Development of LiPb-SiC Blanket; Present status and Strategy

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Kyoto, Japan

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How fusion affects?

Environment, Society

Facility

Blanket

Plasma

Heat Transfer

Generation Plant

Wastes (Solid nuclides, T,C-14)

Exhausts (T, heat)

Fuel, Material (D,Li-6,..)

Energy (Electricity) (Recycle)

Economy

Fusion will be evaluated
- what it consumes
- what it exhausts
- what it generates, and
- what it leaves

Blanket is the key
For Socio-economic Feature of fusion

Institute of Advanced Energy, Kyoto University
Thermo-hydraulic study (heat transfer)
LiPb chemistry control (monitoring, purification)
MHD effect measurement with actual SiC/LiPb contact.
Compatibility test with SiC, RAFM and other.
SiC insert development
Hydrogen permeation, recovery and control
System and component design (nuclear)
IEC neutron source and trace nuclear test
Application study (hydrogen production, supercritical CO₂)
Socio-economic assessments
Japanese Strategy toward DEMO

- National program confirmed the combined DEMO/Proto strategy

- Pursues earlier introduction of fusion into the market.

- Multiple generations of blanket and materials will be studied in the DEMO phase.
  1st – early introduction
  next – demonstration of possible better economy

Advanced, more efficient blanket is needed.
Roadmap for Materials and Blanket Development in Japan

<table>
<thead>
<tr>
<th>Approximate calendar year</th>
<th>2015</th>
<th>2020</th>
<th>2030</th>
<th>2040</th>
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<tbody>
<tr>
<td>1st commercial plant</td>
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<td>Power Generation Plant</td>
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<td>ITER</td>
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<tr>
<td>Materials and Blanket System Development</td>
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<tr>
<td>Reference Material (RAFM) and System</td>
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<tr>
<td>Advanced Materials (V-alloy, Flibe, SiC/SiC --) and System</td>
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<tr>
<td>ITER</td>
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<tr>
<td>IFMIF</td>
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<tr>
<td>Blanket Module Test</td>
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<tr>
<td>Irradiation Test, Materials Qualification and System Performance Test</td>
<td>(Staged construction and operation)</td>
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<tr>
<td>Design</td>
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<td>Construction</td>
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<tr>
<td>Operation</td>
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<tr>
<td>modification</td>
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<tr>
<td>Design</td>
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</tbody>
</table>

Reference Blanket (Mostly JAERI responsibility)
Advanced option (Mostly NIFS/University responsibility)
- Reference is solid, water cooled concept. to be tested in ITER TBM.

- Possible improvement is supercritical water concept.

- Other Advanced concepts: He-cooled, Li/V, LiPb/SiC will be studied under international collaboration framework. to be attempted for the test in ITER.

- Advanced concepts: He-cooled, Li/V, LiPb/SiC will be attempted for the test in ITER and DEMO.
JA’s Interest presented at TBWG

- JA Delegation to TBWG has presented the interest in Five Test Blanket Module (TBM) concepts.
- JA’s tentative position to each of the TBM concepts is shown below.

<table>
<thead>
<tr>
<th>Proposed TBM Concept</th>
<th>JA Position</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water-cooled Ceramic Breeder Blanket (WCCB) with reduced activation Ferritic/Martensitic steel</td>
<td>Take a lead</td>
</tr>
<tr>
<td>Helium-cooled Ceramic Breeder Blanket (HCCB) with reduced activation Ferritic/Martensitic steel</td>
<td>Participate as a Partner</td>
</tr>
<tr>
<td>Li self-cooled/He cooled Li Breeder Blanket with Vanadium alloy structural material (Li/V)</td>
<td>Participate as a Partner</td>
</tr>
<tr>
<td>Helium-cooled LiPb Breeder Blanket with reduced activation Ferritic/Martensitic steel (LiPb/He)</td>
<td>Participate as a Partner</td>
</tr>
</tbody>
</table>

- R&D efforts will be continued in Japan to introduce TBMs base on FLIBE and other advanced concepts in the Extended Operation Phase.
1) LiPb-RAFM blanket with SiC insert (DCLL)
   - compatibility issue
   - thermal insulation
   - MHD pressure drop
   - tritium solubility

2) SiC Heat Exchanger program
   - Dual coolant for high temperature heat
     → heat extraction with He from LiPb using SiC components.

     → high temperature He as secondary heat transfer medium.
Module concept

Module box temperature made of the RAFS kept under 500 ºC.

LiPb outlet temperature target 900 ºC.

We propose the new model of active cooling in LiPb blanket.

This concept is equipped He coolant channels in SiC/SiC composite and provides more efficient isolation between the RAFS and high temperature LiPb.

We evaluate the feasibility of high temperature blanket in this model.
Fabrication technique for cooling panel and other blanket parts such as FCI and HX are being tested.

SiC cooling panel unit

Fabrication process
Compatibility tests

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SiC/SiC composite tube was installed in the LiPb loop.
Tube section was heated above 600 degree C with LiPb flow.
Possible corrosion is observed with microscopes.

SiC/SiC tube

Inner surface of SiC after exposure

Test section: heated and cooled
LiPb Loop Experiment
Kyoto University Institute of Advanced Energy

Test sections at 900°C

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>temperature [°C]</td>
<td>350~450</td>
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<tr>
<td>inventory [liter]</td>
<td>6</td>
</tr>
<tr>
<td>Flow rate [l/min]</td>
<td>0~5</td>
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<tr>
<td>fluid</td>
<td>Li-Pb</td>
</tr>
<tr>
<td>material</td>
<td>SUS316</td>
</tr>
</tbody>
</table>

LiPb loop in Kyoto University
LiPb Loop Experiment
Kyoto University Institute of Advanced Energy

Research activities
- Compatibility
- Hydrogen permeation and transport
- Heat transfer
- MHD pressure drop
- LiPb purity control
Emission dominated by normal detritiation from coolant.

Water based heat transfer requires isotope separation.
TRITIUM containing medium will be confined:
- expansion volume: He
- expansion pool: water (easy)
- other liquids

IN CASE OF SPILL, TRITIUM IS RECOVERED BEFORE GOING OUT TO THE NEXT BARRIER

Against accidental release, Pressurized Helium requires huge vacuum volume to keep sound confinement.

Accidental spill can be recovered with normal detritiation. Heat transfer media and pressure requires different confinement.
Tritium released from the facility diffuses but not disappear.

According to the LNT hypothesis by ICRP, detriment increases with distance.

Normal release accumulates in the environment.

Dose is negligible compared with natural radiation, but detectable in environment, foods and drinking water. Same thing happens with C-14 and worse.
The device consists of two lines with high and low pressure divided with disk sample. Permeation of deuterium was measured by using quadrupole mass spectrometer.
The deuterium gas pressure at the low-pressure line ($P_l$) was measured under evacuation. Permeation flow rate was calibrated with a He standard leak. It takes over 10 hours for the permeation to become constant.
Sample: CVD SiC
Thickness: 2.79 [mm]
Temp: 800 [ºC]
Gas: 100%D₂ 1.0x10⁵ [Pa]

Permeation flow rate of CVD was larger than that of Hexoloy by 2 orders.
Sample: CVD SiC
Thickness: 2.79[mm]
Gas: 100%D₂

The pressure of high-pressure line ($P_h$) was changed ranging $10^2$ to $10^5$ Pa.

Slope of the double logarithmic plots is 1/2 when $P_h$ is high. And it is possible that the slope is 1 when $P_h$ is low.
Comparative arrhenius plot of the obtained permeability.

\[ K = \frac{n \cdot d}{A \cdot \sqrt{P_h}} \]  

\[ \text{[mol}\cdot\text{Pa}^{-1/2}\cdot\text{s}^{-1}\cdot\text{m}^{-1}] \]

- **K**: permeability
- **n**: permeation flow rate
- **d**: thickness of the sample
- **P_h**: the pressure of high pressure line
- **A**: geometrical area of the sample
It is considered that the time taken to start the permeation is related to diffusivity.

The time required to start the detection of permeation gas is...

- SUS316: a few seconds
- CVD: a few minutes
- Hexoloy: a few hours

Activation energy of the diffusion of Hexoloy is 110 kJ/mol.
Solubility was calculated by permeability and diffusivity.

The solubility in SiC material is ranging $10^{-4}$ to $10^{-3}$ [mol m$^{-3}$ Pa$^{-1/2}$] at the temperature above 700 degree C.
Solid electrolyte cells for purity control

Solid oxides: YSZ for oxygen
SrCeYbO for hydrogen

- Inside electrode was made of Pt mesh and Pt paste exposed to air or a standard gas
- Liquid LiPb was used as outside electrode
- Fuel cell and concentration cell modes were used.

Fig. The cell structure
Vessel is filled with He and swept.
Ceramic cell dipped in the liquid metal.
The other side of LiPb is in air.
Gas is analyzed with Micro GC at the outlet.
EMF of the cell is measured with potentiostat.
Oxygen Potential in LiPb

- Oxygen Potential can be measured with solid electrolyte cell.

\[ E = \frac{RT}{4F} \ln \frac{P_{O_2}^{in\ air}}{a_{O_2}^{in\ metal}} \]

- Theoretical \(a_{O_2}\) obtained from Gibbs free energy for LiPb system

\[ \ln a_{O_2} = \{\Delta G^0[Li_2O] / RT\} - 4 \ln a_{Li} \]

\[ \ln a_{Li} = -0.2882 - \frac{6732}{T} \quad \text{(at Pb-17Li)} \]

*Peter Hubberstey; Pb-17Li and lithium: A thermodynamic rationalisation of their radically different chemistry

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Institute of Advanced Energy, Kyoto University
Observation of electrolyte

After 3 hours dipping in LiPb, YSZ was discolored.

It is suspected that YSZ was reduced by LiPb

Fig. close-up electrolyte surface (×1000)
Proton conductor used for hydrogen measurement.

Equilibrium pressure of H2 in LiH−H−Pb system measured. (hydrogen not added but detected both in metal and gas.)
Availability and stability of fuel resource will be important.

ONLY LiPb blanket can control the lithium concentration continuously.

Li concentration in LiPb can be measured with the electrolyte cell when oxygen or hydrogen concentration is known.

TBR should be controlled at the time constant of days. Continuous monitoring of Li-6 and its control is needed. LiPb-solid electrolyte system can do it.
Ultimate goal of this program in Kyoto is to develop a concept of high temperature blanket.

Small scale blanket module will be demonstrated in 4 years.

System and component design will be made.

Small neutron source will be used for tritium transfer experiment.

DCLL and advanced SiC-LiPb configuration will be possible to be tested under TBM.

Feasibility of high temperature blanket is of extreme importance for efficient generation and hydrogen production process. (We also study socio-economics of fusion in future market.)
Above experiments are already funded by internal effort in Kyoto University and ongoing.
Kyoto university is ready to accept collaborators either with or without agreements.
Both LiPb loop and SiC programs are open for collaboration.
Several visitor programs are available.
JA party now encourages collaboration.
Liquid TBM program is now a part of national program.
LiPb-SiC blanket concept is now actively studied in Japan at Kyoto University.

Fusion plant will have to be designed and evaluated from socio-economic aspects, i.e., safety, fuel supply, waste, economic value and strategy.

Both experimental and design studies are open for international collaboration.

Some of the experiments are unique and valuable for international efforts for liquid blanket development.