ASIPP

SanDiego2001

Transmutation Research Activities at ASIPP

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Contents

- Fusion-fission hybrid reactor program in China
- Transmutation-related fusion core conceptual study at ASIPP
- Transmutation blanket conceptual study at ASIPP
- Development of calculating and analysis tools

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Contents

- Fusion-fission hybrid reactor program in China

Why to develop hybrids in China

Two basic facts:

❖ Fission nuclear industry has been falling on hard times

- Nuclear radioactive waste disposal ?
- Nuclear fuel supply shortage ?
- Nuclear proliferation ?

❖ Fusion development has a good progress, but still needs hard work to economical utilization

- **Great advances in plasma physics and technological experiments, R&D activities on fusion energy**

  ➔ Fusion neutron source application

- **New concepts on economical application of fusion**

  ➔ Further efforts to economical fusion energy

Why to develop hybrids in China ?

- **From the energy supply point of view, we have a big gap between fission energy and fusion energy !**

- From the technology development point of view, we need to pass a middle step to pure fusion energy

  There hardly is a possibility to make a commercial use of pure fusion energy before 2050.
  But we could have a near-term application of fusion as a neutron source (FDS).

Predicted Situations at 2050 in China:

Population : ~1.5 billion

Total GNP : ~6000-12000 billion US$

Energy demand : ~5 billion tons of standard coal

Capacity of electricity: ~1200-1500 GW

➔ Power supply shortage ?

(in the present, nuclear electricity ~1%)

Nuclear electricity would make an important contribution.

±í 1 Ô€ ?âµÃ2050 ÄêºËÄÜ?æÄ£ºÍÕ??ÜµçÁ|µÄ±ÈÀ?

Table 1 Predicted fraction and capacity of nuclear energy supply in 2050 in China

· ?°¸ scenario	ºËµçÕ??Ü µçÁ|±ÈÀ(%) fraction A	ºËµç · ¢Õ? ?æÄ£(GW) capacity	Õ?Ò»´Î ÄÜÔ´±ÈÀ(%) fraction B	±¸ ?¢ (?Ü?æÄ£Ë®Æ? approximate scale
µÍ · ?°¸ (I)	10	120	6	?Ó?üÄ¿Ç° · ¨?úºËµçÁ?±¶ double nuclear electricity in France
ÖD · ?°Ç(II)	20	240	12	Ïàµ±Ä¿Ç°ÃÀ · ¨ËÕÈ??úºËµçÖ◐ sum of nuclear electricity in US,France and RF
¸ß · ?°¸(III)	30	360	18	?¬??Ä¿Ç°È«ÊÀ?çºËµç?Ü°Í **sum of nuclear electricity all over the world**

Fraction A: fraction of nuclear electricity in total electricity supply.
Fraction B: fraction of nuclear electricity in total primary energy supply.

If nuclear power would make a substantial contribution(>10%) to the energy demand, we would need construct more than 100 nuclear power stations.

Questions: How to solve these problems:

- Nuclear fuel supply ?
- Radioactive waste disposal ?
- Safety problem ?

FDS:

Fusion Neutron Source Driven Subcritical System

--- hybrid reactor with multi-functions

- Long-lived waste transmutation
- Fuel breeding
- Tritium self-sustain
- R&D for pure fusion energy

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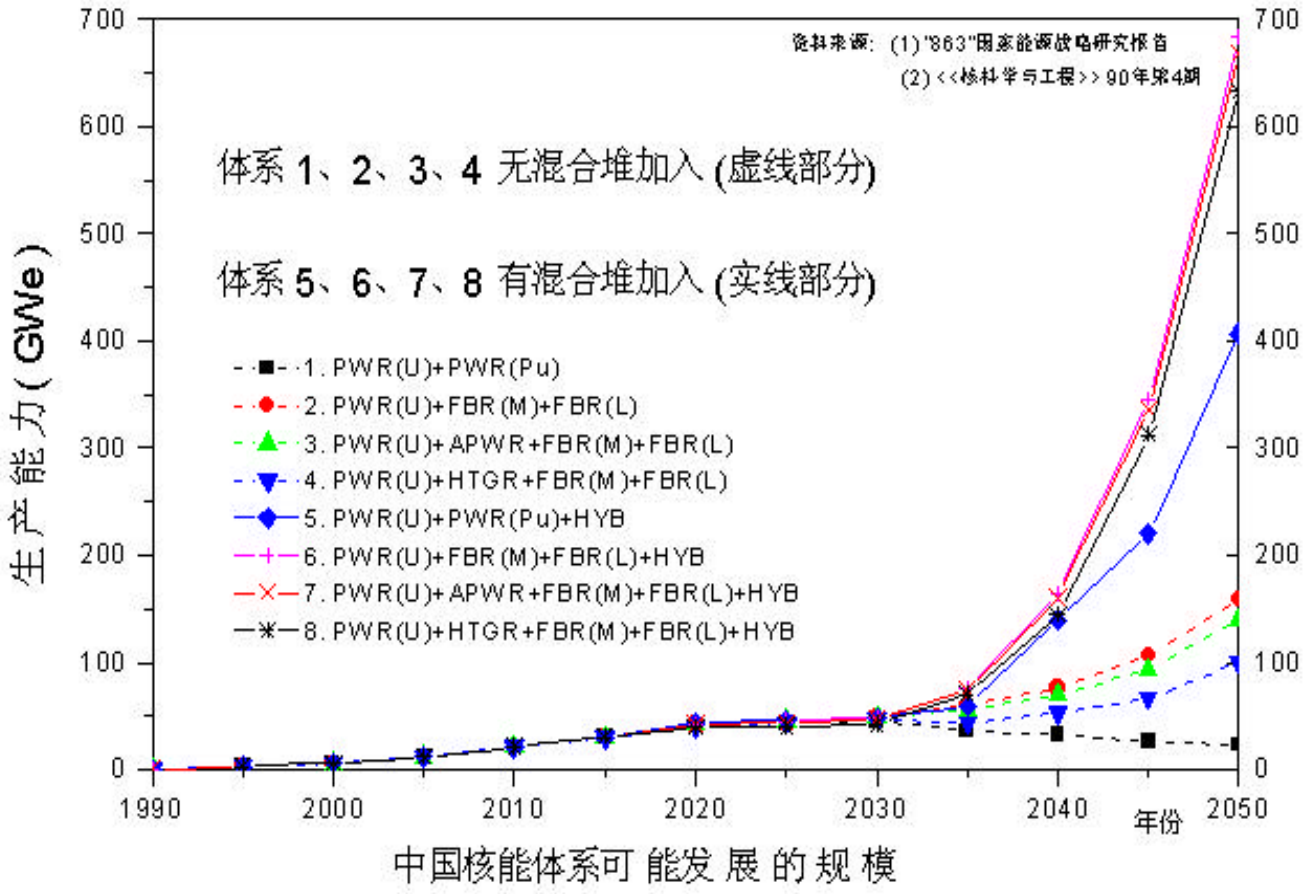
Nuclear Energy Prediction in China



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Phase I (1986-1990): conceptual design

To identify objectives & characteristics of experimental reactor

To assess the technical database

To study critical technical issues

Phase II (1991-1995) : detailed conceptual design

To carry out detailed design (jointly by ASIPP and SWIP)

To conduct plasma core experiment, R&D of Technology

To study on transmutation in hybrid reactors

Phase III (1996-2000) : outline eng. design of key components --- FEB

Blanket design

Divertor design

Plasma experiments and technology R&D

New concepts study (blanket and core)

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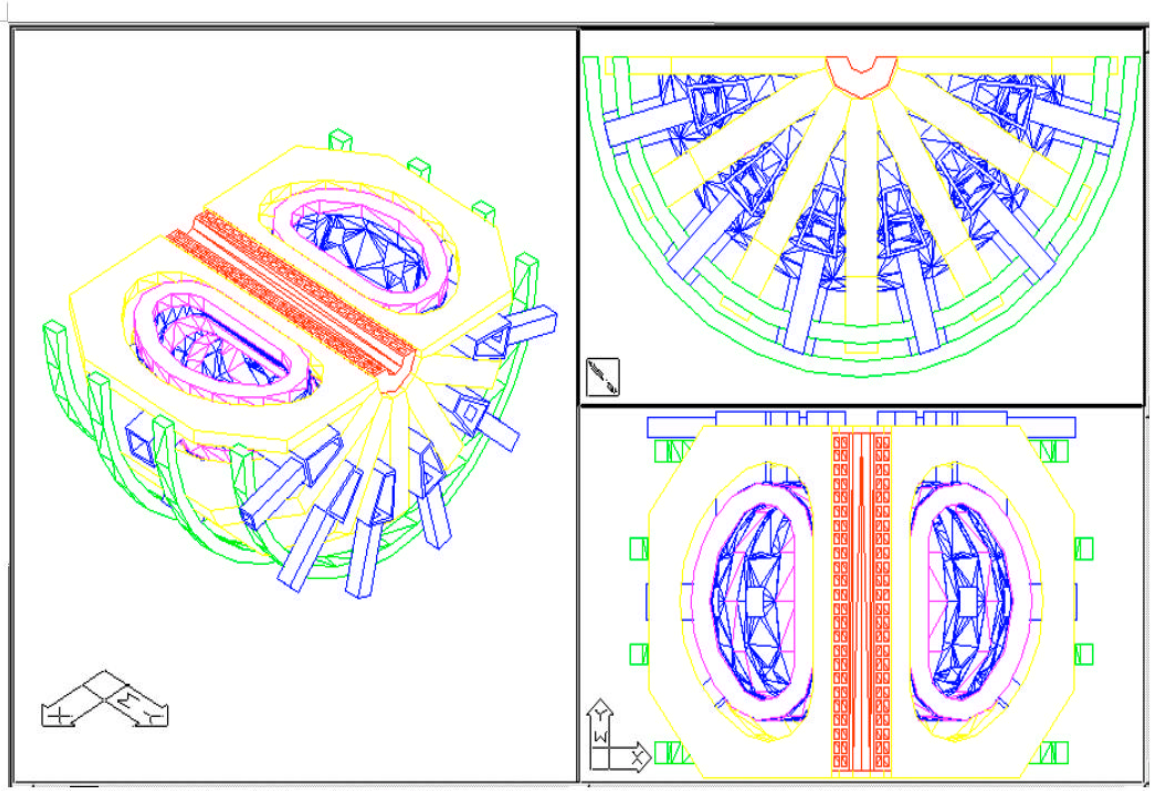
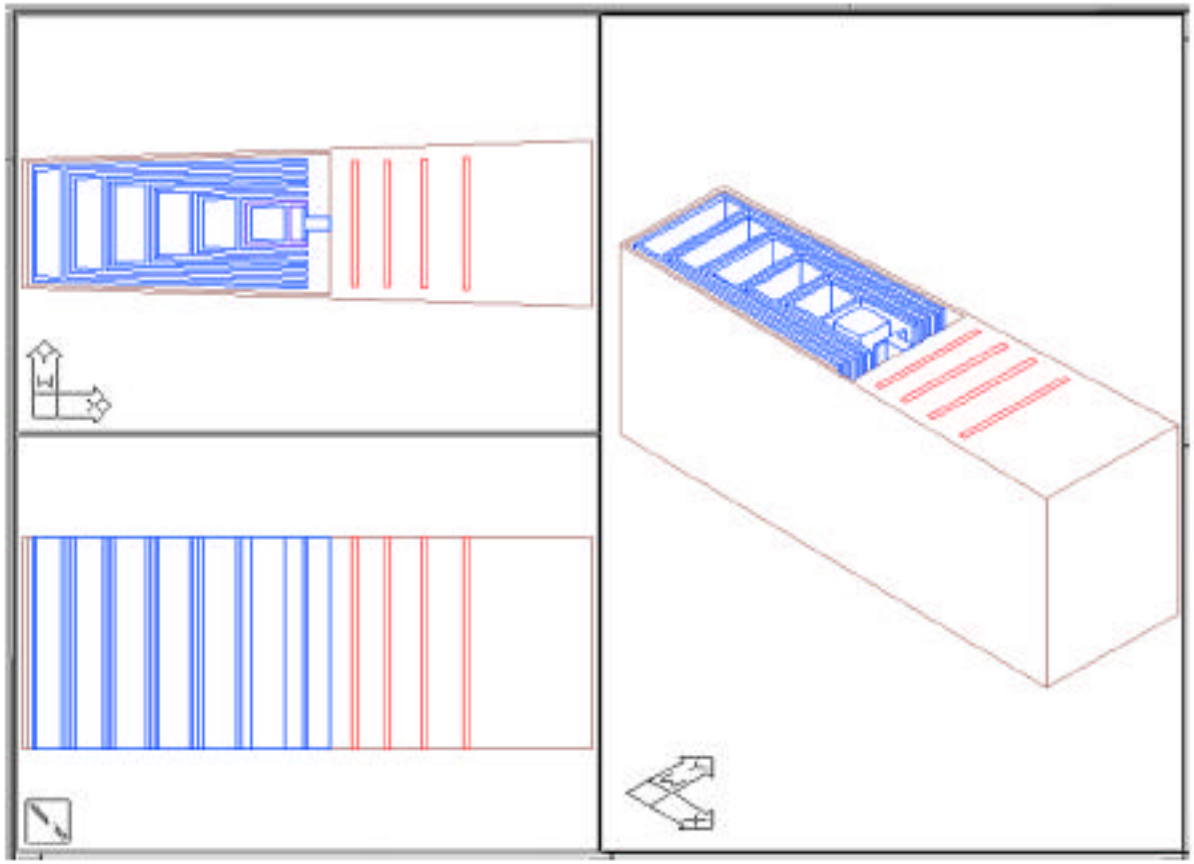
Device	HT-6M	HT-7	HT-7U	HL-1	HL-1M	HL-2A
R[m]	0.45	1.22	**1.7**	1.02	1.02	**1.64**
a[m]	0.20	0.3	**0.4/0.8**	0.20	0.26	**0.50**
κ			**2**			**1.6-1.8**
R/a	2.25	4.1	**4.5**	5.0	4.0	**3,3**
B_T[T]	1.5	2.5	**3.5**	3.5	3.0	**3-3.5**
Ip[MA]	0.15	0.40	**1.0**	0.30	0.35	**0.8-1.0**
t_d [S]	0.12	1-5	**~1000**	0.3	1.0	**5-10**

View of FEB



图十四　FEB结构装配图　（剖面三）



图十六、包层结构图

Structure Mat.: 316SS

Fuel: U-pebble bed

Tritium Breeder: Li2O

Coolant: He

Eng. Design and R&D of key components before 2010

Definition and design study of next device under way

To build experimental reactor 2010-2020

To build Demo reactor 2020-2030

To **build commercial reactor around 2030–2040**

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Contents

- Fusion-fission hybrid reactor program in China
- Transmutation-related fusion core conceptual study at ASIPP

- Heating, current drive and analysis
- Energetic -particle confinement
- Fueling and ash exhausting
- Plasma burning control
- Simulation of plasma evolution process
- Diverter design with gas puffing and electromagnetic plug
- Core parameter design (table)
- Sensitivity of plasma parameters to uncertainty

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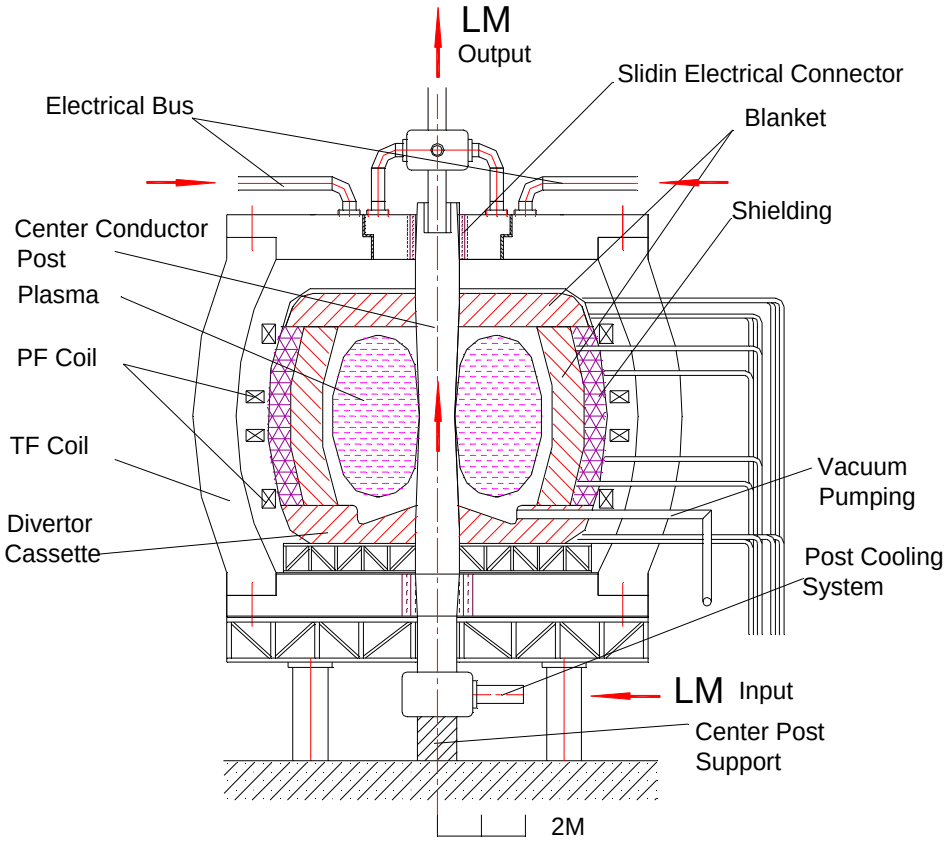
Device or Design	HT-7U	FEB	FDT-ST		JET	ITER
			Option 1	Option 2		(ITER-FEAT)
Major radius R[m]	1.7	4.0	1.4	1.4	2.9	6.2
Minor radius a[m]	0.4	1.0	1	1	1.2	2.0
Plasma current Ip[MA]	1	5.7	9.2	7.0		15
Toroidal field B_t[T]	3.5	5.2	2.5	2.5		5.3
Average density [$10^{20}m^{-3}$]		1.1	1.6	1.1		1.1
Average temperature[kev]	3	10	10	9.5	10	10
Plasma volume[m^3]		134	50	50		837
Bootstrap current fraction		0.53	0.72	0.81		
Fusion power [MW]		143	100	50	16	500~700
Auxiliary power[MW]		50	28	19		73~100
Neutron wall loading [MWm^{-2}]		0.43	1.0	0.5	~0.2	0.5~0.8
DT neutron rate(n/sec)	$3*10^{15}$	1. $1*10^{19}$	$3.6*10^{19}$	$1.8*10^{19}$	$5.7*10^{18}$	
Power gain Q		~3	~3	~2.5	~1	~10
Operation availability		50%	80%	80%	/	~40%

- **Core parameter design**
  (table)
- **Natural diverter study**
  --- Modeling and design
- **Center Conductor Post Study**
  Irradiation effects analysis on conventional concept
  Novel concepts on liquid metal cooled CCP


LM
Output
Slidin Electrical Connector
Electrical Bus
Blanket
Shielding
Center Conductor
Post
Plasma
PF Coil
TF Coil
Divertor
Cassette
Vacuum
Pumping
Post Cooling
System
LM Input
Center Post
Support
2M

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Parameters	Value	Comments
Total fusion power [P][GW]	0.1	
Major radius a[m]	1.4	Set by wall loading and fusion power
Neutron wall loading P_w[MWm^{-2}]	1	Balance between breeding and neutron damage
Plasma current Ip[MA]	9.2	Determined by fusion power
Center post current[MA]	9.0	~Ip to minimize recirculating power
Aspect ratio A	1.4	Minimum permitted by dissipation in CCP
Elongation	2.5	To maximize
Triangularity	0.45	Compromise between MHD stability and CCP 'tapering'
	6.5	10% below MHD ballooning limit
%	35	Low recirculating power, high P_f
l	0.2	Hollow J profile, high
Poloidal β_p[%]	0.95	
Bootstrap current fraction [%]	0.81	
Toroidal field B_t[T]	2.5	
Plasma edge q	5.5	Monotonic q profile with 2nd stability access
Average density $<n_e>$[$10^{20}m^{-3}$]	1.1	
Average temperature <T>[keV]	9.5	
Plasma volume[m^3]	50	
Auxiliary power P_{aux} [MW]	19	

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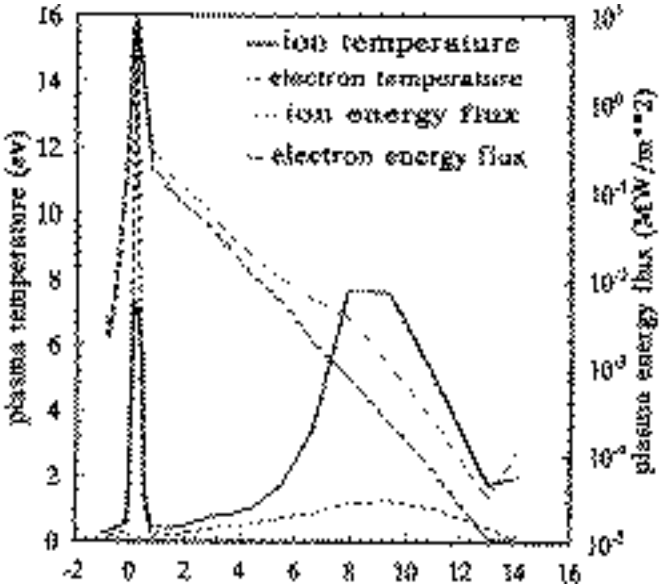
Main difference of plasma parameters near divertor target plate

Peak temperature [eV]	SOL thickness Δ=15cm	Gas puffing Δ=15cm	SOL thickness Δ=5 cm
Ion temperature	7.692	7.166	7.853
Electron temperature	15.55	0.9557	78.85
Ion energy flux[W/m^2]	5.222	2.241	4.084
Electron energy flux[MW/m^2]	8.965	1.620	25.05
Ion density[10^{22}/m^3]	0.5361	0.946	0.1868
Pressure [Pa]	2576	2678	2723
Total energy flux [MW/m^2]	13.37	3.861	27.92



B2 modeling results of plasma parameters distribution near the natural divertor target plate

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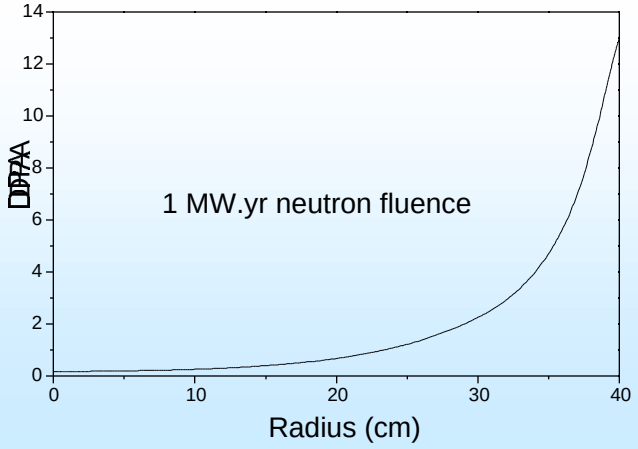
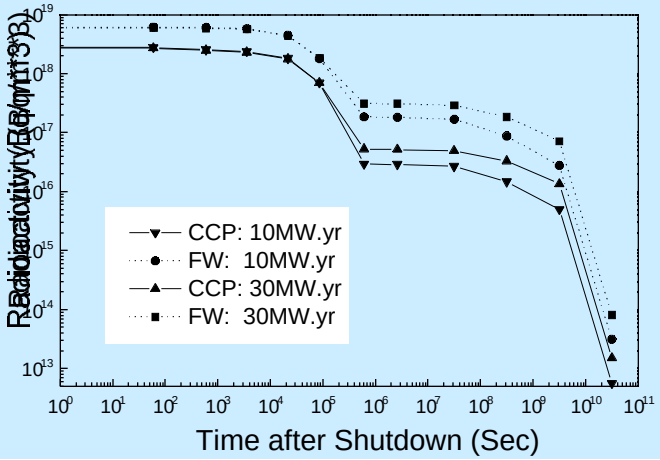
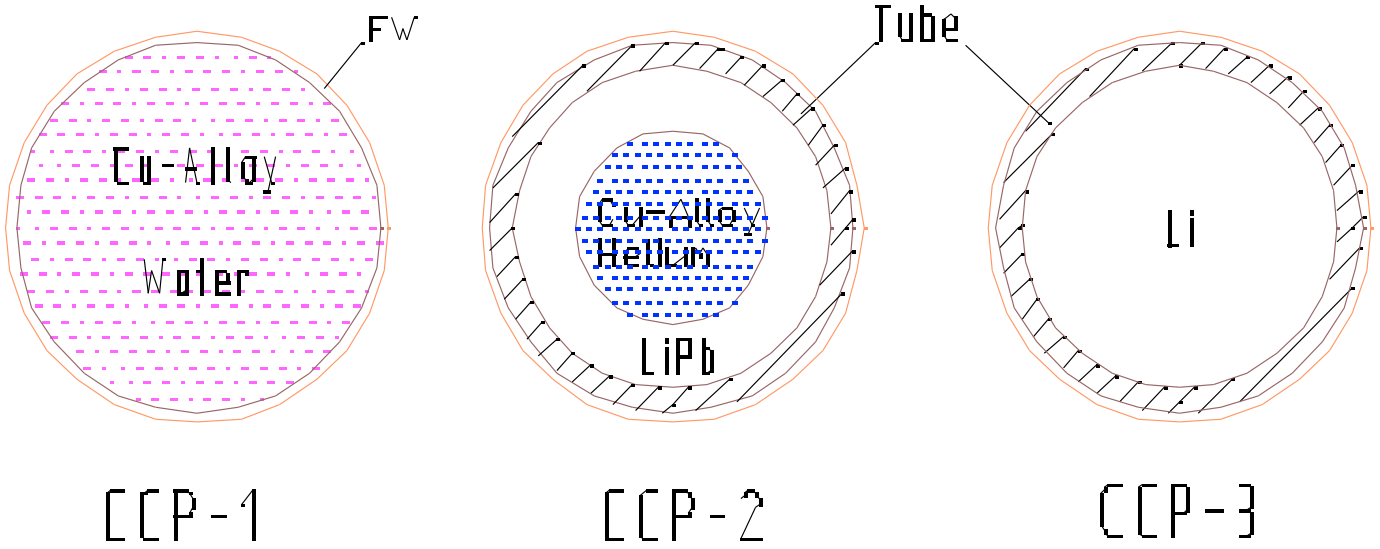
Coolant	Water	Helium	Li	$PbLi_{17}$
Diameter of the post (m)	0.8	0.8	0.8	0.8
Diameter of cooling channels (m)	0.015	0.015	0.015	0.015
Plasma current I_p(MA)	9.5	9.5	9.5	9.5
Current through the post I_c (MA)	13.8	13.8	13.8	13.8
Resistive heat dissipation (MW)	76.6	77.3	81.5	83
Nuclear heat deposition (MW)	7.1	7.1	7.1	7.1
Pressure drop of coolant (bar)	0.06	0.009	0.1	0.02
Coolant fraction	0.26	0.26	0.26	0.26
Coolant system pressure (bar)	10	100	10	10
Inlet temperature of coolant (K)	300	300	460	510
Outlet Temperature of coolant (K)	318	440	627	555
Flowing velocity of coolant (m/s)	8.6	56	2.1	5.8
Peak temperature in the post	358	516	676	580



Reactor and Component	ST			RT		UWM AK-I	ITER	
	Whole CCP	Inner FW	outer FW	inner FW	outer FW	FW	FW	
Materials	Cu	Cu	Cu	Cu	Cu	316ss	316ss	Cu
DPA/yr	3.0	12.1	15.0	14.0	17.1	18	9.3	10.1




FW
Cu-Alloy
Water
Tube
Cu-Alloy
Helium
LiPb
Li
CCP-1
CCP-2
CCP-3

CCP Type	CCP-1	CCP-2	CCP-3
Component configuration	Cu-alloy	Cu+LiPb+ODS	Li+ODS
Conductor material	Cu-alloy	Cu-alloy	Li
Electric Conductivity (10^{10} $^{-1}$.m^{-1} at 500K)	32	32	6
Conductor Lifetime (yr)	4.1	5.7	No limit
Tritium breeding ratio Contributed by CCP	/	0.04	0.15
Electric resistivity Relative increase (%)&	77	45	/
Resistive dissipation power at the end of lifetime (MW)	987	2920	2216
Nuclear heating power (MW)	71	56	58

* calculated with MCNP4B + FENDL-2.
& relative change percentage at the end of lifetime.

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Neutronics:

Effective transmutation for all fission products could be accomplished in the highly moderated blankets in which the highly efficient neutron multiplier (fissile plutonium-239 or uranium-233) is added

He-cooled nitride particle fuel of actnides or the liquid metal (LiPb eutectic or Na) cooled metallic alloy (e.g. Y/Zr alloy of actinides) fuel is used.
Metallic fuel or nitride fuel is preferred to oxide fuel because it may provide harder neutron spectrum or it allows to implement a compact fuel cycle concept based on pyrochemical process, and liquid metal cooled fuel or particle fuel allows higher power density because of high heat transfer capacity

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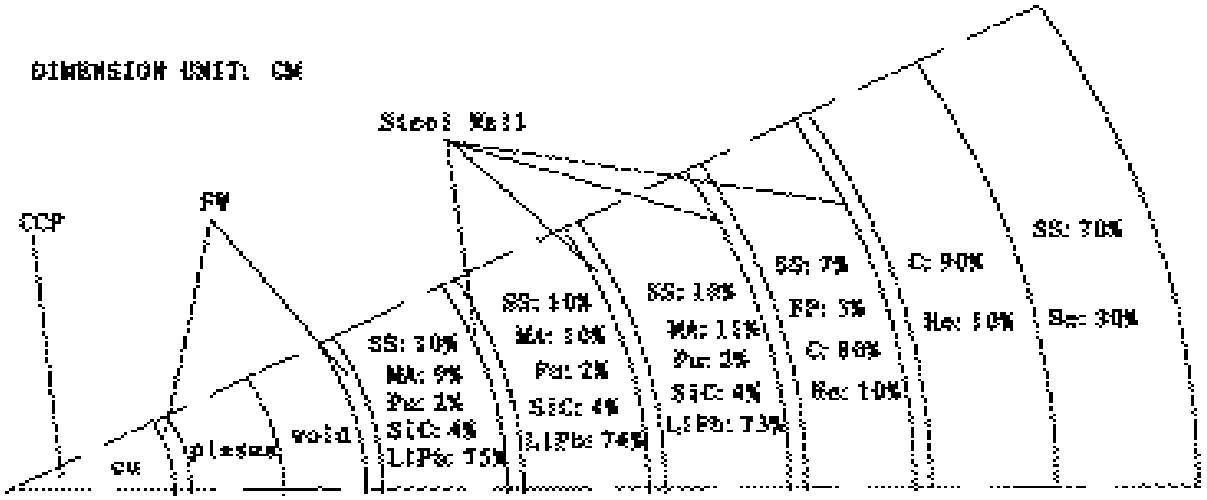

: ODS coated by SiC

: pressurized helium gas for FW, FP transmutation zone

LiPb eutectic for MA transmutation zone

: small balls

- MA is initially loaded into the blanket in the form of pebble beds in the inner zone closed to the first wall.
- T-breeding zone with Li2O is arranged between the actinide transmutation zone, in which MA mixed with U-233 are loaded, and fissile fuel U-233 breeding zone with natural TH-232.
- FP (^{135}Cs, ^{129}I and ^{99}Tc) can be efficiently transmuted in the outer zone with good neutron moderator.
- To be used to achieve several functions: HLW transmutation, fissile material breeding, tritium self-sustaining and energy amplification

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Device or Design	HT-7U	FEB	FDT-ST		JET	ITER
			Option 1	Option 2		(ITER-FEAT)
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Power gain Q		~3	~3	~2.5	~1	~10
Operation availability		50%	80%	80%	/	~40%

Calculational results for the three concepts

Blanket Concept	FEB (producing Fuel)	FDT-E (transmuting wastes)	FDT-ST (transmuting wastes)
Production/Transmutation Capacity (/yr)	~100 kg (PU239)	~400(AC)+30(FP) (Actinides)	~6000(AC)+375(FP)
Tritium breeding ratio T	~1.1	~1.6	~1.1
k_{eff}	<0.4	~0.91	~0.97
Peak power density (W/cm^3)	<20	<90	<800
Total thermal power (GW)	~0.4	~0.75	12
Neutron wall loading(MW/m^2)	0.42	0.20	1.0
Availability	50%	50%	80%

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Development of Calculating and Analysis Tools

- Thermal-hydraulics
  - –Gas cooled pebble-bed blanket, adapting macro-homogeneous model for binary phase flow.
- Neutronics: revised from BISON1.5
  - –1-D SN method for neutron transport (BISON1.5)
  - –46n+21γ, 100nuclides from ENDF/B-VI
  - –Generalized solution for complicated burnup chains which can deal with many types of fuel cycle to meet the demands for waste transmutation and fuel breeding
  - – Resonance self-resonance effect into consideration
  - –Built-in interface to the thermal-hydaulics analysis

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Development of Calculating and Analysis Tools

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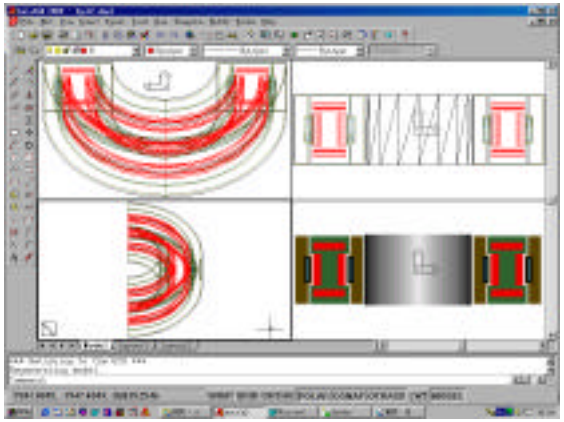
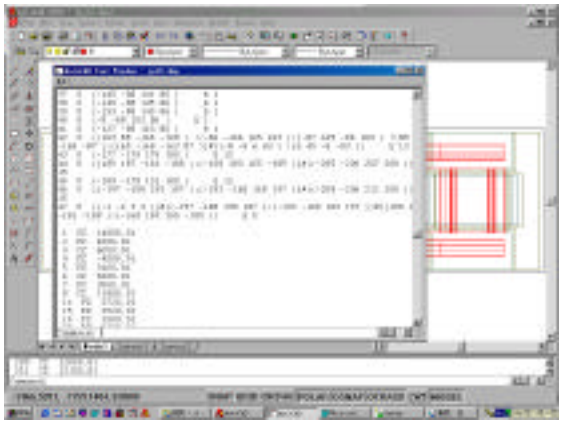
Development of Calculating and Analysis Tools

Automatic Modeling of Numerical Simulation Calculations



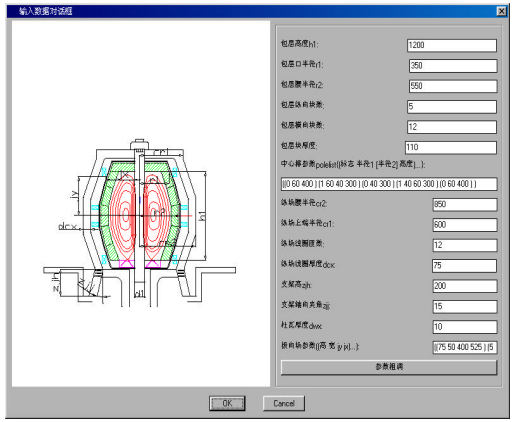


- Geometrical models is very time-consuming.
- Automatic transformation from CAD to MCNP
- Examples: HT-7U & FFHR.

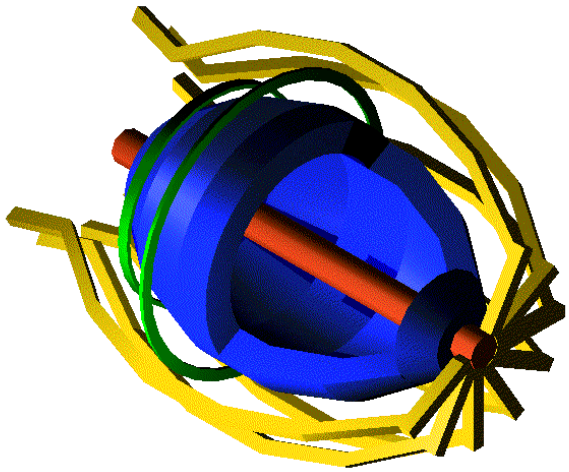
Development of Calculating and Analysis Tools

Visual Design

Interface & Result



- Parameters Modification
- Structure variation



The End

Thank you very much for
your attention !