Concept of Multi-function Fusion Reactor

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1. Motivation

- The ultimate goal of the fusion R&D is energy.
- The construction of ITER starts the real course to realize the peaceful use of the fusion energy.
- To really use the fusion energy and utilize fusion as a main energy in the world could need more than 30 years.
- Before the fusion may be used as a main energy, to speed up the fusion application is very important.

- The fusion society is eager to do something to contribute to the public society and get support for fusion development from government.
- DEMO is very essential step toward the fusion application as energy. But it should not be the second moving target in the fusion society!
- The technologies developed in the world are feasible to built fusion facilities or reactors with fusion core plasmas.
- Some concepts as immediate step of fusion application have been studied to utilize its large volume neutron source.

- Based on the fusion technologies developed in the past years, a concept of multi-function fusion reactor (MFFR) is being proposed.
- The main functions of MFFR, at least, can be:
  - fission waste disposal
  - ^{239}Pu breeding from ^{238}U
  - hydrogen producing
  - tritium producing
  - components test for fusion reactors
  - or even electricity generation demonstration.

- The preliminary considerations of MFFR are:

  a) reasonable size and changeable in-vessel function blanket modules,
  b) enough flexibility to realize multi-functions separately at the same time in the facility,
  c) suitable plasma core parameters and blanket concept,
  d) fully superconducting toroidal and poloidal magnets for long pulse or steady-state operation.

2. MFFR Concept

MFFR

Tokamak fusion core

- Fusion power can be from hundreds MWs to several GWs
- Large volume neutrons
- Long pulse or steady-state

Different functional blankets

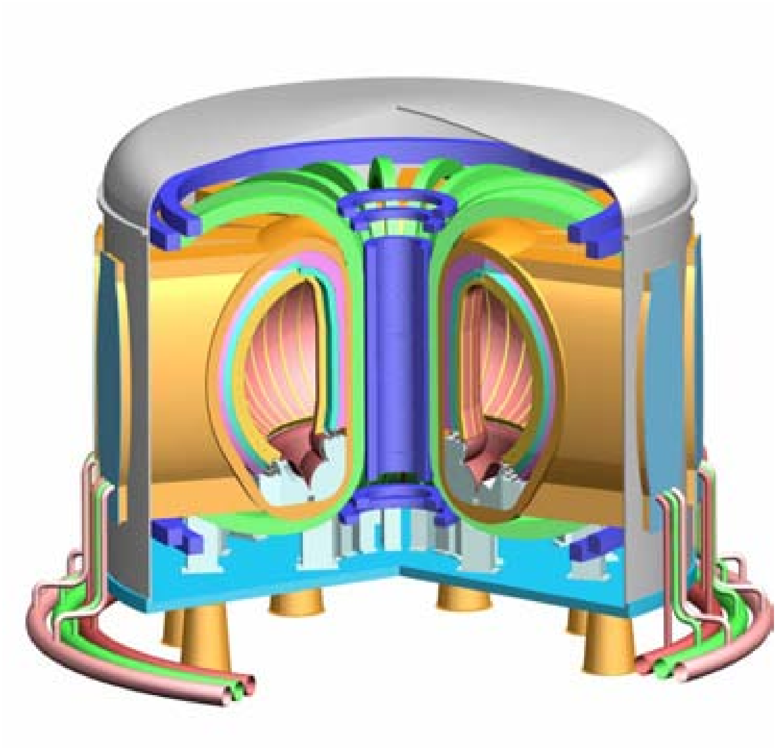
- Sub-critical blanket and Energy exchange blanket
- Energy density can be around several 10 to 100 MW/m^3
- Changeable remotely

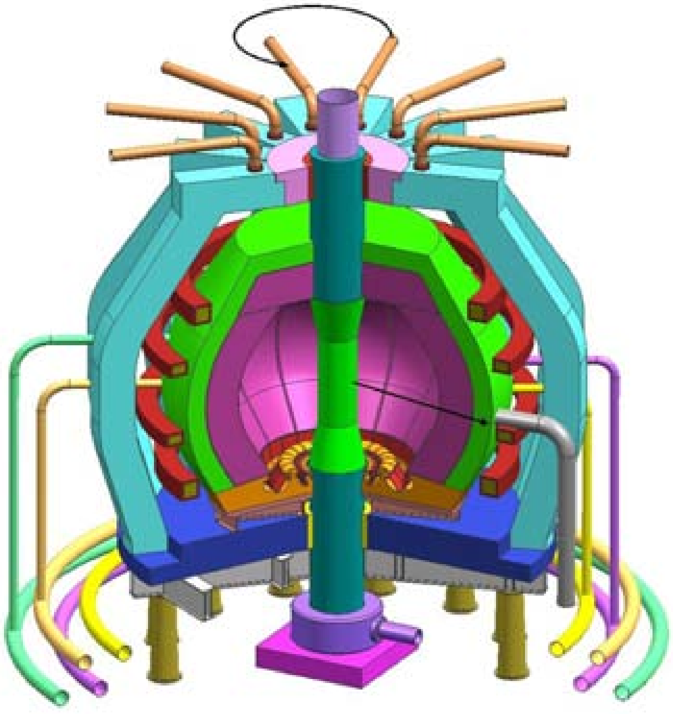
2.1 Fusion Core

- MFFR technologies are being developed and will be demonstrated during the construction phase and operation phase of ITER:
  - Test blanket module for tritium breeding
  - Plasma control
  - Inductively/non-inductively plasmas driven and heating with Q⩾5-10 of D-T plasmas
  - Superconducting magnets
  - Remote maintenance

- Several reactor concepts based on the up-to-date fusion technology have been assessed:
  - Two fusion-driven sub-critical systems: the tokamak-based reactor (named FDS-I) and the spherical tokamak-based compact reactor (named FDS-ST) for exploiting the possibility of earlier application of fusion energy as volumetric neutron sources.
  - Other two fusion reactor concepts: for the fusion electrical generation (named FDS-II) and the fusion-based hydrogen production reactor (named FDS-III)

- Both tokamak-based reactor and spherical tokamak-based reactor are options for the fusion core of MFFR.





The configuration draft of MFFR

- The tentative plasma parameters are selected on the basis of reactor concepts mentioned above and both physics and engineering/technology considerations.

Parameters	FDS-II	ITER
Fusion power (MW)	2500	500
Major radius (m)	6	6.2
Minor radius (m)	2	2
Aspect ratio	3	3.1
Plasma elongation	1.8	1.70
Triangularity	0.6	0.33
Plasma current (MA)	15	15
Toroidal-field on axis (T)	5.93	5.3
Safety factor/q_{95}	5	3
Auxiliary power (MW)	80	73
Average neutron wall load (MW m^{-2})	2.72	0.57
Average surface heat load (MW m^{-2})	0.54	0.2

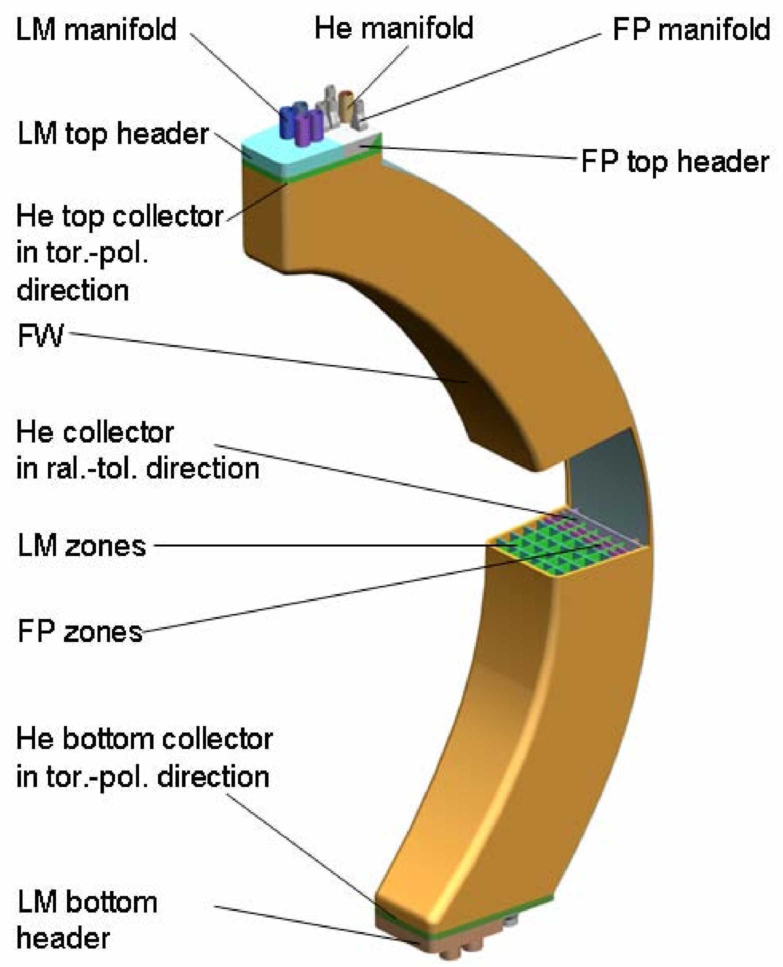
2.2 Blanket Concepts

- Except for the fusion reactor components test module, two major types of functional blankets are defined in MFFR:
  - **Sub-critical blanket:** mainly used for fission waste transmutation and ^{239}Pu breeding from ^{238}U
  - **Energy exchange blanket:** transferring the fusion energy from MFFR to produce hydrogen and even to drive turbines for electricity generation demonstration.

- Both types have common function for tritium breeding.
- The liquid lithium lead breeder blanket is considered as primary option for both of blankets due to their potential attractiveness of economy and safety and relatively mature technology base:
  - He/LiPb Dual-cooled Waste Transmutation (DWT) blanket
  - He Single-cooled LiPb (SLL) tritium breeder blanket
  - Dual-cooled He/LiPb (DLL) blanket
  - High Temperature Liquid LiPb (HTL) blanket

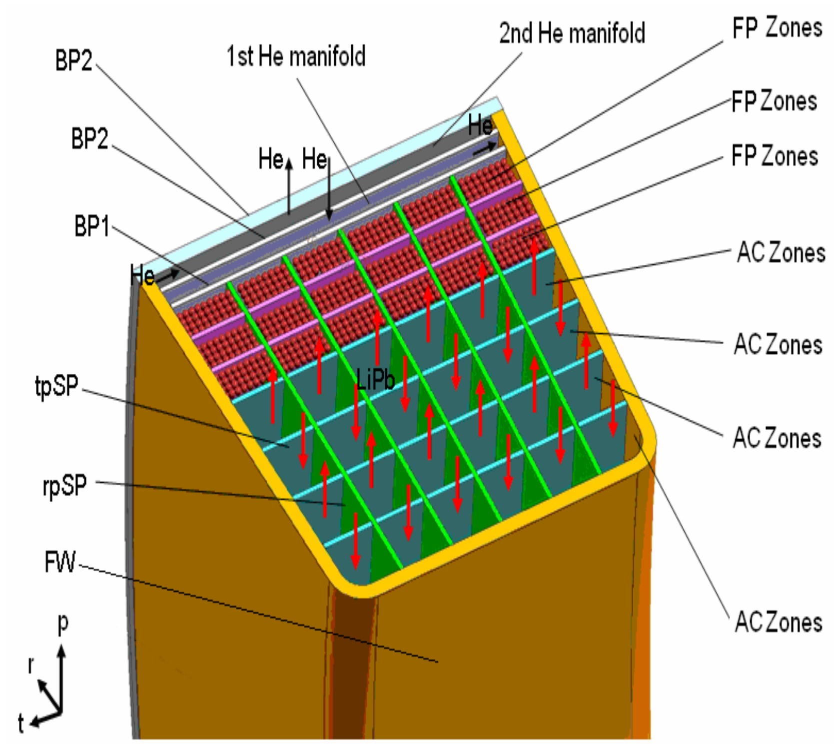
2.2.1 Sub-critical Blanket Concept

- It can be He-gas/liquid LiPb dual-cooled high level waste transmutation (DWT) blanket.
- A design and its analysis with Carbide heavy nuclide Particle fuel in circulating Liquid LiPb coolant (named DWT–CPL) has been studied for years.



DWT–CPL blanket concept

- Helium gas to cool the structures and long-lived fission product (FP) transmutation zones (FP-zones).
- Actinide (AC) zones (AC-zones) including Minor Actinides (MA) transmutation zones (MA-zones) and Uranium-loaded fissile breeding zones (U-zones) is to be self-cooled by liquid metal (LM) LiPb.

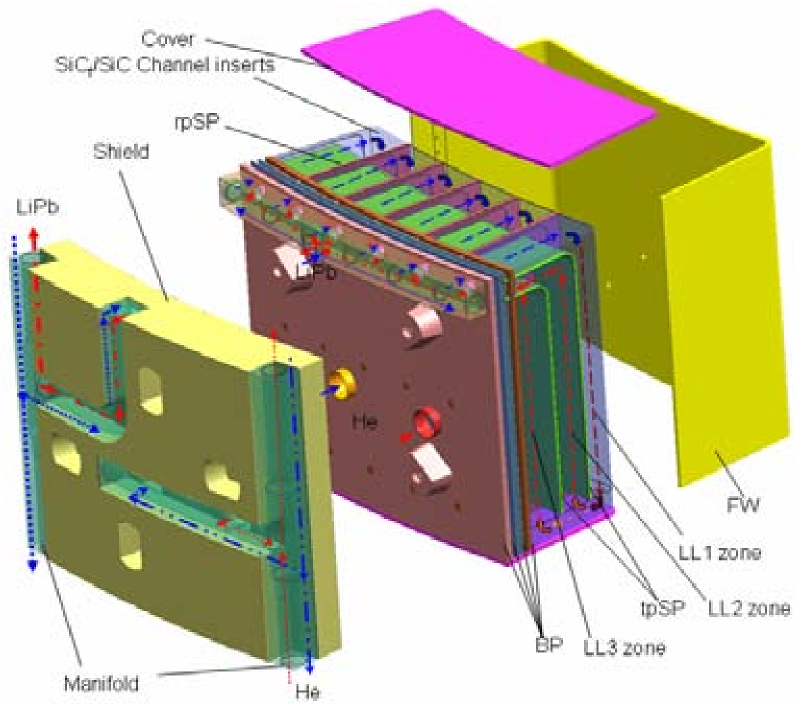


2.2.2 Energy Exchange Blanket Concept

- Two optional concepts of liquid LiPb blankets are developed:
  - Reduced Activation Ferritic/Martensitic (RAFM) steel-structured He-gas/liquid LiPb dual-cooled (DLL) blanket
  - RAFM steel-structured He-cooled LiPb tritium breeder (SLL) blanket
- A high temperature Lithium Lead (HTL) breeder blanket is also proposed and under development.

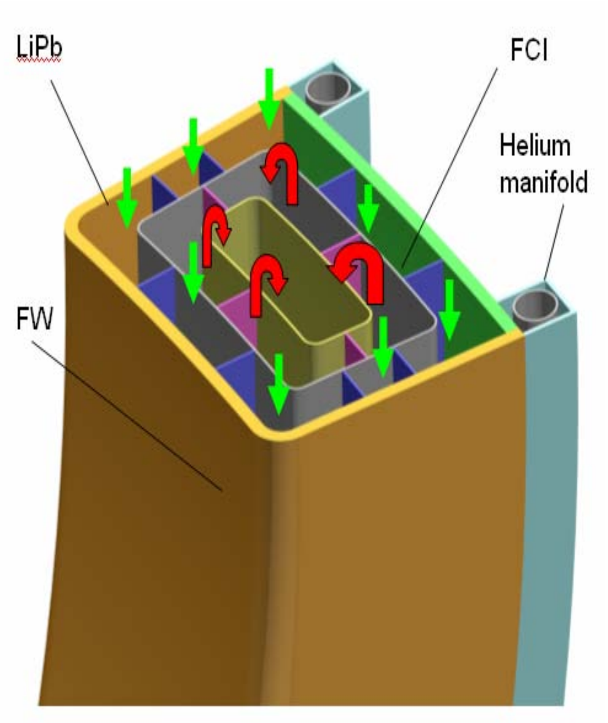
RAFM structured DLL blanket

- The DLL blanket consists of self-cooled LiPb breeding zones and helium-cooled structures.
- The thermal and electrical insulation FCIs (Flow Channel Inserts) are designed and used inside the LiPb coolant channels to act as both thermal and electrical insulation.
- Coating (e.g. Al_2O_3) is considered to reduce tritium permeation and protect the steel structure against corrosion of LiPb.



HTL breeder blanket (from Dr. S.Liu and H. Chen)

- A so-called “multilayer flow channel inserts (MFCIs)” with thermal insulating and electricity insulating are proposed in the coolant flow channels.
- Some refractory materials with low thermal conductivity and low electricity conductivity can be used as FCI material, such as SiCf/SiC composite.
- High pressure helium is used to cool the blanket structures. The LiPb temperature exported from the blanket can be higher than 900 ºC



RAFM structured SLL blanket

- A backup option for energy exchange blanket if the critical issues of the DLL blanket, such as MHD effects and FCI technology, could not be solved and validated by testing in ITER.
- It is designed to use quasi-static LiPb flow instead of fast flow LiPb with similar basic structure, material and auxiliary system of the DLL module.

- China Party has proposed the SLL/DLL blanket to be one of two options for ITER TBM.
- A Dual-Functional Lithium Lead–Test Blanket Module (DFLL–TBM), which is designated to demonstrate the integrated technologies of both He single coolant (SLL) blanket and He–LiPb dual coolant (DLL) blanket, is proposed for test in ITER. The technology R&D is underway in China.

3. Summary

- The energy demand of China in the near future will be increased tremendously.
- To use large volume neutron of fusion earlier, based on the R&D of the fusion technology and previous study, especially expectation of successfully construction and operation of ITER, the concept of MFFR with different functional blankets is proposed.
- The DFLL–TBM is planned to be tested in ITER.
- Even though some uncertain in technologies and politics ahead, to start the fusion application study can not be delayed.

Thanks for your attention!