Topic 2: ITER TBM program status, DEMO needs and satellite facilities needed

JP facilities anticipated for DEMO **BB** preparation

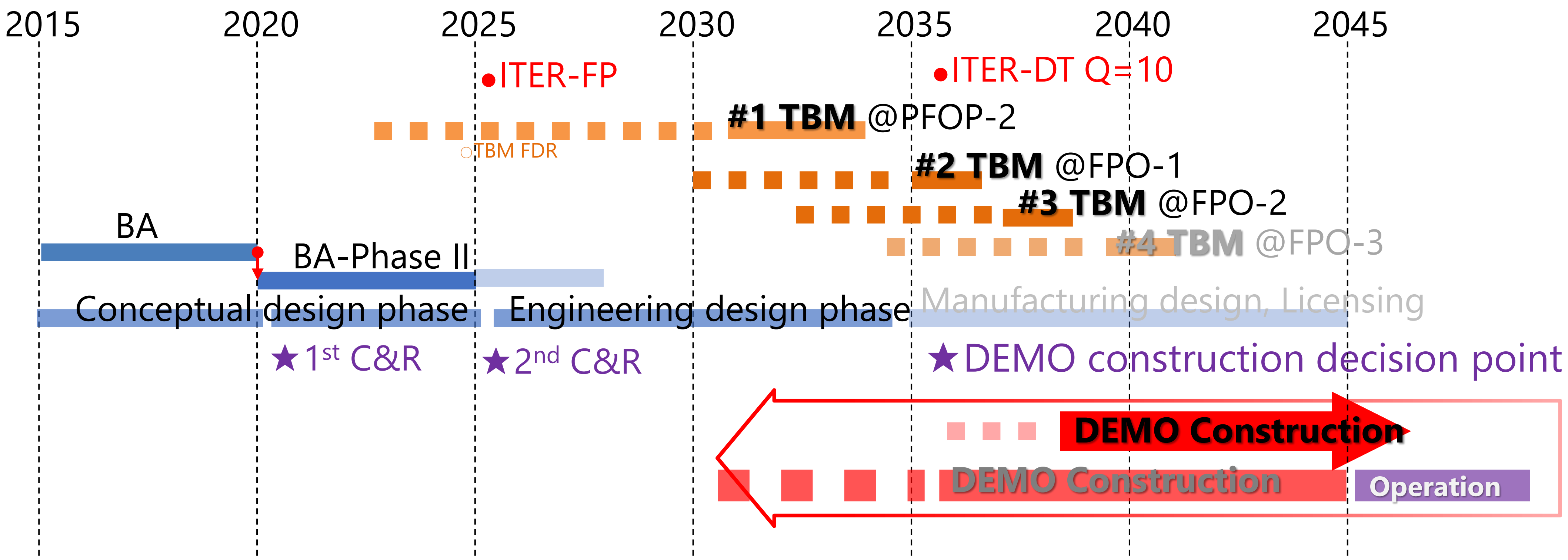
Breeding Blanket

Hiroyasu Tanigawa

QST

JAPAN

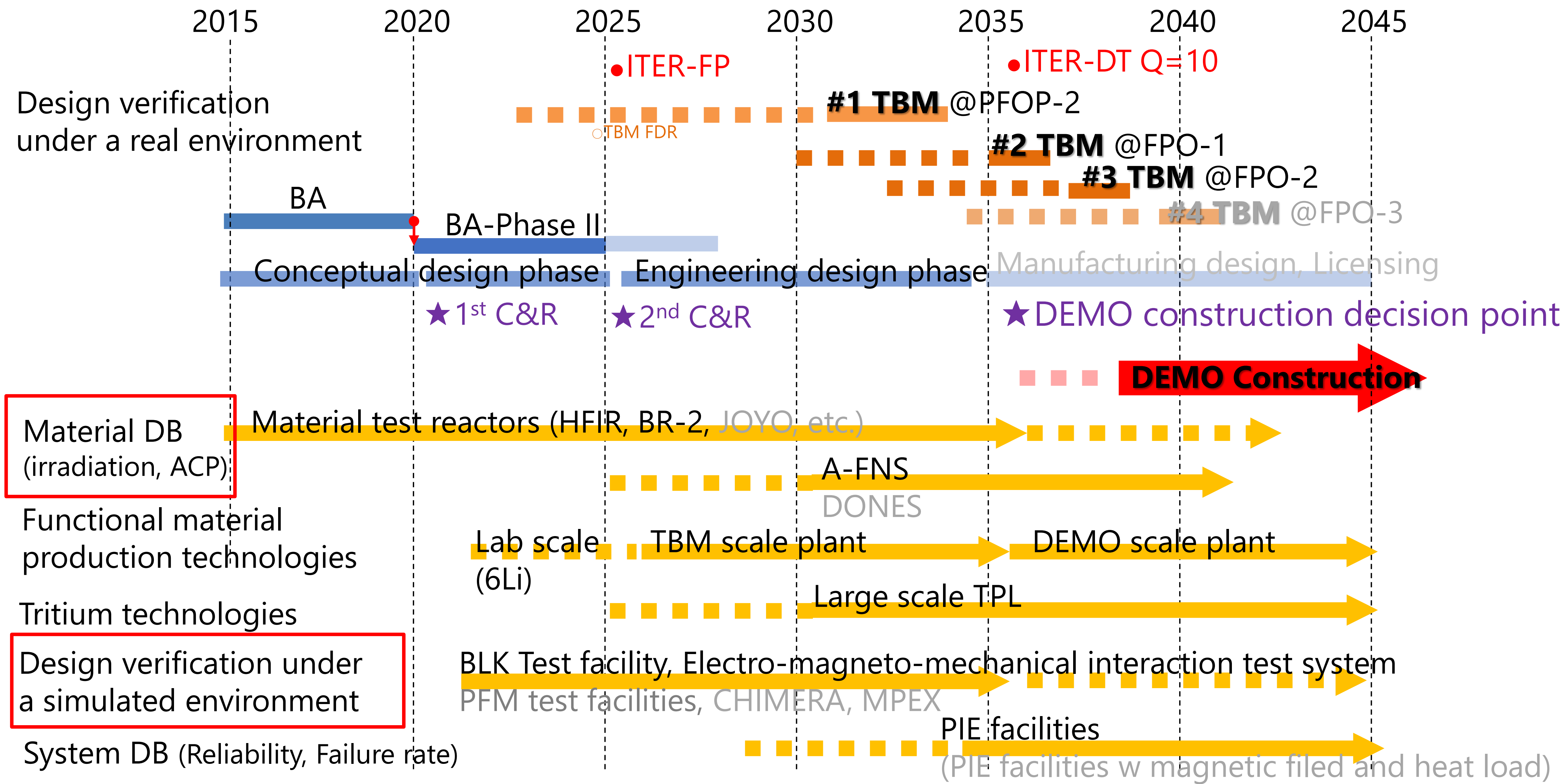
JA Fusion DEMO development schedule



- JA aim to make a decision on the construction of JA-DEMO when ITER achieves Q=10 DT plasma.
  - JA start to look for the possibility to accelerate DEMO program by starting DEMO construction immediately after the decision.

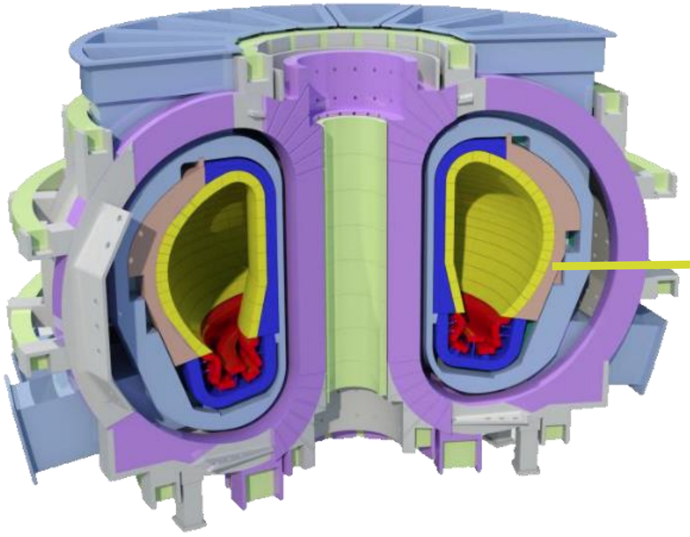
  ✓ FPO-2 TBM design will be the JA-DEMO blanket design.

JA facilities anticipated for DEMO BB preparation



JA Fusion DEMO Breeding blanket

JA DEMO



P_{fusion}=1->1.5GW, Major radius=~8.5m

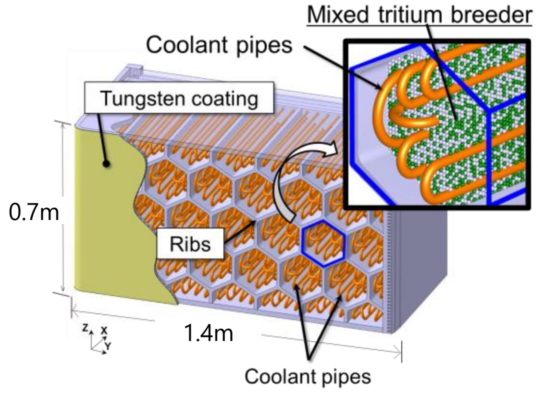
First operation campaign (~2050)
Pulse operation
Irradiation dose: a few to ~20 dpa

Second operation campaign (2050~)
Steady state operation
Irradiation dose: ~20 dpa →~ 80 dpa

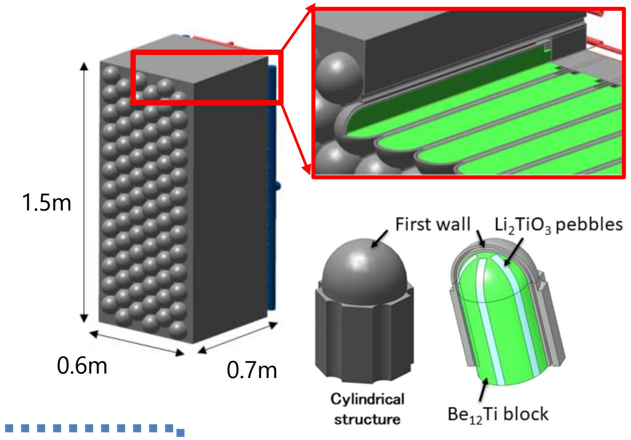
Breeding blanket

DEMO design – Water cooled / solid breeder blanket (with W as PFM)

Mixed breeder/multiplier pebbles
Fabricated by HIP method

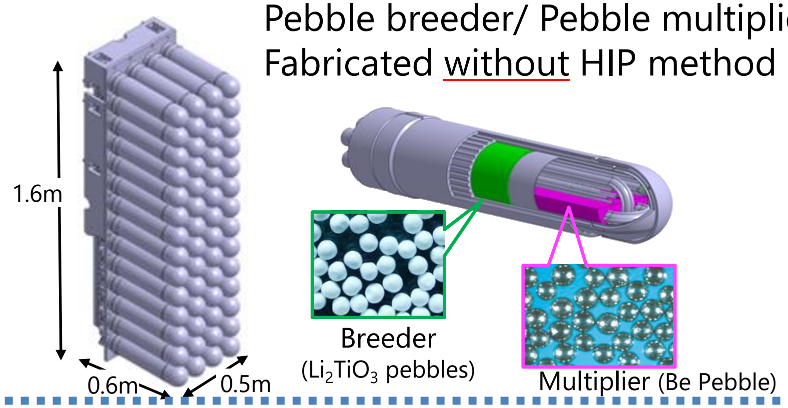


Pebble breeder/ Beryllide Block multiplier
Fabricated without HIP method

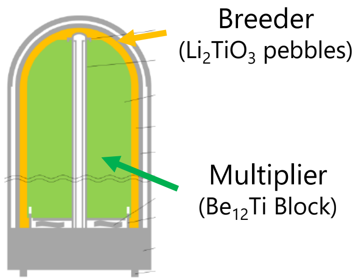


ITER-WCCB TBM design (wo W as PFM)

Pebble breeder/ Pebble multiplier
Fabricated without HIP method

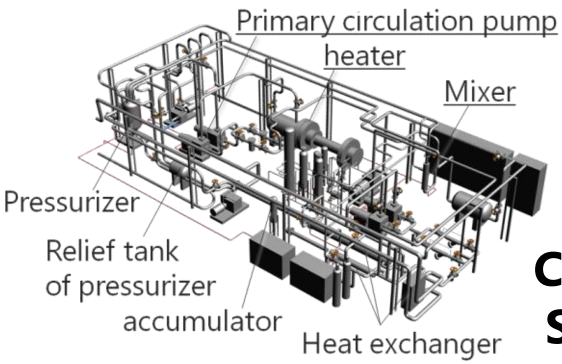


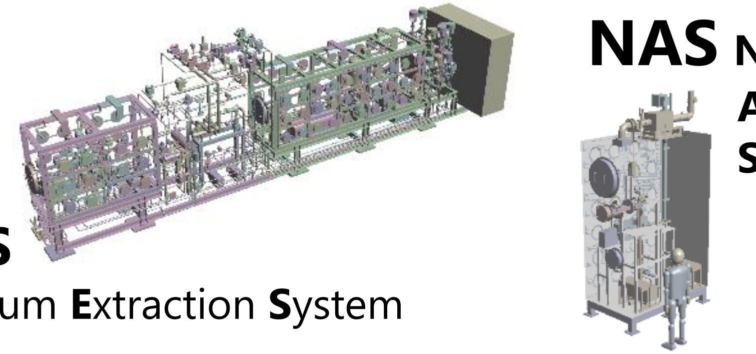
Pebble breeder/ Beryllide block multiplier
Fabricated without HIP method

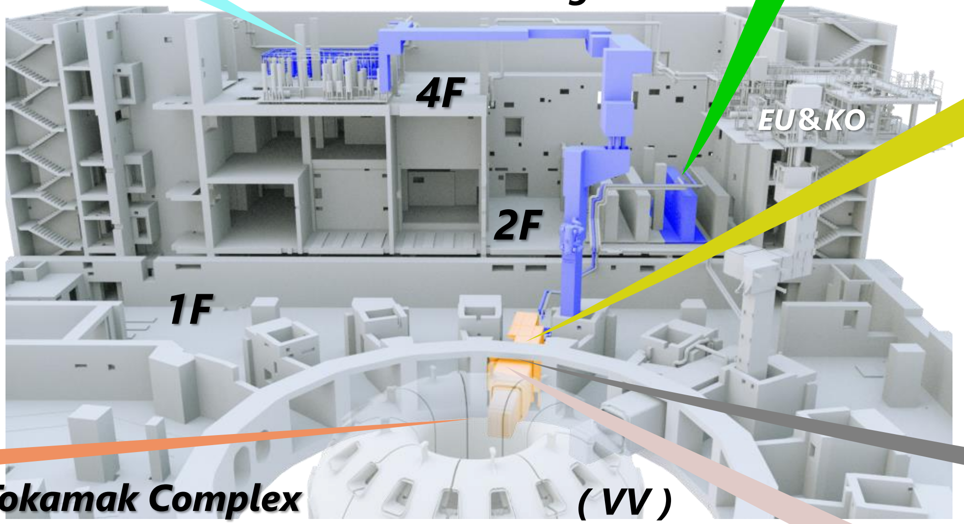


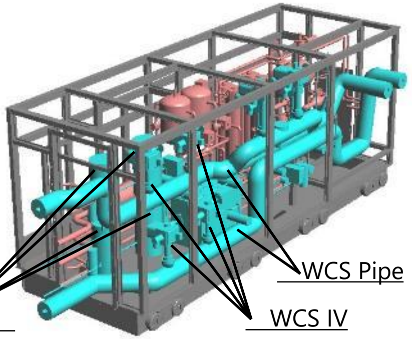
WCCB-TBS

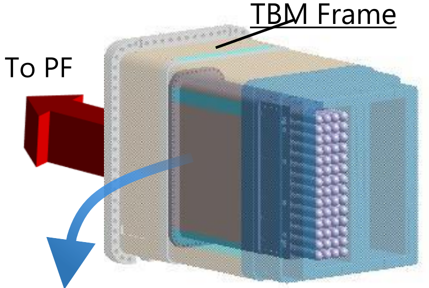
The first chance to test BB under a real fusion in-vessel environment.

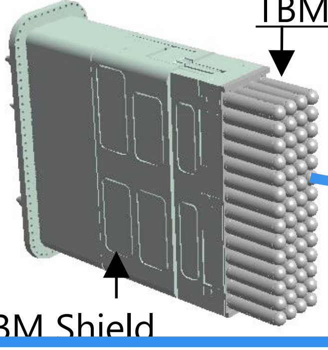


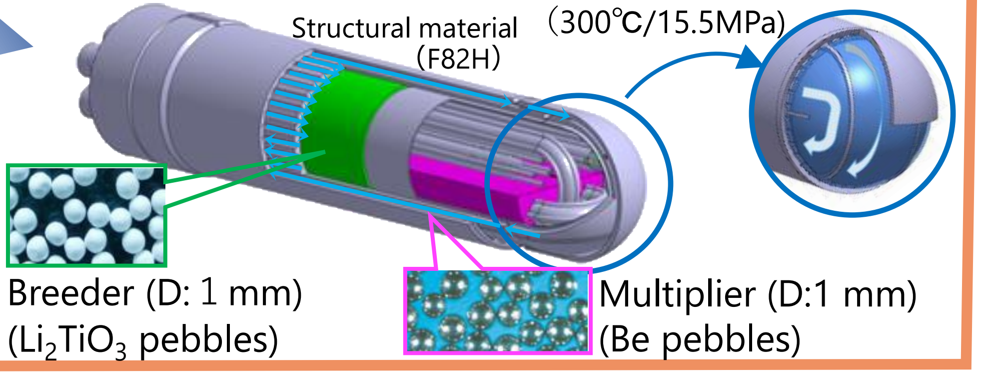


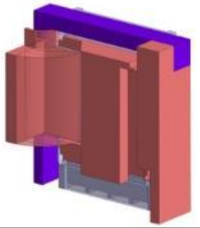


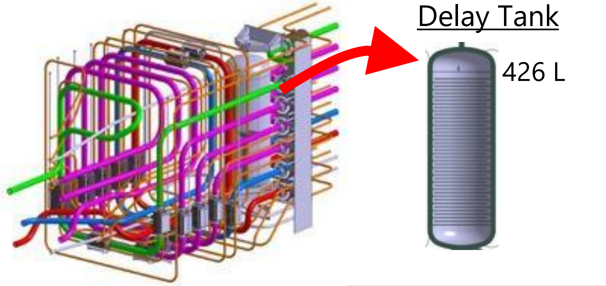












Fusion in-vessel environment which cannot be achieved in TBM

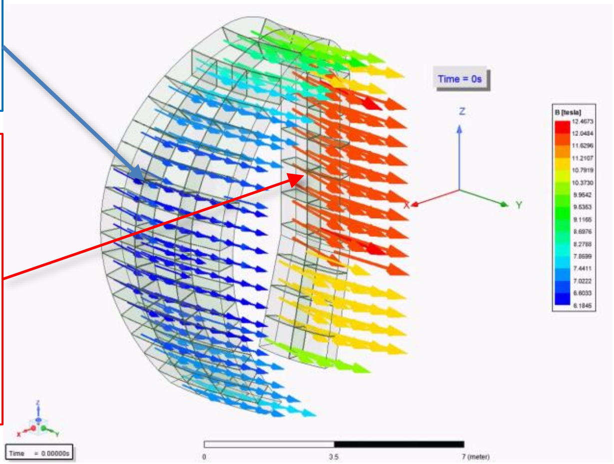
Higher 14MeV neutron irradiation dose

	Unit	ITER-TBM	DEMO-BB
Surface heat load	MW/m^2	0.25	0.5
Neutron wall load (aver./max.)	MW/m^2	0.55 / 0.78	1.0 / 1.66
Max. damage	dpa	~1 (3)	1~10 → 20~80
Discharge duration		400 sec – 2000 sec	Pulse (a few hours) → Steady state (4 years)
Number of discharges	Cycles	Min. 30,000 cycles	~1000 → 1
Lifetime		16 m	3 m ~ 1 y → 4 y
Number of blanket		1	~1040

Inboard magnetic field condition

Outboard position
- ✓ 4.3T~ 4.7T

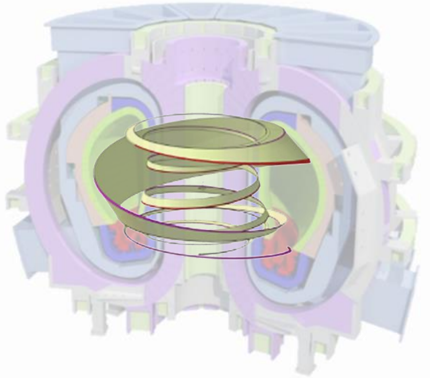
Inboard position
- ✓ Magnetic field gradient : 8.7T~ 9.5T
- ✓ Vector change : ～15 degree



Plasma heat flux along a magnetic field line

Plasma heat in the peripheral plasma reaches the BLK first wall (top of the hemi-spherical FW)

wo Limiter: $2MW/m^2$
-> w Limiter : $0.3MW/m^2$



W. Chen et al., IEEE Trans. Plasma Science, (2022) doi:10.11109/TPS.2022.3176443

Y. Miyoshi et al., Fusion Eng. Des. 151 (2022) 111394

Facilities need for material DB development

- Fission irradiation DB is essential for structural and functional materials to
  - Ensure the structural integrity not to violate primary safety boundary (VV) in any events/accidents throughout the lifetime.
  - Estimate the lifetime of BLK in view of availability (and quality assurance)
  - Evaluate the impact of irradiation on tritium behavior (inventory etc.)
  - ➢ HFIR (ORNL/USA) is an essential for the JA irradiation program.
  - ➢ JOYO (Experimental fast reactor) is expected to be back in operation around 2025.
    - ➢ JOYO is valuable for W irradiation, especially.
  - ➢ BR-2 (SCK CEN/Belgian) is planned to be used for functional material irradiation tests as part of the BA activities.
- Corrosion experiments under neutron irradiation should be conducted to validate the ACP code.
  - ➢ The gamma-ray irradiation facilities with Co-60 source (QST/Takasaki) will be used.
  - ✓ Need to find an accessible facility.

Material DB status based on attribute evaluation

Structural material F82H	Base metal				Weld/Joint			
	Non-irrad.		Irrad.		Non-irrad.		Irrad.	
	As-received	Aged	Ion & LWR	FNS	As-received	Aged	Ion & LWR	FNS
SPECIFICATION OF MATERIAL								
Material production method		n/a	n/a	n/a		n/a	n/a	n/a
Chemical composition		n/a	n/a	n/a		n/a	n/a	n/a
Metallurgy			HFIR	FNS			HFIR	FNS
PHYSICAL PROPERTIES								
Coefficient of thermal expansion		n/a	HFIR	FNS	(blank)	n/a	HFIR	(blank)
Elastic properties		n/a	HFIR	FNS	(blank)	n/a	(blank)	(blank)
Density		n/a	(blank)	(blank)	(blank)	n/a	(blank)	(blank)
Thermal properties		n/a	(blank)	(blank)	(blank)	n/a	(blank)	(blank)
Electrical resistivity		n/a	HFIR	FNS	(blank)	n/a	HFIR	(blank)
Magnetic properties		n/a	HFIR	FNS	(blank)	n/a	(blank)	(blank)
Melting temperature		n/a	n/a	n/a	n/a	n/a	n/a	n/a
Sputtering	(blank)	(blank)	(blank)	(blank)	(blank)	(blank)	(blank)	(blank)
MECHANICAL PROPERTIES								
Hardness			HFIR	FNS			HFIR	FNS
Tensile properties			HFIR	FNS			HFIR	FNS
Impact strength				(blank)				(blank)
Fracture toughness			HFIR	FNS			HFIR	FNS
Fatigue		(blank)	(TBD)	FNS		(blank)	(TBD)	FNS
Creep		(blank)	n/a	FNS		(blank)	n/a	FNS
Creep-fatigue		(blank)	n/a	FNS		(blank)	n/a	FNS
Ratcheting	(blank)	(blank)	(blank)	(blank)	(blank)	(blank)	(blank)	(blank)
FUSION-SPECIFIC PHENOMENA								
Swelling	n/a	n/a	HFIR	FNS	n/a	n/a	(blank)	(blank)
Irradiation creep	n/a	n/a	HFIR	FNS	n/a	n/a	(blank)	(blank)
ENVIRONMENTAL PROPERTIES								
Corrosion		n/a	(blank)	FNS		n/a	(blank)	(blank)
Compatibility		(blank)	(blank)	(blank)		(blank)	(blank)	(blank)
ANALYSIS DATA								
Design stress intensity values (Sm and S)		n/a	HFIR	FNS		n/a	(blank)	(blank)
Time-dependent stress intensity limit (St)		n/a	n/a	n/a		n/a	n/a	n/a
Minimum creep rupture stress (Sr)		n/a	n/a	n/a		n/a	n/a	n/a
Fatigue curves at saturation		n/a	(blank)	(blank)	(blank)	n/a	(blank)	(blank)
Isochronous and creep deformation curves		n/a	n/a	n/a	(blank)	n/a	n/a	n/a
Values of SRh and SRc		n/a	n/a	n/a	(blank)	n/a	n/a	n/a
Symmetrisation factor, Ks		n/a	(blank)	(blank)	(blank)	n/a	(blank)	(blank)
Creep-fatigue interaction diagram		n/a	(blank)	(blank)	(blank)	n/a	(blank)	(blank)
Cyclic curves, values of Ke and Kn		n/a	(blank)	(blank)	(blank)	n/a	(blank)	(blank)
Minimum true stress-strain curves		n/a	HFIR	FNS	(blank)	n/a	(blank)	(blank)

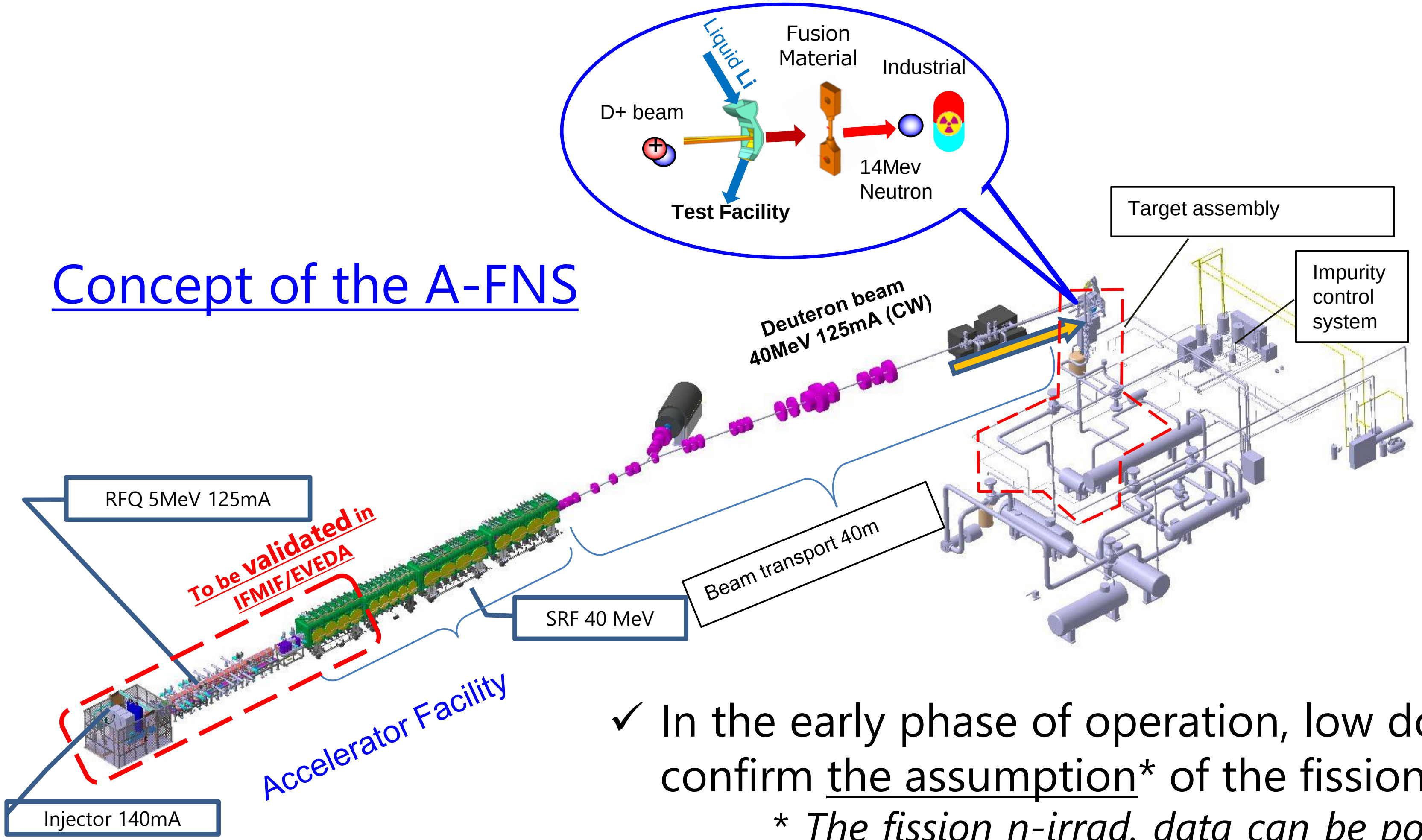
Neutron Multiplier Be, Beryllide	Non-irradiated	Reactor irradiation (T_{irr}=320、600、800℃)		14MeV neutron irradiation
		~3dpa	~10dpa +	~20dpa +
Physical properties				
Thermal expansivity (Block)				FNS
Young's modulus (Block)				FNS
Poisson's ratio (Block)				FNS
Density (Block)				FNS
Thermal conductivity (Block)				FNS
Effective thermal conductivity (Be-Pebble Bed)		(blank)	(blank)	FNS
Effective thermal conductivity (Be12V-Pebble Bed)		(blank)	(blank)	FNS
Electrical resistivity (Block)		(blank)	(blank)	FNS
Electrical resistivity (Be-Pebble Bed)		(blank)	(blank)	(blank)
Electrical resistivity (Be12V-PB)		(blank)	(blank)	(blank)
Swelling (Block & Single Pebble)	(blank)			FNS
T inventory (Block & Pebble bed)				FNS
Mechanical properties				
Tensile (Block)				FNS
Compression (Block)				FNS
Compression (Be12V-Single Pebble)				FNS
Bending (Block)				FNS
hardness (Block)				FNS
Toughness (Block)				FNS
Impact properties (Block)	(blank)	(blank)	(blank)	(blank)
Others				
H2O reactivity to Be12V (Block)				FNS
H2O reactivity to Be12V (Pebble Bed)				FNS
H2O reactivity to Be (Block)				FNS
H2O reactivity to Be (Pebble Bed)				FNS
Mass production (Block)		n/a	n/a	n/a
Mass production (Pebble Bed)		n/a	n/a	n/a
Refinement process				FNS
Recycling process (Block & Pebble Bed)				FNS

(*) color code :

- ✓ White (blank) for properties not addressed, lack of data
- ✓ Black : potential showstopper identified
- ✓ n/a : not applicable
- ✓ Red : lack of data and potentially challenging
- ✓ Blue : lack of data, NOT challenging
- ✓ Orange : data available, results not good enough, further optimization needed
- ✓ Green : data available, results are good, concept is mature

JA Fusion neutron source : A-FNS

Concept of the A-FNS



Beam	Particle Energy Current Foot print Incident angle Availability	Deuteron 40 MeV 125 mA (CW) 200 x 50 mm^2 Normal 33% at least
Target	Material Temp. Velocity Thickness Window	lithium Liquid target (jet) 250 ℃ 10-15 m/s at target 25 mm Free surface (no window)
Neutron	Intensity (at back plate) Average flux Helium P. R Displacement HePR/dpa	6.8×10^{16} neutron/s 6.0×10^{14} $n/cm^2/s$ 312 appm/fpy 24.7 dpa/fpy 12.6

fpy: full power year

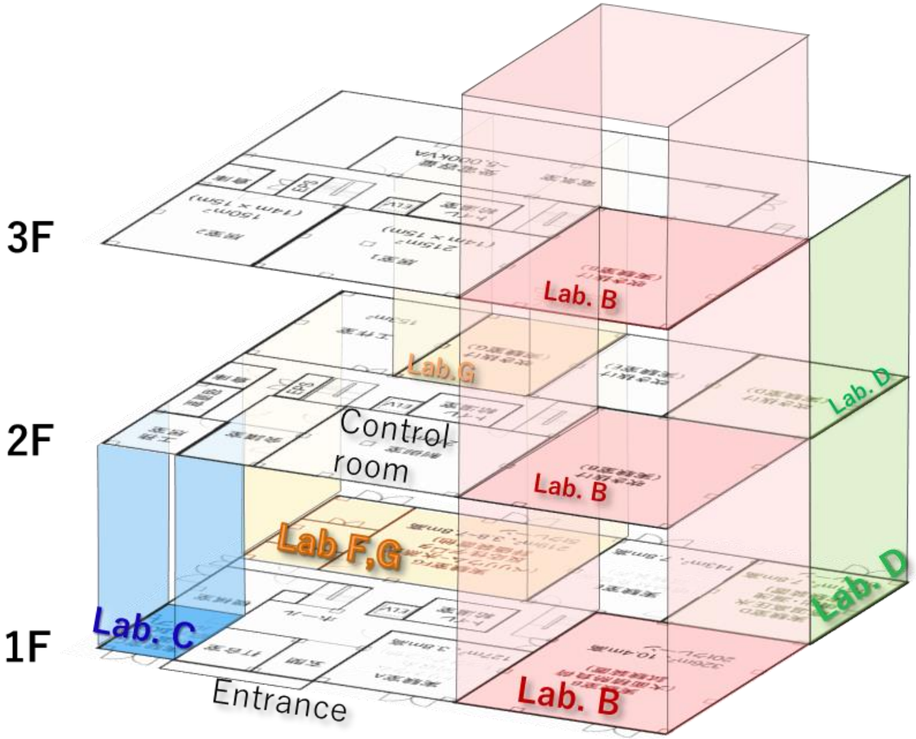
- ✓ In the early phase of operation, low dose irradiation is performed to confirm the assumption* of the fission irradiation DB
  - * *The fission n-irrad. data can be postulated as the equivalent data to that of fusion data up to the critical condition.*
- ✓ In the late operation phase, high dose irradiation is essential to extend the DEMO operation period.

Facilities need for Design verification under a simulated environment

- The new blanket test facility (QST:Rokkasho) is for design validation of TBM system.
- Electro-magneto-mechanical Interaction in ferromagnetic structure (with internal pressure) under high magnetic and gradient field under thermal loading and fusion neutron irradiation need to be evaluated.
  - It is necessary to confirm that, in any event or accident, the failure caused by the effects of these interactions is not likely to violate the primary safety boundary (VV).
  - JA has initiated a survey of potential facilities to validate the analysis.
  - ✓ CHIMERA (UKAEA/UK) is expected as the potential facility. QST and UKAEA have started discussion on future collaboration.
- Irradiation tests of the modeled structure would be essential to validate the design methodology for heavily irradiated structures.
- Plasma heat in the peripheral plasma reaches the BLK first wall (top of the hemi-spherical FW) along a magnetic field line.
  - Experimental facilities for Divertor development are under discussion.
  - ✓ MPEX (ORNL/USA) is expected as the next JA/US collaborative item to investigate irradiation effects on PFM.

Blanket Test Facility @ Rokkasho Fusion institute

- Construction of the blanket test facility was completed by June 2021.
- Tests using physical mock-up are going to perform until FDR and FD approval.
- TBS demonstration test is planned during the manufacturing phase.
- The installation of test apparatuses was completed by June 2022.



Test apparatuses for Physical mock-up test related to high pressure and high temperature coolant water

High heat flux test

600 kW EB Gun
WCS : 15.5MPa 300C
~0.9 kg/s flow
X ray camera
High resolution high speed thermography camera
Pyrometer

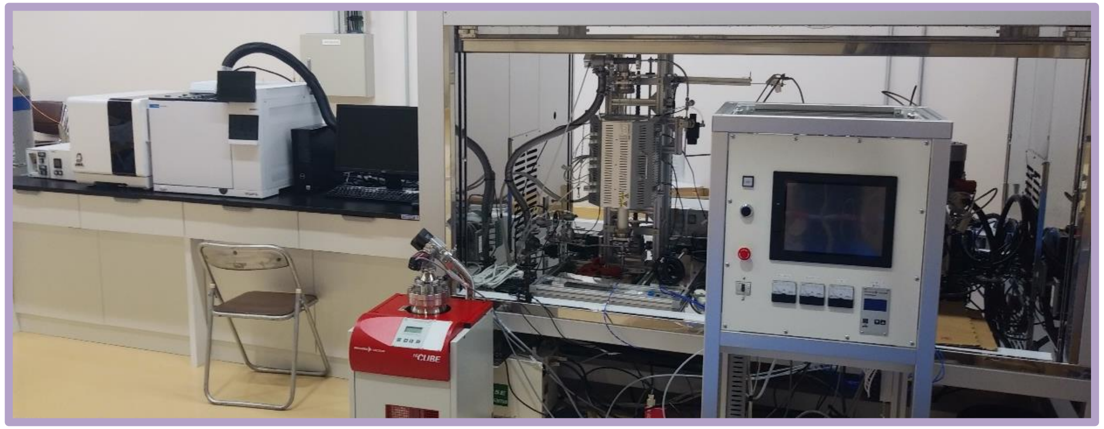
Flow accelerated corrosion test

WCS : ~0.6 kg/s flow w DO, DH control

In-Box LOCA test

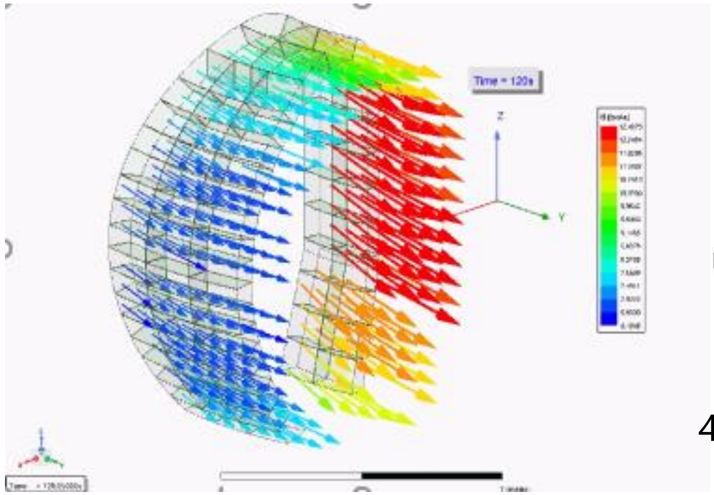
WCS condition water injection using rupture disk

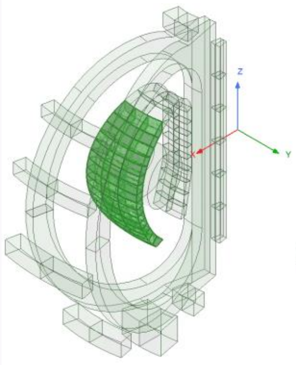
Beryllium – water reaction evaluation



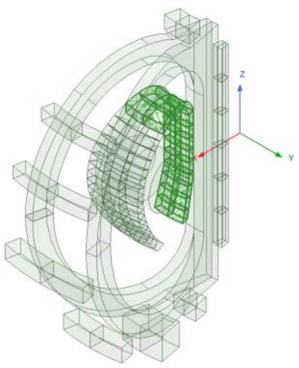
TG-DTA, DSC, GC, Qmass

Consideration of a strong magnetic field inside VV





4.3T-> 4.7T



8.7T-> 9.5T
～15 tilted

RAFM steels are ferromagnetic material, that is magnetized (~2T) until fully saturated in the direction of magnetic field lines.

The Maxwell forces will be applied as <u>a primary stress</u> on the ferromagnetic structure.

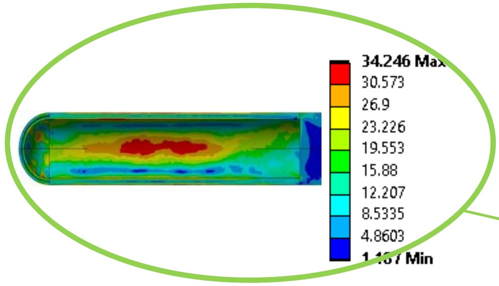
- ✓ It will become significant under the magnetic field with gradient.

$$\vec{F} = \mathrm{V} \times J_m \times \vec{\nabla}(H)$$

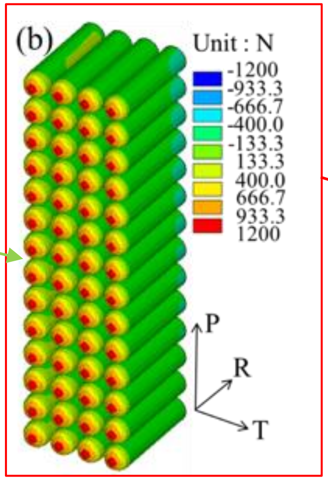
V: Volume
J_m: Saturated magnetization
H: External magnetic field

→ The effect will become significant as the total volume become larger.

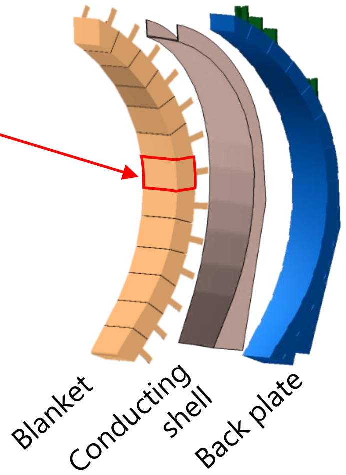
Sub module
Φ~0.1 L~0.6 (m)



Blanket (TBM)
W~0.5 x D~0.6 x H~ 1.6 (m)



Blanket segment
W~1.6 x D~1.0 x H ~10 (m)



- ✓ Some technical difficulties (uncertainties) were identified in EM load analysis.
- ✓ It may be important to conduct bidirectional coupled analysis between EM Load analysis and thermal/structural analysis.
- ✓ It is necessary to validate the code so that the blanket in various in-vessel positions (conditions) can be analyzed with high reliability.

<-> Alternatively, a 10T test facility may need to be considered.

Summary
JA facilities anticipated for DEMO BB preparation