2013.2.26-27

Kyoto University

Overview of Recent Reactor Design in JAEA

JAEA

Kenji Tobita

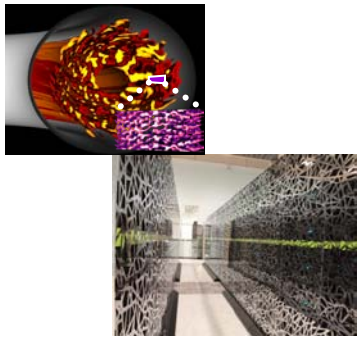
Outline

- DEMO Design under Broader Approach
- Recent Development in DEMO Design
- Safety Research

Outline of BA DEMO Design

IFERC *International Fusion Energy Research Center*

DEMO design | **R&D** | **CSC** | **REC**



2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017

PHASE ONE
WS (twice/year)

PHASE TWO
Joint design work

Structure of JA-HT

DDA Unit of IFERC-PT

Rokkasho
~ 2 PPY

EU-HT

Garching,
~6 PPY (full time)
70-80 PPY (parttime)

JA-HT

Rokkasho

JA policy:

To implement DEMO design
on a Japan-wide basis

JAEA

8 PPY in full-time

Research collab.

Contract

Universities

30-40 PPY

Industry
Software company

15-20 PPY

TOSHIBA Leading Innovation >>>

MITSUBISHI HEAVY INDUSTRIES, LTD. Our Technologies, Your Tomorrow

MNEC

RIST

KCS Corp.

IX Knowledge Inc.

Meetings for close communication

TECHNICAL COORDINATION MTG.

- Planning and sharing of joint work
- 1-2/ year

University of Tokyo, FEB. 2012

TASK MTG.

- Technical discussion
- As needed

Garching, MAR. 2012

Rokkasho, NOV. 2011

Approach of BA DEMO design

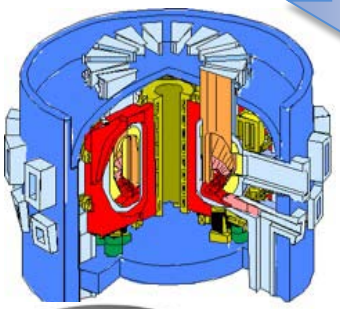
Previous DEMO design

"Top-down" approach

Requirements:

- **Small power core as ITER**
- **GWe-level electric power**
- **Year-long SS operation**
- **Self-sufficient tritium**

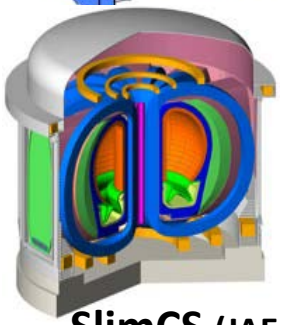
AEC Report (2005)



SSTR (JAEA)

R_p = 7.0 m, β_N = 3.5

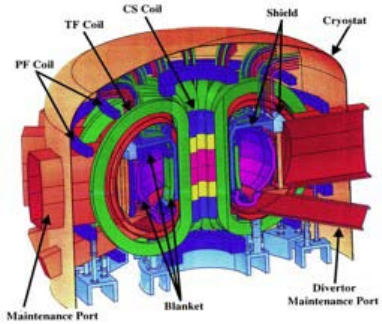
First SS tokamak concept



SlimCS (JAEA)

R_p = 5.5 m, β_N = 4.3

To improve economy



Demo-CREST (CRIEPI)

R_p = 7.3 m, β_N = 1.9-4.0

Step-wise development of development

BA DEMO design

"Bottom-up" approach

DEMO concept

Assume technology development by post-BA projects

ITER

On-going projects

- Know-how on design
- Target achievement

JT-60SA

R&D

IFMIF

Master plan of DEMO design

System code

- Benchmark of JA/EU codes

→

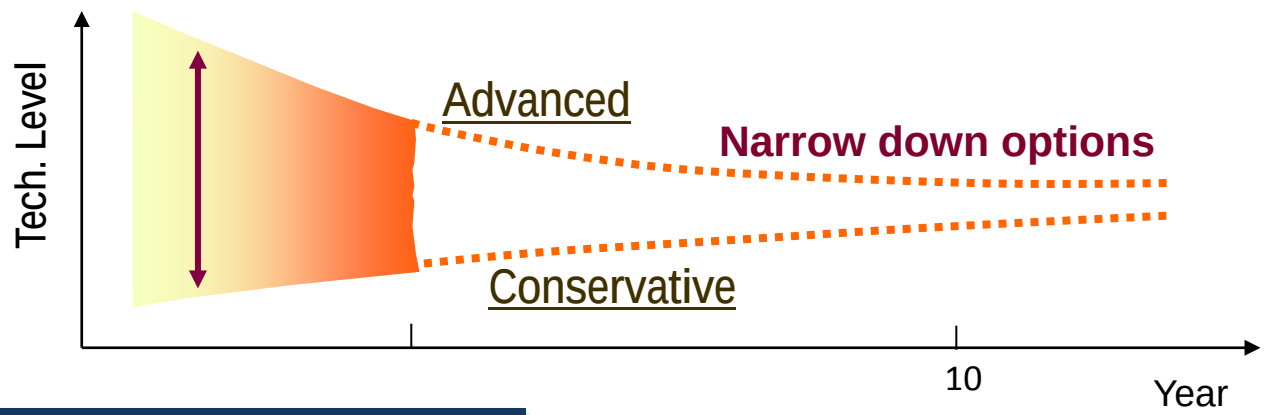
- DEMO scoping study

Critical design issues

- Assess design options on RM, divertor, T breeding, etc.

→

- Narrow down options



Design DB, guidelines

- Materials DB, physics guidelines, design tools, etc.

→ **"Pre-conceptual" design options**

Outline

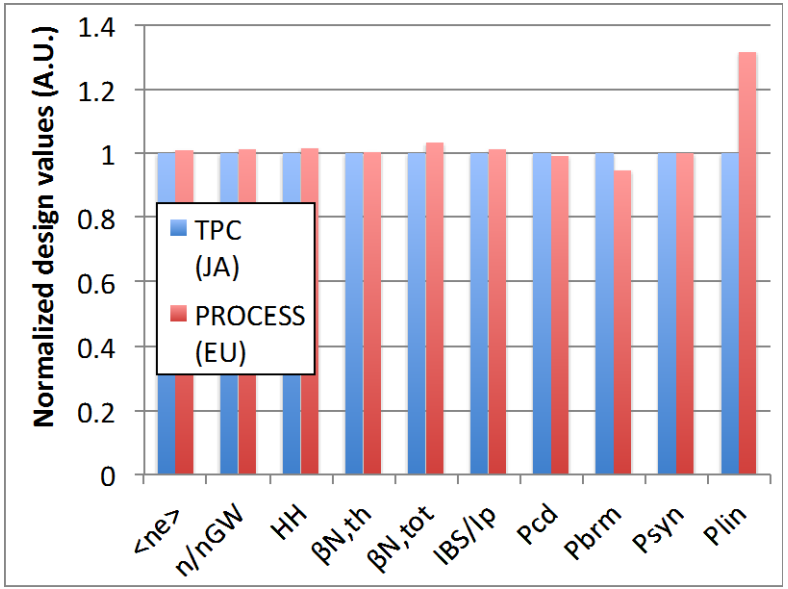
- ❖ DEMO Design under Broader Approach
- ❖ **Recent Development in DEMO Design**
  - (1) Syetems code study
  - (2) Tritium breeding
  - (3) Divertor heat removal
  - (4) Remote maintenance
- ❖ Safety Research

(1) SYSTEMS CODE STUDY

- ❖ TPC (JAEA)
- ❖ PROCESS (CCFE)

- **Benchmark and model comparison carried out in preparation for DEMO scoping study.**

- **After bug fixing, both codes are in good agreement.**



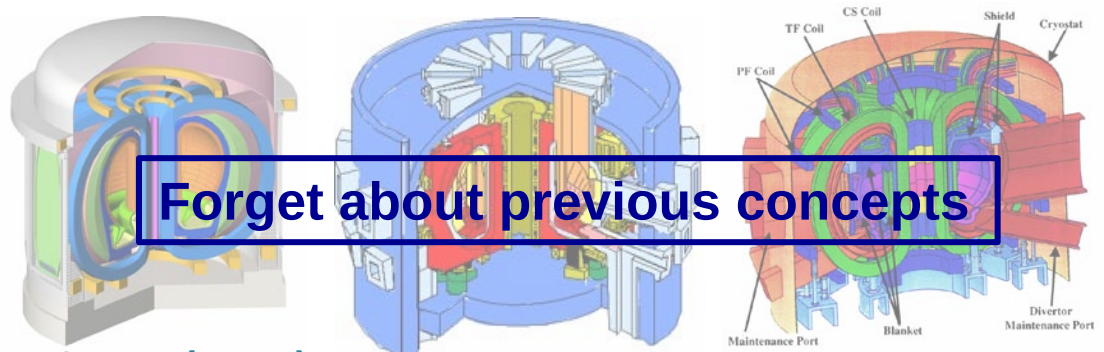
Improvement under discussion

- ✓ profile consideration
- ✓ bootstrap current model
- ✓ impurity content
- ✓ engineering models

Scoping study of DEMO

- **J-AEC's requirements for DEMO**
  - "steady state"
  - compact as ITER

    ➔ still required



Forget about previous concepts

SlimCS (2005) SSTR (1990) Demo-CREST (2005)

- **A trade-off on "steady-state" tokamak**

	small ⟵ R_p ⟶ large	
CD capability $\eta_{CD} \propto 1/R_p$	lower P_{CD}	huge P_{CD}
Volt-second	limited	sufficient

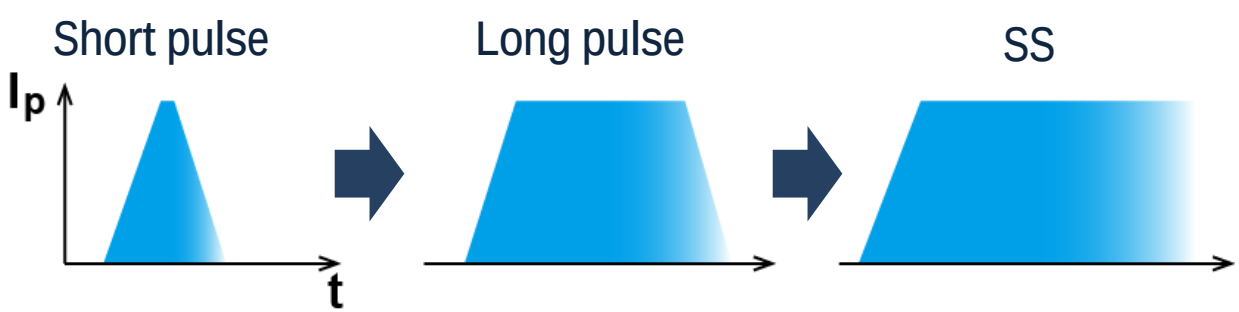
I_p ramp capability of previous concepts

		R_p (m)	A	$\Delta I_p^{CS}/I_p$
SlimCS	JAEA, 2006	5.5	2.6	~23%
Demo-CREST	CRIEPI, 2006	7.3	3.4	~70%
SSTR	JAEA, 1990	7.0	4.1	~100%

- All concepts based on a sacrifice of CS
- Even in SSTR, no extra volt-second prepared for pulsed operation

All these DEMO concepts assume mature technology on non-inductive CD in the beginning of operation. Who guarantees?

PROGRESS OF OPERATION



Approaches to SS DEMO with sufficient Vsec

(1) Conventional CS winding

- Volt-second of ~$L_p I_p$ needs to be ensured with large R_p (~8 m)
- + "volt-second saving" in I_p-ramp phase with external CD

(2) Inter-linked CS winding

- Inter-linked with TF, but out-of-vessel coil
  - >> separated from plasma chamber
  - >> shielded for n and γ
- Lower R_p ~ 7.5 m

~4 T

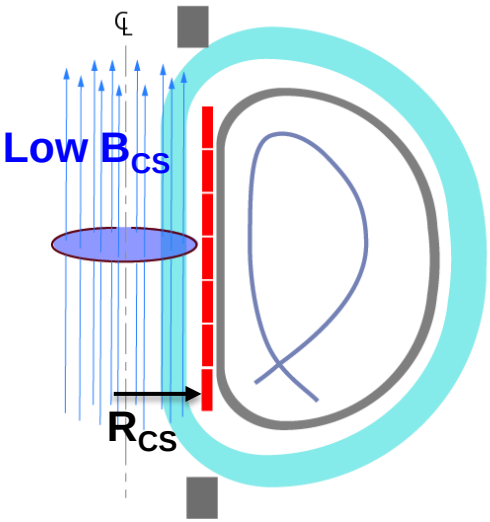
several times of conventional

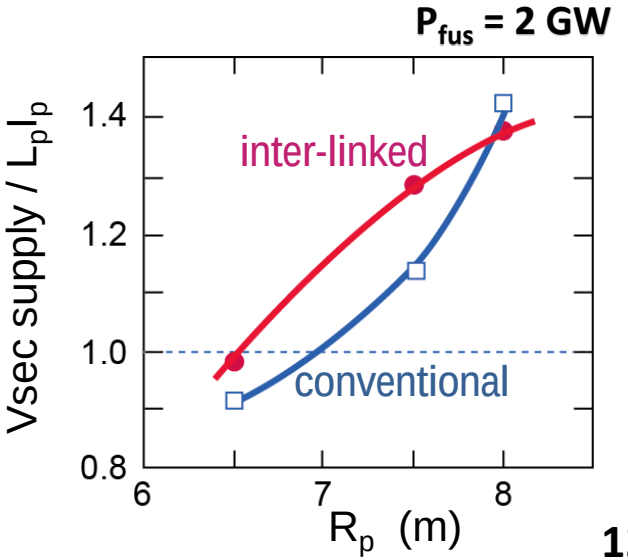
$$\Delta\Psi_{CS} \approx 2B_{CS} \cdot \pi R_{CS}^2$$

(3) High field CS

- Evaluate the possibility of B_{CS} ~ 20 T
- lower R_p ~ 7.5 m

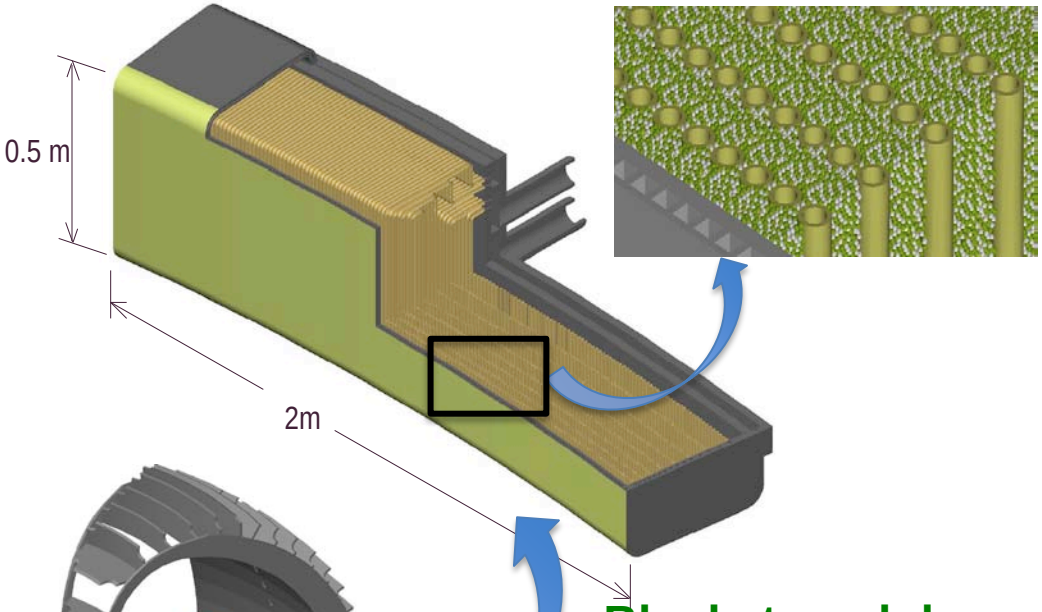
Inter-linked CS



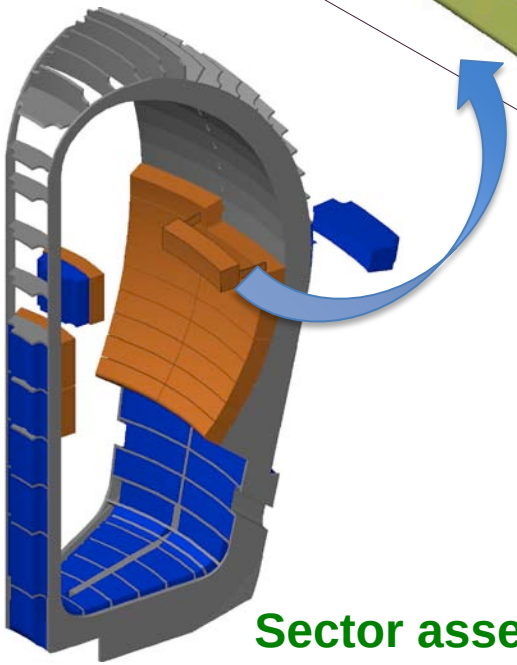


(2) TRITIUM BREEDING

WATER-COOLED SOLID BREEDING BLANKET



Blanket module

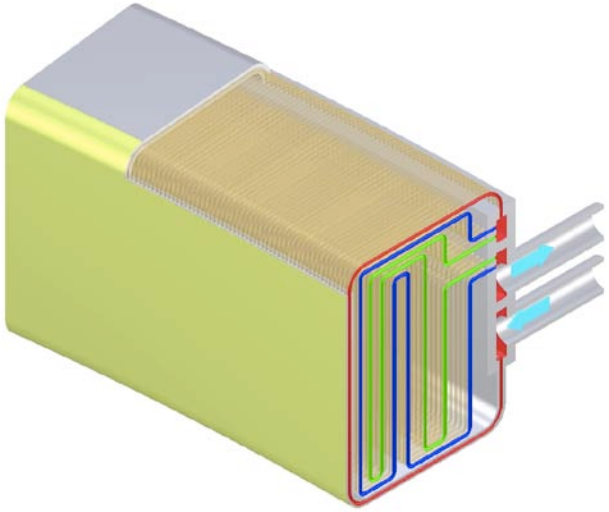


Sector assembly

Mixed pebble bed

- Li_2TiO_3 (^{6}Li-90% enriched)
- $Be_{12}Ti$

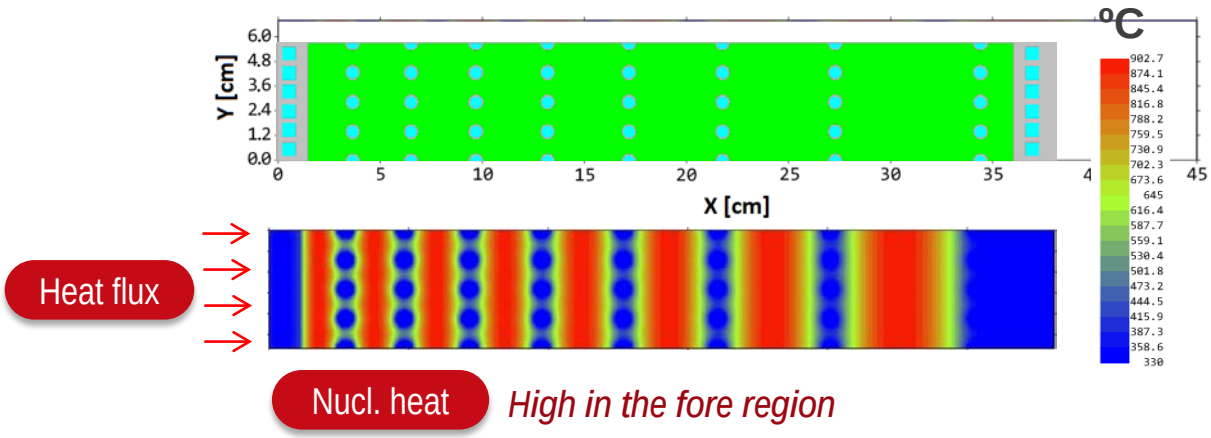
Coolant: water, PWR condition
15 MPa, 290° C (in) - 330° C (out)



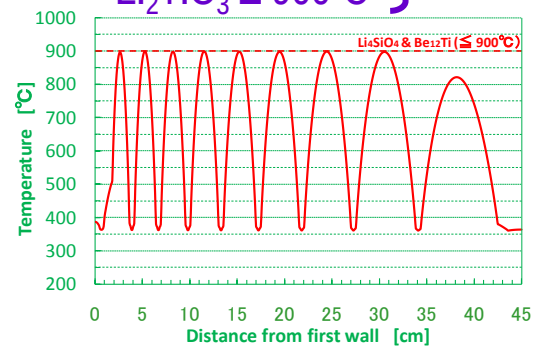
Routing of cooling tubes

Efficient arrangement to maximize TBR

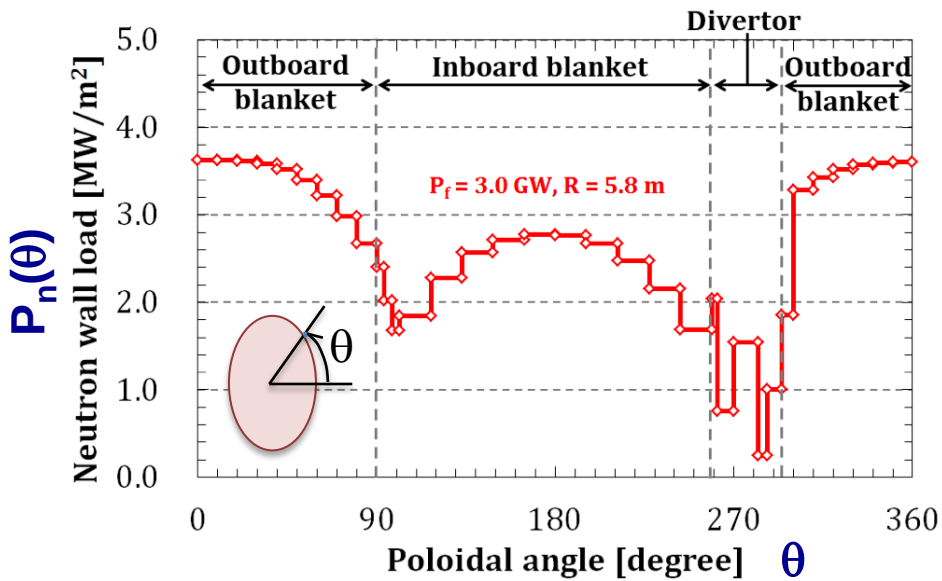
(1) To satisfy the op. temp. of materials but minimize N of cooling tubes



F82H ≤ 550°C
$Be_{12}Ti$ ≤ 900 °C
Li_2TiO_3 ≤ 900°C



(2) To change the detailed arrangement in accordance with $P_n(\theta)$



(1) + (2)

➡ **Overall TBR ≈ 1.05**

(pbl packing frac.: 0.65, ^{6}Li-90% enrich)

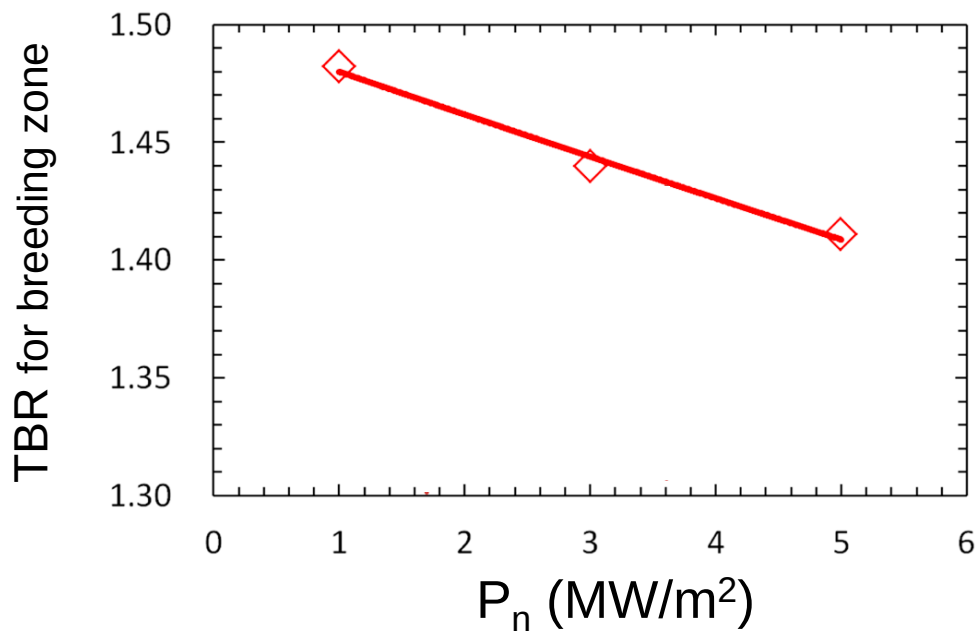
Still marginal

Lesson from blanket design

- **Lower P_n (< 3 MW/m^2) seems favorable to facilitate the fabrication.**

  Higher P_n (e.g., ~ 5 MW/m^2) requires cooling tube arrangement in a submm-accuracy in the fore blanket region

- **Additional benefit of low P_n ➔ design margin in TBR**



Low P_n

➔ Frac. of cooling tube ↘

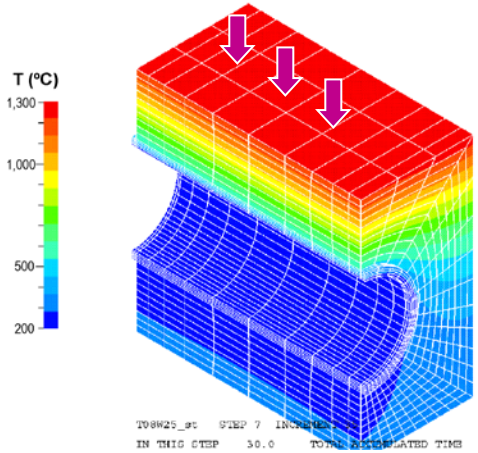
➔ TBR ↗

(3) DIVERTOR HEAT REMOVAL

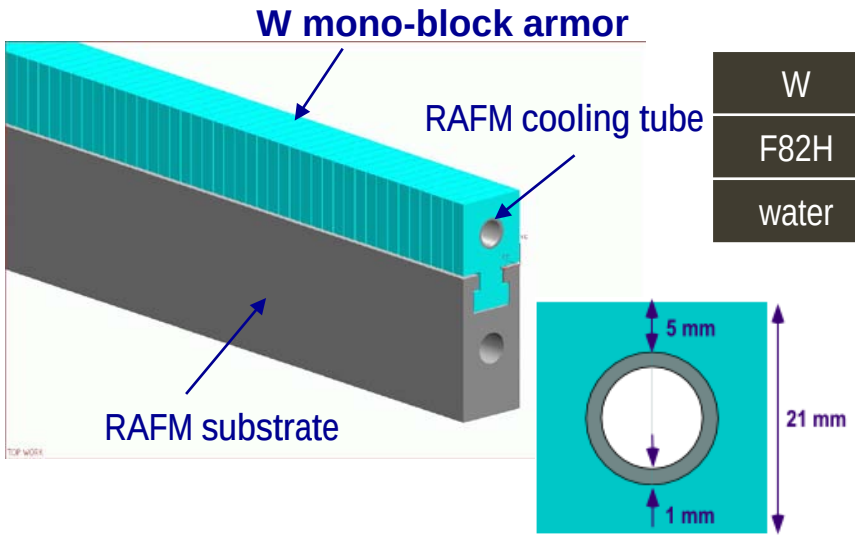
➡ Asakura-san's talk

Allowable heat flux

q_{max} ~ 6-7 MW/m^2



Water-cooled divertor concept



	Requirement
W	T ≤ 1,200°C
F82H	290°C ≤ T ≤ 550°C
water	290°C

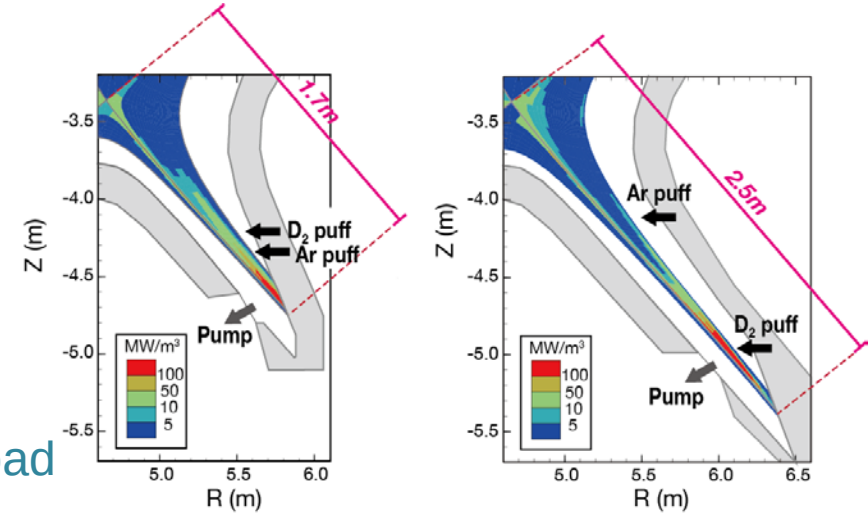
	ITER	DEMO (JA)
Structural mat.	**Cu alloy**	**RAFM (F82H)**
Armor	W	W
Coolant	Water (100˚C, 4 MPa,10 m/s)	Water (~300˚C)
q_{div} (design)	10 MW/m^2 (20 MW/m^2)	~7 MW/m^2

$\kappa_{F82H} \sim \kappa_{Cu}/10$

Approaches to resolve divertor problem

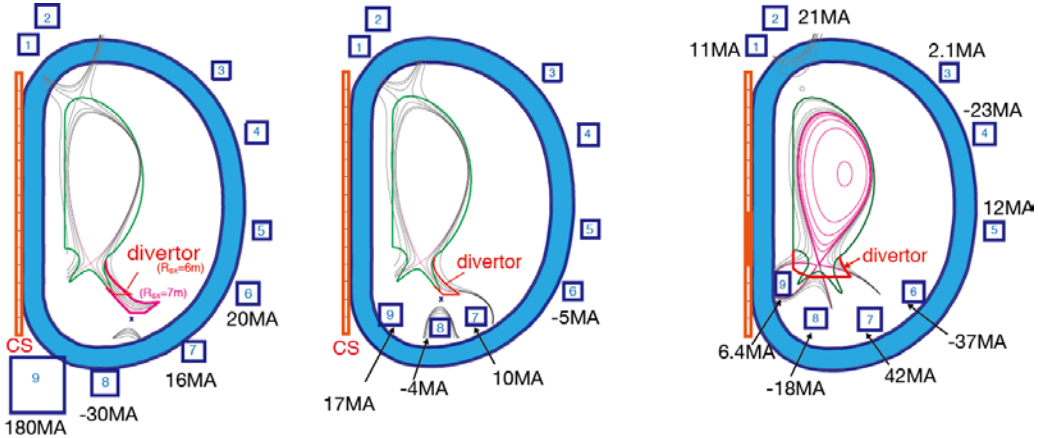
SIMULATION OF CONVENTIONAL DIVERTOR

- Impurity species
  Detachment by Ne, Ar and Kr injection
- Extended divertor
  x1.5 times longer divertor leg
- Impact of cross-field transport in SOL
  1 → 2 m^2/s, significant reduction in heat load



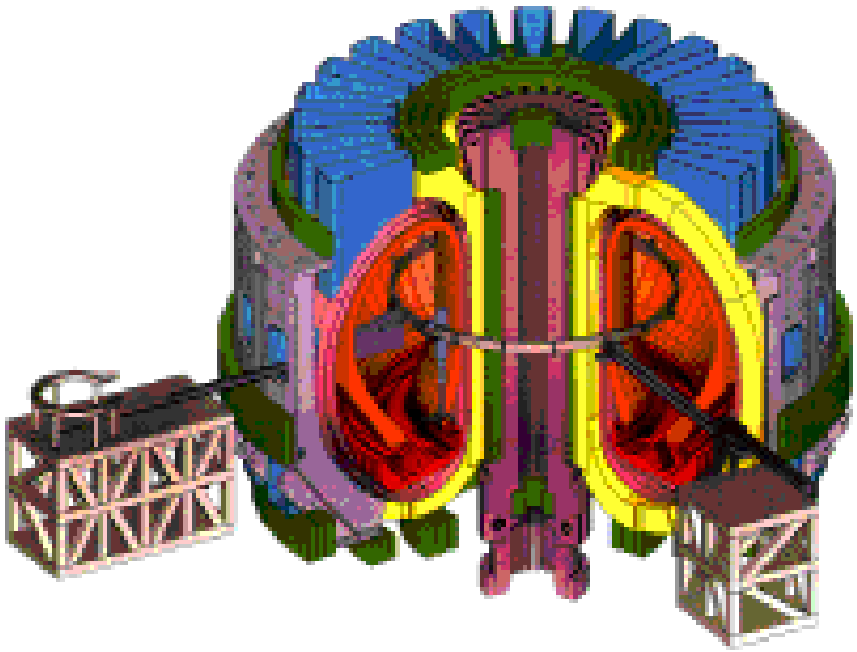
APPLICATION OF ADVANCED DIVERTOR

- PFC currents required for super-X and snowslake config.



(4) REMOTE MAINTENACE

"In-vessel maintenance"



In-vessel vehicle

The ITER scheme, not applicable to DEMO

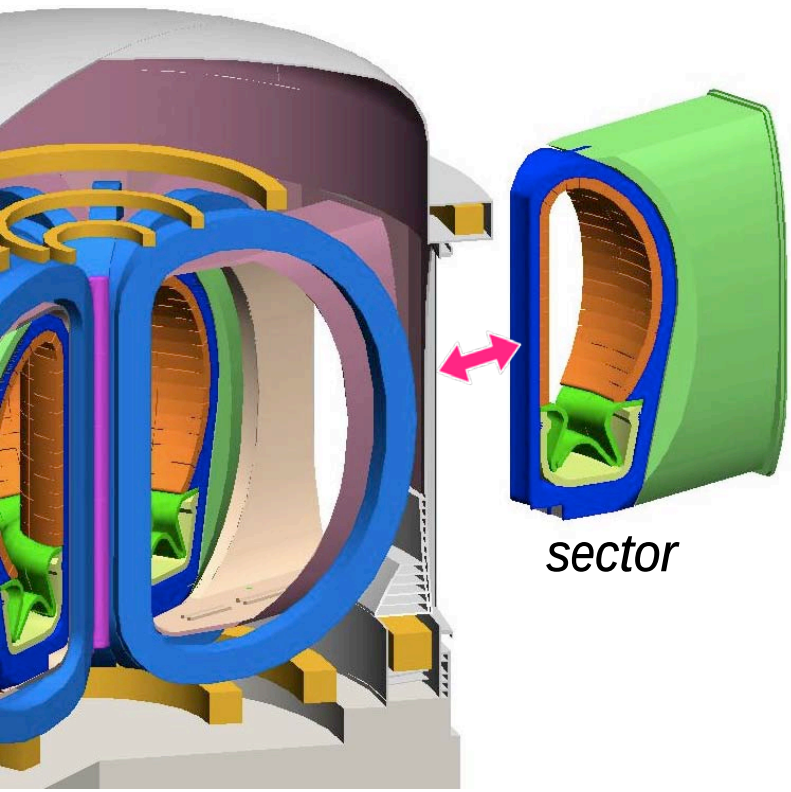
- Replace all blanket and divertor in a reasonable period
- Dose in VV: ~3×10^4 Gy/h (1 month after shutdown) , x100 of ITER

➔ Few RH equipment of ITER, durable in the environment

RM scheme for DEMO

“Hot cell maintenance”

Most feasible RM scheme in DEMO



Unit of maintenance

- Sector, or ← JA-HT
- Multi-module segment (MMS) ← EU-HT

Work sequence

1) During tokamak operation

↓ *Prepare spare sectors (or MMS) in the hot cell*

2) Reactor shutdown

↓ *Remove used sectors and install spare sectors*

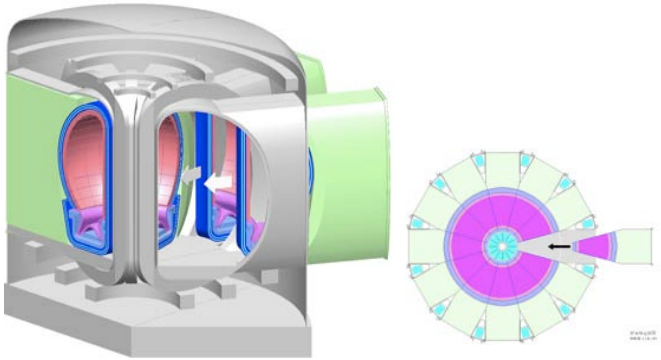
3) Resume reactor operation

↓ *Replace blanket and divertor modules and inspect in the hot cell*

Possible RM schemes for DEMO

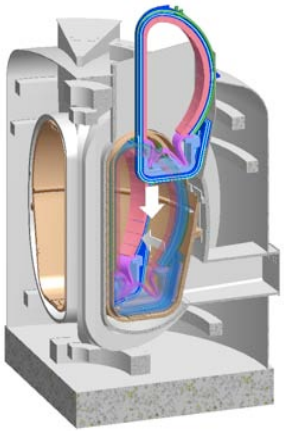
Horiz. Transport

(1) RM port arrang. in all sections



Difficult to support TFC turn-over forces

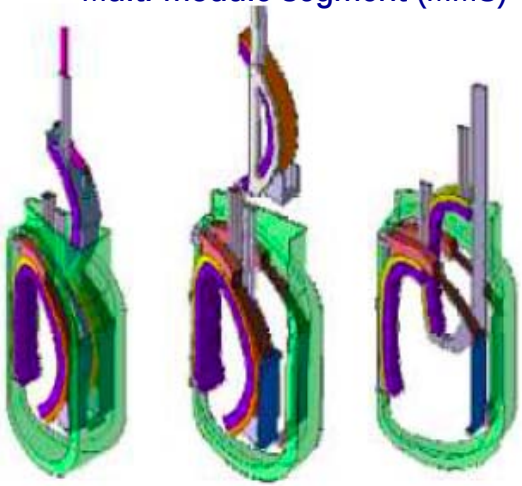
Vert. Transport



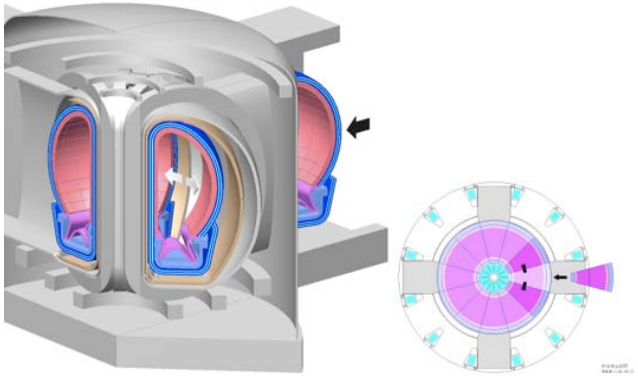
TFC turn-over forces, resolved

Banana type

Multi-module segment (MMS)

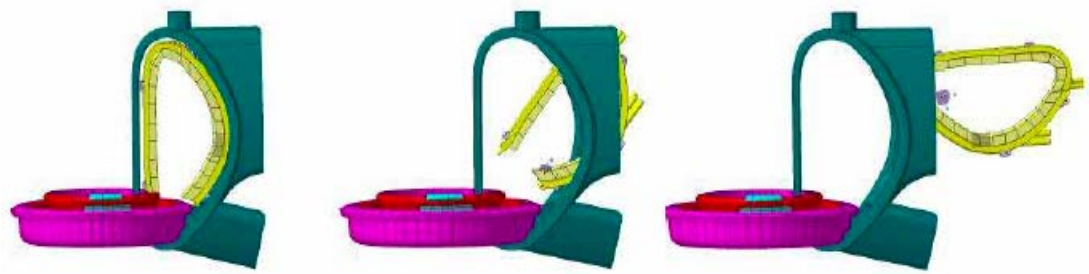


(2) RM port arrang. in partial sections



TFC turn-over forces, resolved

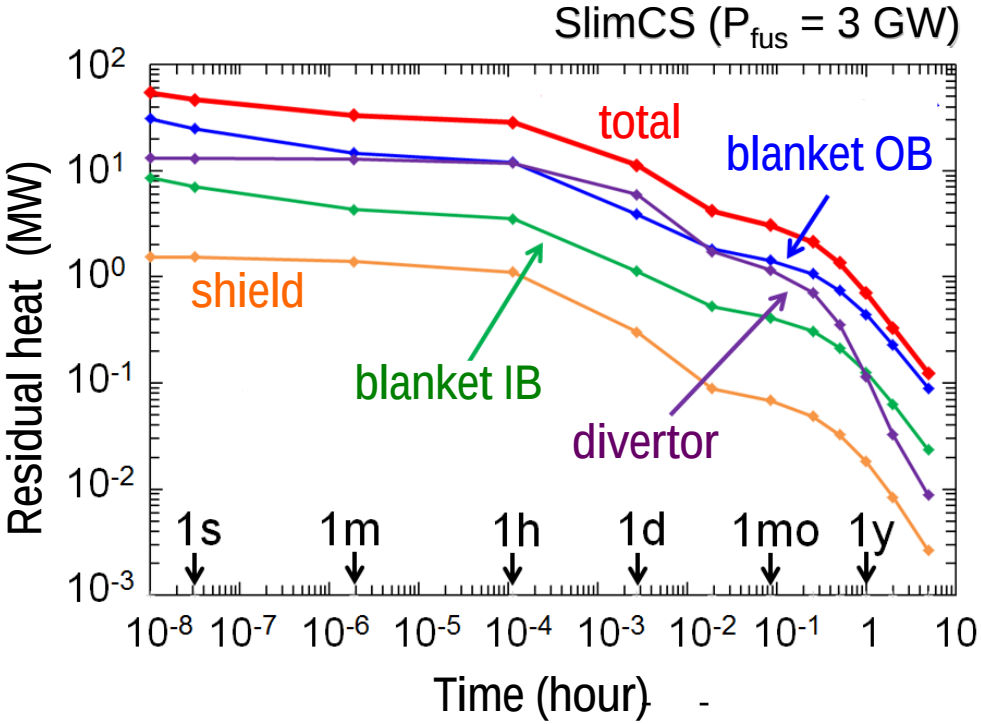
Rotating extraction



New issue on maintenance

Decay heat removal during maintenance

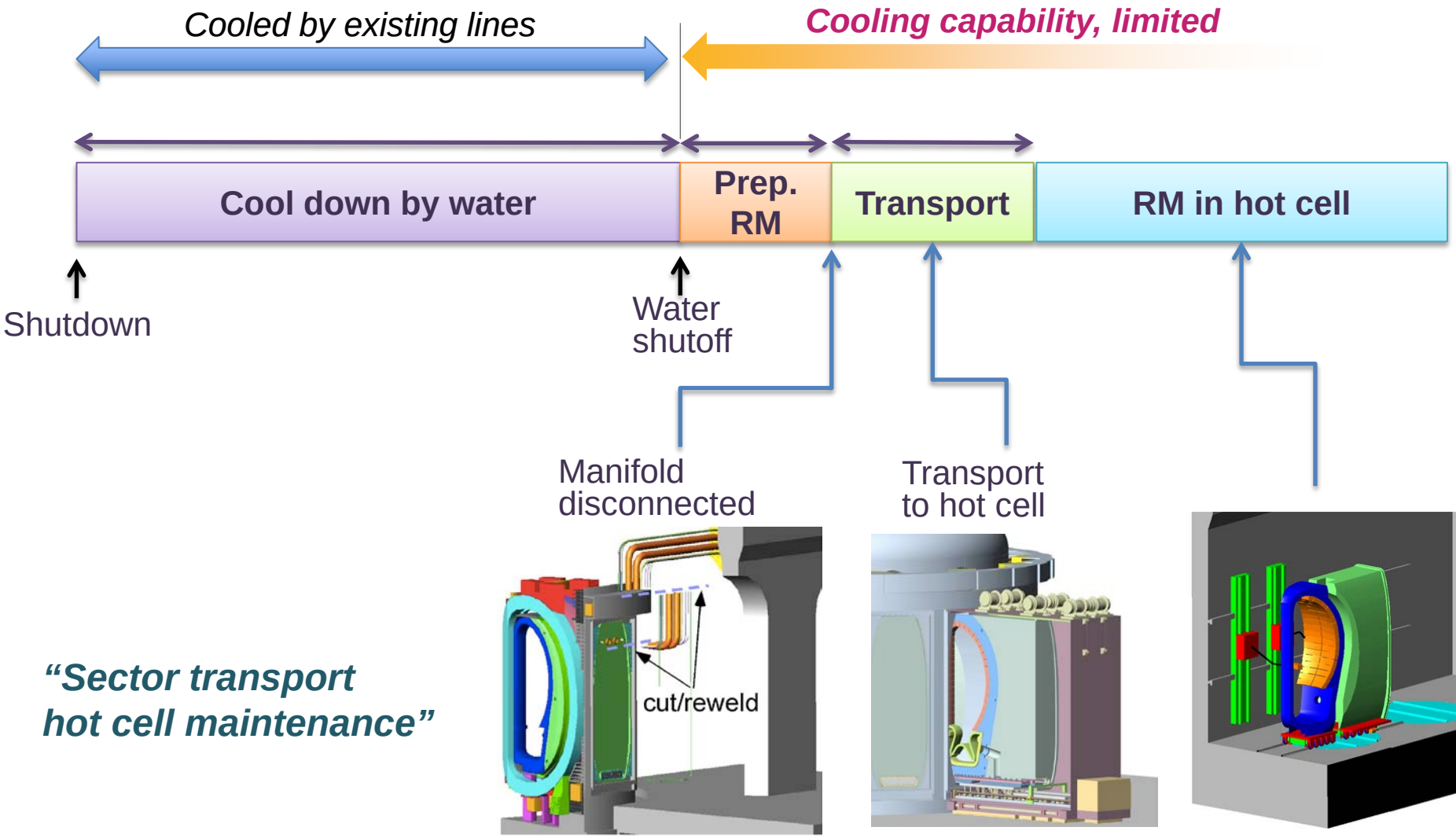
how to remove residual heat of ~ 3 MW with limited cooling



	Residual heat (MW)		
Time	0	1 day	1 month
Blanket	39.5	5.0	1.8
Divertor	13.1	6.0	1.2
Shield	1.8	0.3	0.1
Total	54.4	11.3	3.1
ITER	10	1	~0.1

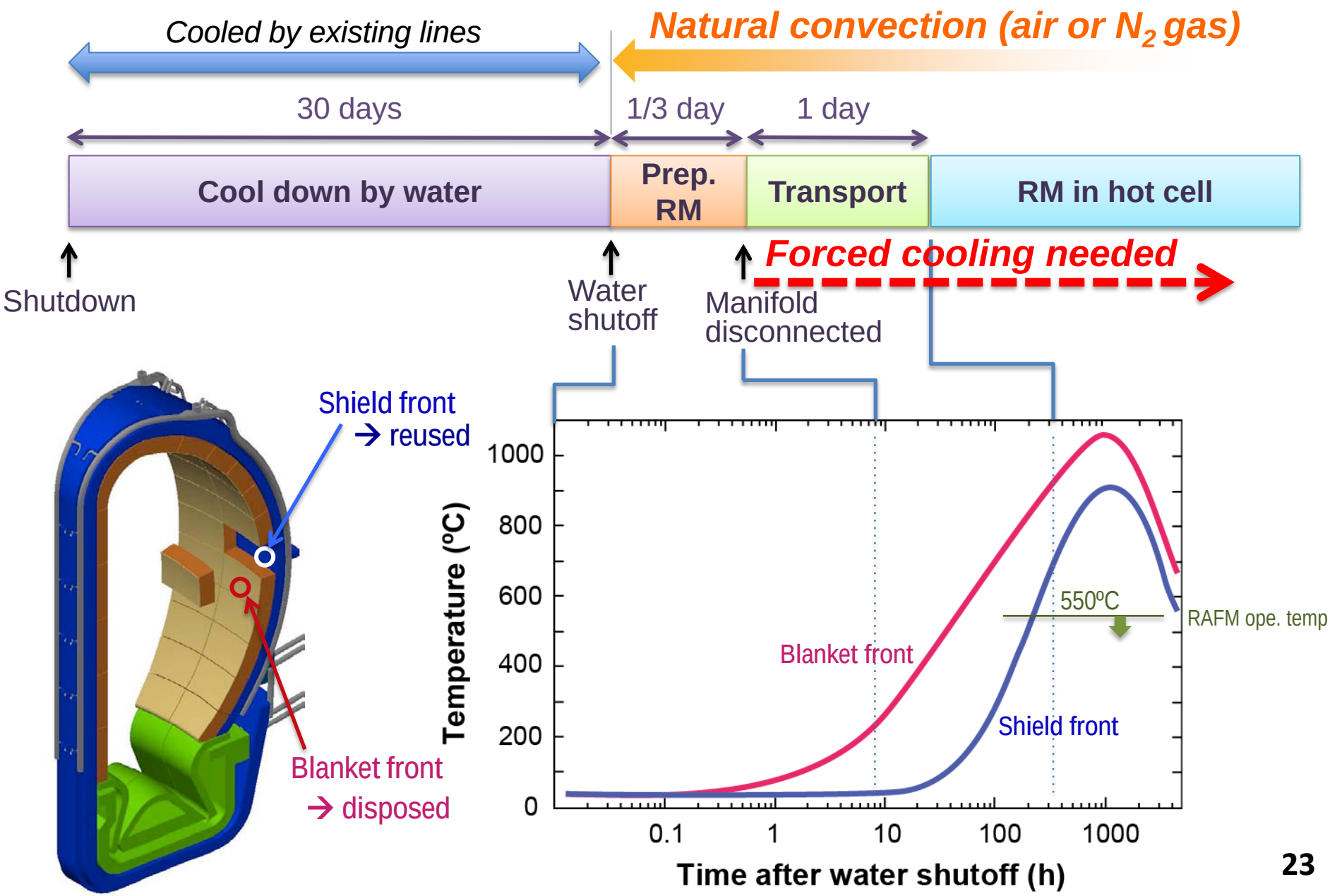
DEMO: x10 higher than ITER

Maintenance scenario and cooling issue



"Sector transport hot cell maintenance"

Natural convention cooling



Outline

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- ❖ Recent Development in DEMO Design
  - (1) Syetems code study
  - (2) Tritium breeding
  - (3) Divertor heat removal
  - (4) Remote maintenance
- ❖ **Safety Research**

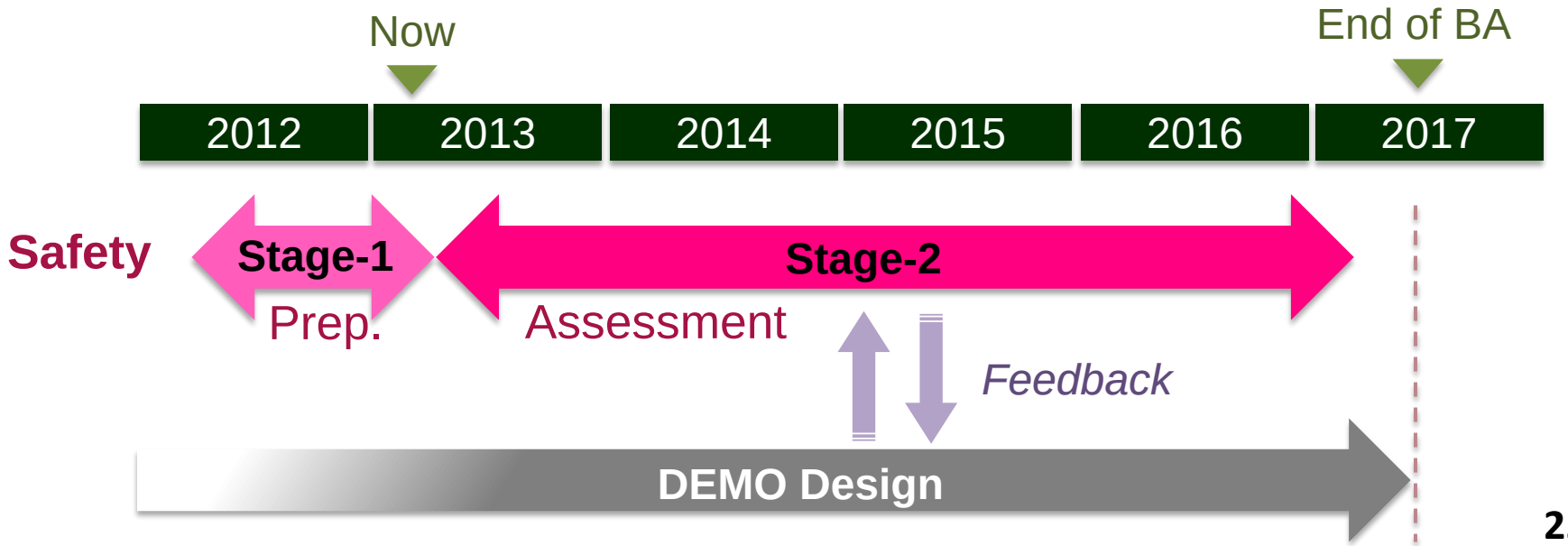
Safety Research

✓ Started in 2012, in response to the growing interest in safety

☐ Targets

- Characterize safety on DEMO
- Formulate DEMO safety guidelines
- Foster young specialists

☐ Schedule



Status of safety research

➡ Nakamura-san's talk

- **Preparation of framework**
  - Team building (10-15 PPY)

- **Tasks done so far or doing now**
  - Source terms and energies of DEMO
  - Preparation of codes (e.g., MELCOR-FUS from INL)
  - Defined accidental sequences on DEMO
  - Planning of the research program for Stage-2 (2013-2016)

- **Collaboration with EU expert**

Rokkasho, Apr. 2012

Garching, Oct. 2012

Tokyo/Rokkasho, Nov. 2012

Emphasis on the safety research

- **Assess posulated events and bounding sequences**

Feedback of information

- **Consider active and passive safety systems**

Show an overwhelming feature of fusion
as a radiologically secure nuclear energy source

Target: public dose < 20 mSv

Summary

1. BA DEMO design with EU is right on track.

2. Progress is seen on design study on divertor, maintenance and blanket, but the study has not grown our confidence on DEMO. Further work is necessary.

3. Safety research will be start in a full-scale program in FY2013.