Accomplishment of DEMO R&D Activity of IFERC Project in BA activity and Strategy toward DEMO & Progress of conceptual design study on Japanese DEMO

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**Technical demands on DEMO Design and R&D activity**

**Conceptual design of JA DEMO**

*Fusion Power* compatible with *divertor heat-handling*  
=> $P_f = 1.5 - 2.0 \text{ GW}$

*Device size* compatible with *operation flexibility including pulse operation*  
=> $R = 8 \text{ m class}$

*Breeding Blanket system* consisted with the rational combination  
=> *Water Cooled Ceramic Breeder for primary system and advanced option for DEMO-TBM*

**Need to establish basic strategy of safety assurance of fusion system**

**Design challenges** to overcome weaknesses in water-cooled DEMO

- $T$ permeation into the primary coolant in in-vessel components
- $T$ management in the primary coolant loop
- Confinement concept for $T$ release from the primary coolant loop in a pipe rupture accident.

**Technical challenges** on materials and technologies related to breeding blanket

- Structural material which fulfill the technical demands
- Neutron multiplier and $T$ breeder compatible with water-cooled system
- Advanced material for functional structure application (flow channel insert) of dual-coolant liquid metal breeding system (DEMO-TBM)
- $T$ handling technologies which form the technical basis of safety and $T$ breeding
Highlight: DEMO plant concept related to tritium handling in the primary coolant system is developed.

1. T permeation into coolant
   T permeation into coolant was estimated to be as low as 5.7 gT/day = 2.5% of produced T

2. T extraction from coolant
   T permeation 5.7 gT/day
   Management of T concentration in the coolant is viable by applying an existing water detritiation system (WDS) of CANDU.

3. Confinement of T at LOCA
   Combination of “cooling water vault” and “suppression pool” is effective to mitigate T environmental release due to a large scale ex-vessel LOCA.

   Early public dose: as low as 1.8 mSv < 50 mSv of no evacuation limit
T permeation into water can be resolved in DEMO

- Tritium permeation was estimated for three pathways via: 1) blanket surface, 2) inside blanket, and 3) divertor surface.

  **Blanket pathways**
  
  1.8 gT/day
  
  2.3 gT/day

  **Divertor pathway**

  1.6 gT/day

- Tritium permeation was estimated to be as low as **5.7 gT/day** at most.

(K. Katayama et al, Estimation of Tritium Permeation Rate to Cooling Water in Fusion DEMO Condition, 4B-6, Tritium 2016, US)

- For the permeation of **5.7 gT/day**, T concentration in the coolant can be kept at **1 TBq/kg or lower** by applying an existing water detritiation system (WDS) of CANDU.

- Actually, the required water to be processed is 94 kg/h for DEMO, which is satisfied with the specifications WDS in Wolsong (Korea).

**Wolsong WDS (Korea)**

**Water throughput:** 100 kg/h  
**T concentration:** 0.04 – 2.2 TBq/kg
A new concept of T confinement in ex-VV LOCA

(Y. Someya et al., FEC2016 SEE/P-7.5)

- Ex-VV LOCA discharges the tritiated coolant (1TBq/kg) in the final confinement barrier.
- Installation of a Suppression Pool (SP) is proposed to mitigate the pressure increase in the Upper Tokamak Hall (UTH), constituting the final barrier.
- The SP can reduce the pressure in the UTH to less than 0.12 MPa.
- The resultant release of tritium from UTH can be drastically reduced.

The resultant early dose to the public can be reduced to 1.8mSv ≪ 50mSv.
*(“no-evacuation” dose limit recommended by IAEA)*
Requirement for the blanket system

**Required function**
- Shield the high energy fusion neutron
- Breed Tritium (Tritium Breeding Ratio > 1.05)
- Convert neutron energy into heat

**Expectation to R&D**
Materials & tritium technologies for blanket system is expected to provide sound engineering bases for **Safety**, reliability and feasibility of blanket designs.

* Blanket is not the safety barrier, but is expected not to challenge the integrity of the primary safety barrier, the Vacuum Vessel.
**Highlights:**

- **Reduced Activation Ferritic/Martensitic (RAFM) steel**
  - Demonstrate JA-RAFM steel F82H's good reproducibility in DEMO scale production technologies.

- **Tritium handling technologies**
  - Successfully developed Be$_{12}$V single phase pebbles, which has suppressive reactivity with water and good T release properties.
  - Prove the stability of SiC/SiC composite at high temperature for functional structure application.
  - Found suppression of passivation behavior of SS304 by tritiated water, but not the case for SS316.
  - Good compatibility with high temperature liquid Pb-Li.

- **Advanced Neutron Multiplier**
  - Be$_{12}$V pebbles produced by plasma sintering method & rotating electrode method.

- **Advanced Tritium Breeder**
  - LTZO$_{20}$: Li$_2$+(x)TiO$_3$+(y) with 20 wt.% Li$_2$ZrO$_3$.
  - LIZO pebbles produced by emulsion method.
  - Tritium release rate during and after 14 MeV n irradiation.

- **Tritium handling technologies**
  - X-ray Photoelectron Spectroscopy analysis after 1hr corrosion test at RT.

- **Functional structures**
  - Good high temperature property of new grade SiC/SiC.
Strategy toward DEMO beyond BA activity

**Blanket Technologies**
*Technical Readiness Level (TRL)*

**RAFM Steel**
*Structural material*

1: Conceptual idea
2: Realization of basic technology
3: Proof of technical principle
4: Lab. Scale demonstration
5: Industrial level demonstration
6: Ready for Fusion application
7: DEMO mockup operation
8: DEMO construction / operation
9: Ready for Power plant

**SiC/SiC**
*Flow channel insert for DEMO-TBM*

**Tritium**

**Breeder**

**Multiplier**
Strategy toward DEMO beyond BA activity

Blanket Technologies
TRL Technical Readiness Level

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Tritium

SiC/SiC Flow channel insert for DEMO-TBM

Breeder
Multiplier
Strategy toward DEMO beyond BA activity

Operation of ITER-TBM in DT phase
- The important demonstration to prove its feasibility (But, <3dpa)

An intense fusion neutron source
Relatively large volume, constant / high dose fusion n. irradiation facility
- Verification of materials and expertise of blanket technologies under DEMO-like environment.

To get ready for Fusion DEMO application.
Demonstration and endorsement of these developed technologies in industrial level, under DT fusion in-vessel environment.
Summary

Demo concept development

✓ Plant concept related to tritium handling in the primary coolant is developed.
   - Tritium permeation into the coolant in the in-vessel components is evaluated to be 5.7gT/day.
   - T management keeping 1TBq/kg in the primary coolant is found to be possible using the existing tritium removal facility of CAMDU.
   - Confinement concept of T release at ex-vessel LOCA is proposed using suppression pool system, resulting early dose to the public 1.8mSv.

Demo R&D activity

✓ Five R&D tasks on blanket technologies were conducted in the BA DEMO R&D activity, and the major accomplishments are as follow.
   - Demonstrate **RAFM steel, F82H**, potential as the DEMO structural material
   - Prove the stability of **SiC/SiC composite** for functional structure application
   - Developed **Beryllide (Be_{12}V)** as the advanced neutron multiplier
   - Developed **Li-titanete/Li-Ziroconate ceramic** as the advanced tritium breeder
   - Found no T water effects in SS316 in **Tritium handling technologies R&D**

Next step

✓ Need an intense fusion neutron source for verification and expertise of these technologies.