R&D Liquid Metal Breeding Blanket Program in RF

I.R. Kirillov * and RF TBM Team
D.V. Efremov Institute of Electrophysical Apparatus,
St. Petersburg, Russian Federation
Conceptual design of LLCB blanket for RF DEMO-S reactor (1)

• RF for many years has been developing Li-V breeding blanket for tests in ITER after revealing its high potential performance in DEMO-S reactor study of 1998-2000. Due to lack of financial resources and adequate support from international community, RF has been switching since 2009 to the development of lead lithium ceramic breeder (LLCB) test blanket module (TBM) proposed by Indian TBM Team. It uses lead lithium eutectic (LL) and ceramics as breeder materials and helium and LL as coolants.
Conceptual design of LLCB blanket for RF DEMO-S reactor (2)

• Conceptual design of LLCB blanket for RF DEMO-S reactor was finished to show some advantages over pure LL blanket

• DEMO-S reactor main parameters:
  Plasma major radius 7.8 m; minor radius 1.5 m
  Average neutron load 2.5 MW/m2 (outboard), 2 MW/m2 (inboard)
  Average heat load 0.4 MW/m2 (outboard)
  Fusion power 2.44 GW

• Neutronic, thermo hydraulic calculations and conceptual design were made.
Conceptual design of LLCB blanket for RF DEMO-S reactor (3)

- **Main conclusions:**
  - Insertion of CB into LL blanket provides for TBR increase in comparison with pure LL blanket (for inboard/outboard blanket radial thickness 420/500 mm and 6Li 90% in CB and LL – 3-D TBR is 1.16).
  - Blanket life time is increased in comparison with pure CB blanket due to possibility of keeping 6Li enrichment at the proper level outside of the reactor (3-D TBR for 6Li 50% in CB and 6Li 90% in LL is high enough – 1.14).
  - LL outlet temperature is around 500°C may be obtained at currently available structure material with gross electrical efficiency on the level of 40% (inlet temperature is 325°C). LL outlet temperature may be increased to around 700°C with good progress in developing thermo and electro insulating insertions from SiCf/SiC and He cooling of the partitions.
  - Optimum distribution of CB and LL from TBR point of view is provided with LL ducts close to the first wall with total dimension around 1/3 of blanket radial thickness and the rest part – with optimized CB and LL layers/ducts taking account of temperature limitations. (See also similar conclusion in presentation of C. Danani et.al. at ISFNT-9).
New LLCB TBM design was initiated with distribution of LL and CB zones as in DEMO design.

Radial configuration of TBM breeding zone reflects the one of DEMO blanket.

Limited number of CB layers are chosen to simplify the design.

Parallel and series connection of LL ducts is considered.

Thermal hydraulic analysis in the first approximation is made for 3-D neutronic analysis.

Ferromagnetic material mass is around 800 kg at present, possibility of its decreasing will be estimated.
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>PbLi inlet/outlet temperature, °C</td>
<td>325/489</td>
</tr>
<tr>
<td>PbLi warm up in upward ducts, °C</td>
<td>~ 109</td>
</tr>
<tr>
<td>PbLi warm up in downward ducts, °C</td>
<td>~ 55</td>
</tr>
<tr>
<td>PbLi flow rate, kg/s</td>
<td>19.5</td>
</tr>
<tr>
<td>PbLi velocity (maximum), mm/s</td>
<td>73</td>
</tr>
<tr>
<td>MHD pressure drop in TBM (with insulation)/in TBM system, 10^5Pa</td>
<td>0.245/1.6</td>
</tr>
<tr>
<td>Maximum temperature at the interface PbLi-ferritic steel, °C</td>
<td>495,4</td>
</tr>
<tr>
<td>Ceramic maximum temperature, °C</td>
<td>919.8</td>
</tr>
<tr>
<td>Ceramic total thickness, mm</td>
<td>96</td>
</tr>
<tr>
<td>PbLi ducts radial dimensions, mm</td>
<td>41 - 58</td>
</tr>
</tbody>
</table>
R&D program for LLCB TBM

- R&D program for LLCB TBM has been worked out including the following aspects:
  - Corrosion tests of ferritic martensitic steels in LL with and without electroinsulating barriers.
  - LL technology development (LL loop).
  - MHD/HT tests of TBM elements and TBM mock-ups.
  - Development of Tritium Production Rate monitoring system for TBM.
  - Development of in-reactor loop with LL for tests of tritium production and extraction, tritium permeation and structure materials compatibility.
  - Hydrogen isotope permeation through structural materials study.
Corrosion tests of ferritic martensitic steels in LL

• Rotating disc facilities for screening tests of steels with different type of electroinsulating/anti corrosion barriers are manufactured (T=350-550°C, V - up to 0.5 m/s).

• Samples for screening corrosion tests of ferritic steel (uncovered and with barriers) in LL are being prepared.

• Variants to be investigated:
  - Ferritic steel surface modification with pulsed intense electron beams.
  - Implantation of Al layer with successive oxidation.
  - Implantation of multi layer structure (Al, Cr, Mo).
  - Vacuum arc technique and diffusion bonding for multi layer structures (metals + insulator).

• LL loop for corrosion tests is planned to be manufactured next year.
LL technology development

• LL loop is planned for liquid metal technology development (2011-2012):
  - development of sensors for measuring of oxygen thermodynamic activity in LL;
  - Development of sensors for hydrogen isotopes;
  - Development of technique for impurities control.
MHD/HT tests of TBM elements and TBM mock-ups

Thermal hydraulic tests of small size mock-ups:
- Existing NaK loop: magnetic field ~ 1 T in a volume 120x120x600 mm with ITER like orientation;
- Estimation of MHD characteristic parameters of LLCB TBM shows that preliminary mock-up tests may be performed with NaK for the following TBM parts: poloidal ducts in uniform and inclined magnetic field; collector between round pipe and rectangular duct; round duct in non uniform magnetic field.
- Thermal gravitation flow is to be tested on LL, though some results may be obtained with NaK.
- Mock ups design is under way.
- Loop conversion into LL is under design as well.
Development of Tritium Production Rate monitoring system for TBM, tritium permeation and extraction study (1)

- A system is being developed for performing tritium production rate (TPR) and neutron flux measurements inside the TBM with the use of detectors. The detectors are delivered to tritium breeding zone of the TBM and out with pneumatic or mechanical means.
- Development of in-reactor loop with LL for tests of TPR and tritium extraction, tritium permeation and structure materials compatibility is under way (IVV-2M reactor; $T=200^\circ$C (active zone), neutron flux $\sim 2\times10^{14}$ n/cm$^2$, time of neutron irradiation $\sim10$min).
- Laboratory (out of reactor) facility for investigation of hydrogen permeation through structural materials is assembled.
• Laboratory (out of reactor) facility for investigation of hydrogen isotopes permeation through structural materials is being designed.

• Design of in-reactor experimental facility for investigation of tritium permeation through structural materials under irradiation is under way.
Conclusion

• R&D program will be described in separate presentations at this Workshop.
• Design and R&D program is going to be performed in close collaboration with Indian TBM team. The details of this collaboration are discussed between Indian and RF TBM teams.