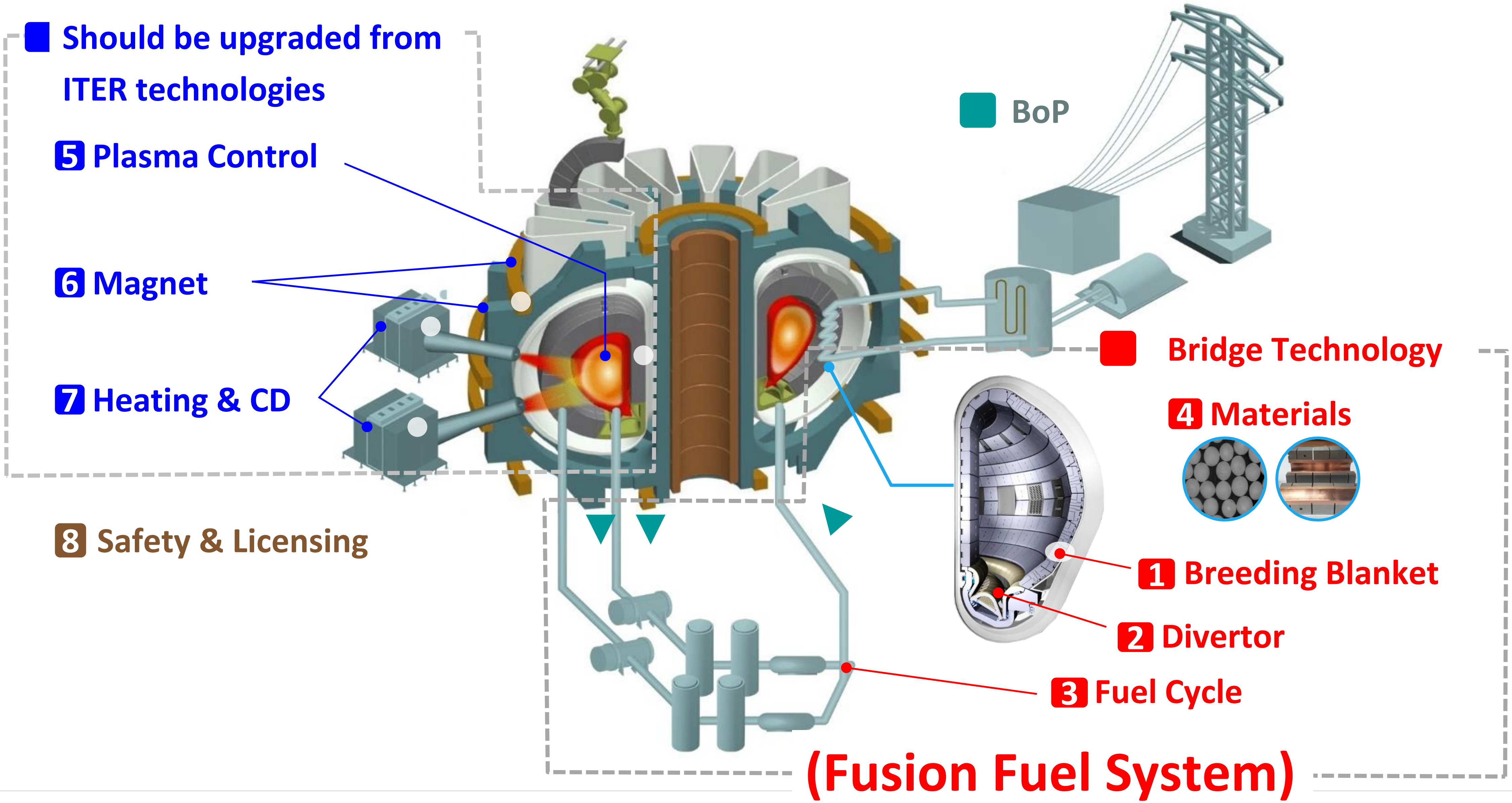
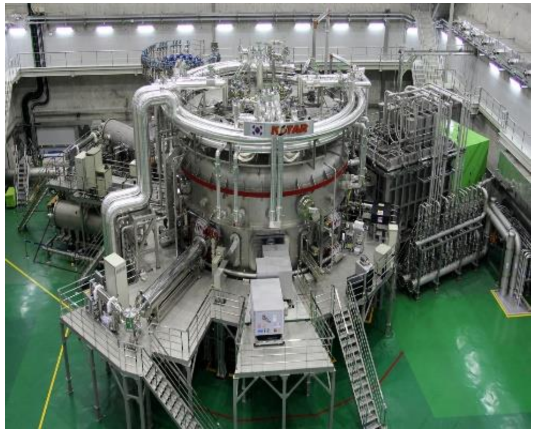
Core Technologies for DEMO



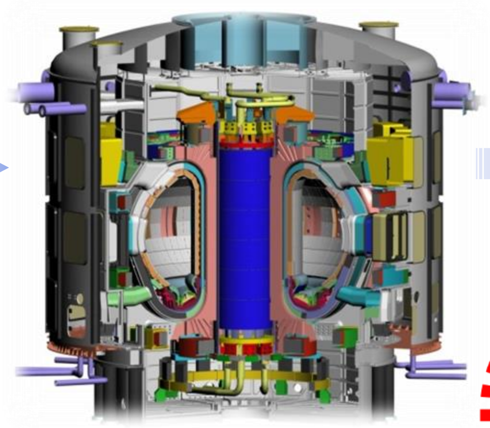
The Most Important Gap Technology

KSTAR



High Performance
Plasma Control

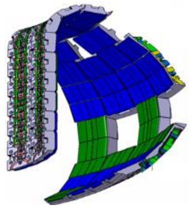
ITER



Burning Plasma
Demonstration

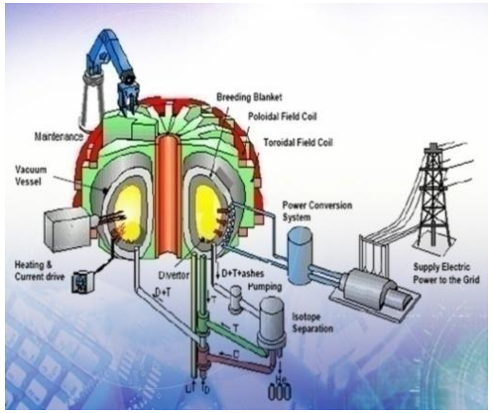
ITER TBM Program

Fusion Fuel System
(Breeding Blanket)



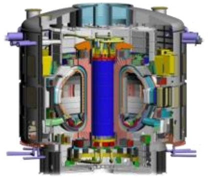
Tritium self-Sufficiency
Energy Extraction
Long-term Continuous

DEMO

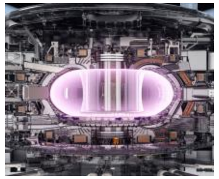


Net Electricity Demo
Commercial Feasibility

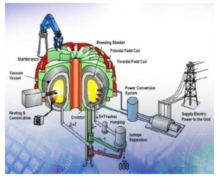
Roadmap for Demonstration of Producing Electricity



ITER
First Plasma



ITER
Burning Plasma



Net Electricity
Demonstration

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

Establish R&D infrastructure
(Fusion Fuel System)

Golden Time

Decision/Start
Construction
of DEMO

Secure Gap Technologies btw. ITER and DEMO

Turning point
of Fusion Energy Development

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KO DEMO Breeding Blanket Concepts

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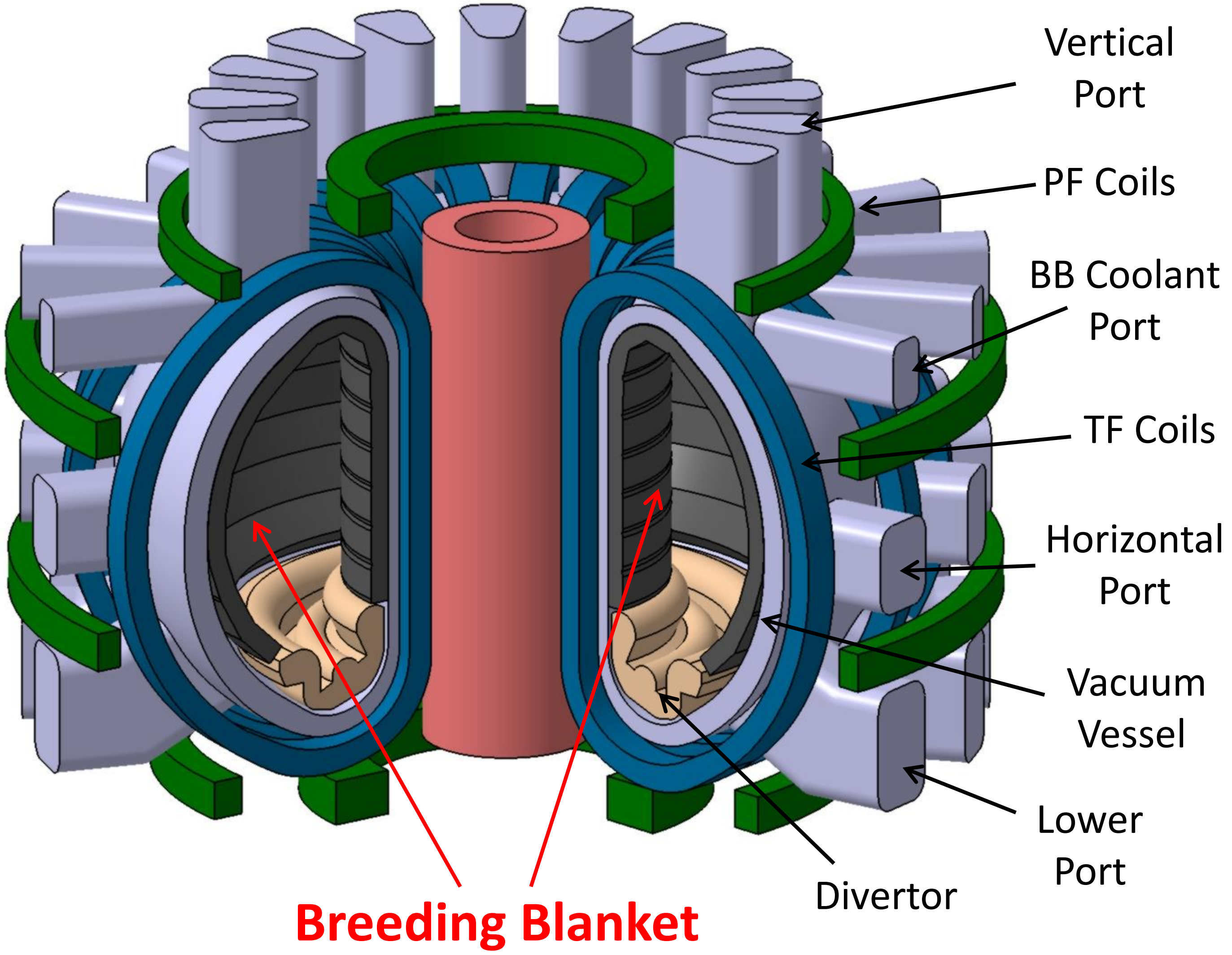
KO DEMO Breeding Blanket Operating Conditions

- The breeding blanket which fully surrounds the plasma and contains the Fist Wall (FW), is exposed to severe working conditions, in particular:
  - High surface heat flux: > 0.5 MW/m^2 on FW
  - High neutron wall loading : ~1.5 MW/m^2
  - Long irradiation time, at least 5 years: 20~50 dpa(Fe) in FW
  - Operation in vacuum (plasma) → low coolant leakages
  - High magnetic field (~7 Tesla)



KO Breeding Blanket Concept

- Helium-cooled ceramic reflector (HCCR) blanket
  - Adopted to be tested in ITER
  - To be merged to HCCP blanket based on the KO-EU TBM Collaboration Partnership Arrangement
- HCCP (Helium Cooled Ceramic Pebble) TBM : joint KO/EU TBM based on EU HCPB TBM concept
  - EU materials will be chosen in the first TBM, and KO materials in the second TBM

Parameters	HCCR DEMO	ITER HCCR TBM	ITER HCCP TBM
FW Heat Flux	0.5 MW/m^2	0.3 MW/m^2	0.3 MW/m^2
Neutron Wall Loading	1.5 MW/m^2(avg)	0.78 MW/m^2	0.78 MW/m^2
First Wall Armor	Tungsten/Vanadium	-	-
Structural Material	ARAA	ARAA	EUROFER-97
Breeder	Li_2TiO_3	Li_2TiO_3	Li_2TiO_3 or Li_4SiO_4
Neutron Multiplier	Be or Beryllide	Be Pebbles	Be Pebbles
Reflector	Graphite	Graphite	-
Primary Coolant	Helium	Helium	Helium
Coolant Inlet/outlet Temperature	300/500 ^oC	300/500 ^oC	300/500 ^oC
Coolant Pressure	8 MPa	8 MPa	8 MPa
Purge Gas	He with 0.1% H_2	He with 0.1% H_2	He with 0.1% H_2
Enrichment (^6Li)	90%	70%	40-60%

Comparison ITER/DEMO Operating Condition

Parameters	ITER H phase Design Values	ITER DT phase Design Values	KO DEMO	Comparison ITER versus DEMO
Surface heat flux on First Wall (MW/m^2)	**0.17** (typical 0.08)	**0.30** (typical 0.15)	**0.5**	Lower but relevant for DEMO using engineering scaling
Neutron wall load (MW/m^2)	-	**0.78**	**~1.5**	Lower but relevant for DEMO using engineering scaling
Pulse length (sec)	Up to **400**	400 /up to **3000**	(Quasi-) Continuous	Much shorter, need of tests in other appropriate facilities
Duty cycle	**0.22**	**> 0.22**	-	-
Average neutron fluence on First Wall (MWa/m^2)	-	**0.1** *(first 10 y)* **up to 0.3** *(EOF)*	**3.5**	Much lower, need of tests in other appropriate facilities

- Except for the long-term continuous neutron irradiation effects, the tritium breeding blanket performance and behavior can be validated in ITER by operating the Test Blanket Systems provided the TBMs are made with the same materials and technologies as for the DEMO Breeding Blankets.

  → Additional facilities are required to test the performance of a long-term breeding blanket in a fusion-like environment.

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DEMO Blanket Research Facilities in KO (Plan)

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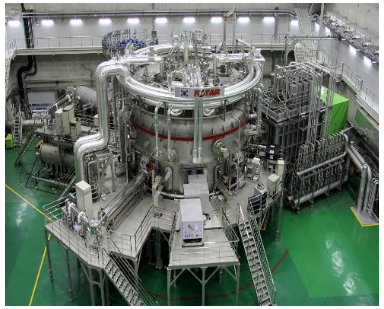
Gap Technology between ITER TBM and DEMO Blanket

KSTAR



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Plasma Control

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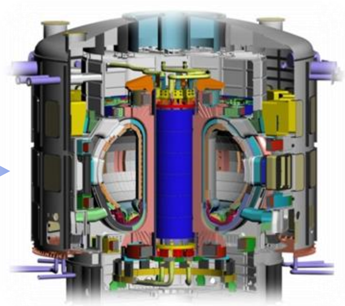

Burning Plasma
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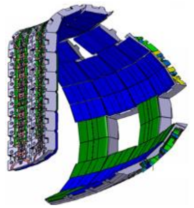
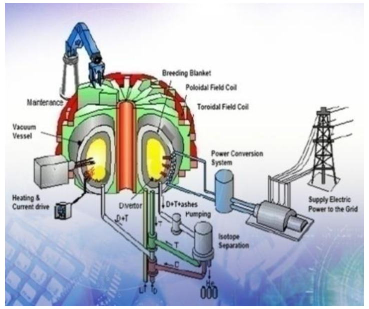
ITER TBM Program

Fusion Fuel System



Tritium self-Sufficiency
Energy Extraction
Long-term Continuous

DEMO

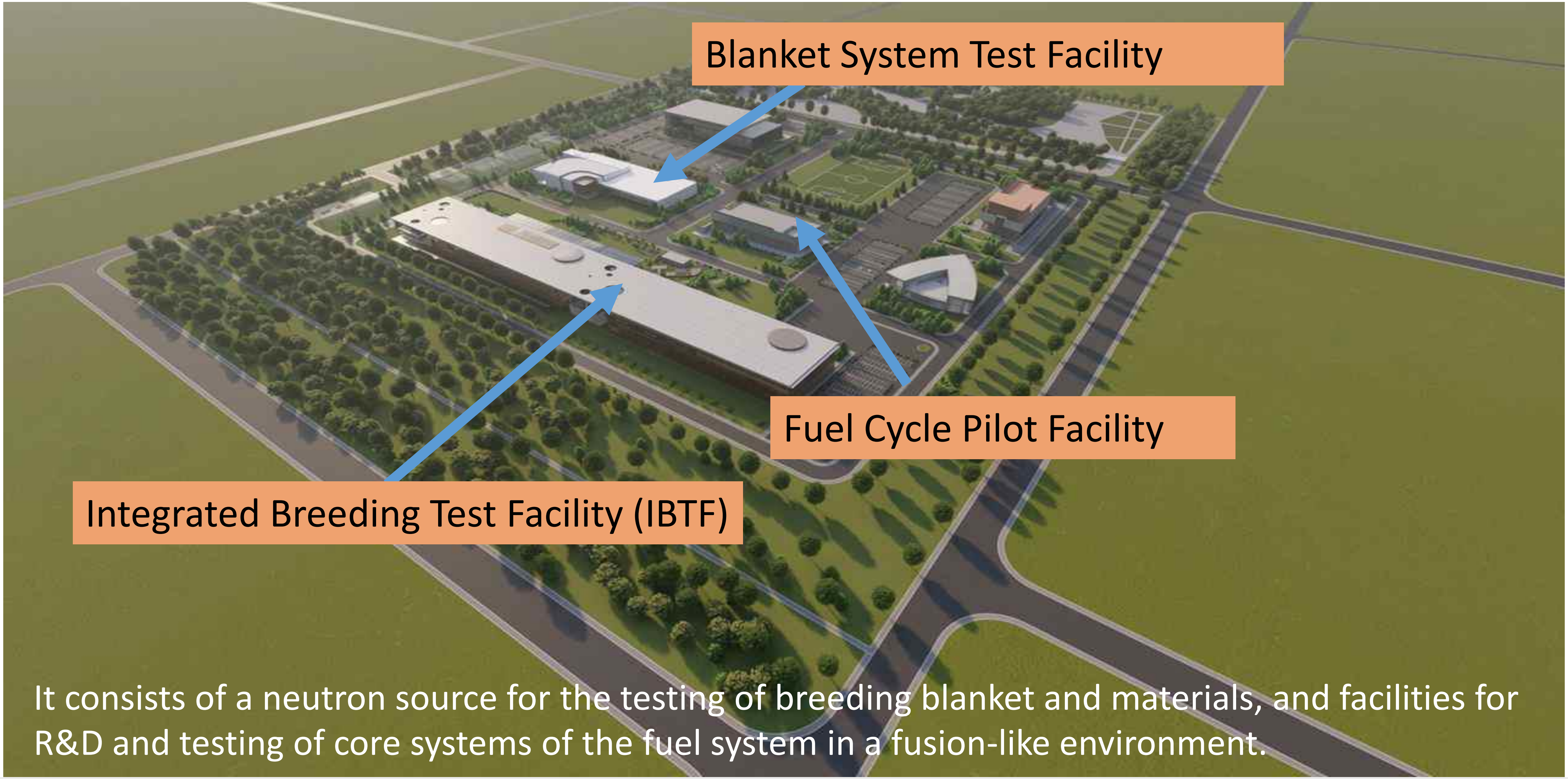


Net Electricity Demo
Commercial Feasibility

Korea Fusion Engineering Advanced Test Complex (KFEAT) Project :

Facilities to demonstrate engineering solution for fuel self-sufficiency and energy extraction and to develop and verify fuel systems in a fusion-like environment

Korea Fusion Engineering Advanced Test Complex (KFEAT)



It consists of a neutron source for the testing of breeding blanket and materials, and facilities for R&D and testing of core systems of the fuel system in a fusion-like environment.

Difference and Synergy between ITER TBM and KFEAT

ITER TBM

- Verification of the validity of the Breeding Blanket (BB) in ITER condition
  - TBM is a unique opportunity to demonstrate the a BB concept in a fusion environment
  - The developed design and core technology must pass the ITER's verification process, and a license must be obtained from the French regulatory agency, so important experience and data for future nuclear fusion safety and licensing can be secured.

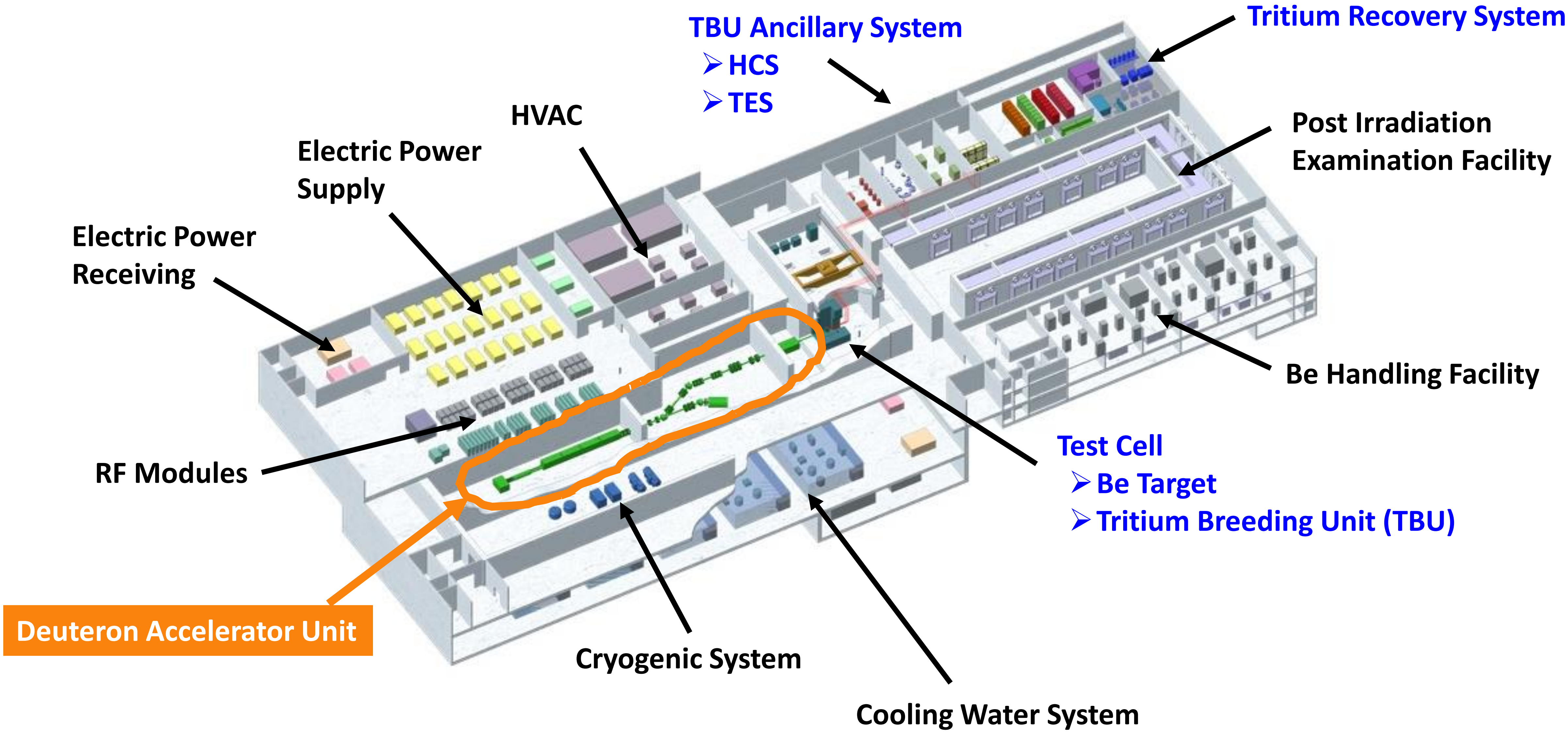
Synergy

- Share the experience of construction codes and securing of safety/licensing in design/construction/operation stage.
- Share the results of demonstration of tritium breeding and heat extraction in a fusion (-like) environment
- Share the verification of the DEMO-relevant process and reliability

KFEAT

- Verification of the design of the DEMO breeding blanket system in fusion-like environment
  - For DEMO aiming to produce large-capacity electricity, it is essential to design a BB suitable for (quasi) continuous operation and verify it
  - Verification of the performance (tritium generation/recovery rate and heat extraction, etc.) and structural integrity of the BB in a long-term continuous irradiation environment
  - Verification of reliability, such as data (failure rate, repair time, replacement cycle, etc.) for long-term operation of the BB system.

Integrated Breeding Test Facility (IBTF) (1/9)



IBTF (Integrated Breeding Test Facility) (2/9)

- Dedicated long-term neutron irradiation facility for breeding blanket test under fusion-like environment
  - Validation of performance and structural integrity under DEMO-relevant irradiation time and scenario ((quasi-)steady-state)
  - Demonstration of long-term reliability
  - Testing flexibility for DEMO blanket candidates
  - Securing engineering data for the design of the DEMO breeding blanket under fusion-like environment
  - Measuring the tritium breeding ratio using a breeding blanket 1:1 scale mockup that reflects the actual design
  - Verifying the possibility to produce and extract tritium
  - Verifying the design lifespan and safety of breeding blanket materials
  - Experience of tritium management and handling technology

Integrated Breeding Test Facility (IBTF) (3/9)

Requirements/Capability

- To Provide nuclear fusion-like environmental conditions for the test of the breeding blanket mock-up (Breeding Unit)
  - Provides >10^{12} n/cm^2/s of neutron flux and >10 MeV of neutron energy for more than 24 hours continuously
  - Securing an irradiation area of 20X20 cm^2 for Breeding Unit testing
  - Securing space/facility for installation/replacement of Breeding Units, and post-irradiation material testing
  - Securing neutron irradiation dose measurement for TBR evaluation of Breeding Unit, tritium on-line recovery and measurement system, and tritium handling facility
- To provide conditions for verification of design lifespan and safety of breeding blanket materials
  - He production rate by high-energy neutrons: ~10 appm/dpa
  - Possible to irradiation test ~0.6 dpa/fpy using 20X20 cm^2 specimens (D-Be)
  - Applicable to irradiation test ~5 dpa/fpy using 4X4 cm^2 specimens (D-Li) - Upgrade Stage
  - limitation to build DB, but sufficient for comparison and validation tests with properties with other facilities

Integrated Breeding Test Facility (IBTF) (5/9)

Deuteron Accelerator Unit

- Accelerate Deuterons up to 40 MeV and deliver the beam to target

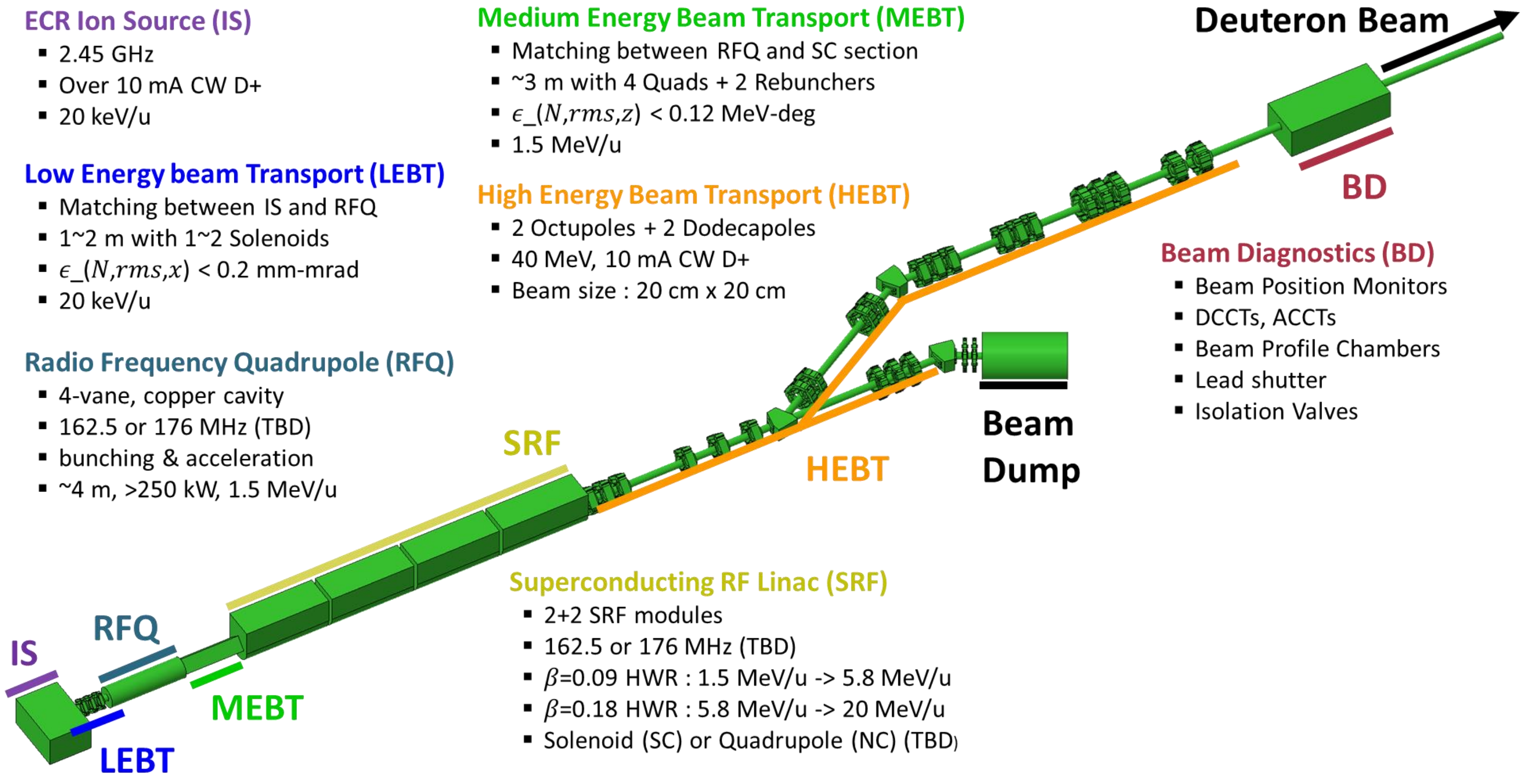
ECR Ion Source (IS)
- 2.45 GHz
- Over 10 mA CW D+
- 20 keV/u

Low Energy beam Transport (LEBT)
- Matching between IS and RFQ
- 1~2 m with 1~2 Solenoids
- $\epsilon_{(N,rms,x)}$ < 0.2 mm-mrad
- 20 keV/u

Radio Frequency Quadrupole (RFQ)
- 4-vane, copper cavity
- 162.5 or 176 MHz (TBD)
- bunching & acceleration
- ~4 m, >250 kW, 1.5 MeV/u

Medium Energy Beam Transport (MEBT)
- Matching between RFQ and SC section
- ~3 m with 4 Quads + 2 Rebunchers
- $\epsilon_{(N,rms,z)}$ < 0.12 MeV-deg
- 1.5 MeV/u

High Energy Beam Transport (HEBT)
- 2 Octupoles + 2 Dodecapoles
- 40 MeV, 10 mA CW D+
- Beam size : 20 cm x 20 cm



Beam Diagnostics (BD)
- Beam Position Monitors
- DCCTs, ACCTs
- Beam Profile Chambers
- Lead shutter
- Isolation Valves

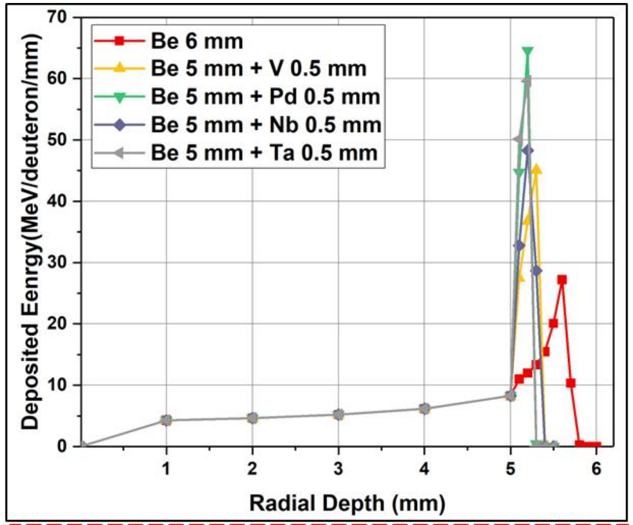
Superconducting RF Linac (SRF)
- 2+2 SRF modules
- 162.5 or 176 MHz (TBD)
- β=0.09 HWR : 1.5 MeV/u -> 5.8 MeV/u
- β=0.18 HWR : 5.8 MeV/u -> 20 MeV/u
- Solenoid (SC) or Quadrupole (NC) (TBD)

Parameter	Value
Ion species	Deuteron
Max. beam energy	40 MeV
Max. beam current	CW 10 mA
Max. beam size	20 cm x 20 cm
Neutron yield	~2x10^{15} n/s (forward)
Neutron flux	~5x10^{12} n/cm^2·s
Operation	~7000 hours/year
Maintenance	Hands-on + Remote
Target	Solid Beryllium

Integrated Breeding Test Facility (IBTF) (6/9)

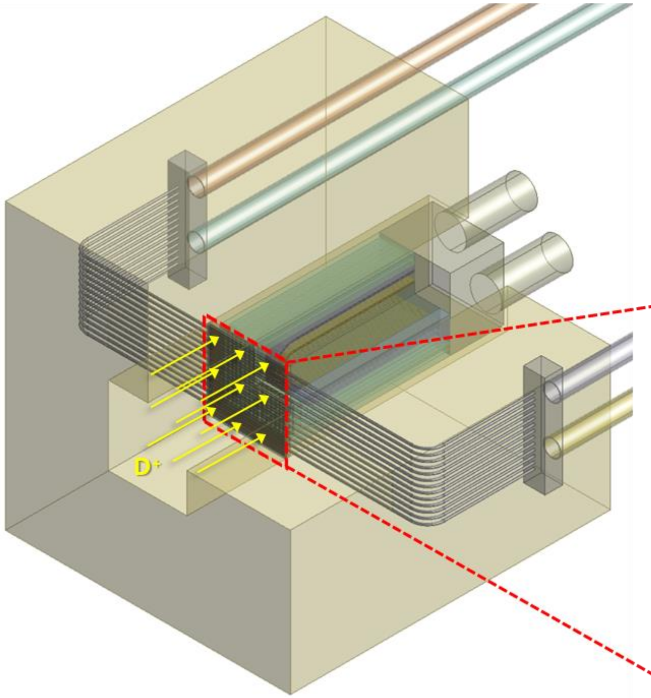
Neutron Source Target

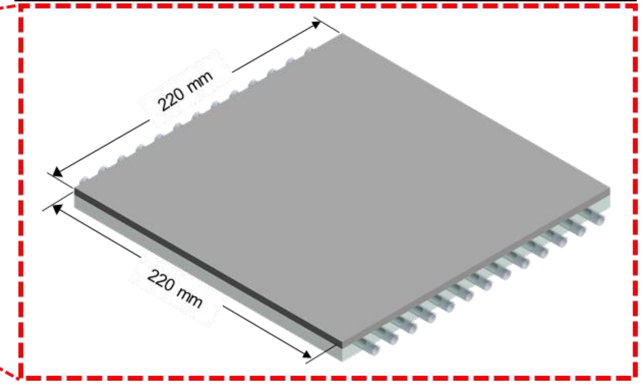
- Generating neutrons by a nuclear reaction between a target and charged particles from accelerator



➢ **Target**
- Material: Beryllium
- Size : 220 mm x 220 mm x 5 mm
- Allowable Max. Temperature: 730 °C

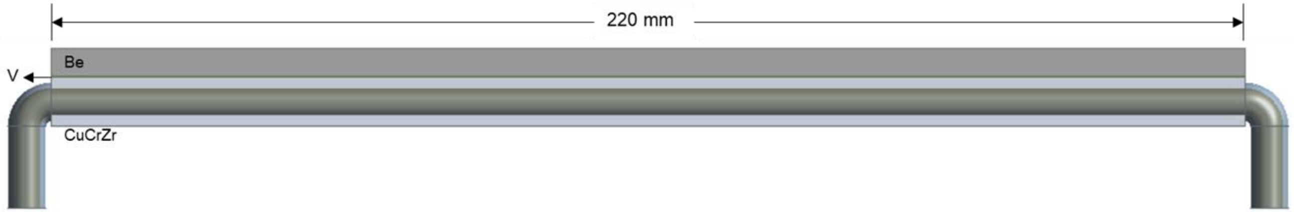
➢ **Blistering Mitigation Layer**
- Material: Vanadium
- Size : 220 mm x 220 mm x 0.3 mm
  (beam footprint: 200 mm x 200 mm)





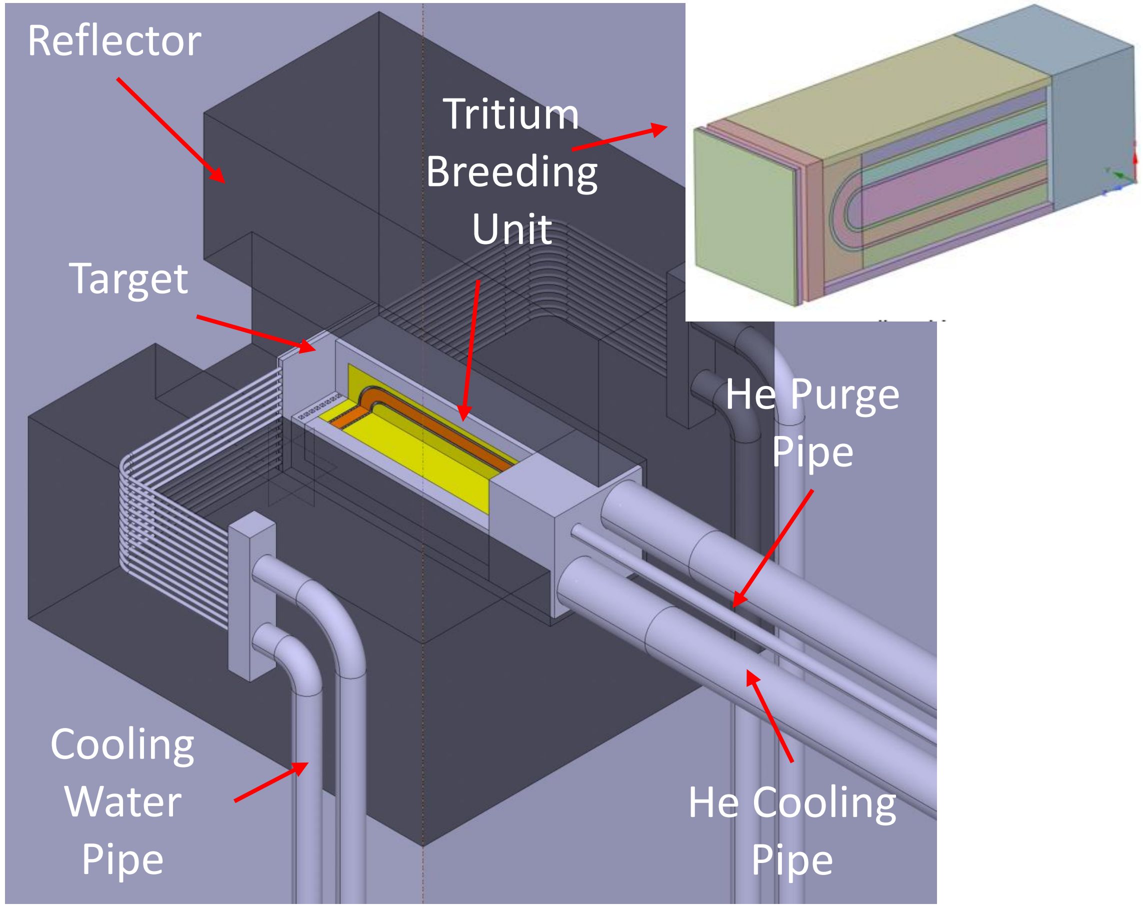
➢ **Back-plate & Tube**
- Material: CuCrZr
- Size : 220 mm x 220 mm x 9 mm
- Tube: Φ5, 1t

➢ **Coolant**
- Water
- 1 MPa, 25 °C, 15 m/s @ inlet



Integrated Breeding Test Facility (IBTF) (7/9)

- Tritium Breeding Unit (TBU)
  - Validating long-term performance (Tritium production/recovery, heat extraction) and structural integrity of the DEMO breeding blanket candidates

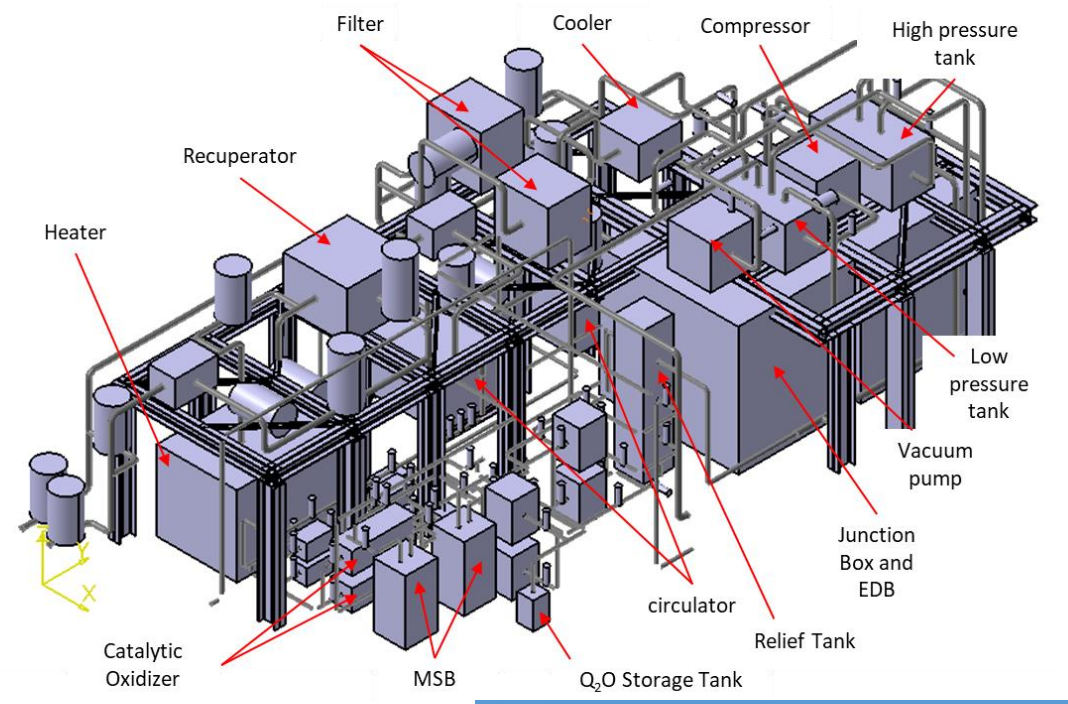


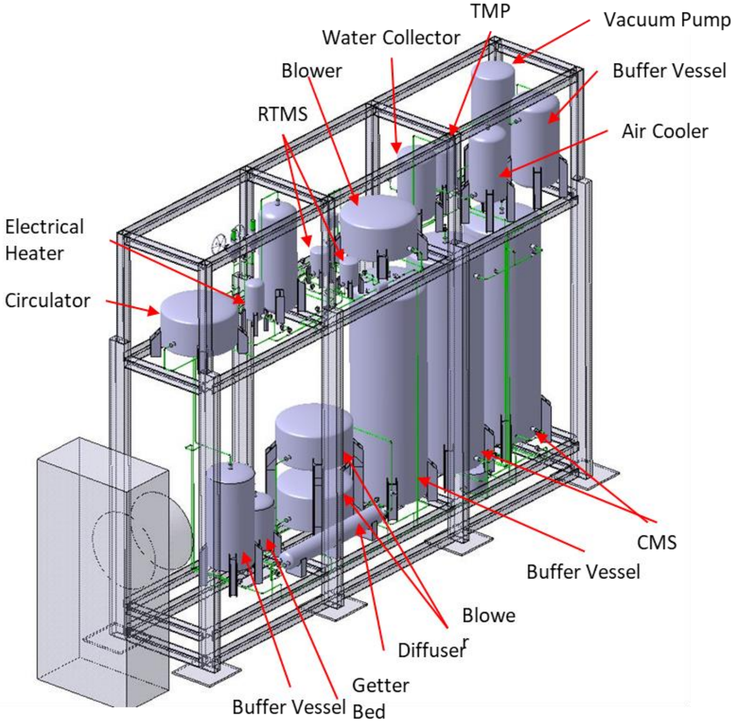
Parameter	Tritium Breeding Unit
Structural Material	ARAA
Neutron Multiplier	Be (or Beryllides)
Tritium Breeding Material	Li_2TiO_3
Coolant	Helium
Coolant Pressure	8 MPa
Coolant Temperature	Avg. 450℃
Neutron Irradiation area	0.2 x 0.2 m^2
Radial length	0.6 m
Tritium Production Rate	0.16 mg/day*

* 0.1 g/day for TBM

Integrated Breeding Test Facility (IBTF) (8/9)

- Breeding Unit Ancillary System
  - Helium Cooling System (HCS)
  - Tritium Extraction System (TES)

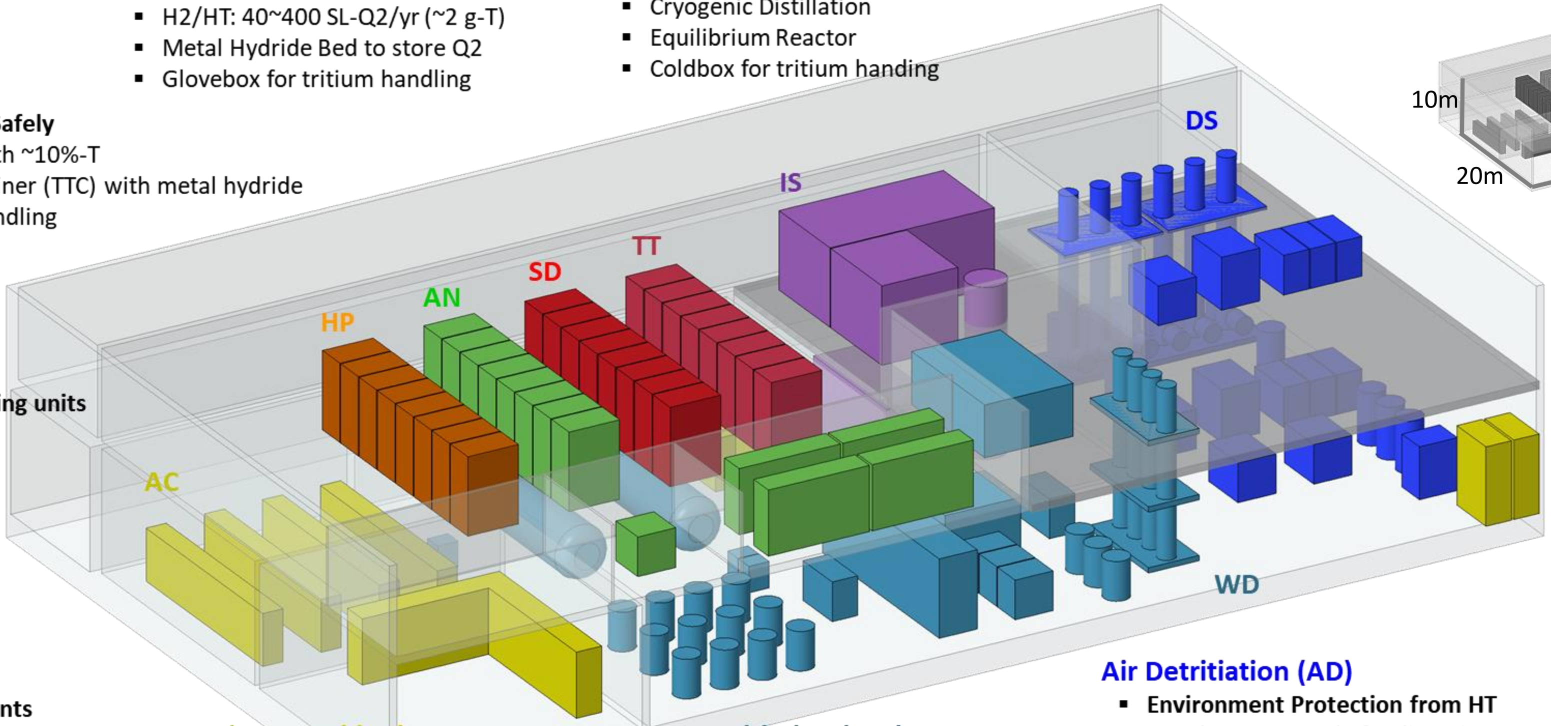


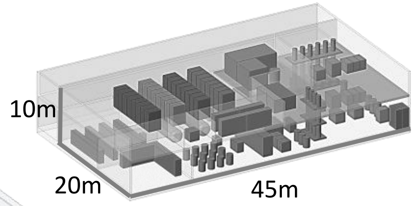


Parameter	HCS	TES
Nominal Pressure (NP)	~ 8 MPa	0.1~0.4 MPa
Nominal Inlet Temperature (NT_{in})	Around 300 ^oC	25 ^oC
Nominal Flow Rate (NF)	~ 1.5 kg/s	~ 0.1 g/s

Tritium Recovery System

- 60 mg-T/yr produced in the tritium breeding unit shall be recovered: purified, separated, and stored.





Isotope Separation (IS)
- **Hydrogen Isotope Separation (H2/HT/T2)**
- Products: 10%-T/10ppm-T
- Cryogenic Distillation
- Equilibrium Reactor
- Coldbox for tritium handing

Storage/Delivery (SD)
- **Q2 Storage Safely**
- H2/HT: 40~400 SL-Q2/yr (~2 g-T)
- Metal Hydride Bed to store Q2
- Glovebox for tritium handling

Tritium Transport (TT)
- **Q2 Long-term Storage Safely**
- H2/HT: 1 g-T storage with ~10%-T
- Tritium Transport Container (TTC) with metal hydride
- Glovebox for tritium handling

Hydrogen Purification (HP)
- **Q2 Separation from the breeding units**
- H2/HT/HTO
  60 mg-T/yr (7000 hrs/yr)
  40~400 SL/yr
- Permeators to separate Q2
- Reactor to crack HTO
- Glovebox for tritium handling

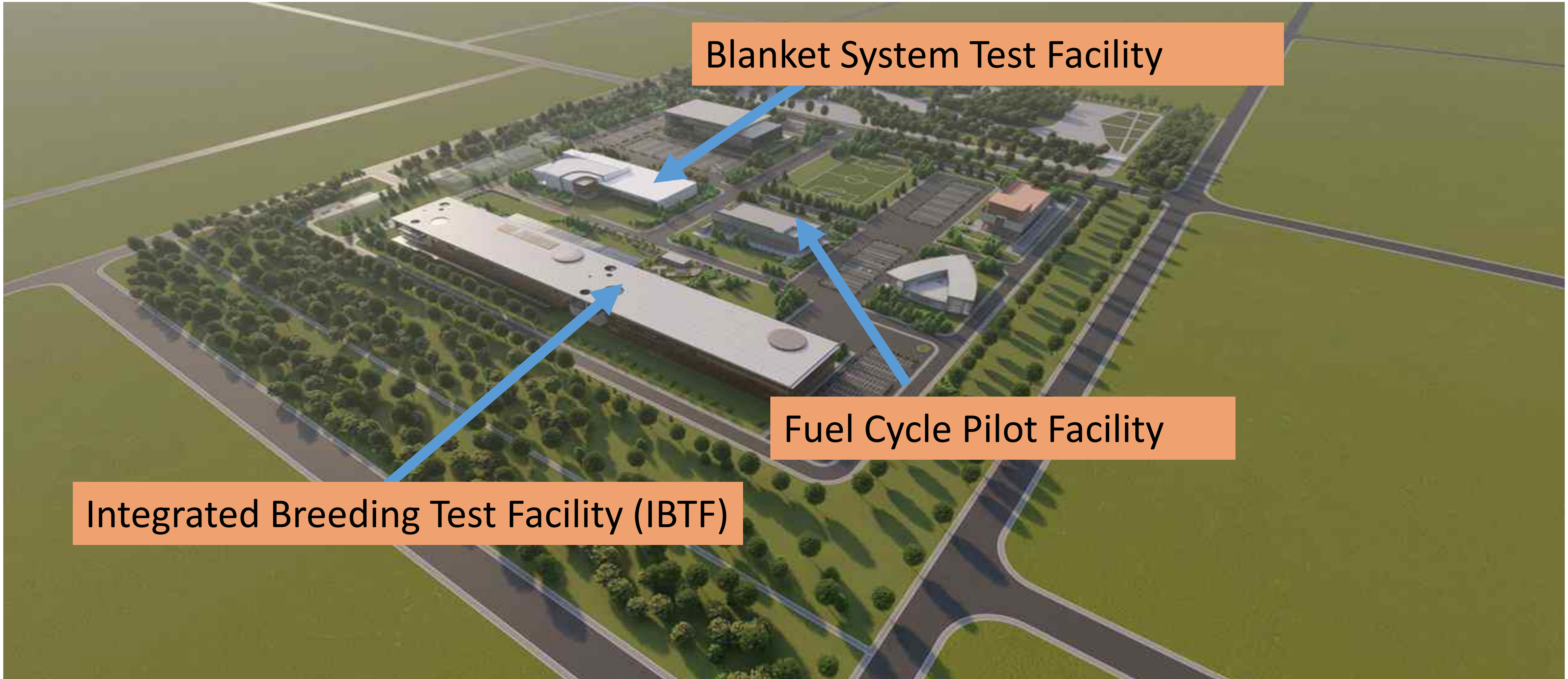
Tritium Analytics (AN)
- **Measurement of tritium amounts**
- Process gas sampling
- TTC Calorimeter
- Enclosure air monitoring
- Low-T sampling in environment
- Glovebox for tritium handling

Automatic Control (AC)
- **Process Control**
- Data acquisitions and utility supplies
- Monitoring and cubicles

Water Detritiation (WD)
- **Tritium Recovery from tritiated Water**
- ~ ppm-T HTO handling
- Electrolyzer and Permeator
- Liquid Phase Catalytic Exchange (LPCE)

Air Detritiation (AD)
- **Environment Protection from HT**
- Regulatory control of radioactive discharges mainly tritium
- ~ ppm-T HT handling
- Molecular Sieve Beds and/or Scrubbers

Korea Fusion Engineering Advanced Test Complex (KFEAT)



It consists of a neutron source for the testing of breeding blanket and materials, and facilities for R&D and testing of core systems of the fuel system in a fusion-like environment.

Blanket System Test Facility

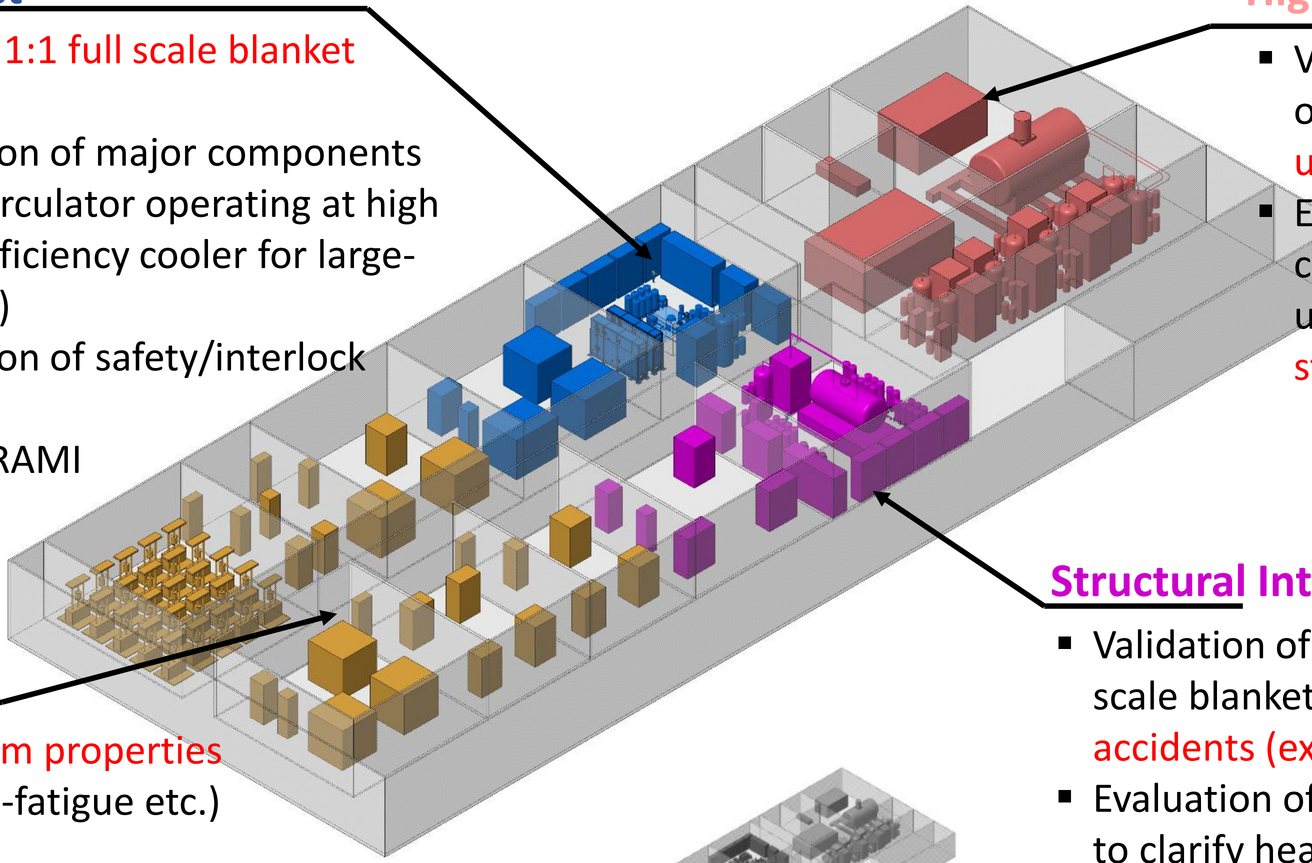
- Reliability and safety demonstration for DEMO-relevant long-term operation

Ancillary System Test

- Process validation of 1:1 full scale blanket ancillary systems
- Performance validation of major components (high-performance circulator operating at high temperature, high-efficiency cooler for large-capacity cooling, etc.)
- Performance validation of safety/interlock device
- Data production for RAMI

High Heat Flux Test

- Validation of structural integrity of 1:1 full-scale blanket mock-ups under high heat head loads
- Evaluation of thermal/mechanical characteristics of blanket mock-ups under steady or transient state

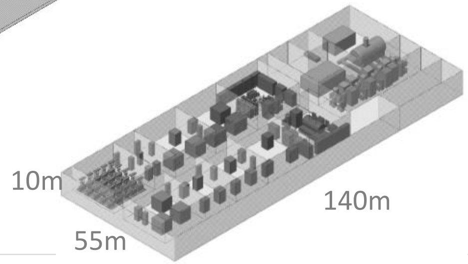


Material Test

- Validation of long-term properties (creep, fatigue, creep-fatigue etc.) of fusion materials
- Evaluation of physical/thermal/ mechanical properties of fusion materials

Structural Integrity Test

- Validation of structural integrity of 1:1 full-scale blanket mock-ups under postulated accidents (ex. in-box LOCA)
- Evaluation of temperature/pressure responses to clarify heat transfer and fluid dynamics phenomena under postulated accidents



Fuel Cycle Pilot Facility

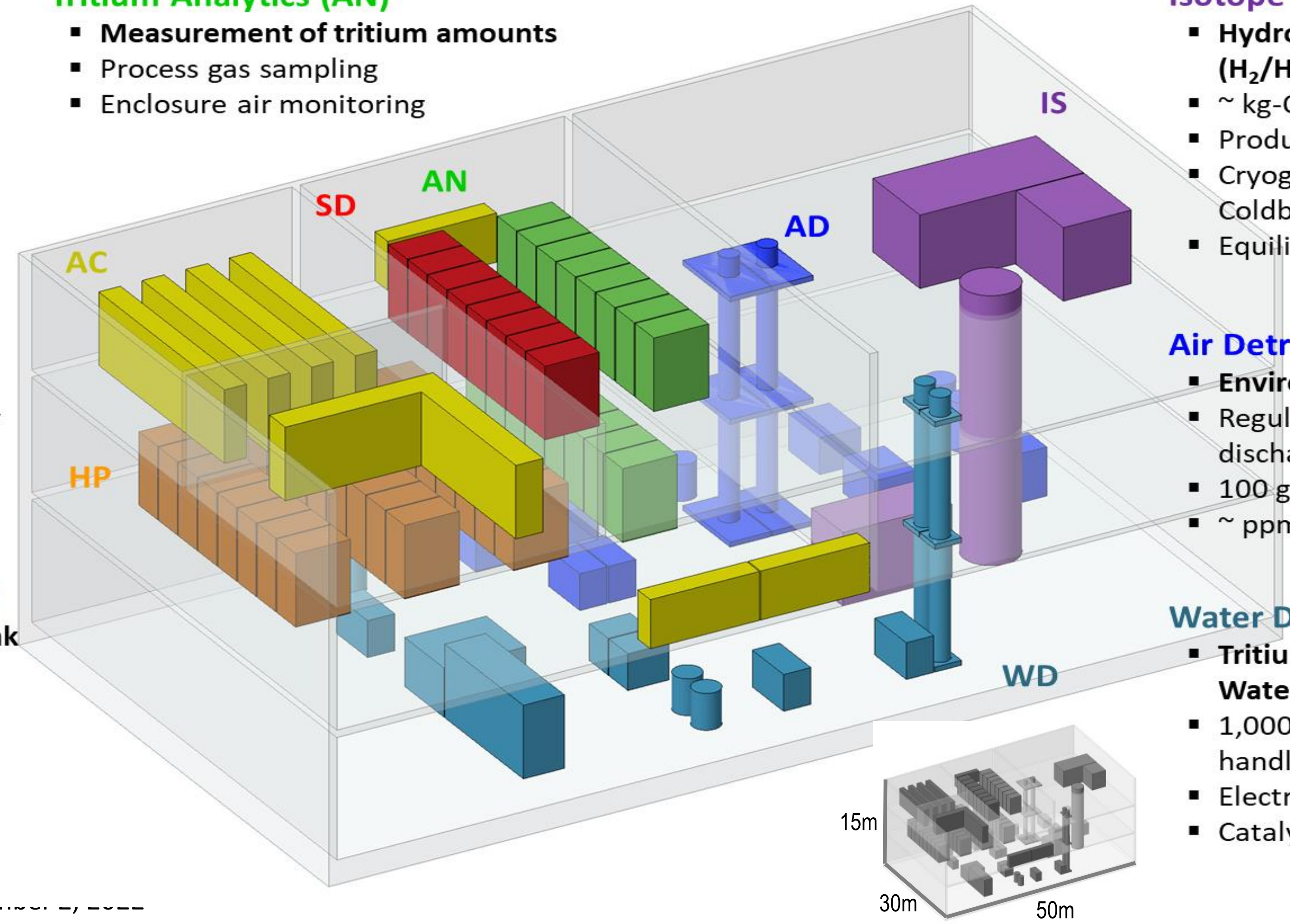
- 1/10 Scale Pilot of the K-DEMO Fuel Cycle shall verify the continuous operation performance of a few kg-T treatment using H/D.

Storage/Delivery (SD)
- **Q_2 Storage Safely and Delivery Stably**
- ~ kg-Q_2 storage
- 40 Pa·m^3/s Q_2 Delivery
- Enclosure

Automatic Control (AC)
- **Plant Control System**
- Data acquisitions and utility supplies
- Monitoring and cubicles

Hydrogen Purification (HP)
- **Q_2 Separation from Tokamak Exhaust**
- $Q_2/Q_2O/CQ_4$
  40 Pa·m^3/s for $H_2/HD/D_2$
- Permeators to separate Q_2
- Reactor to crack Q_2O/CQ_4
- Enclosure

Tritium Analytics (AN)
- **Measurement of tritium amounts**
- Process gas sampling
- Enclosure air monitoring



Isotope Separation (IS)
- **Hydrogen Isotope Separation ($H_2/HD/D_2$)**
- ~ kg-Q_2 handling
- Products: 90%-T/10ppm-T Target
- Cryogenic Distillation with Coldbox
- Equilibrium Reactor

Air Detritiation (AD)
- **Environment Protection**
- Regulatory control of radioactive discharges mainly tritium
- 100 g-T recovery target
- ~ ppm-D H/D handling

Water Detritiation (WD)
- **Tritium Recovery from tritiated Water**
- 1,000 kg/h with ~ ppm-T HTO handling target
- Electrolyzer and Permeator
- Catalytic Exchange Extractor

4

Summary

A Way to DEMO Blanket from ITER TBM with KFEAT

- Benefits from the experience of ITER TBM and fuel cycle is not sufficient for DEMO blanket
- Need to find a way to reduce the Gap between ITER and DEMO Blanket :
- A new facility, Korea Fusion Engineering Advanced Test Complex (KFEAT), is introduced as a way to DEMO blanket from ITER TBM reducing the Gap technologies
  - Dedicated long-term neutron irradiation facility for breeding blanket test under fusion-like environment
  - Validation of performance and structural integrity under DEMO-relevant irradiation time and scenario
  - Validation of design lifespan and safety of breeding blanket materials
  - Reliability and safety demonstration of blanket systems for DEMO-relevant long-term operation
- Need collaboration among countries/organizations for the successful DEMO Blanket

감사합니다

Thank you for your attention

Q&A