ASIPP

Brief Overview
FDS Series Fusion Reactor Conceptual Designs and R&D Activities in China

Presented by Qunying Huang

Contributed by FDS Team

Institute of Plasma Physics, Chinese Academy of Sciences
http: //www.fds.org.cn
E-Mail: qyhuang@ipp.ac.cn

Outline

I. Development of Concepts

1. Reactor Concepts

- FDS-I: Fusion-driven sub-critical system, for early application of fusion
- FDS-II: Fusion power reactor, for advanced electricity generation
- FDS-III: High temperature fusion reactor, for hydrogen production etc.
- FDS-ST: Spherical tokamak-based reactor, to exploit innovative conceptual path

2. Blanket Concepts

- DWT: Dual-coolant (He/LiPb) Waste Transmutation Blanket (temp.<450° C)
- SLL : Single-coolant (He) Lithium Lead Breeder Blanket (temp.~450° C)
- DLL: Dual-coolant(He/LiPb) Lithium-Lead Breeder Blanket (temp.~700° C)
- HTL: High Temperature Liquid Blanket (temp. ~1000° C)

II. Test Blanket Modules & Development Strategy

- Material R&D + Out-Of-Pile Mockup Test
- TBM Test in EAST
- TBM Test in ITER

III. R&D Activities

1. Software

- Codes & Data libraries
- Integrated platform for design and analysis

2. Hardware

- RAFM steel (CLAM -China Low Activation Martensitic)
- LiPb loops (corrosion, MHD, dual-cooled)
- Functional Materials (Al_2O_3 coating, SiCf/SiC FCI)
- Waste process and Radiation measurement

I. Development of Concepts

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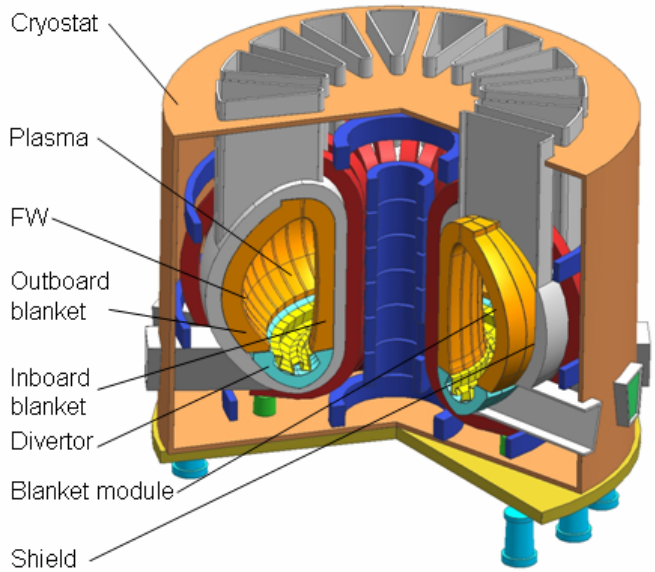
FDS-I: Fusion-Driven Subcritical System

(Core based on Easy Plasma Physics/Engineering Level)

Blanket: He/LiPb Dual-cooled Waste Transmutation (**DWT**) blanket

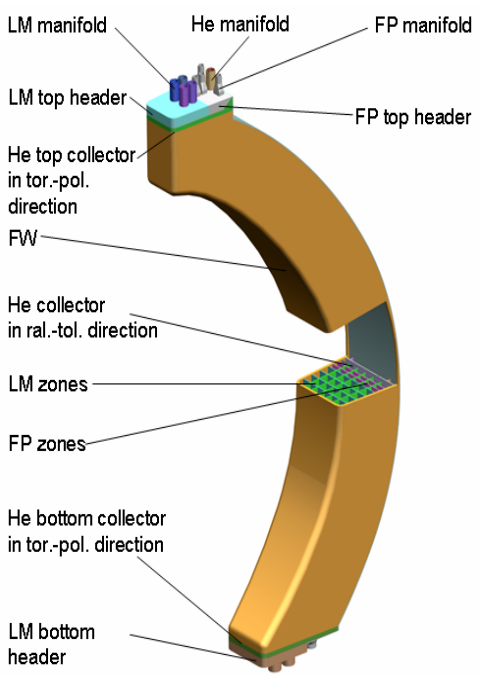
- **Goal:**
  Early application of fusion
  (waste transmutation/fuel breeding/energy generation)
- **Plasma Core:**
  Fusion power: 100~200MW
  Power Gain ~3
  Neutron wall loading ~0.5MW/m^2
- **Fission Blanket:**
  Structural Mat.: RAFM /316SS
  Coolants: He/LiPb (<450°C)
  Circulating particle fission fuel
  Blanket Options: carbide/nitride/oxide/metal fuel -based



Y. WU et.al, J. of Nuclear Materials, 307-311 (2002) 1629-1636.
Y. WU et. al, Fusion Eng. Design 81 (2006) 1305-1311

DWT Subcritical Blankets for FDS-I/ST

Blanket: He/LiPb Dual-cooled Waste Transmutation (**DWT**) blankets



Blanket design --- high energy multiplication

Emphasis on circulating particle or pebble bed fuel configurations considering geometry complexity of tokamak, frequency of fuel discharge and reload

Concept options:

DWT-CPL: the He&LiPb DWT blanket with **Carbide** heavy nuclide Particle fuel in circulating Liquid LiPb coolant.

DWT-OPG :**Oxide** heavy nuclide Pebble bed fuel in circulating helium-Gas

DWT-NPG: **Nitride** heavy nuclide Particle fuel in circulating He-Gas.

The circulating fuel form has the advantages of good compatibility with complex geometry, easy control of fuel cycle and fast response to emergency fuel removal etc.

Y.C. WU et.al, Fusion Eng. Design 81(2006)1305-1311

FDS-II: Fusion Power Reactor

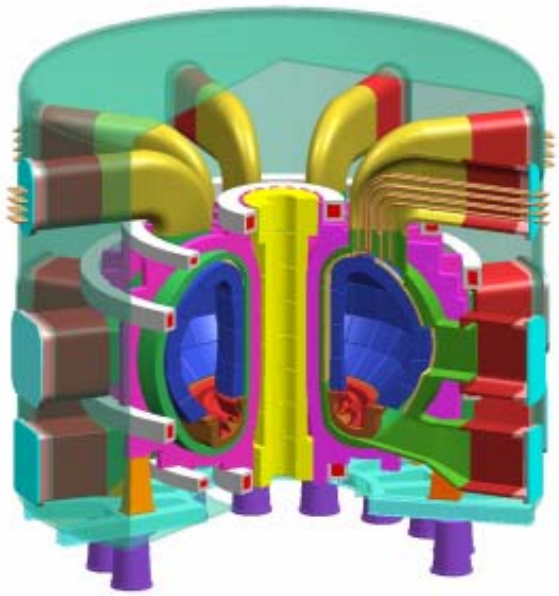
(Core based on Advanced Plasma Physics/Engineer Level)

Blanket:

(1) He/LiPb **D**ual-cooled **L**ithium **L**ead (**DLL**) Blanket

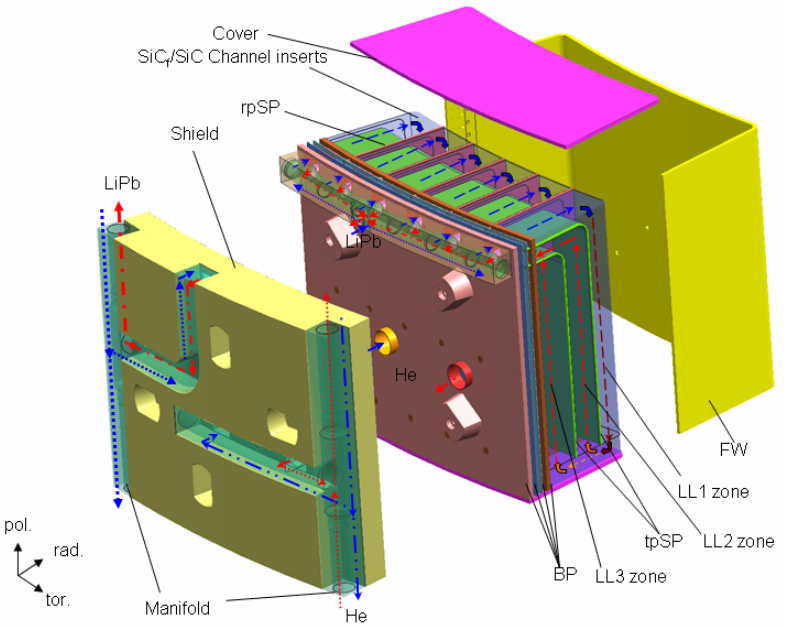
(2) He-cooled Quasi-**S**tatic **L**ithium **L**ead (**SLL**) Blanket

- **Goal:**
  Electricity generation
  (high thermal power density & high thermal efficiency)
- **Plasma Core:**
  fusion power = 2~3 GW
  power gain ~30
  neutron wall loading 2～3MW/m^2
- **Breeding Blanket:**
  Structural Mat.: RAFM /ODS-RAFM
  Coolants: He/LiPb (450/700°C)



WU Yican et. al., Chinese J. of Nucl. Sci. & Eng., Vol.25, No.1 (2005)
Y. Wu et, presentation at the ISFNT-8, Heidelburg, Oct.1-5, 2007

DLL/SLL Blanket for FDS-II



SLL: He-cooled Quasi-Static Lithium Lead Blanket

- **Single Coolant:** He-gas (R-T + P-directions)
- **T-Breeder:** Quasi-Static LiPb: (slowly flowing in P-direction, outlet temp.~450° C)
- Coating: to protect the steel structure and to reduce T- permeation and MHD effects.

DLL: He/LiPb Dual-cooled Lithium Lead Blanket

- **Coolant 1:** He-gas (R-T + P-directions)
- **Coolant 2 & T-Breeder:** LiPb (flowing in P-direction, (outlet temp.~700°C)
- Thermal and electric insulators: to avoid RAFM working at high temp. 700°C

To avoid the potential critical problems (MHD effects and FCIs, relevant to DLL), SLL blanket is designated to use quasi-static LiPb flow instead of fast moving LiPb in DLL

Y. Wu et al, Journal of Nuclear Materials. 367-370(2007)1410-1415

FDS-III: High Temperature Fusion Reactor

(Core based on Advanced Plasma Physics/Eng. Extrapolation Level)

- **Blanket:**
  - SiC/Si_fC Single-cooled Lithium Lead Blanket
  - He/LiPb **D**ual-cooled multi-layer FCIs **L**ithium **L**ead Blanket

– **Goal:**

Production of hydrogen or advanced application of energy (high thermal power density & high thermal efficiency)

– **Plasma Core:**

fusion power = 2.6 GW

power gain ~32

neutron wall loading ~4MW/m^2

– **Breeding Blanket:**

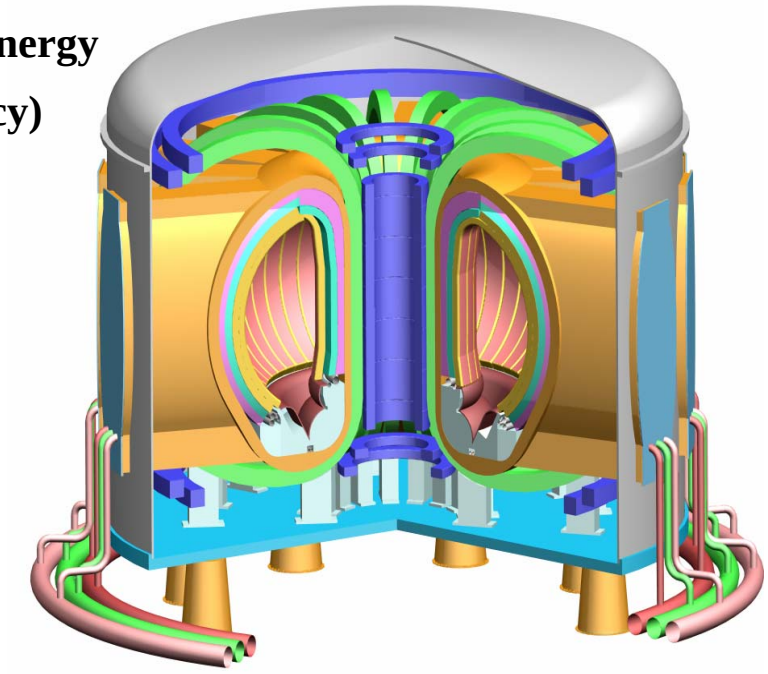
Structural Mat.:

Option 1：RAFM Steel and FCI

Option 2： SiC_f/Si_fC

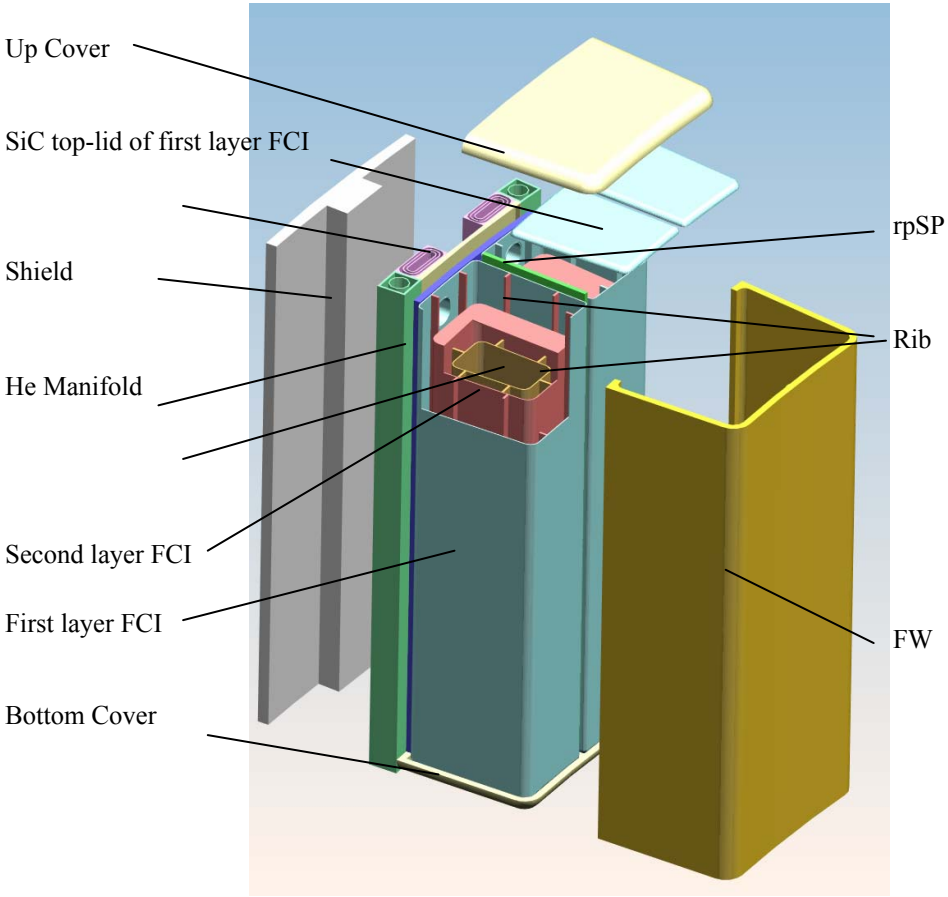
Other Options: under developement

Coolants: He/LiPb ~1000° C



Y. Wu et al, presentation at the ICFRM-13, Nice, Dec.11-14, 2008

HTL High Temp. Lithium Lead for FDS-III



– Materials:

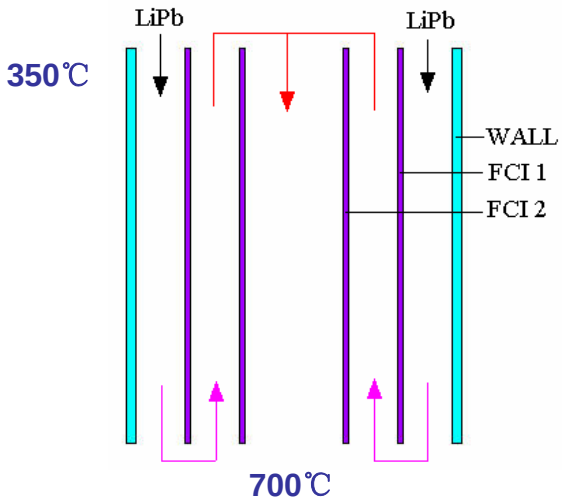
RAFM or ODS-RAFM steel as structural material

SiC_f/SiC composite as FCIs

– Blanket scheme:

Multilayer FCIs in LiPb channel:

- Increasing LiPb temp. above 900°C
- Reducing interface temp. RAFM steel /LiPb below 550°C
- Limited temp. gradient across FCIs



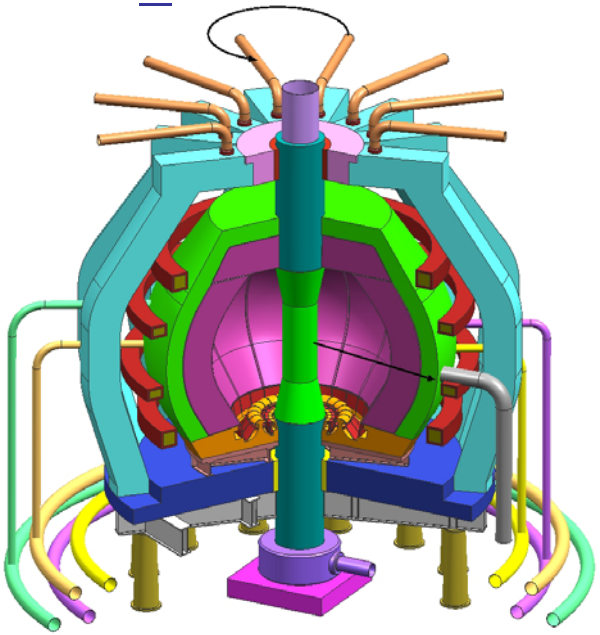
Schematic drawing of multilayer FCIs

FDS-ST: Spherical Tokamak-Based Reactor

(Core based on Spherical Tokamak --- Neutron Source)

Blanket: optional (DWT);

CCP: innovative concepts of Center Conductor Posts



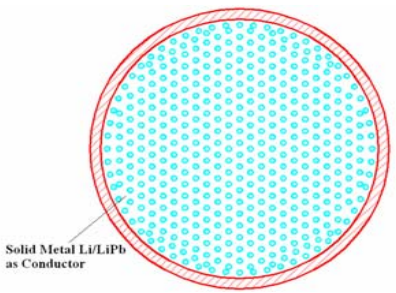
- **Goal:**
  Exploit and assess innovative approach of fusion energy
- **Plasma Core:**
  Fusion power: 100~200 MW
  Power Gain ~5
  Neutron wall loading 0.5~1 MW/m^2
- **Blanket:**
  Sub-critical outboard, high energy multiplication to compensate the large fraction of re-circulating power
- **CCP:**
  Innovative liquid metal CCP concepts to prolong lifetime, to increase tritium breeding

L.J. QIU et.al, Nuclear Fusion, Vol.40, No.3y (2000)
Y. WU et.al, Fusion Technology, Vol.35, No.1, 1999.
Y. KE et al, Plasma Science and Technology, No.3, 2002.
Y. WU et.al, Fusion Eng. and Design 51-52, 2000.
J. YU et.al, Vol 307-311, 2002
Y. KE et al, Nuclear Techn. (in Chinese)，Vol. 26, 2002.

Central Conductor Post

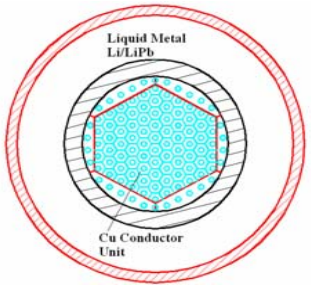
Four new concepts of CCPs:

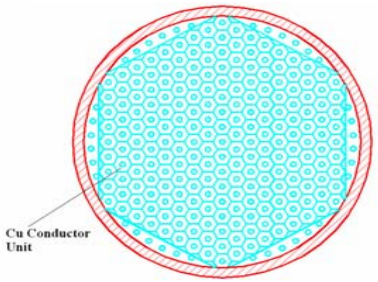
- Li/LiPb as conductor and coolant
- Li/LiPb as conductor, water as coolant
- Cu as conductor, Li/LiPb as coolant
- Cu as conductor, water as coolant



Y .Wu et al, Fusion Eng. Des. 51-52 (2000) 395-399
J. Yu et al, J Nucl. Mater. 307-311, p.1670-1674
Y. Ke et al, Plasma Sci. Tech., No.3, 2002
Ke Y. et al, Nucl. Techniques, Vol.26, No.9, 2003.

Y. Wu et al, Fusion Technology, Vol.35, No.1, pp.1-7, 1999





Plasma Core Parameters of FDS Reactors

Parameters	FDS-I	FDS-II	FDS-III	FDS-ST	EAST*	ITER**
Fusion power (MW)	150	2500	2600	100	0.08	500
Major radius(m)	4	6	5.1	1.4	1.95	6.2
Minor radius(m)	1	2	1.7	1.0	0.46	2
Aspect ratio	4	3	3	1.4	4.2	3.1
Plasma elongation	1.78	1.9	1.7	2.5	1.8	1.70
Triangularity	0.4	0.6	0.47	0.45	0.45	0.33
Plasma current (MA)	6.3	15	16	9.2	1.5	15
Toroidal field on axis (T)	6.1	5.9	8	2.5	4.0	5.3
Safety factor /q_95	3.5	5.0	4.8	5.5	/	3
Auxiliary power /Padd(MW)	50	80	80	19	/	73
Energy multiplication /Q	3	31	32	5	/	⩾10
Average neutron wall load($MW \cdot m^{-2}$)	0.5	2.72	5	1.0	1E-4~E-3	0.57
Average surface heat load($MW \cdot m^{-2}$)	0.1	0.54	1	0.2	0.2	0.27

* : D-D phase; ** : D-T phase

Y. Wu, Fusion Engineering and Design, 81(2006) 2713-2718.

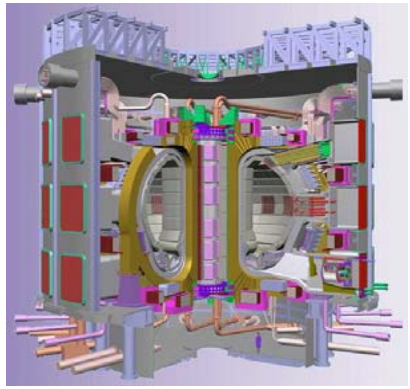
Features of China LiPb Blankets

Function	Material candidates, working conditions & performance requirements			
	DWT	**SLL**	**DLL**	**HTL**
Structure	RAFM (T_{max}~550°C, anti-irradiation, anti-corrosion)			
Tritium breeder	lithium lead eutectic			
Coating	Al-based coating or others (T_{max}~500°C, anti-irradiation, anti-corrosion, low σ_e)			
Coolant (max. temp.)	He & LiPb (LiPb **450°C**)	He (**450°C**)	He & LiPb (LiPb **700°C**)	He & LiPb (LiPb **900~1000°C**)
FCI	No/yes	No	SiC_f/SiC or others (T_{max} ~700° C low σ_{th} and low σ_e)	SiC_f/SiC or others (T_{max} ~1000° C low σ_{th} and low σ_e)
Fission fuel	HLW/U/Pu	No	No	No

Y. Wu et al, Journal of Nuclear Materials. 367-370(2007)1410-1415

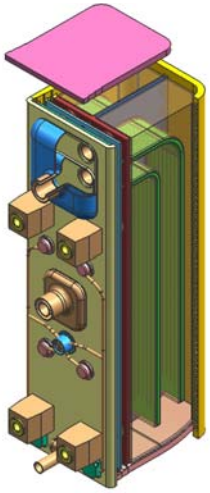
Common Features of Blanket Concepts

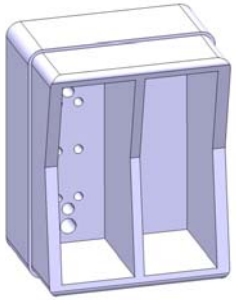
DWT, SLL, DLL, HTL



- **Structural Material:** RAFM (e.g. CLAM)/+ODS
- **Insulation/Anti-erosion/Anti-permeation coating:**
  ---Coating(Al-based) /insert(e.g.SiC)
- **Tritium Breeder/Neutron Multiplier:** LiPb
- **Coolant:** He or He/LiPb

TBM





To define TBM for Testing in ITER:
Dual **F**unction **L**ithium **L**ead liquid breeder TBM

DFLL: SLL/DLL

Y. Wu, Nuclear Fusion 47(2007)1533-1539
Y. Wu，Fusion Engineering and Design 82 (2007) 1893-1903

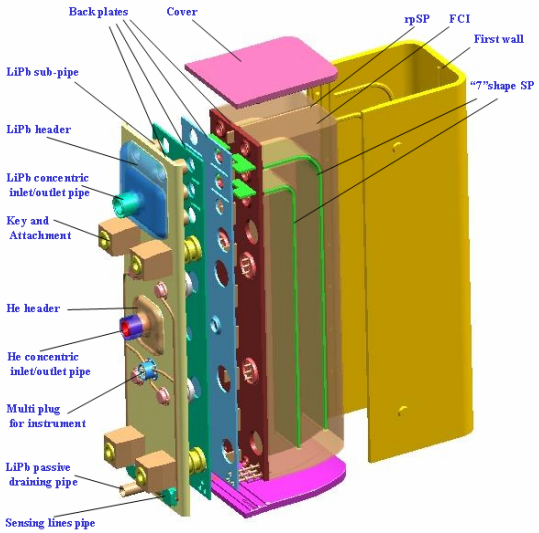
II. TBM & Development Strategy (DFLL)

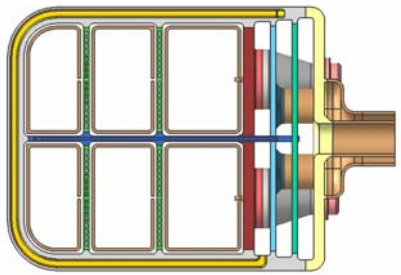
- Material R&D + Out-Of-Pile Mockup Test
- TBM Test in EAST
- TBM Test in ITER

DFLL (Dual-Functional Lithium Lead) -TBM

A flexible and effective approach to test the SLL blanket technologies on the earlier phase, then to test DLL blanket technologies on the later phase

DFLL-TBM consists of four 'act alike' modules with similar structures, such as EM-TBM, NT-TBM,TT-TBM and IN-TBM, which will allow to consecutively realize the objectives of DFLL-TBM during the first 10 years of ITER operation.

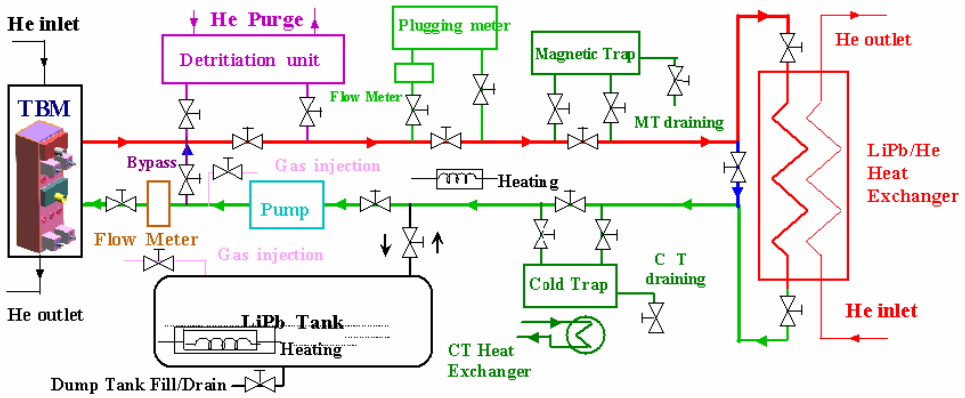




Differences between SLL and DLL testing phases

SLL testing phase: EM-TBM, electro-magnetics performance test
NT-TBM, neutronics performance test;
LiPb flows slowly (~1mm/s), without FCI in LiPb channel
LiPb does not exchange heat with secondary He loops

DLL testing phase: TT-TBM, thermo-mechanics and tritium behaviours test
IN-TBM, integrated performances test
LiPb flows (~10mm/s), with FCI in LiPb channel,
LiPb not only serves as coolant exchanging heat with secondary He loops, but also is used for T extraction .

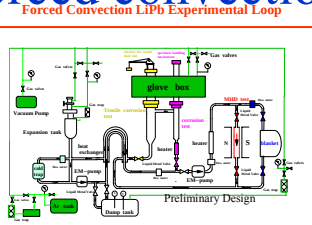


Development Roadmap / Plan of TBMs

Mat.R&D, Out-of-pile Test

2006-2012

Thermal convection loop
Forced convection loop

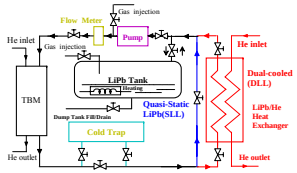


- Mat. R&D (RAFM, Coating, FCI)
- Out-of-pile test (**1/3-sacle mockup**) (MHD, corrosion, instruments)
- Assessment of reliability and safety with regard to ITER standards.
- Diagnostic and Measurement technologies

Test in EAST

2012-2018

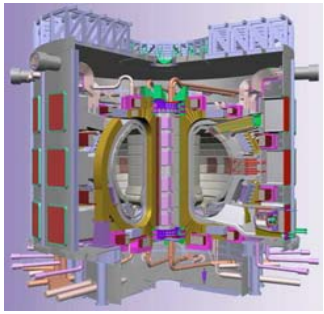
LiPb/He system for TBM in EAST



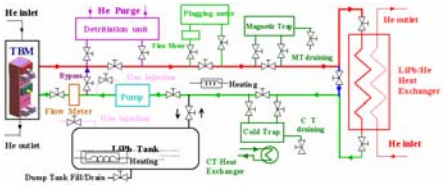
- **1/2-scale mockup** test in EAST
- Performance test of EM and thermo-mechanics, MHD, partially neutronics performance (DD neutrons),
- FM Influence on plasma
- Diagnostic technology

Test in ITER

~2016-2024



LiPb/He system for TBM in ITER



- Confirmation of the results of EM/Thermo-mechanics test in EAST,
- **full size** TBM test in ITER for neutronics, tritium and integration performances

Phase I (1) : Materials R&D and Out-of-pile Mockup Test

Materials R&D

1. Structural material:

CLAM (China Low Activation Martensitic/Ferritic Steel)

2. Tritium permeation barrier material

Coating (TPB/MHD): Al-based etc.

3. MHD control material

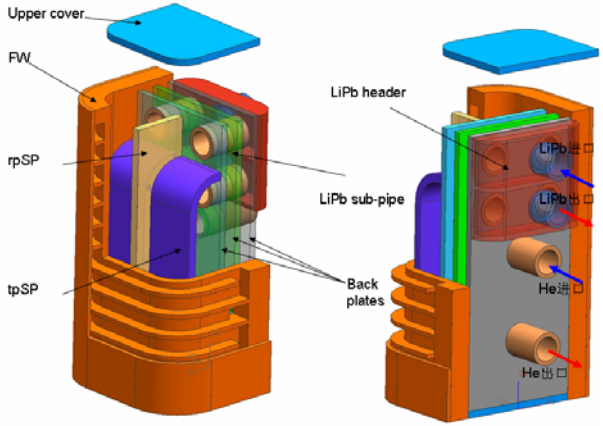
FCIs: SiC_f/SiC

4. Coolant Technology

He/LiPb loops, purification

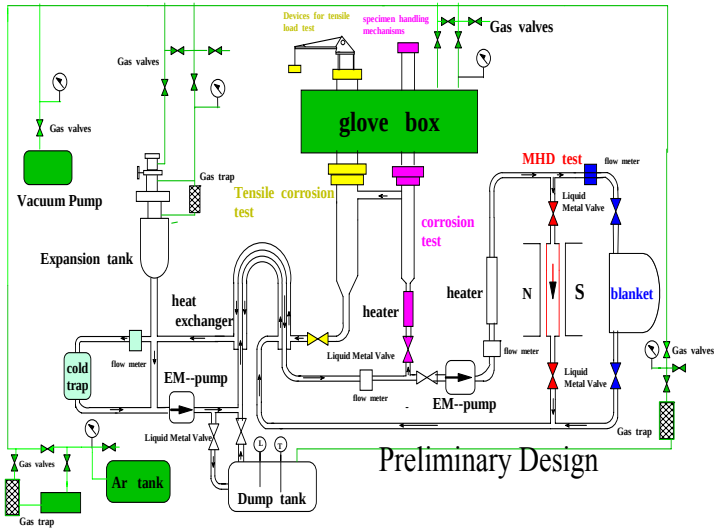
5. Tritium control technology

Purging bubble etc.



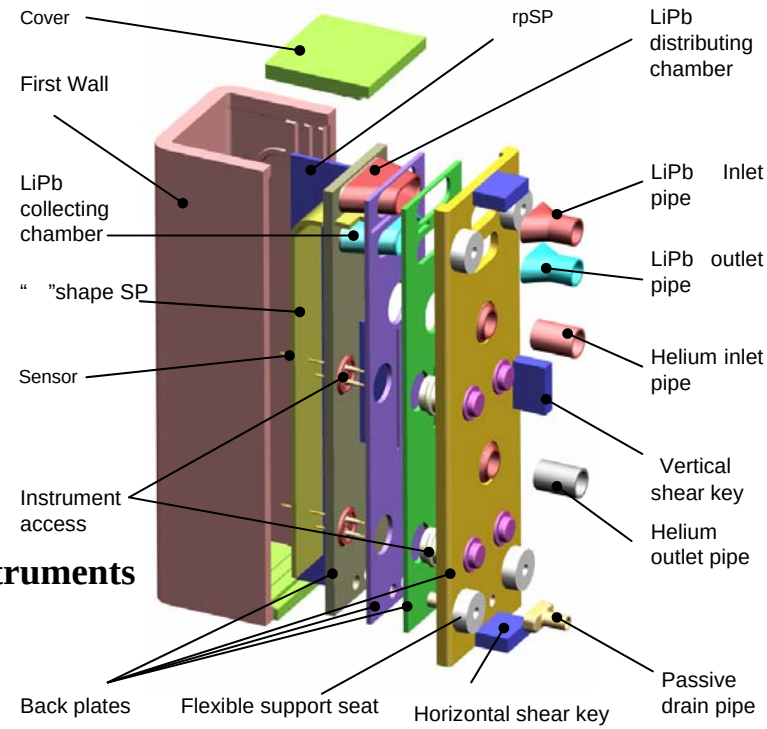
Out-of-pile Mockup Test (1/3-Size TBM)

1. **Validation of the fabrication route and techniques**
2. **Assessment of reliability and safety with regard to ITER standards.**
3. **Diagnostic and Measurement technologies**



Phase II: Test in EAST

(1/2-Size TBM)



Objectives:

- Preliminary validation of design codes and data
- Checking of feasibility & availability of auxiliary system
- FM Influence on Plasma

EAST-TBM Test in EAST:

- **ElectroMagnetic performance**
  (MHD pressure drop, influence on plasma)
- **Thermo-mechanics/Thermofluid dynamics performances**
- **Partially neutronics performance** (DD neutrons), **Diagnostic instruments**

Device	EAST	ITER		
Phase	DD	HH	DD	DT
R (m)	1.95			6.2
A (m)	0.46			2
Bt (T)	3.5-4.0			5.3
Neutron rate (n/s)	10^{15}~10^{17}			1.77×10^{20}
Avg.HF(MW/m^2)	0.1~0.2	0.11		0.27
Port Size	0.97m x 0.53m	2.2 m x 1.7m		
Pulse (sec)	~1000	100-200		400

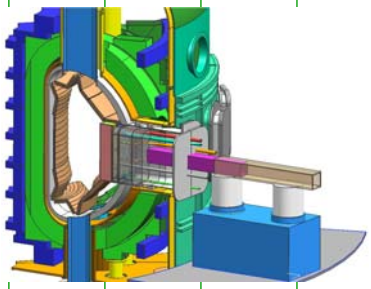
Phase III: Test in ITER
(Full-Size TBMs)

≤2011	2012	2013	2014	2015	ITER Operation (Day 1) 2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	≥2026
	DD	DD	DD	DD	HH	HH	HH	DD	Low DT	Low DT	Low DT	High DT	High DT	High DT	

Mat.R&D
In out-of-tokomak

EAST-TBM

In EAST:
D-plasma(1000sec)
FM-Influence on plasma
Thermo-mechanics/Thermofluid dynamics performances
EM & MHD Test
Corrosion and Coating Test
Auxiliary system



EAST-TBM

In EAST:
D-plasma(1000sec, $10^{15\sim17}$n/s)
Thermo-mechanics/Thermofluid dynamics performances
FCI & MHD Test
Partially neutronics
Diagnostic instruments

EM-TBM

EectroMagnetic-Test:
To confirm results of EM/Thermo-mechanics test in EAST
Auxiliary system

NT-TBM

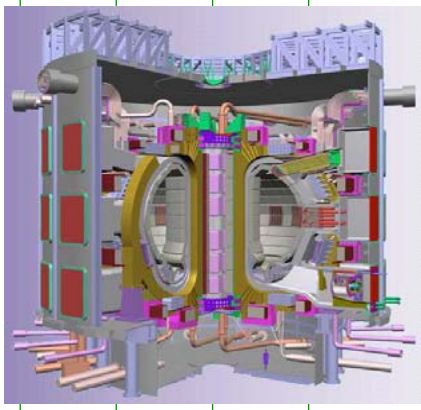
Neutronics Test:
Neutronics performance
N-fluence&gamma spectra
Nuclear heat
T-breeding
Code &Data

TT-TBM

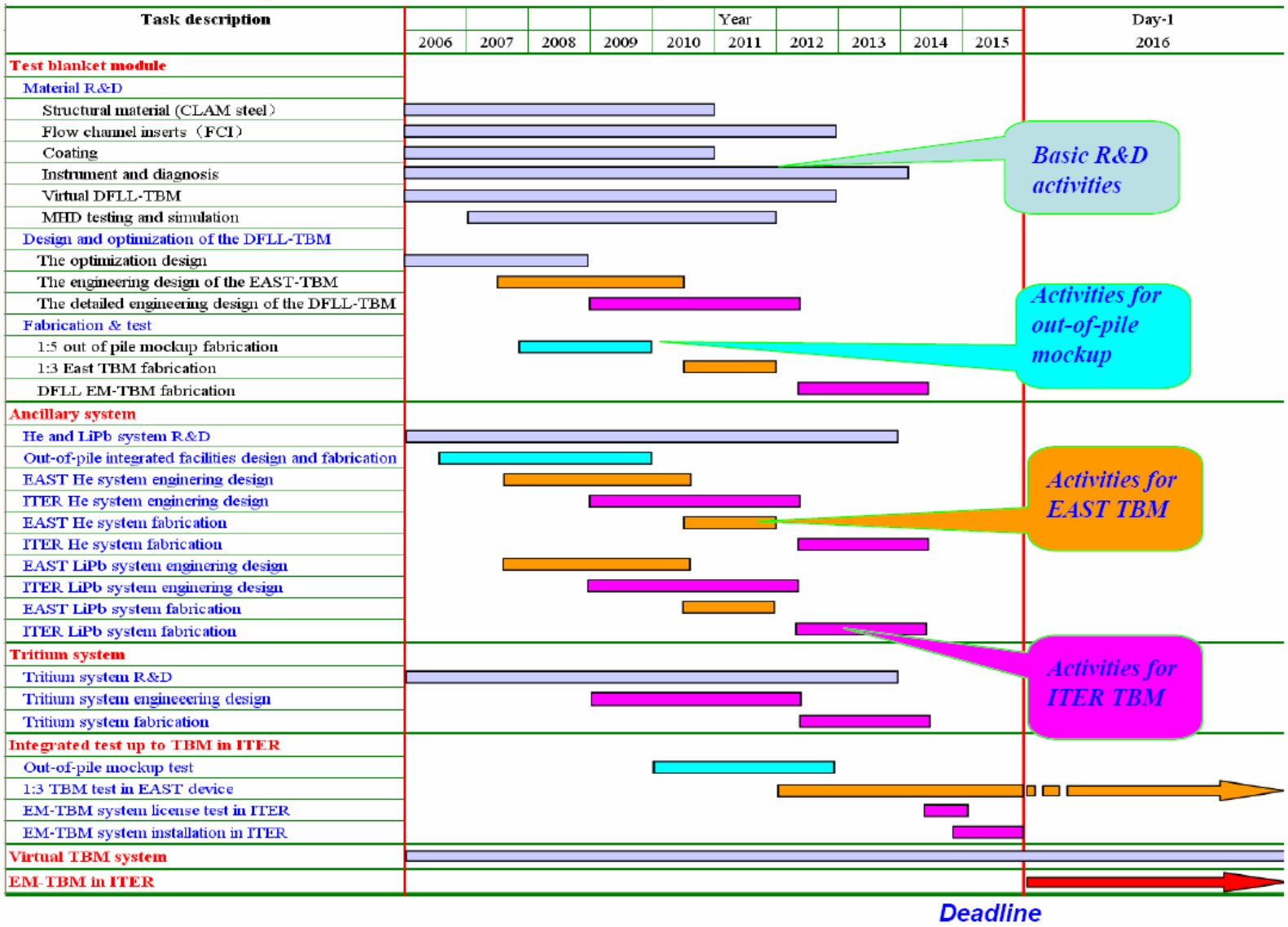
ThermoDynamics&Triu tium Behavior Test:
Tritium recovery
FCI performance
Thermofluid MHD
Code &Data

IN-TBM

Integrated Test:
On-line tritium extraction
Synergic nuclear effects
MHD integrated effects
Reliability and Safety



Program Schedule up to First TBM in ITER



III. Status of R&D (hardware and software)

- **Blanket Material and Technology R&D**
- **Design & Analysis Tools R&D**

R&D Experiments (Hardware)

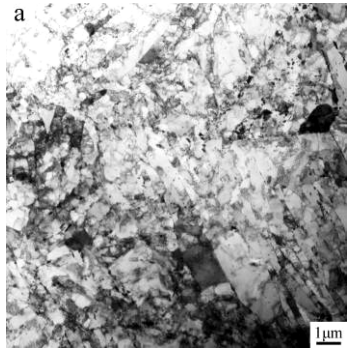
1. China Low Activation Martensitic steel (CLAM)
2. Liquid LiPb Loops (DRAGON-I, II, III, IV)
3. Functional coatings: Anti-corrosion / tritium barrier / electrical insulation
4. SiC_f/SiC composite (FCI / Loop)

⇧

Key Technologies for LiPb Blankets

Progress in Development of CLAM Steel

- Fabrication of CLAM melting
  - Large ingots of CLAM: 300kg
  - 12mm, 22mm, 32mm plates
  - → For 1/3 TBM
  - 500~1000Kg ingot underway
- Joining techniques
  - HIP diffusion bonding
  - Electron Beam welding
  - Tungsten Inert Gas welding
  - → For TBM fabrication
- Coating Technology
  - Al_2O_3/SiC coating
- Compatibility with LiPb
  - >8000h 480°C experiment
  - Series LiPb loops
- Irradiation
  - Neutron Irradiation
  - Ion, Electron Irradiation
- Neutron activation
  - Simulation
  - Experiment



TEM image

Solid HIP diffusion bonding

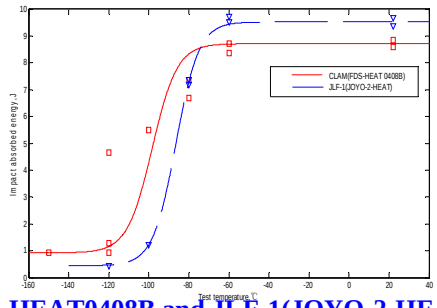
Mockup of FW by SS

Main Chemical Compositions

Element	CLAM	EUROFER97	F82H	JLF-1	9Cr-2WVTa
Fe	Bal.	Bal.	Bal.	Bal.	Bal.
Cr	9.0	9.0	8.0	9.0	9.0
W	1.5	1.1	2.0	2.0	1.1
Mn	0.45	0.4	0.5	0.45	0.4
V	0.20	0.2	0.2	0.2	0.2
Ta	0.15	0.12	0.04	0.07	0.12
C	0.10	0.11	0.1	0.10	0.11

Tensile properties of CLAM and other RAFMs at RT

Steel	Heat treatment(℃)	σ_b (MPa)	$\sigma_{0.2}$ (MPa)	δ_5 (%)	Z (%)
CLAM (HEAT 0408A)	980℃/30min+ 760℃/90min	669	514	24.8	76.9
CLAM (HEAT 0603A)	980℃/30min+ 760℃/90min	699.8	560.8	-	-
Eurofer97	980℃/30min+ 760℃/90min	652	537	20.8	79.9
F82H	1040℃/40mi+ 750℃/60min	669	548	21.7	78



HEAT0408B and JLF-1(JOYO-2-HEAT
DBTT of CLAM: about - 102 ℃, 16℃ lower than JLF-1

Irradiation Experiments of CLAM

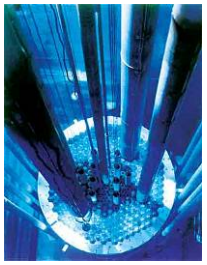
Neutron Irradiation

High Flux Engineering Test Reactor

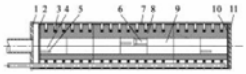
Irradiation Temp.: 250℃, Fluence: $1.51*10^{19}$n/cm^2 (>1MeV), DPA: 0.02

Increase of strength is about 10MPa

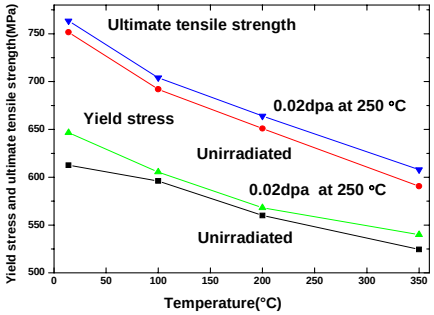
DBTT shift is about 5℃



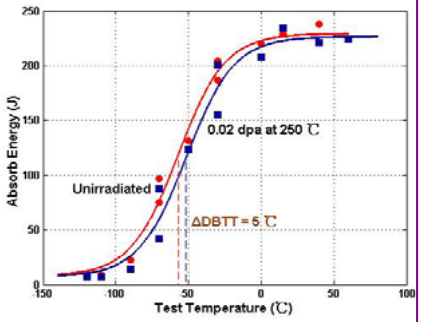
Inside of HFETR



Irradiation capsule



Ultimate strength and yield stress of CLAM (HEAT 0603A)

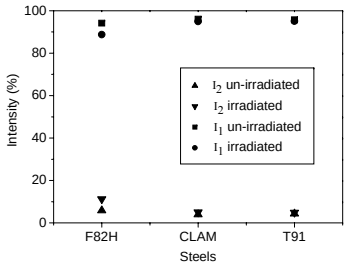


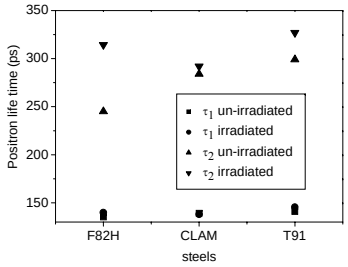
Charpy impact energy of CLAM (HEAT 0603A)

High fluence neutron and ion irradiation are underway.

Ion Irradiation

Irradiation with F ion (80MeV) to 10dpa





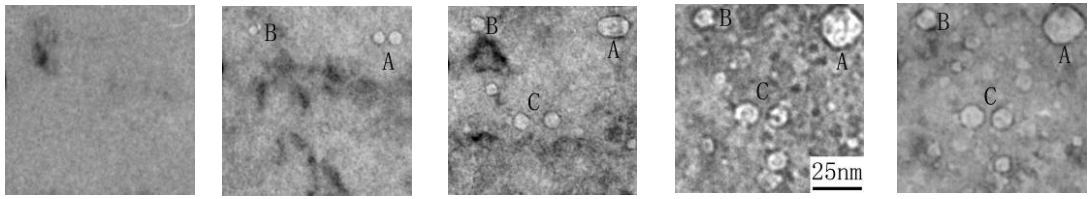
The positron annihilation lifetime and their intensities before and after irradiation

Better irradiation resistance compared with F82H and T91.

Electron Irradiation

Irradiation at 450ºC

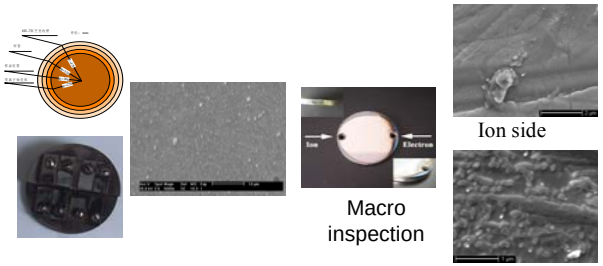
a) 0 dpa b) 1.2 dpa c) 3.6 dpa d) 10 dpa e) 14 dpa



Quantity and diameters of Voids increased with the dose (DPA). But the size of voids (such as A B and C position) didn't continue to increase when DPA > 10.

CLAM steel have good swelling resistance.

Plasma Irradiation



Irradiation at HT-7 in 2003

Irradiation at HT-7 in 2005

No obvious effect to plasma parameters.

Development of LiPb Loop Technology

Operation/Fabrication/Design:

- Thermal convection loop (compatibility)
  - DRAGON-I : 316SS, 500℃ (in operation)
  - DRAGON-II : Inconel, 700℃ (in operation)
  - DRAGON-III: SiC_f/SiC, 700-1000℃ (in fabrication)
- Forced convection loop (MHD)
  - DRAGON-IV: 480-700℃ (in fabrication)
- Auxiliary system for TBM in EAST
- Auxiliary system for TBM in ITER

DRAGON-I

✓ Design Objectives:

- Thermal convection loop (500℃)
- Compatibility of CLAM and 316L steel with LiPb.

✓ Main Parameters:

- Loop Size : 0.5m×0.5m
- Structural Material : SS316L
- Inner-diameter : 22mm
- LiPb inventory : 1 liter
- Temperature : 420 ~ 480℃
- Flow rate : ~ 0.08m/s

DRAGON-II

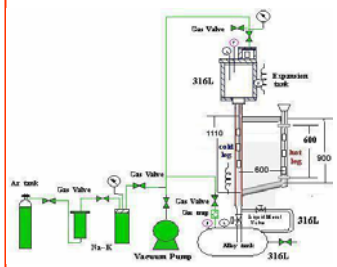
✓ Design Objectives:

- High temperature (700℃) thermal convection loop
  - hot leg: 700℃
  - cold leg: 480-640℃
- Obtain corrosion results for the TBM-DLL concept

✓ Key issues:

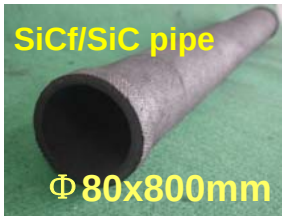
- Material selection (700℃)
- Fabrication technology
- Smelting of Large quantity LiPb

DRAGON-III



✓ Design Objectives:

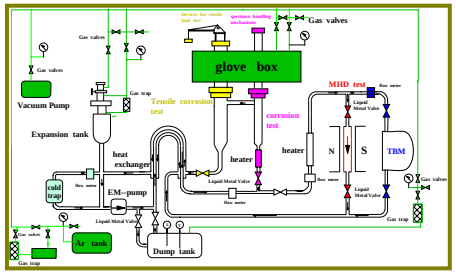
- High temperature (700-1000℃) thermal convection loop
- Pursue the manufacture of SiC_f/SiC materials for fusion
- Compatibility of SiC_f/SiC with LiPb



✓ Key issues:

- Fabrication of SiC_f/SiC Loop
- Connection technology
- Heating method of high temperature (up to 1000℃)

DRAGON-IV



✓ Design Objectives:

- MHD experiment (2T, 2m/s)
- Corrosion in flowing LiPb: -1000 ℃

✓ Key issues:

- Structureal Materials
- LiPb Purification
- Loop construction and measurement technology

Fabrication of SiC_f/SiC Composite

Requirements:

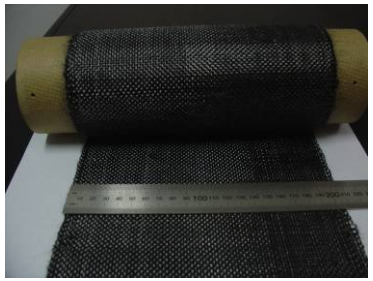
- Low / high thermal conductivity
- Low electrical conductivity
- Good compatibility with LiPb under elevated temp.
- Stable under neutron irradiation

Key issues:

- Fabrication of SiC_f/SiC pipe
- Fabrication of FCI
- Bonding technology of SiC_f/SiC composites

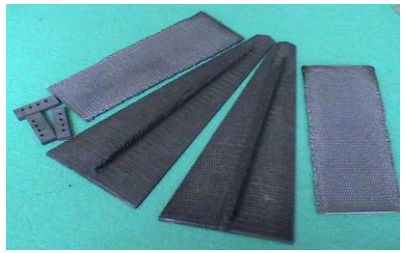
SiC_f/SiC composites

SiC fiber



SiC fiber felt

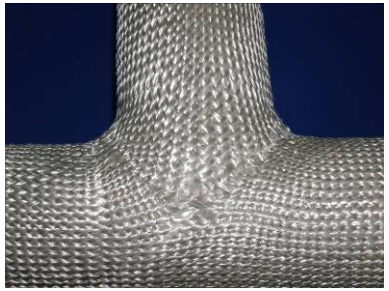
SiC fiber cloths



Continuous SiC fiber reinforced ceramic matrix composites

Strength of Continues SiC fiber reach 2.8-3.0GPa

Loop Technology



Fiber 3D braid preform

SiC fiber braid tube

Connection of metal and SiC composite

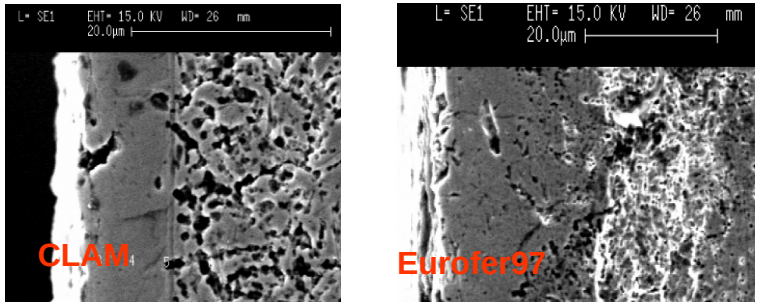
SiC_f/SiC composites were fabricated by CVI + PIP + CVD.

CVI---Chemical Vapor Infiltration
PIP---Polymer Infiltration and Pyrolysis
CVD---Chemical Vapor Infiltration

Coatings and Corrosion Experiments

Coating fabrication

CVD Coating



SEM image of CVD coating

Functions of Coatings

- Tritium permeation barrier;
- Electrical insulator to reduce MHD pressure drop;
- Corrosion barriers against liquid LiPb.

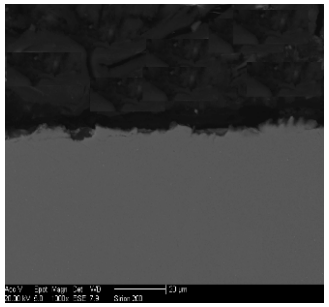
Requirements

- TPRF (tritium permeation reduction factor) ;
  - TPRF > 1000 for testing in gas-phase
  - TPRF > 100 for testing in liquid LiPb
- Electrical resistivity > 100 Ω cm^2 ;
- Compatibility with LiPb at ~550℃.

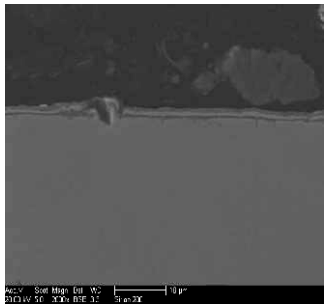
Work done/planned

- Fabricated coating (e.g. Al_2O_3) on CLAM by：
  - -HDA(Hot Dip Aluminizing);
  - -CVD (Chemical Vapor Deposition);
  - -VPS (Vacuum Plasma Spray) ;
- To explore new coating materials and methods

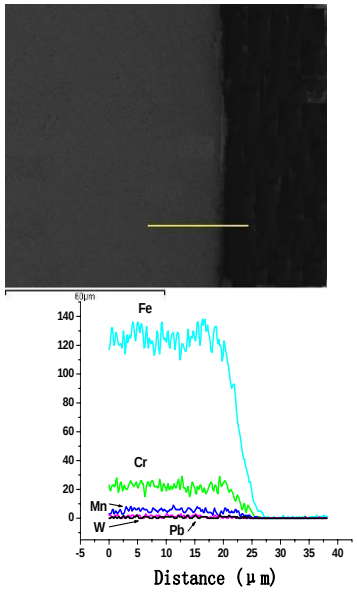
LiPb Corrosion Experiment (2500hr)



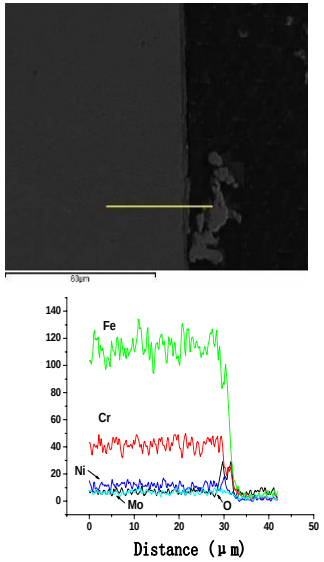
Cross section of CLAM after exposure for 2500h at 480℃ (cleaned)



Cross section of 316L after exposure for 2500 h at 480℃ (cleaned)



EDX line scan on cross section of CLAM after exposure for 2500h at 480℃ (after cleaned)



EDX line scan on cross section of 316L specimen after exposure for 2500h at 480℃ (before cleaned)

Design and Analysis Tools Development (Software)

1. Multi-functions neutronics calculation code system: VisualBUS
2. Multi-physics (neutronics, thermalhydraulics, MHD) coupling simulation codes: NTC/MTC
3. System Engineering (safaty/economy) analysis codes: RiskA, SYSCODE
4. Fusion virtual assembly system: FVAS
5. Material database and component reliability database management system: FUMDS, RiskBase

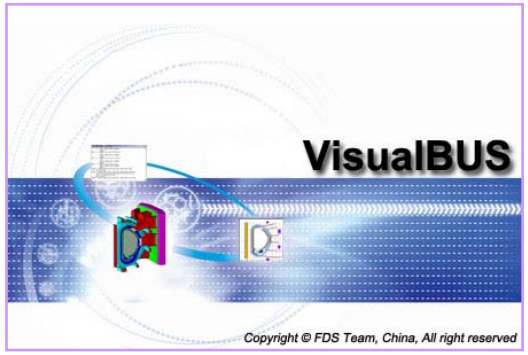
> 50~100 man-years each program

Key Tools for Fusion Reactor Design and Analysis

VisualBUS

Multi-functional Neutronics Analysis System

developed by integrating and improving existing codes
on the basis of the network technology



Basic Functions - Calculation (BUS):

- Particle Transport: SN / MC / MC-SN (1D/2D/3D)
- Isotope Depletion
- Material Activation
- Radiation Damage

Auxiliary Functions – Interface (Visual)

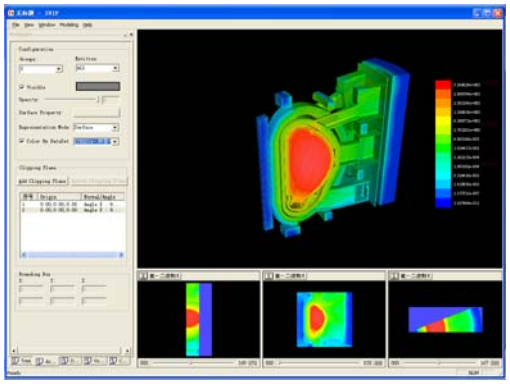
◆**MCAM / SNAM / RCAM**:
CAD-based Automatic modeling for MC / SN / MC-SN

◆**SVIP:** Visualization of mixing models-physical fields
Multi-physics coupling simulation

◆**MOO:** Parameters Optimization using GA/ANN/SA algorithm

◆**NTC:** Neutronics -Thermalhydraulics Coupling

◆**MTC:** Magnetics -Thermalhydraulics Coupling



Data Libraries:

- HENDL/MG/MC (Hybrid Evaluated Nucl. Data Library)
- FENDL 1.0/2.0/2.1
- Others

Y. Wu et.al, Chinese J. Nucl. Sci. & Eng. , Vo.27, No.4 (2007)

MCAM: Monte Carlo Automatic Modeling Program

An integrated modeling environment for Monte Carlo Simulation Codes

◆ Basic Function Modules (achieved in Version 4.2)

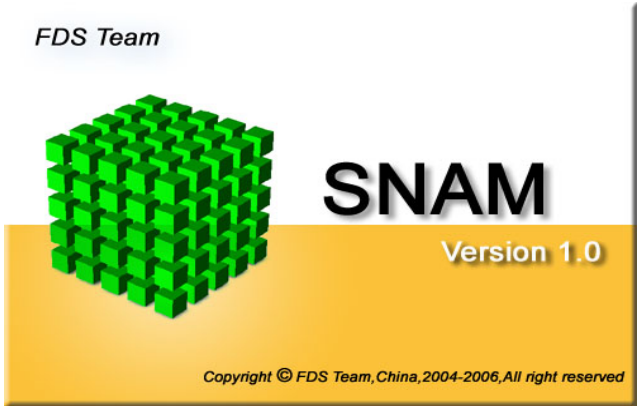
Preprocessor	Model Import/Export, Repairing & Preprocessing
Converter	CAD ➔ MCNP Conversion
Inverter	MCNP ➔ CAD Reverse Conversion
Analyzer	MCNP Model Analyzing & Editing
Creator	2D/3D Model Creating

◆ Extended Function Modules Version 5.0 ~

Adaptor	Convertor for other Monte Carlo simulation codes, e.g. TRIPOLI , EGS4
SNAM	Normalize irregular geometry solids to cylindrical or Cartesian ones for S_N codes
CT-Image Modeler	Virtual human body recreation from serial CT images
SVIP	Visualization of calculation results

SNAM: Discrete Ordinates (SN) Automatic Modeling Program

a bridge between CAD systems and SN codes such as BUS / TORT / THREEDANT.

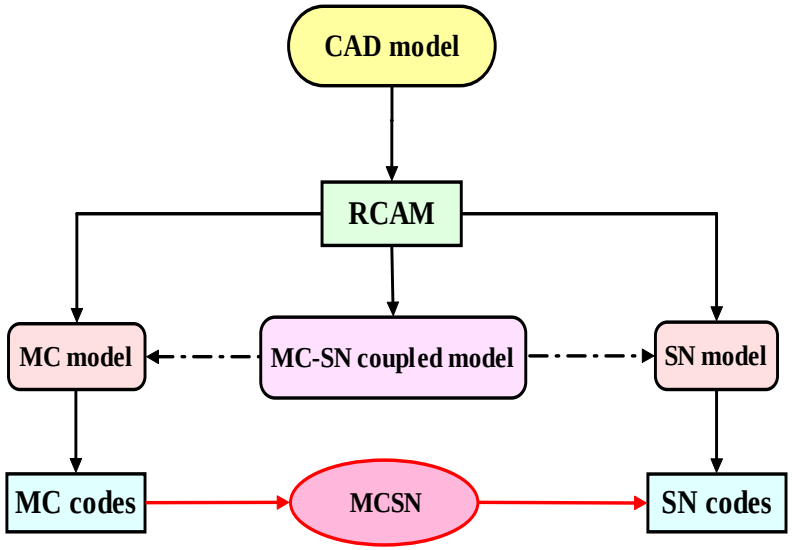


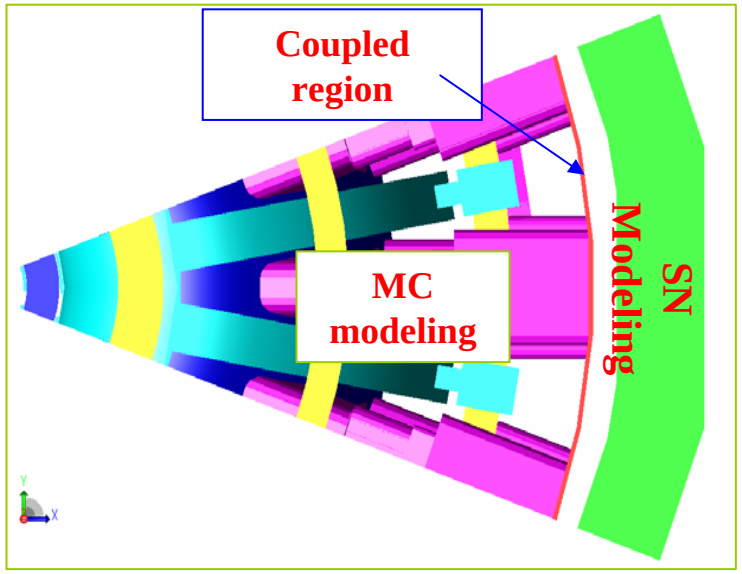
Converting (CAD-SN)	Convert neutronics model of CAD format to S_N input file
Inverting (SN-CAD)	Convert S_N input file to neutronics model of CAD format
Geometry Modeling	Import/export/create CAD geometry model, eliminate entities errors/gaps/overlaps, fill voids with suitable solids
Material Modeling	Display material / zone / structural / mass / volume information of neutronics model
Analyzing	Assign/edit material/zone/auxiliary information of model

RCAM: Radiation Coupled Modeling Program

◆ A Coupled Modeling Tool for MC+SN Particle Simulation Codes

Combine the advantages of both MC and S_N methods to treat shielding problems with deep penetration. RCAM utilizes the technologies & components in MCAM/SNAM and focus on the coupled modeling for both the MC and S_N simulation codes.



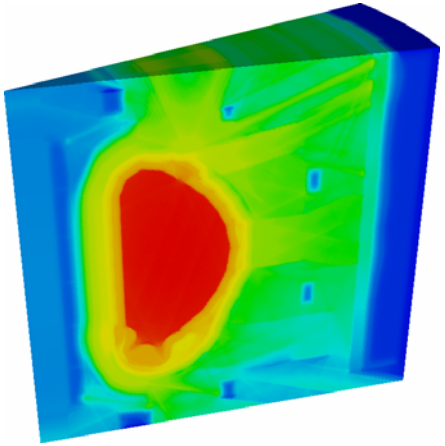


MC: good representation of complex geometry, but bad calculating speed

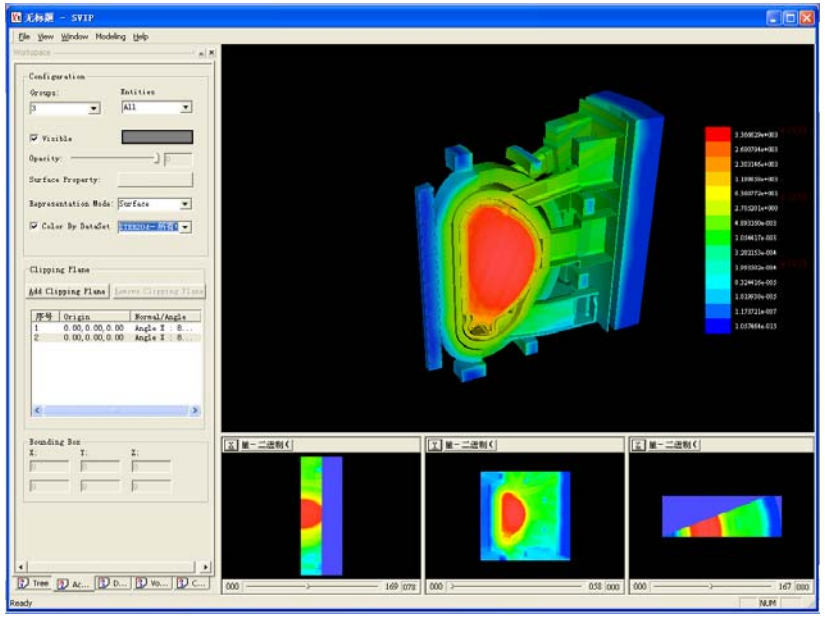
SN: good computing speed, but limited capability of geometrical representation

SVIP: Scientific Visualization Integrated Platform

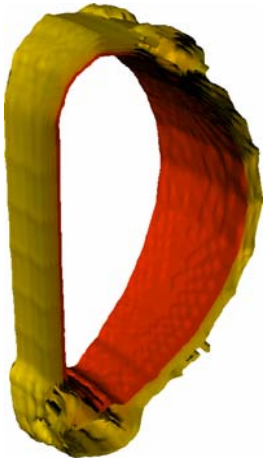
- Fast volume rendering of physical fields data
- Contour extraction and rendering
- Mapping volume data onto any geometry surfaces
- Mixing volume rendering and geometries
- Flexibly coupled with MCAM/SNAM/RCAM/Transport



Volume rendering of neutron flux field



Mapping neutron flux onto geometry model

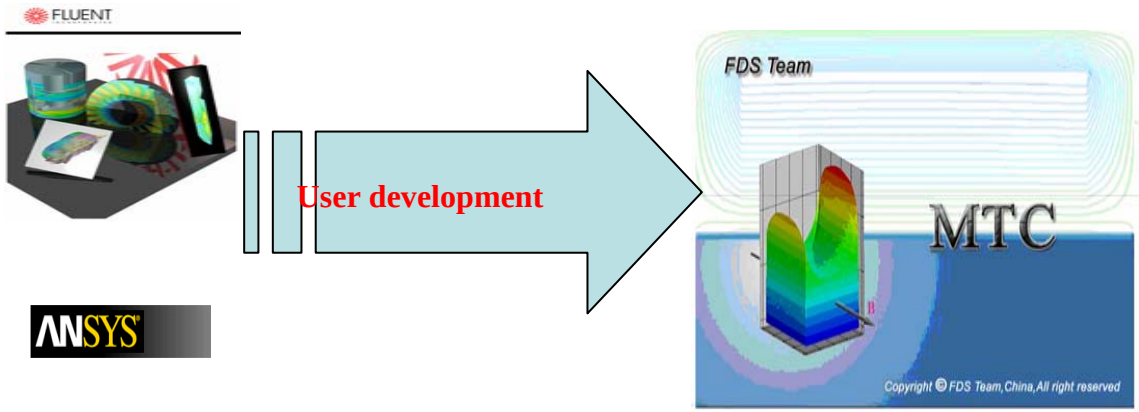


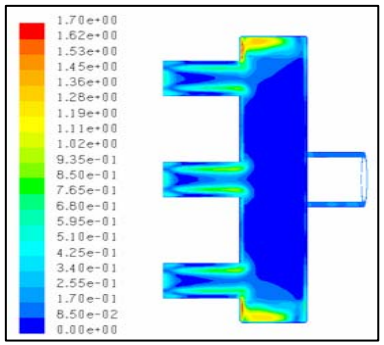
Contour rendering of neutron flux field

MTC/NTC: Multi-Physics Coupling Programs

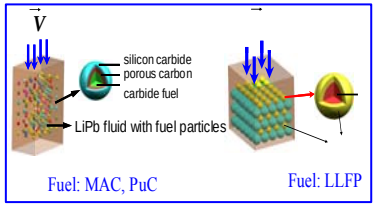
• MTC（Magnetic - Thermohydraulics Coupling Program）

- MHD effects : FLUENT+User-rountine
- CFD simulation : FLUENT
- Stress Analysis : ANSYS



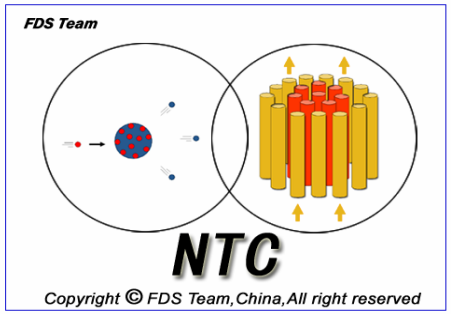


Velocity field of ITER-TBM



Scheme for circle particle fuel design

• NTC （Neutronics - Thermalhydraulics Coupling Program）

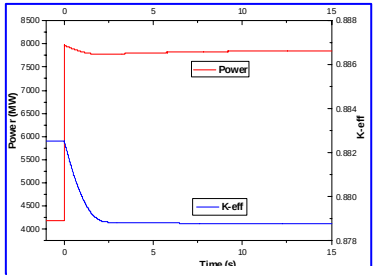


Safty analysis:

- Design basic accidents
- Severe accident analysis

Advanced reactor design

- Couple calculator for neutronics and thermo-hydraulics
- design for sub-critical reactor
- design for new type fuel



The influence of neutron source to reactor power and reactivity

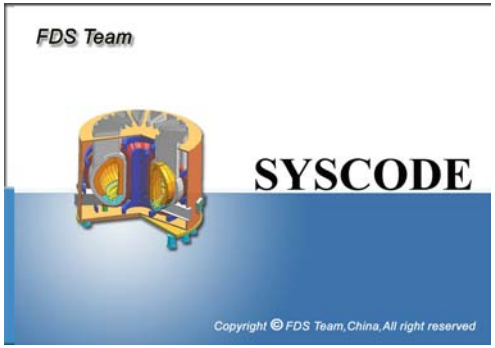
System Analysis Programs

RiskA: An Integrated Reliability/Probabilistic Safety Analysis Program

- FMEA (Failure Mode Effects Analysis)
- FTA (Fault Tree Analysis)
- ETA (Event Tree Analyses)
- Importance Analysis
- Uncertainty & Sensitivity Analyses
- Reliability Optimization
- Reliability Data Management
- RiskAngel (A Risk Monitor Tool)

SYSCODE: A Fusion System Analysis Program for Parameters Optimization and Economics Analysis

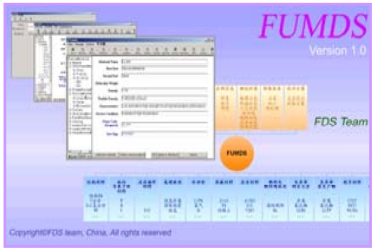
- Cost-benefit calculation for fusion and fusion-fission hybrid systems
- Parameters optimization with multi-objectives and constraints by using the GA/SA algorithms
- Sensitivity/ Uncertainty analyses of parameters by using Monte Carlo or other methods.
- System analyses by integrating Physics model, engineering model and financial models



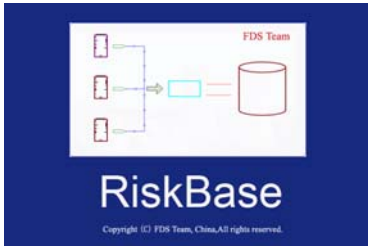
Material and Component Database Management System

(to be published on the website of IEA liquid blanket collaboration)

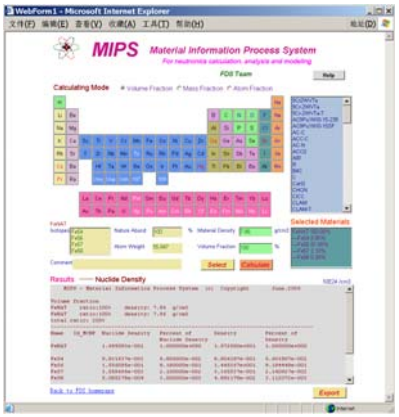
(http: //www.fds.org.cn/LBB)



- **FUMDS (Fusion Mat. Database Management System):**
  - **Browse and edit brief and detailed information of materials**
  - **Search for info by material name and/or type and/or property**
  - **Compare different materials**
  - **Visualize data by drawing figure**
  - Data analysis for material research (underway)
  - Development of material design expertise system (underway)
- **Material Types :**
  - Structure, Plasma Facing Component, Coating,Fuel & Fuel Breeder, Coolant, Shield
- **Materials Data:**
  - Compositions (designed/measured)
  - Properties (physical/mechanical/chemical/irradiation/economic etc.)
  - References (data source)



- **RiskBase (Component Reliability DataBase Management System)**
- **MIPS (Material Information Process System)**



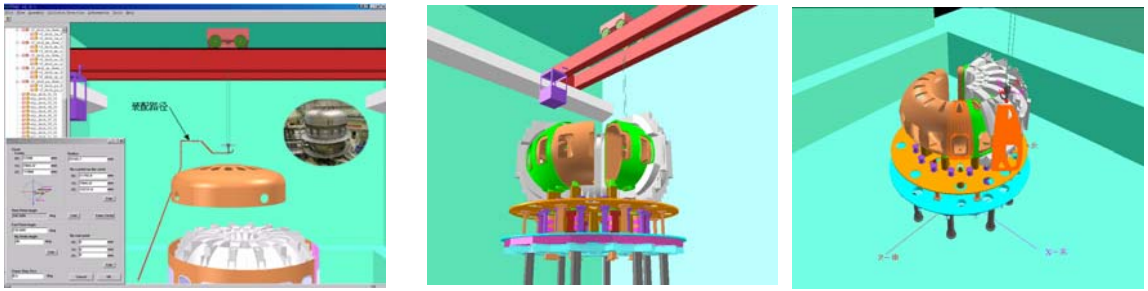
FVAS: Fusion Virtual Assembly System

- **Planning & validation of assembling procedures**

  Manipulating virtual tool, assembling virtual part by interaction; Supporting record of assembly process, aiding analysis of assembly plan

- **Training simulator**

  Improving the skill of trainer, Roaming in virtual real environment



EAST virtual assembly

Summary

- **Designs of four concepts of fusion reactors (FDS-I, II, III, ST) with LiPb blankets, three kinds of TBMs (Out-of-pile mockup, EAST-TBM and ITER-TBM) and the related evaluation of safety, economy and environmental impact are being performed in parallel. The designs are still evolving.**
- **Development strategy and time schedule of TBMs (including related material R&D) have been developed**
- **R&D on RAFM steel, LiPb loops, coating/FCIs are ongoing.**
- **R&D on design & analysis tools are being performed by making full use of advanced computer technologies.**

The End

Thanks for your attention !

FDS Website: www.fds.org.cn

E-mail: fds@ipp.ac.cn