24 Apr 2014

Status of China-ADS project

OUTLINE

I. Introduction

- Motivation
- ADS Roadmap in China
- New Site & Institute for C-ADS

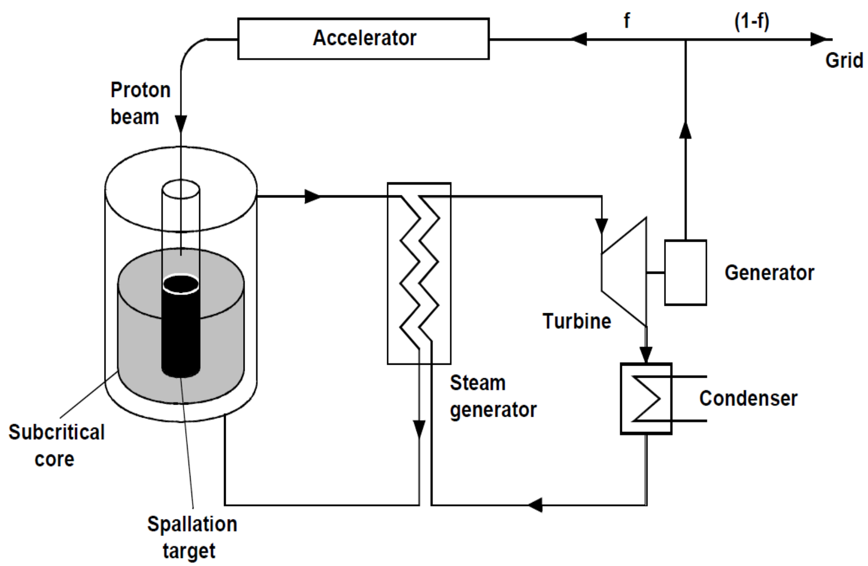
II. Current Progress of C-ADS

- Overview of C-ADS
- Accelerator System
- Spallation Target
- Subcritical reactor

III. Open Questions on ADS

Motivation

- Accelerator Driven System was proposed for nuclear waste transmutation, accelerator driven thorium reactor (ADTR)…, since early 1990's
- ADS produce hard, intense spallation neutron by accelerating high power proton on target for driving subcritical core
- ADS consists of high power proton accelerator & spallation target, subcritical core



ADS and FR in Advanced Nuclear Fuel Cycles — A Comparative Study, NEA/OECD, 2002

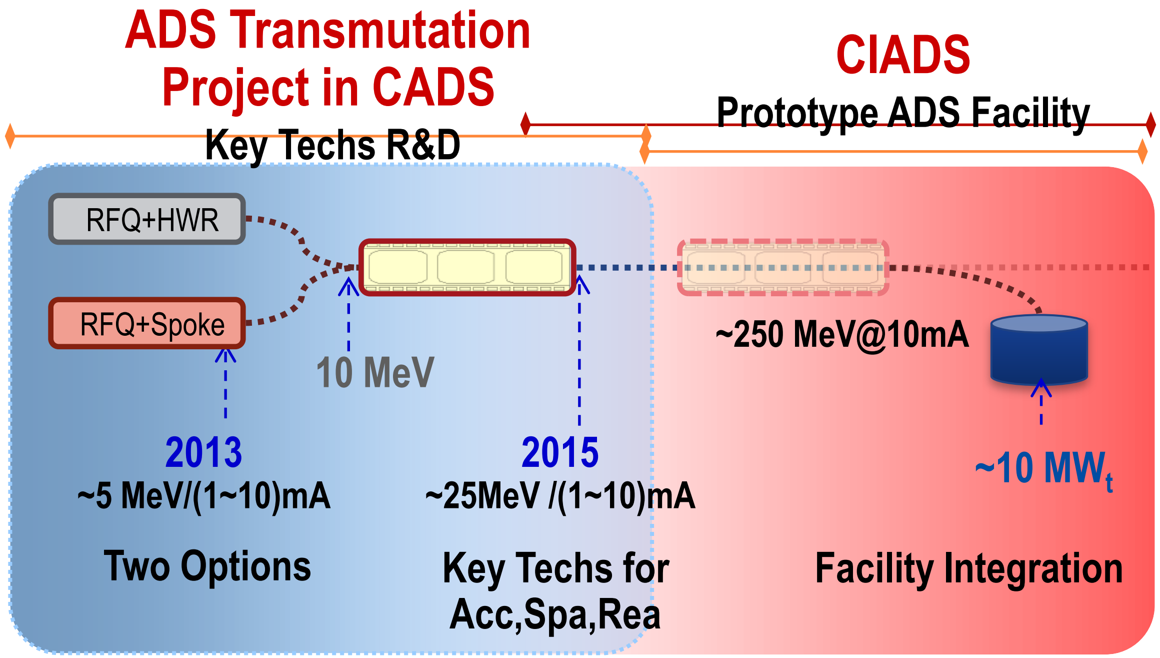
– ADS is better at burning waste than Fast Reactors
– ADS employs a fast neutron spectrum and solid, fertile-free fuel with the primary mission of transmuting transuranics or MA
– ADS could support more PWR waste transmutation
– ……

Nuclear Power Development in China

- **To July 2013** **(http://www.iaea.org/NuclearPower/Systems-and-Databases/index.html)**
  - 18 reactors in operation, 13.860GW$_{e;}$ (6th in the world)
  - 28 reactors under construction, 27.790GW$_e$; (1st in the world)
- **Estimation for the future (slow down after 2011.3)**
  - **2020**: ~58 GW$_e$ NPP in operation
  - **2030**: ~10% of NP to total power capacity
  - **2050**: 350~400 GW$_e$, ~20% of NP to total power capacity → **almost same as the scale of the total in the world today!**

Nuclear Waste Management is a serious issue!

Relationship Between CAS & National Plan



ADS in CAS

- Key Techs R&D
- Team & New Institute Established

- Confirm Technical Route

CIADS

- Construction of ADS facility
- Reliability Test

Next Step in CAS: Nuclear fuel with MA an so on

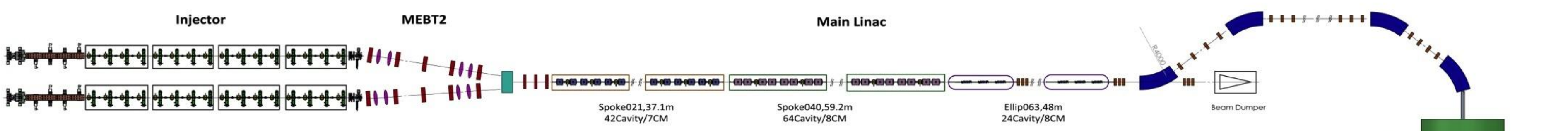
OUTLINE

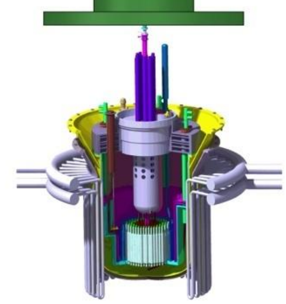
I. Introduction
- Motivation
- ADS Roadmap in China
- New Site & Institute for C-ADS

II. Current Progress of C-ADS
- Overview of C-ADS
- Accelerator System
- Spallation Target
- Subcritical reactor

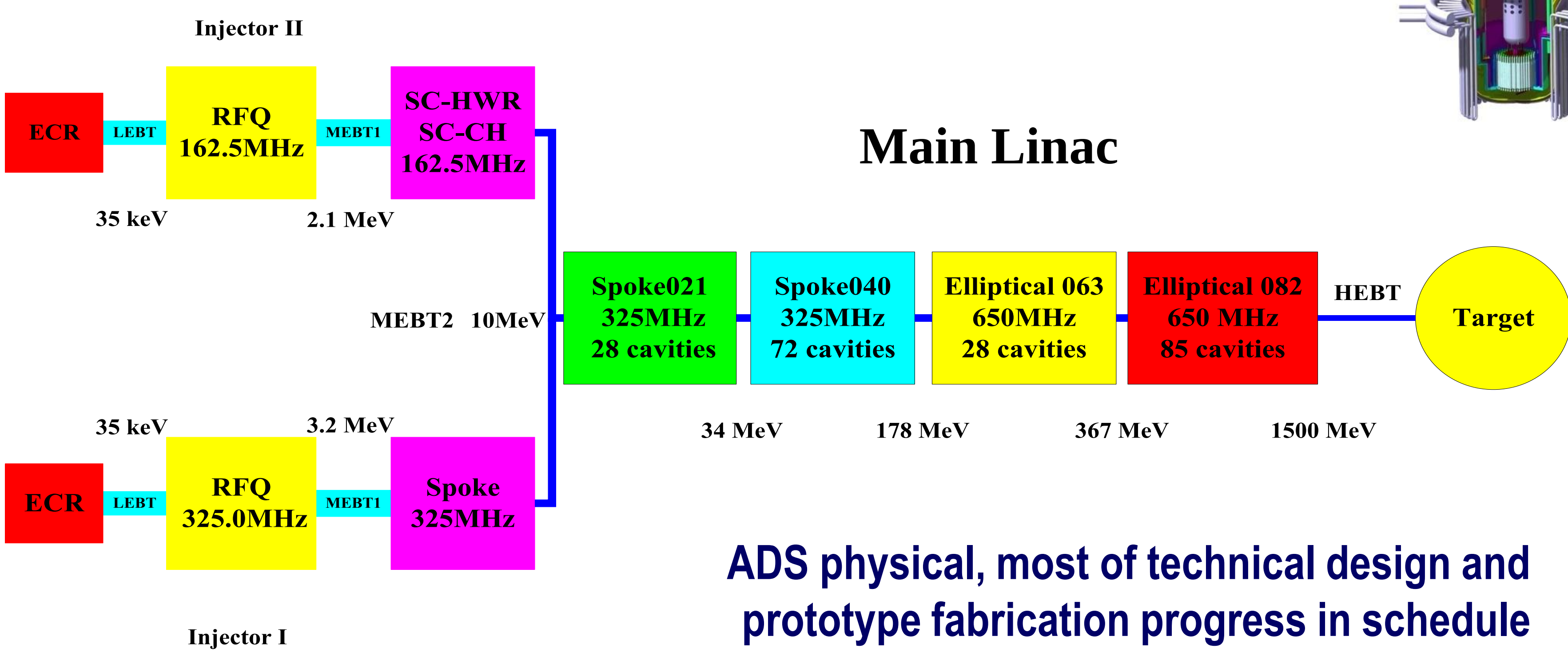
III. Open Questions on ADS

Configuration of C-ADS



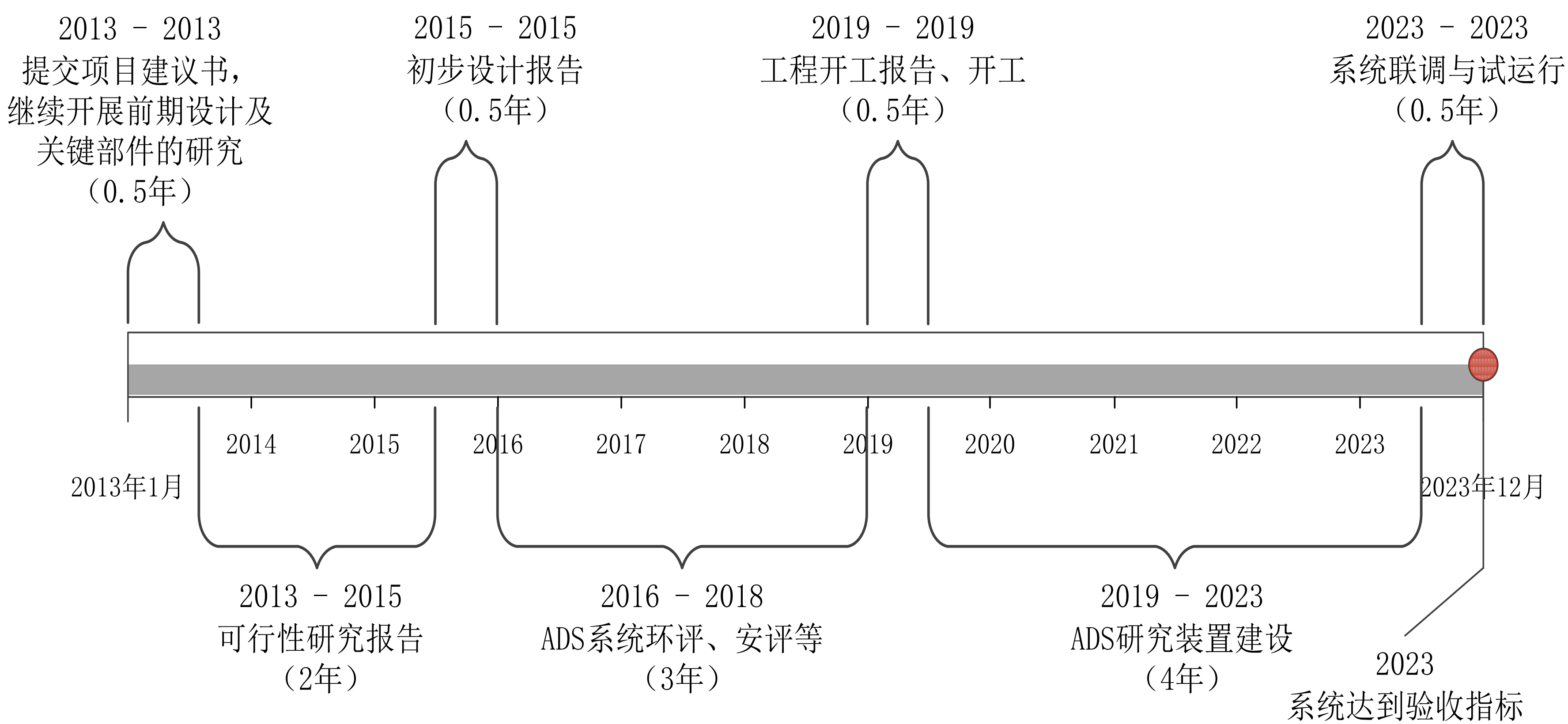


250MeV@10mA， CW mode， $10MW_{th}$



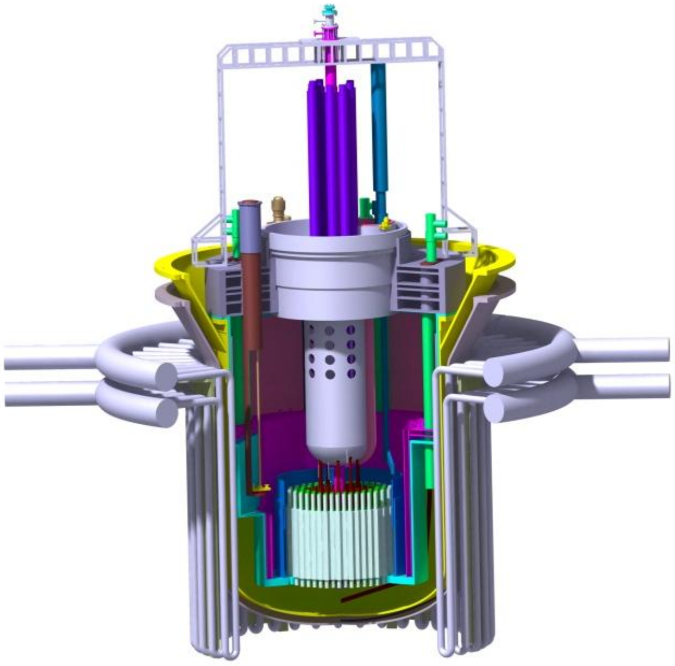
ADS physical, most of technical design and prototype fabrication progress in schedule

Time Schedule for CIADS Project

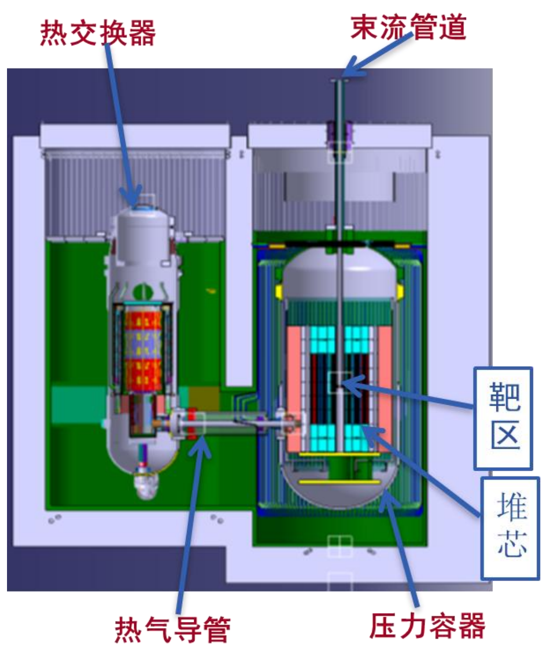


Two Technical Ways

LBE cooled
First

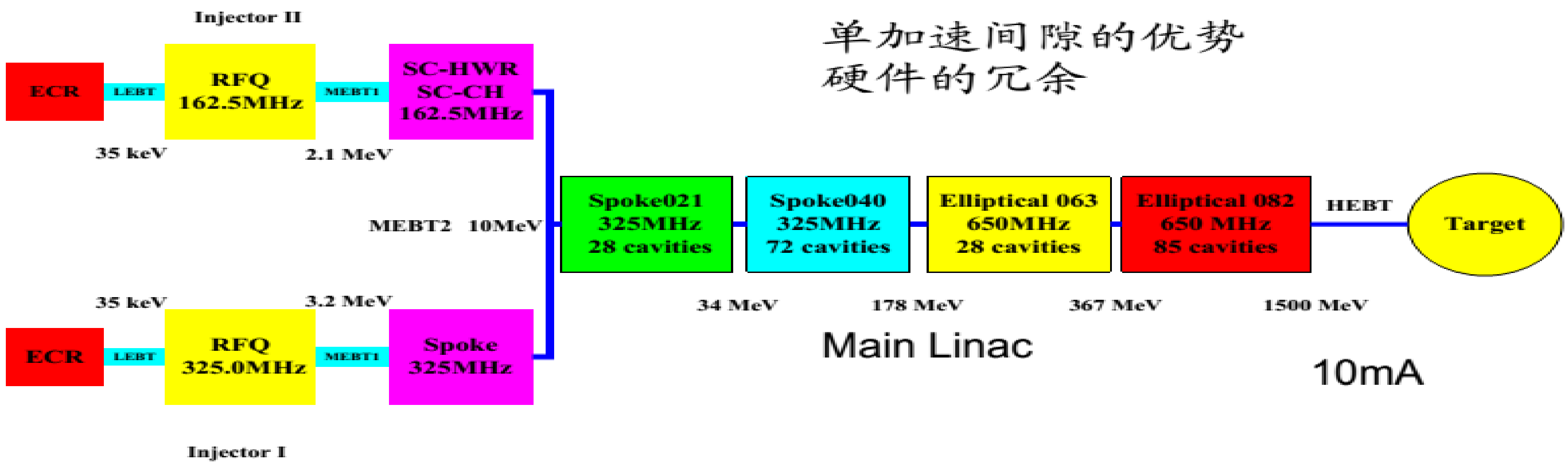


Modified Gas-cooled
Backup



Accelerator

Accelerator System Overview

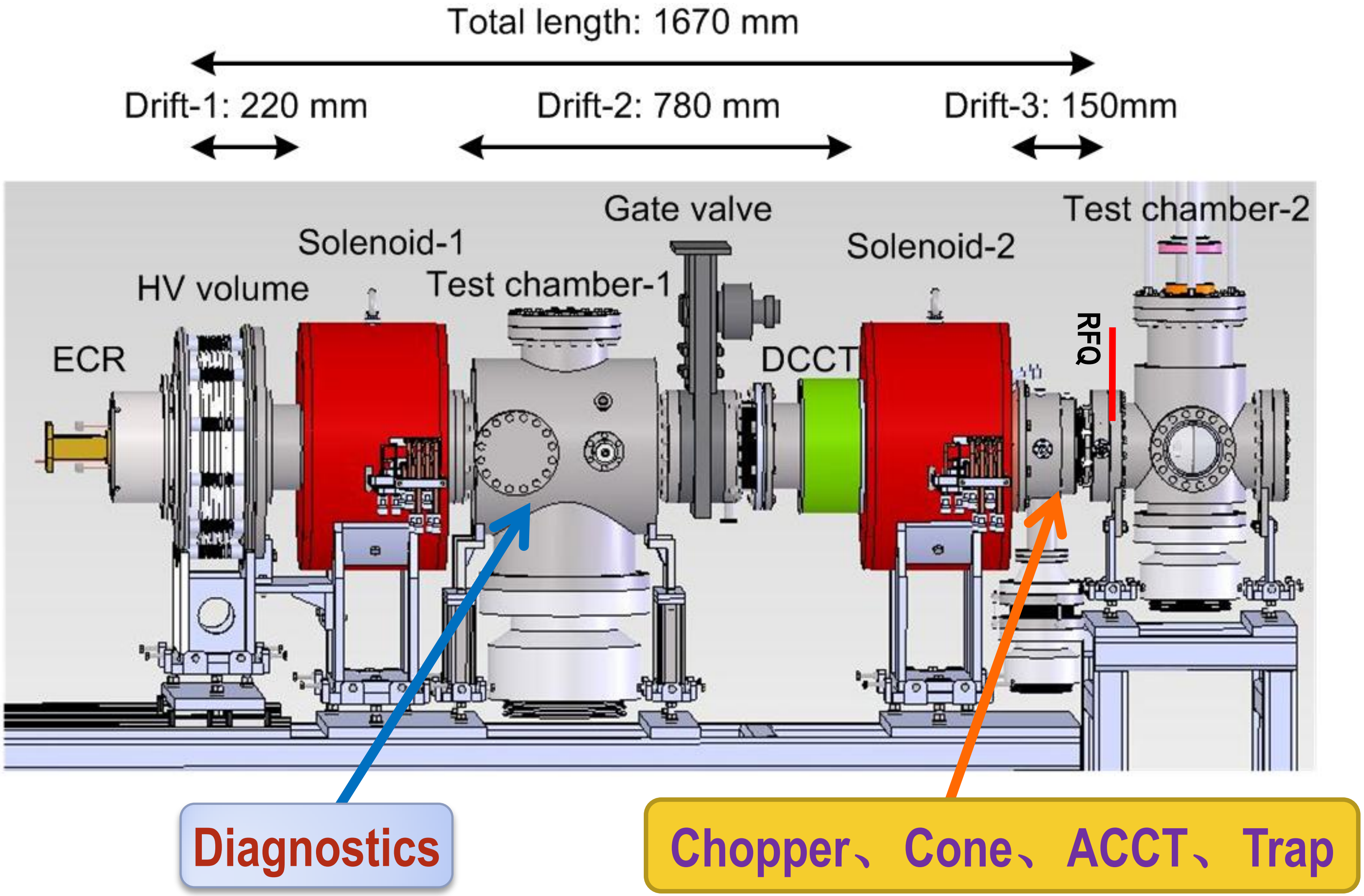


单加速间隙的优势
硬件的冗余

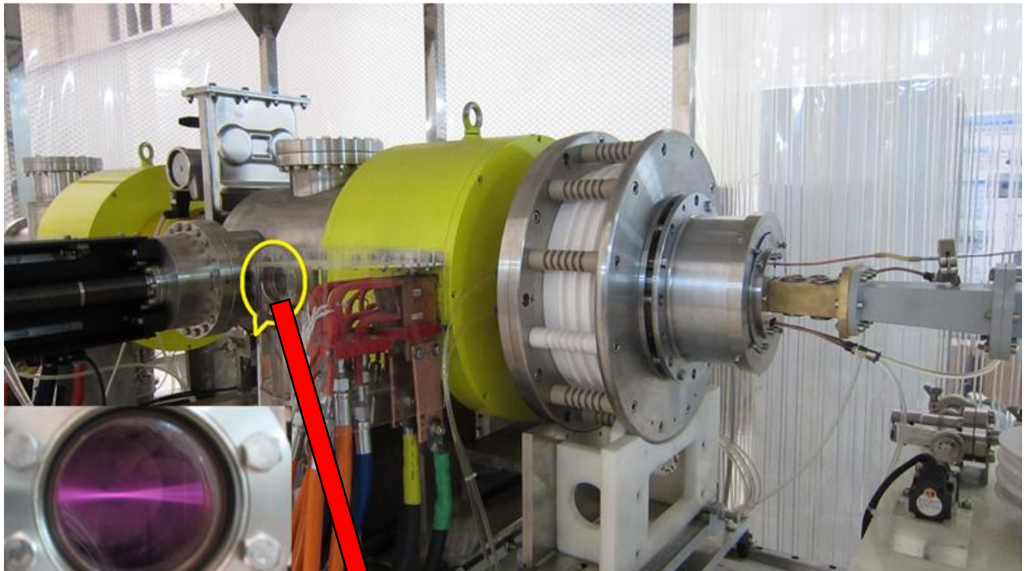
粒子	质子	单位
能量	~250	MeV
最大流强	~10	mA
最大束流功率	~2.5	MW
占空比	100	%
束流损失	<1	W/m
年失束次数	<25000	1s<t<10s
	<2500	10s<t<5m
	<50	t>5m

加速器分段	能量（MeV）	长度（m）
ECR＋LEBT	0.035	~2.5
RFQ＋MEBT	2.0～3.5	~11
Injector	10～20	10～15
MEBT2(双支)	10～20	~15
Main-Spoke021	~40	~42
Main-Spoke040	~160	~62
Main-Ellip063	~250	~50
HEBT	~250	~10

Accelerator System: ECRIS + LEBT



ECRIS+LEBT is commissioning at IMP

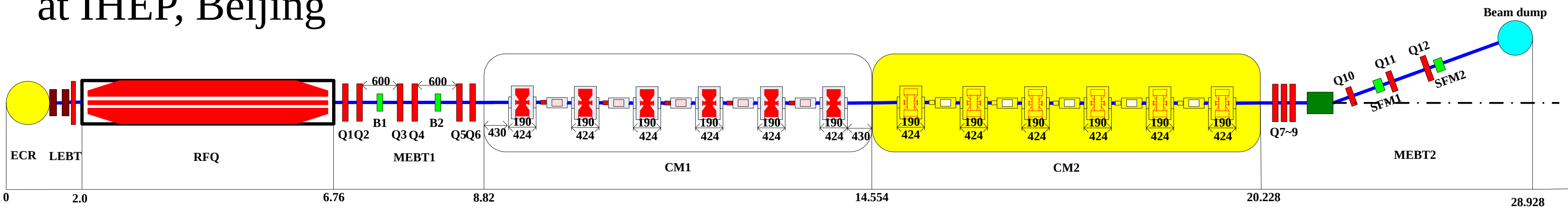


- The first ECR Proton Ion Source is commissioning at IMP.
- 25 mA Proton with 35 keV has been extracted.
- Stability still need to be improved in long time.

Accelerator System: Two options of 10-MeV Injectors

Injector I
at IHEP, Beijing

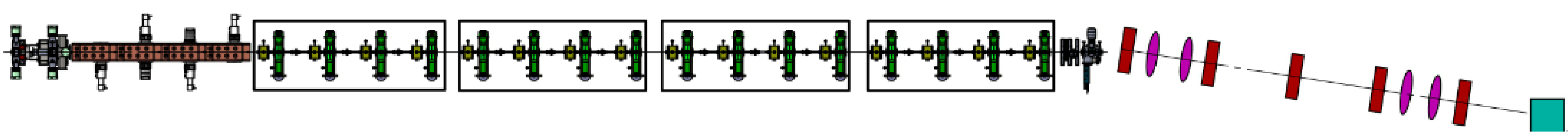
Base on 325 MHz and Superconducting Spoke cavity



35 KeV 3.2 MeV 5 MeV 10 MeV

Injector II
at IMP, Lanzhou

Base on 162.5 MHz and Superconducting HWR cavity

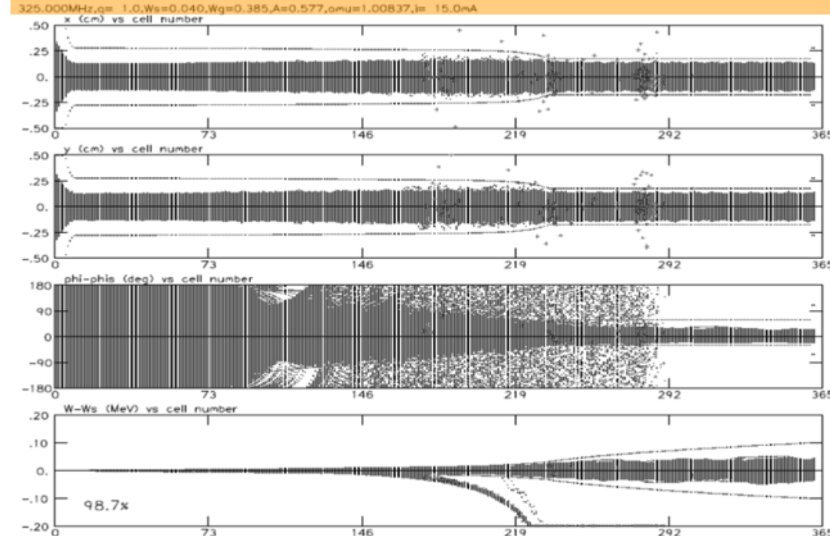


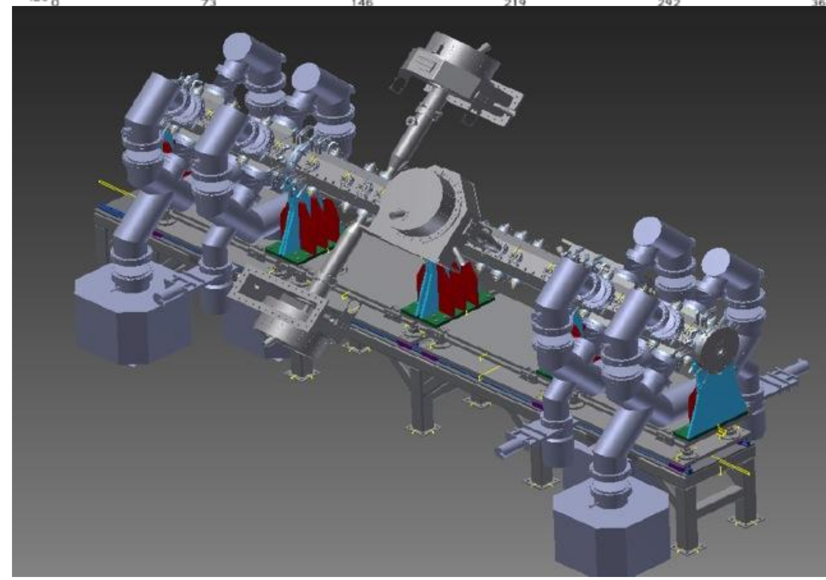
35 KeV 2.1 MeV 5 MeV 10 MeV

Accelerator System: RFQ for Injector I

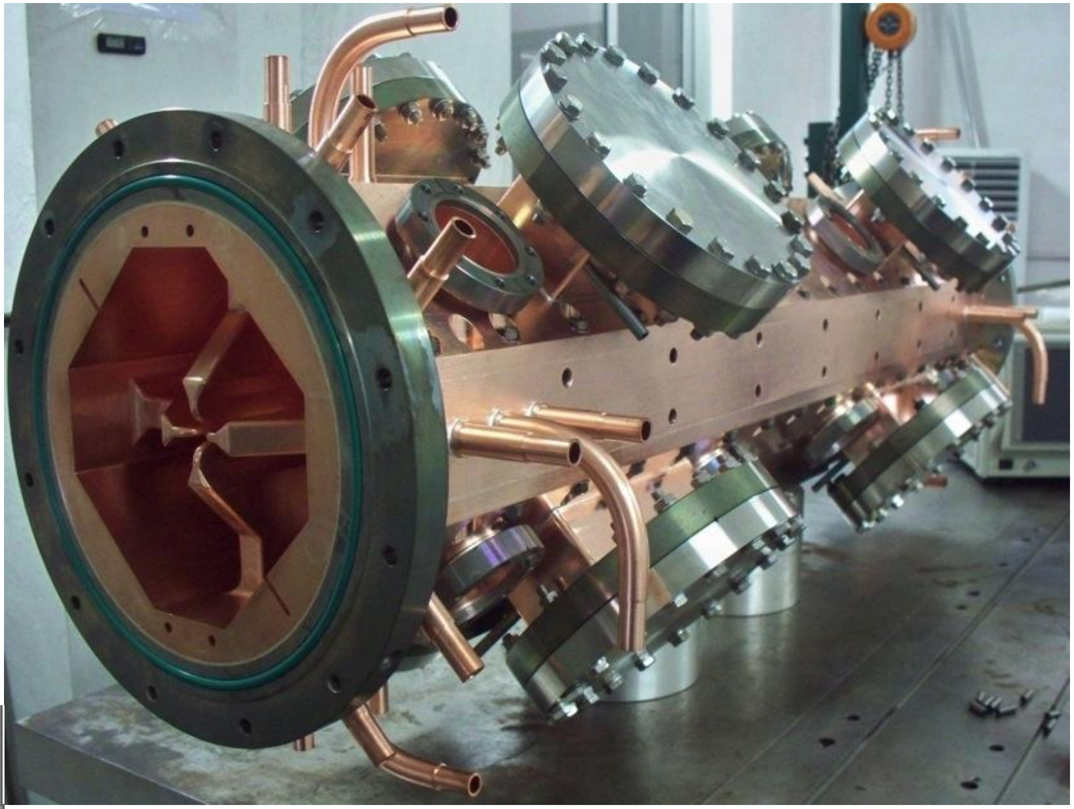
Parameters	Value
Frequency (MHz)	325
Injection energy (keV)	35
Output energy (MeV)	3.2128
Pulsed beam current (mA)	15
Beam duty factor	100%
Inter-vane voltage *V* (kV)	55
Beam transmission	98.7%
Average bore radius r_0 (mm)	2.775
Vane tip curvature (mm)	2.775
Maximum surface field (MV/m)	28.88 (1.62Kilp.)
Cavity power dissipation (kW)	272.94
Max. copper power/Area (W/cm^2)	3.77
In norm. rms e (x,y,z) (πmm.mrad)	0.2/0.2/0
Out norm. rms e (x/y/z) (πmm.mrad/MeV-deg)	0.2/0.2/0.0612
Vane length (cm)	467.75
Accelerator length (cm)	469.95

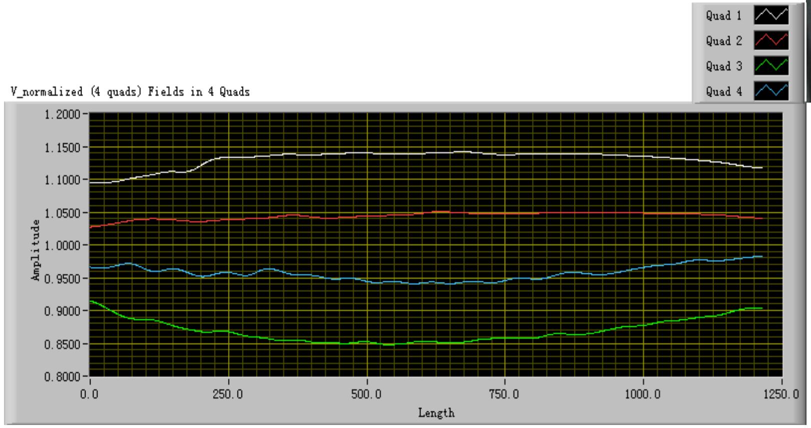
The beam transmission is about 98.7%





Progress of RFQ for Injector I (325MHz)

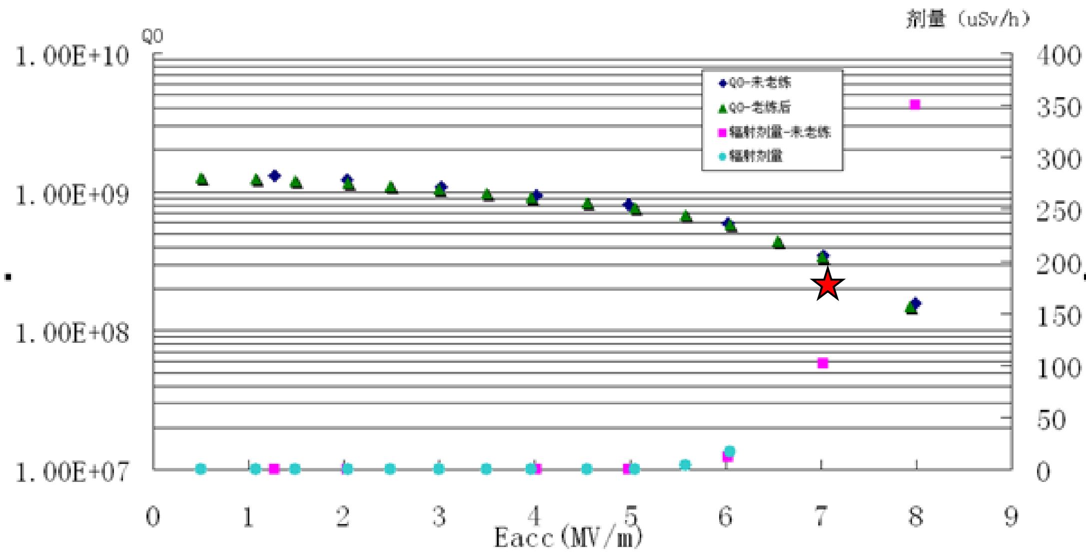




Cold test of all modules has been done.
Commissioning is also has been done.

Spoke012 for Injector I

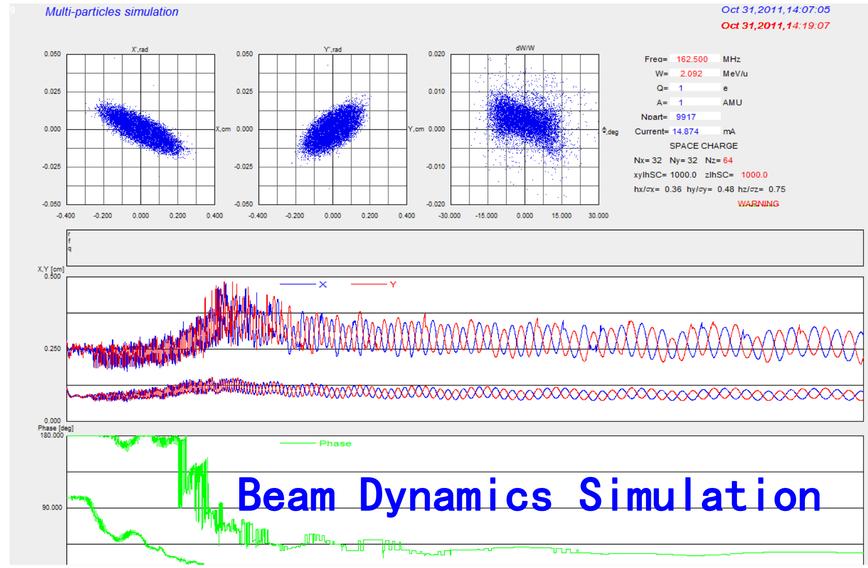
Parameters	Unit	
Freq.	MHz	325
Beta		0.12
Epeak/Eacc		4.3
Bpeak/Eacc	mT/(MV/m)	6.5
Uacc=0.78MV	MV/m	30.1
R/Q	Ω	161

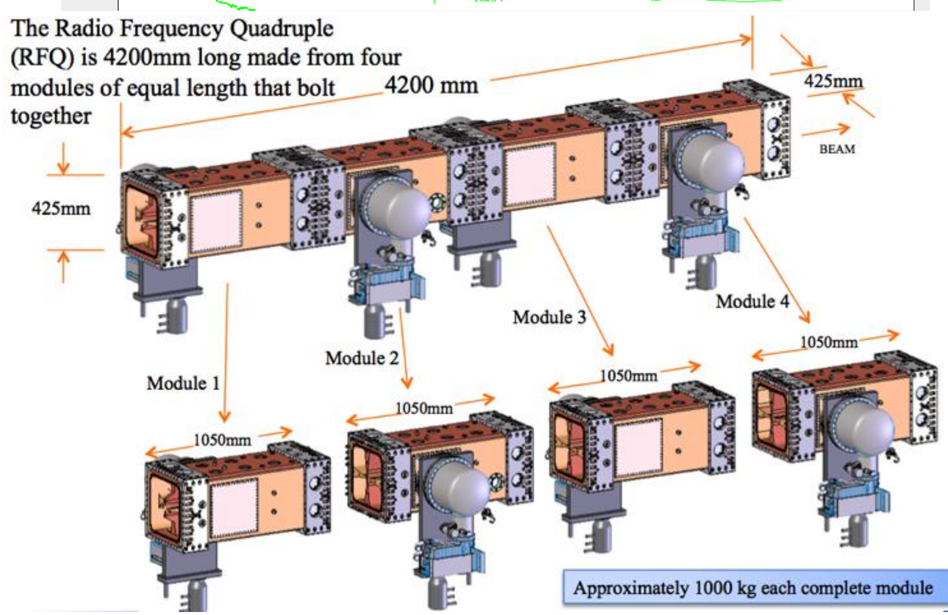


E_{acc} 8.1MV/m@$Q_0$1.5×10^8

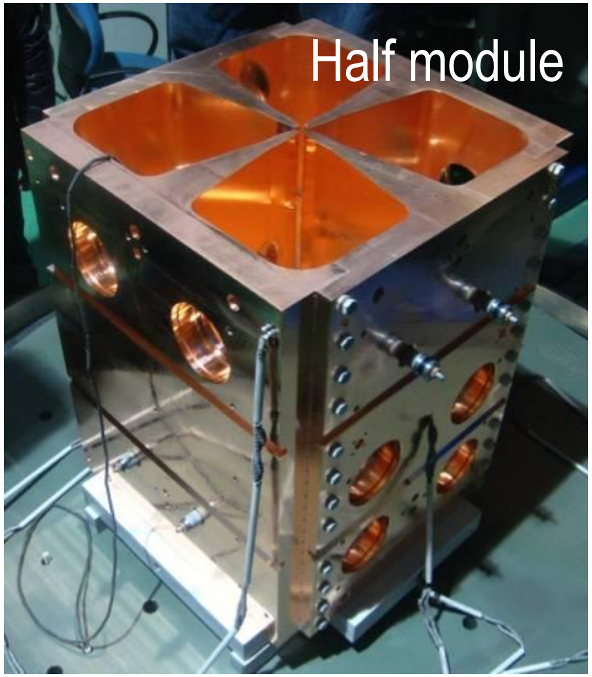
Accelerator System: RFQ for Injector II

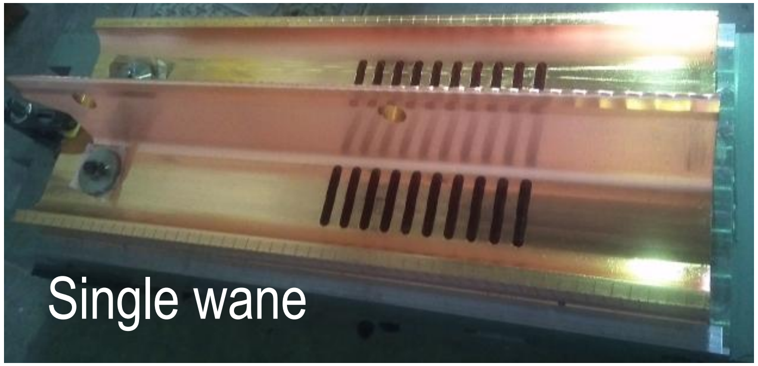
Parameter	Value
Ion species	Proton
frequency [MHz]	162.5
Inter-vane voltage V (kV)	65
Average bore radius r_0 (cm)	0.5731
Vane tip curvature (cm)	0.4298
ρ / r_0	0.75
Vane length / Total length (cm)	419.2 / 420.8
m_{max}	2.38
Number of cells	192 (including 2 T cell)
Maximum surface field (MV/m)	15.7791
Synchronous phase	From -90° to -22.7°
a_{min} (cm)	0.3158
Transverse acceptance (RMS, x/y, πmm.mrad)	0.3/0.3
Input norm. RMS emittance (x/y, πmm.mrad)	0.3/0.3
Output norm. RMS emittance (x/y/z, πmm.mrad, keV.ns)	0.31/0.31/0.92
Overall beam transmission @ 0 /15 mA	99.7% / 99.6%

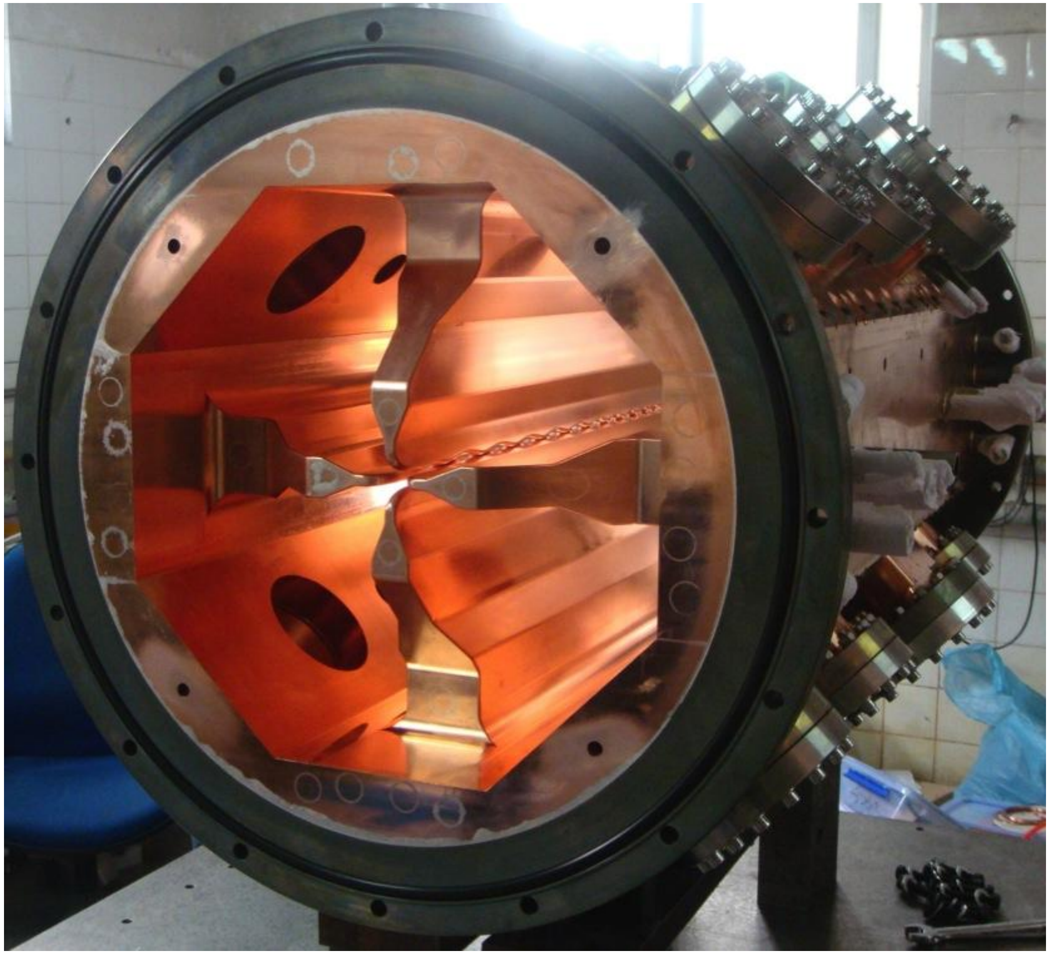




Progress of RFQ for Injector II (162.5MHz)





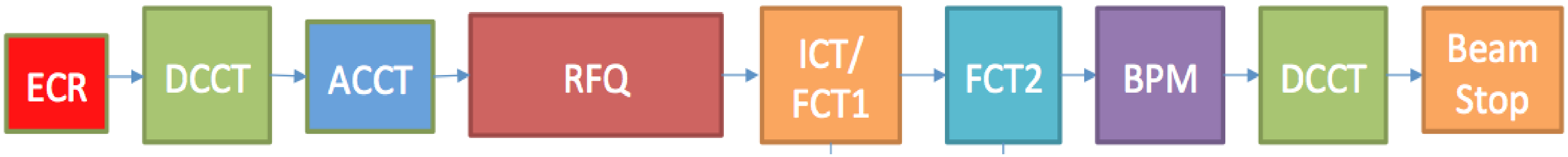


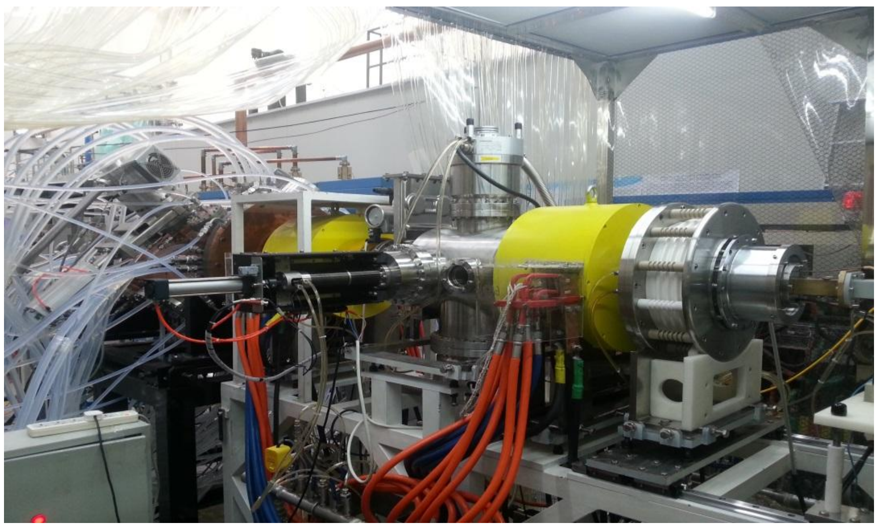
Test module is on high power testing

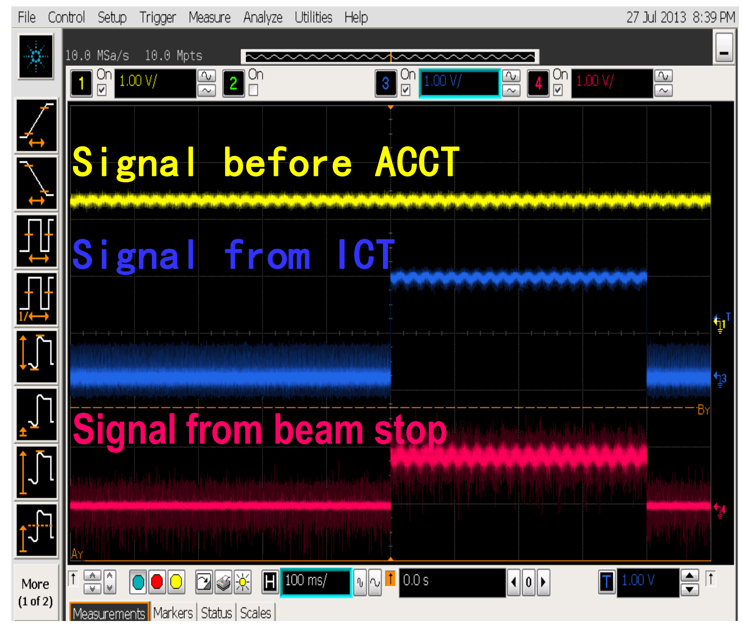
Progress of RFQ for Injector II (162.5MHz)

Commissioning with proton beam

165MHz RFQ module



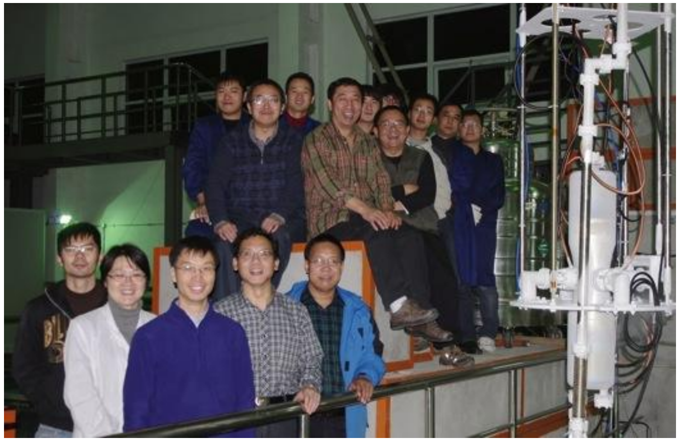




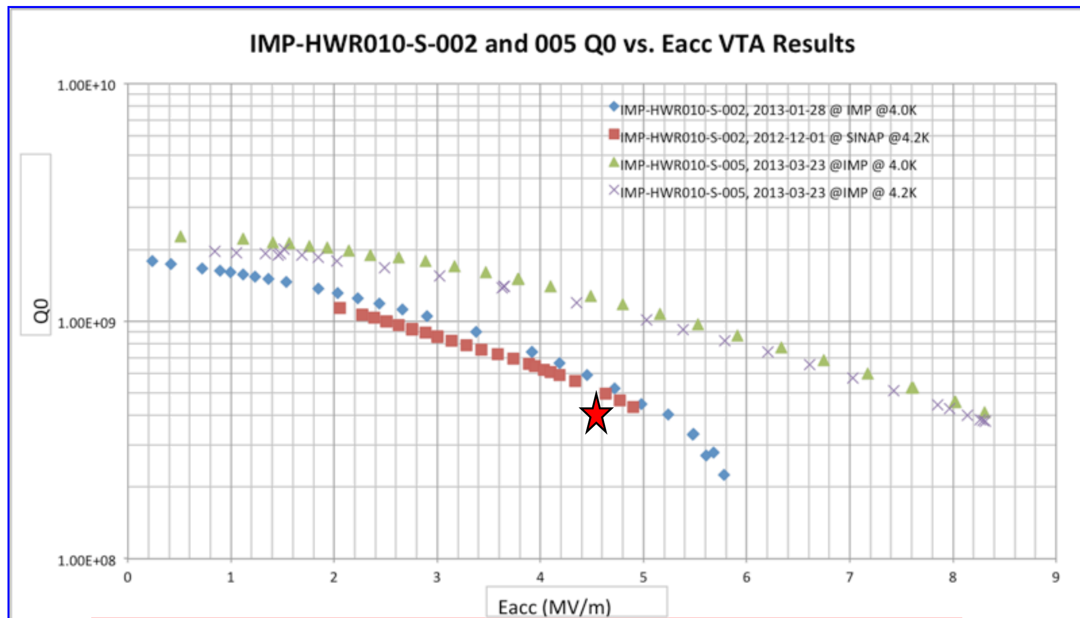
ECRIS: CW 8mA

RFQ: 560keV， Beam duty factor 80%， Transmission>70%

HWR010 for Injector II



Freq. (MHz)	162.5
βopt	0.10
Epk/Eacc	5.34
Bpk/Eacc	10.92
Q0 (@4.5K)	4.1E8
Uacc (MV)	0.78
Pdiss (W)	10



E_{acc} 8.3MV/m@$Q_0$4.1×10^8

RF Couplers Development

325MHz, Spoke
CW, 10kW
Tested

325 MHz, RFQ
CW, 100 kW
Tested

162.5MHz, HWR
CW, 20kW
Tested

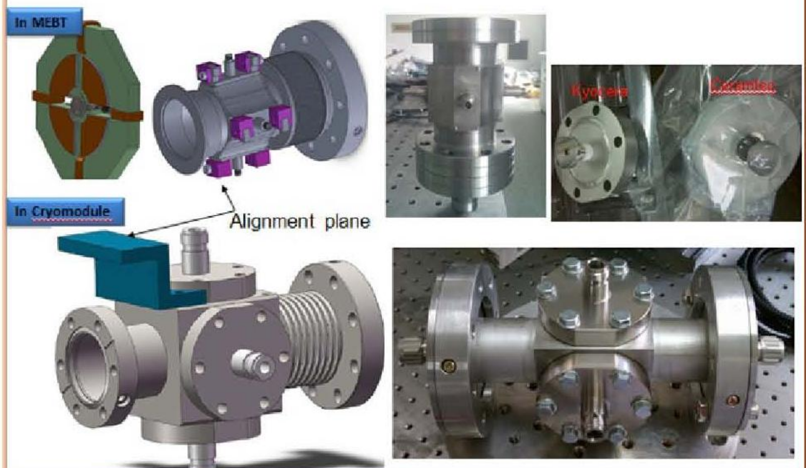
Solid State Amplifiers

Testing Item	Requirements
frequency	162.5 MHz ± 2 MHz
Freq. stability	< ±1×10-8/day
RF standard	0dBm～10dBm continuous tuning
Output Power	≥20kW（CW，Pulse）full reflection
Duty factor	1%～100% tuning
Harmonic	≤-30dBc
Harmonic of PS	≤-50dBc
Random Harmonic	≤-60dBc
Amplitude stability	≤ $\pm 1\times 10^{-2}$/24 hours
Phase stability	≤±5°/24hours, open loop
Output interface	50Ω coaxial, 4-1/2

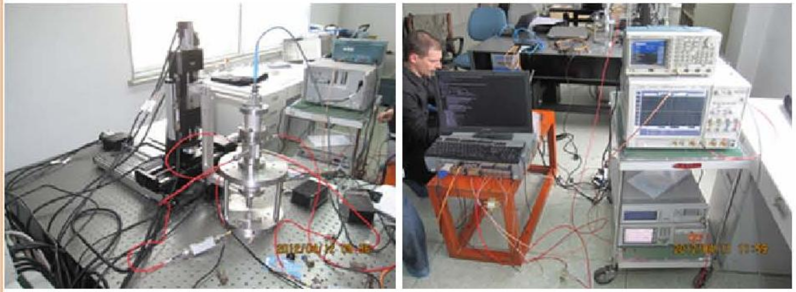
The solid state amplifiers of 162.5 MHz at 20 kW and 325 MHz at 10 kW were tested. All specifications are reached.

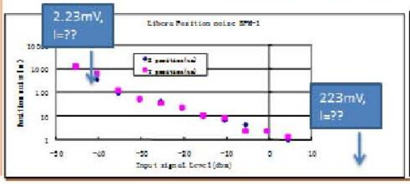
Progress of BPM Diagnostics

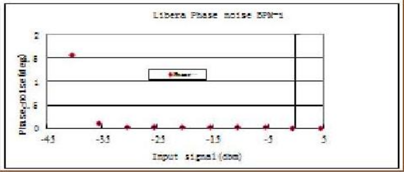
BPM Manufacturing



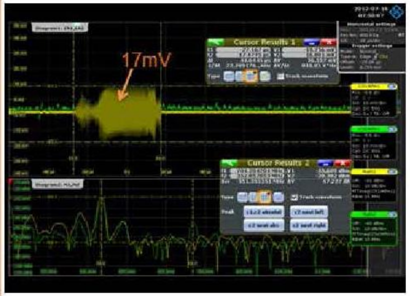
BPM electronics measurement

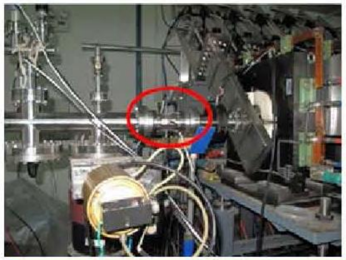






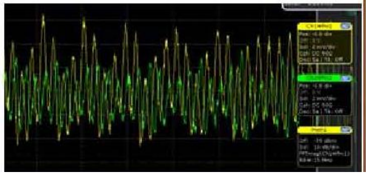
BPM beam measurement in IHEP





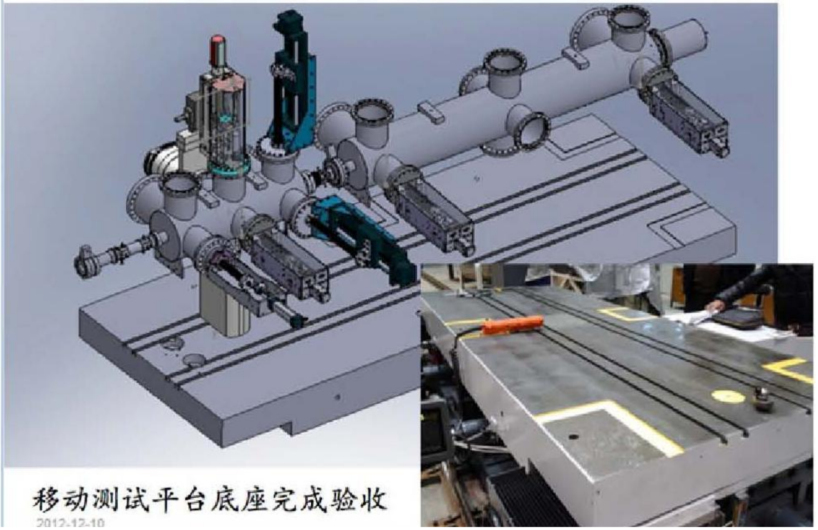
BPM's installation in MEBT of Proton LINAC in the IHEP.

Beam energy	3.5MeV
β	0.086
Bunch frequency	352.2 MHz
Average current	18 mA



2012-12-10

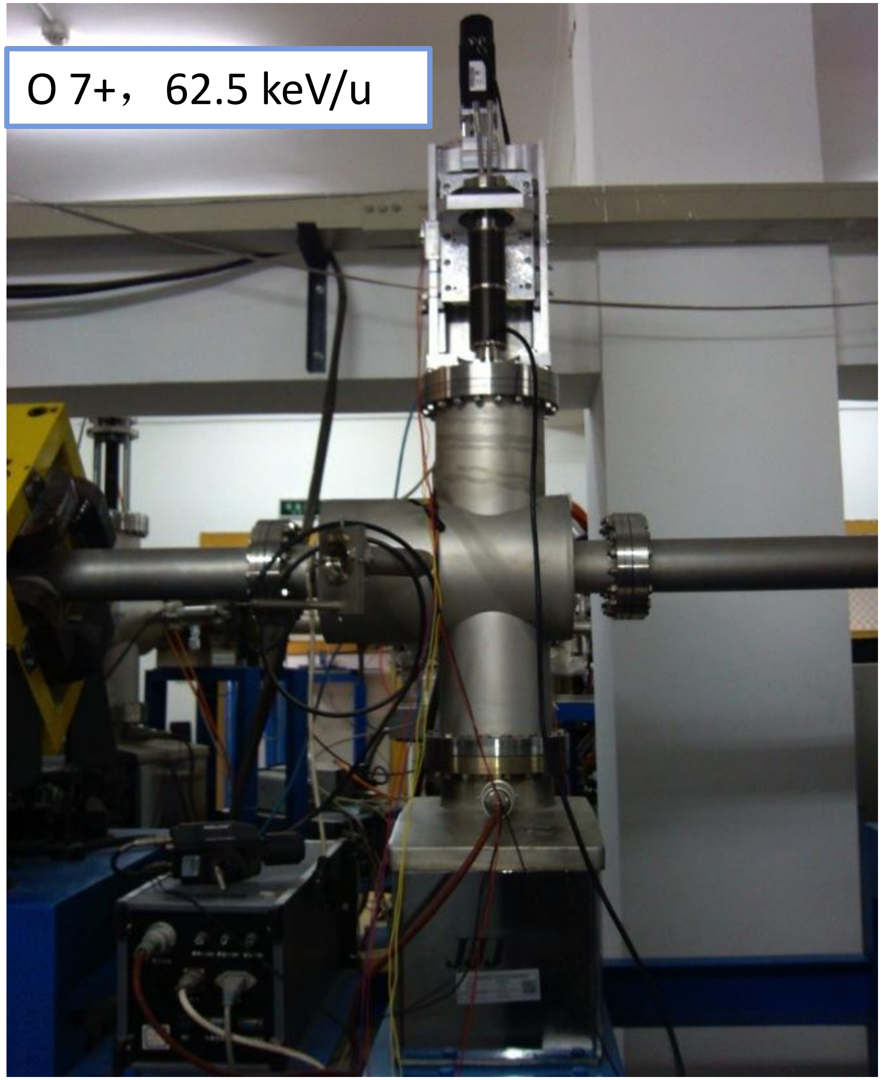
Movable test bench

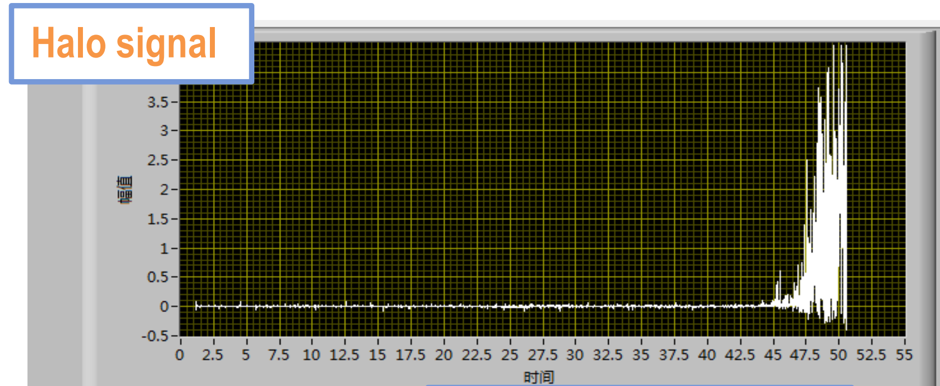


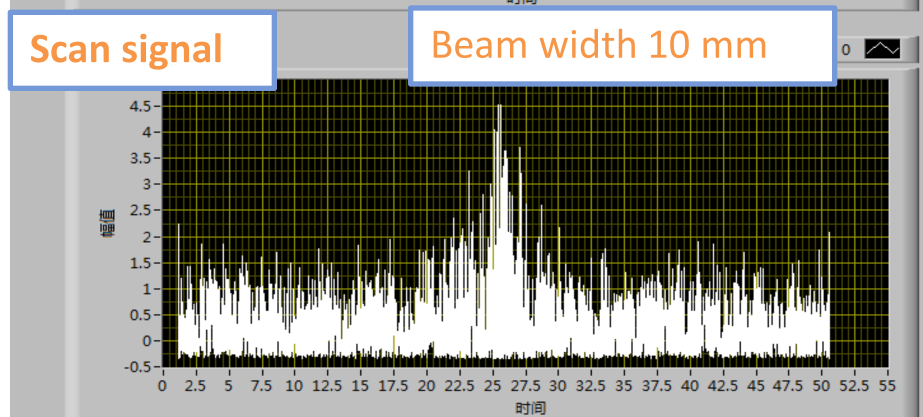
移动测试平台底座完成验收

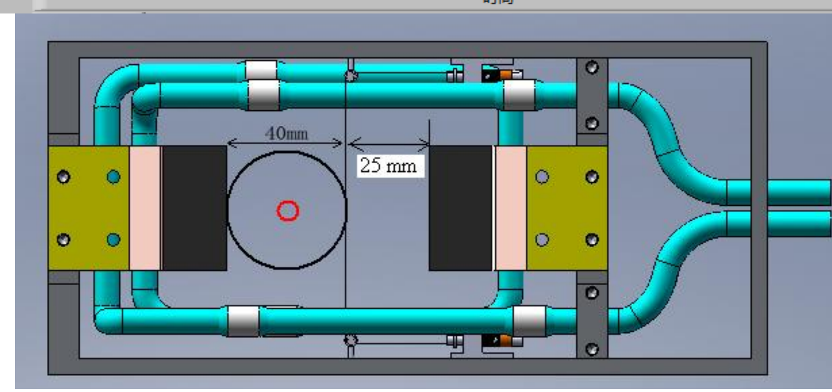
2012-12-10

Test of Single Wire Scanner





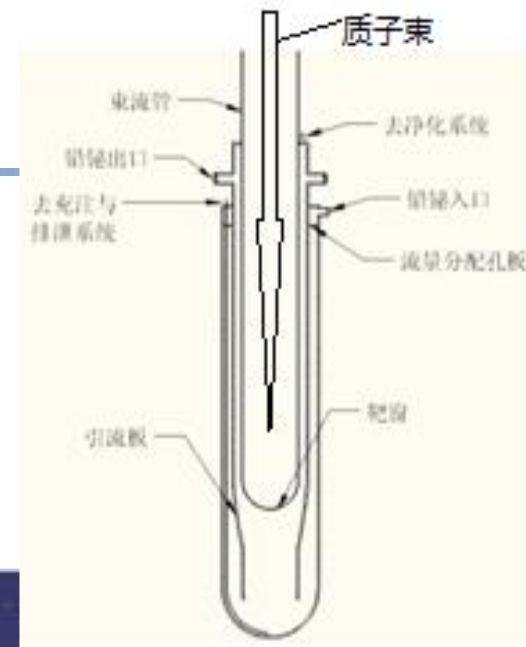


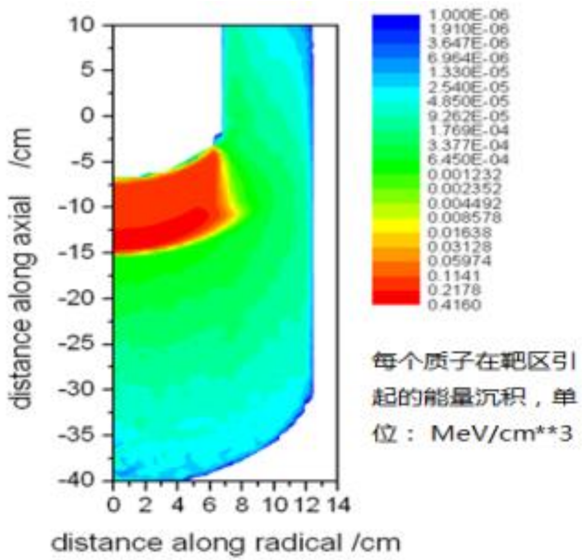


Spallation Target

LBE Spallation Target

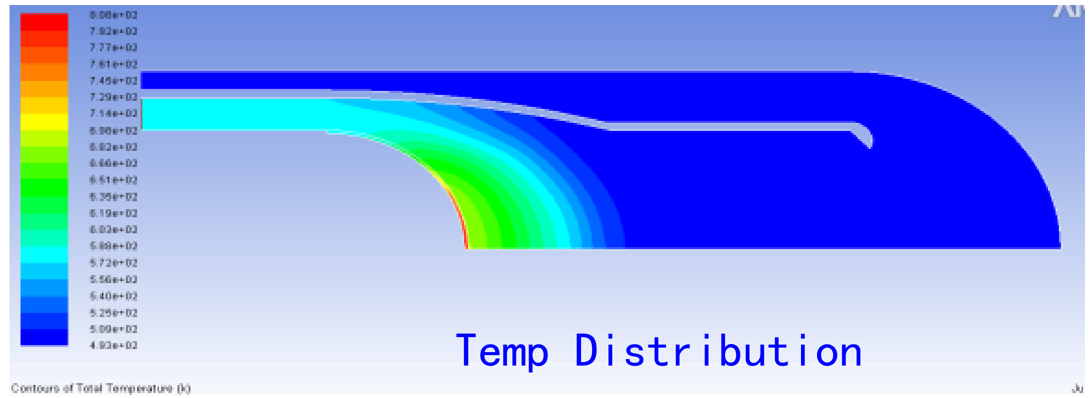
Proton Parameters	
Energy，/ MeV	**250**
Current，/mA	**10**
Physical Dimesion，/cm	
Inner Radius for Window	**7.0**
Outer Radius for Window	**7.3**
Inner Radius for Bottom	**12.0**
Outer Radius for Bottom	**12.3**
Inner Radius for P-Tube	**7.0**
Outer Radius for P-Tube	**7.3**
Effective Hight	**32.3**
Material	
Coolant Material	**LBE**
Structure Material	**T91**

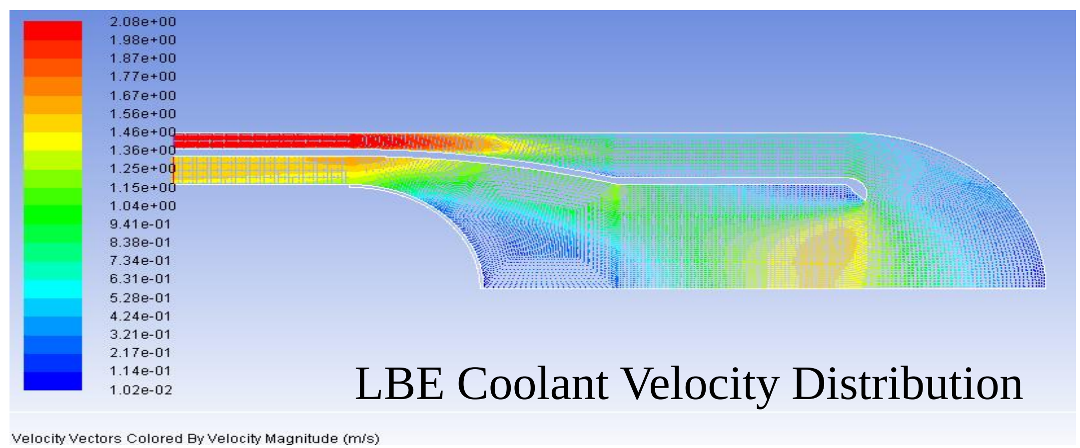




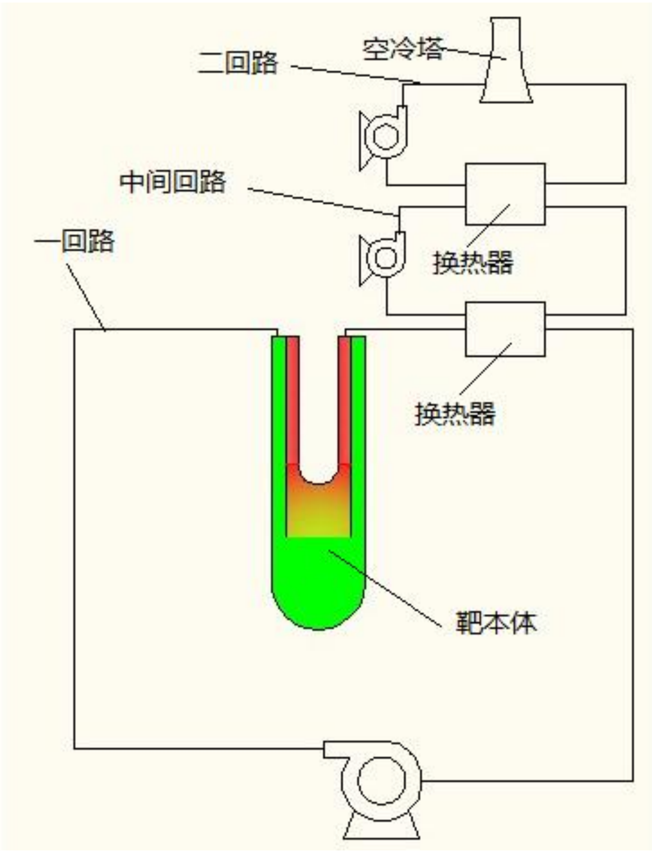
Deposition Energy Distribution

Power	**2.5MW**
Average Power Density for Window	**947.9W/ cm^3**
Highest Power Density for Window	**2099.9 W/cm^3**
Target Region Power Density	**1899.9 W/cm^3**
Target Region Power Density	**5019.9 W/cm^3**
Neutron Flux for Window	**6.2E+14 n/cm^2*s**





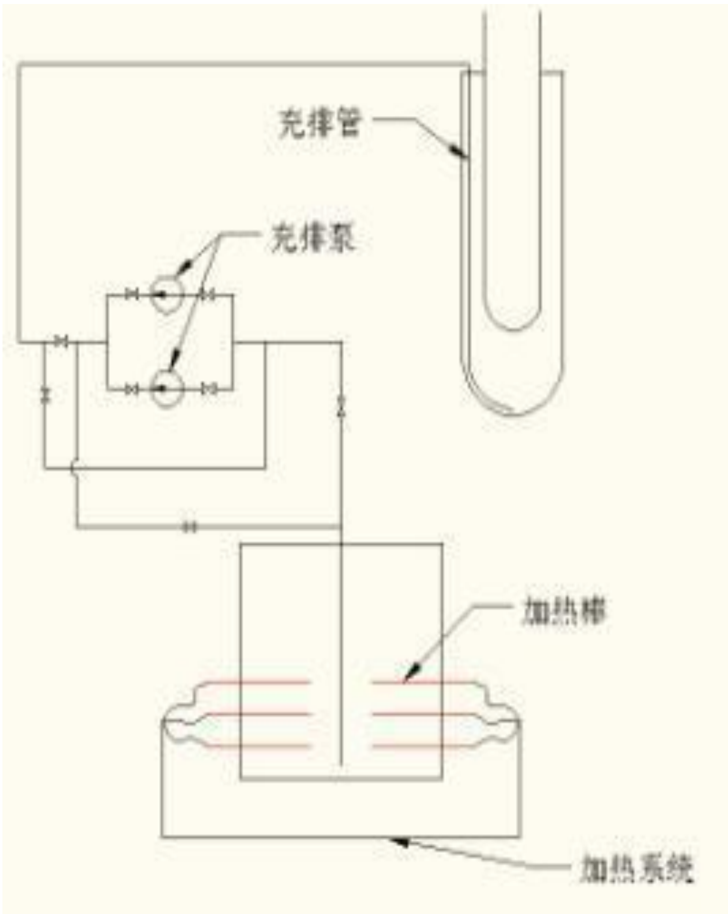
LBE Heat Exchange System



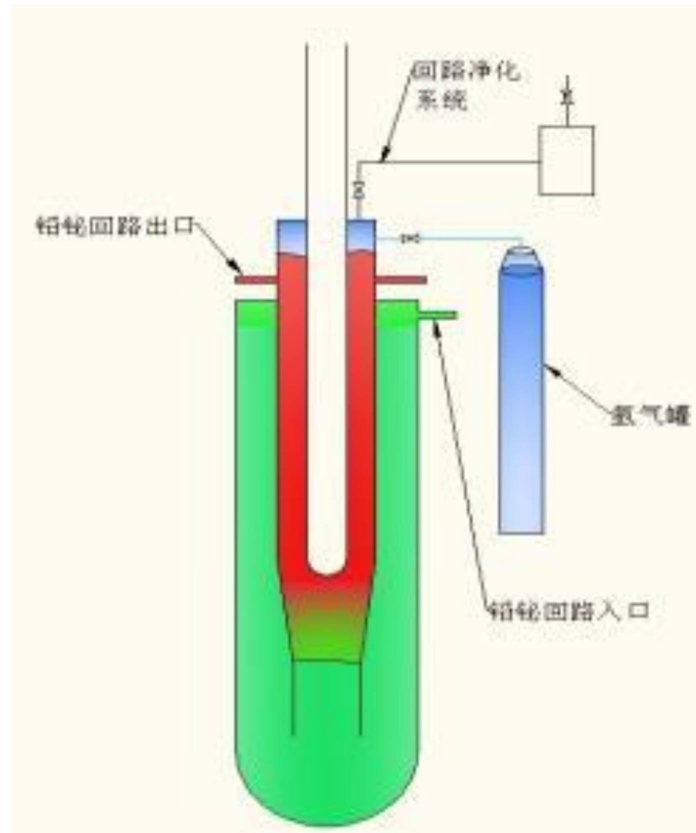
Heat Transfer Diagram

Primary	Coolant	LBE
	Mass Flow Rate（kg/s）	171
	In/Outlet Temp（^{0}C）	302.39/220
Secondary	Coolant	Oil
	Mass Flow Rate（kg/s）	54.34
	In/Outlet Temp（^{0}C）	130/153

Auxiliary System



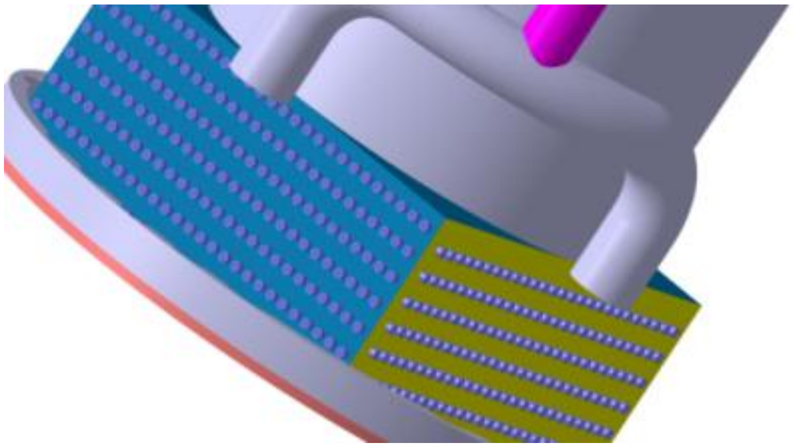
LBE Charge & Discharge System



LBE Purification System

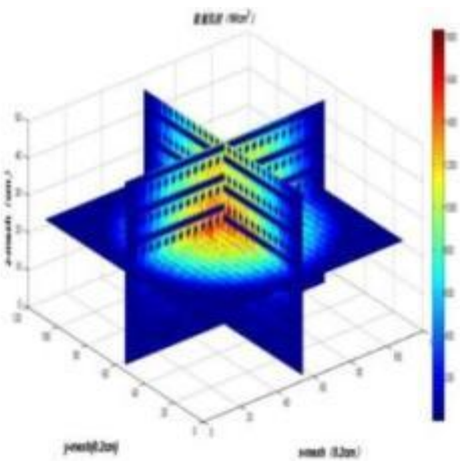
Gas-Cooled Spallation Target

Target structure schematic diagram

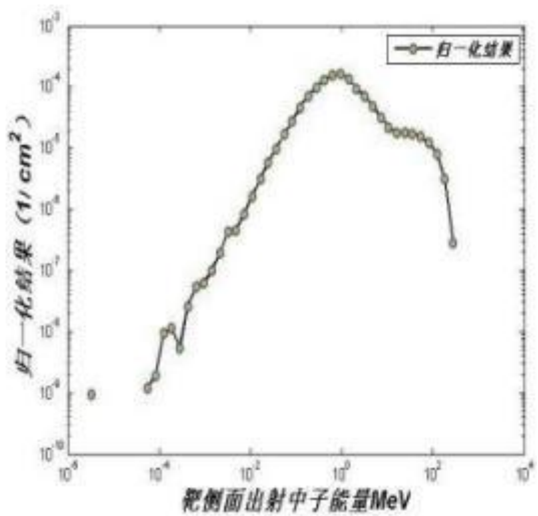


- Tungsten target, length 22cm, width 22cm, height 10cm.
- Helium channel inner diameter 5mm.
- The punching shown in figure, square grid arrangement, 8mm pitch.

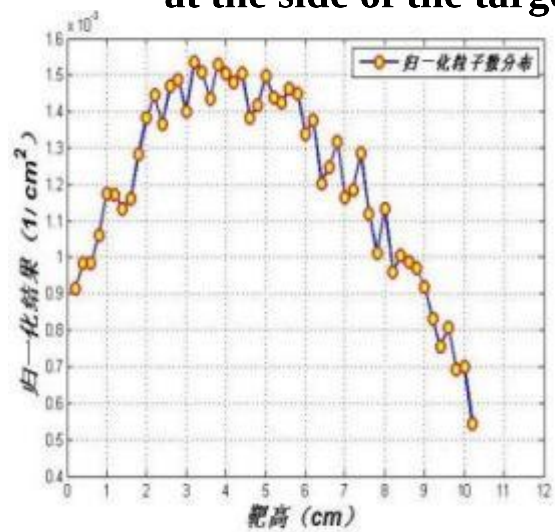
proton energy deposition



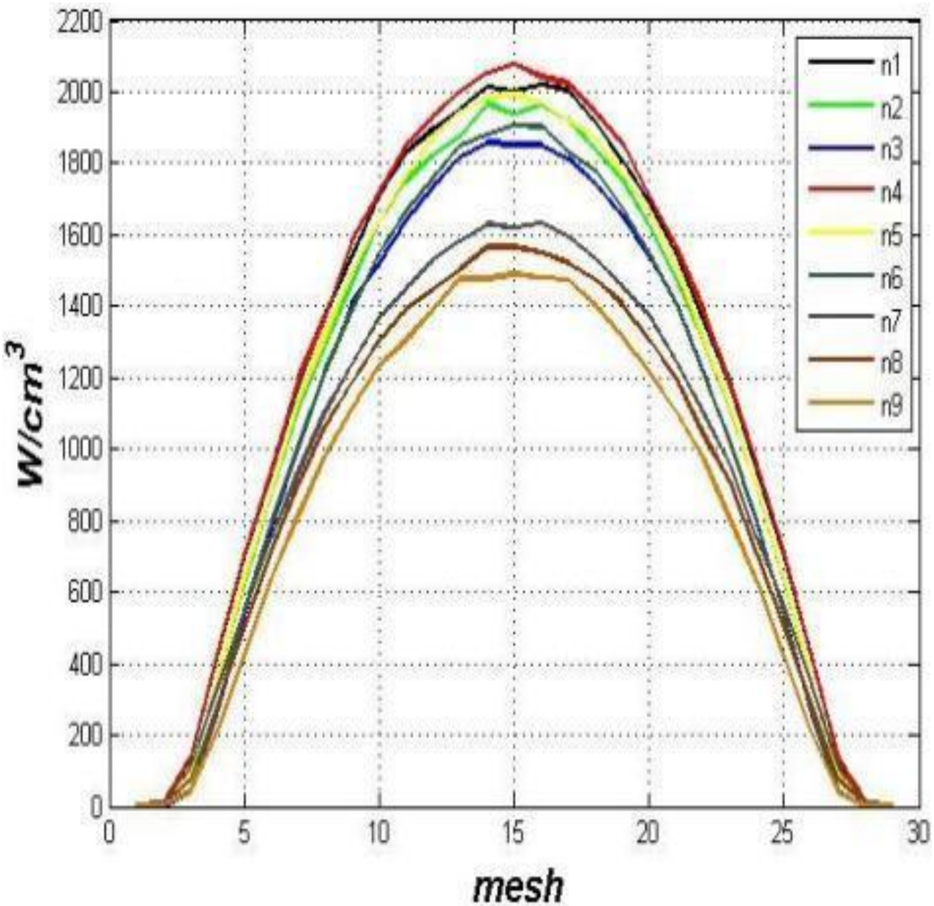
neutron leakage spectrum



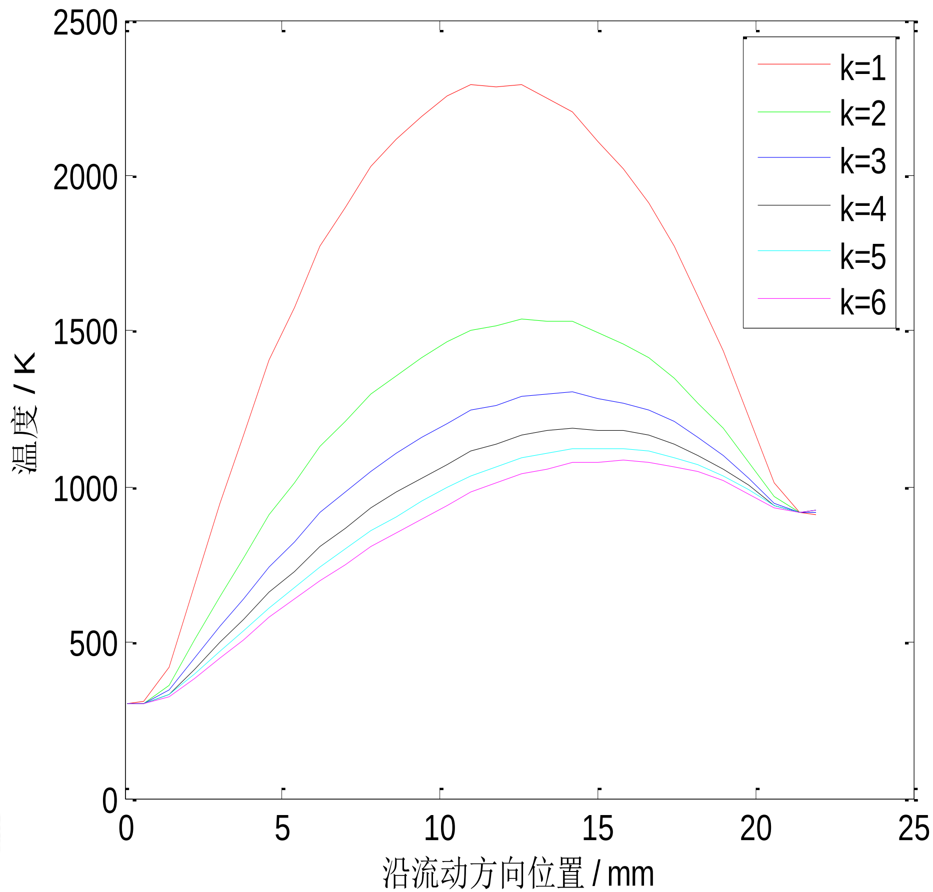
neutron leakage distribution at the side of the target



Pressure：4 MPa; Temperature:300 K; Coolant Inlet Velocity：30m/s

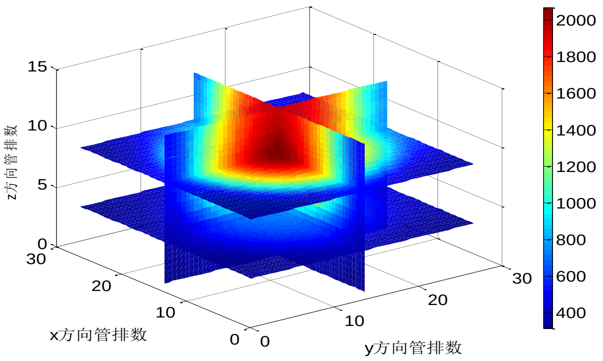


Analysis for the hottest channel 4

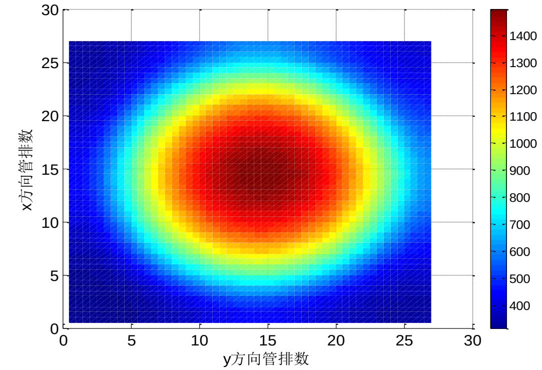


K=1 None forced heat transfer Tmax=2200.4k

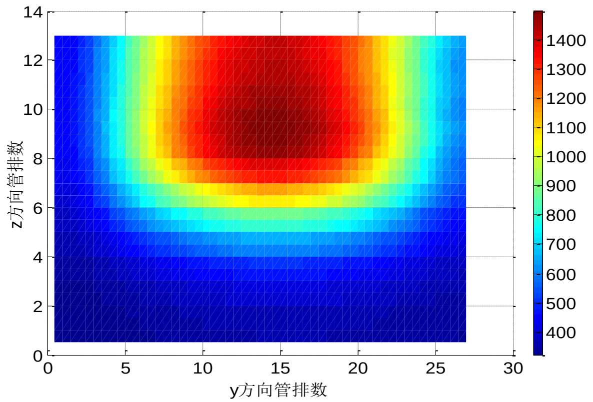
K=2 Double …



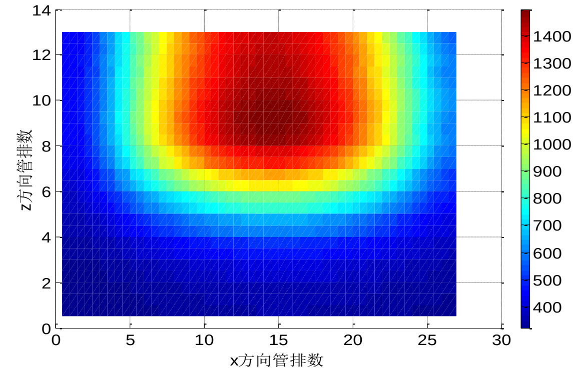
Overview



Z Direction



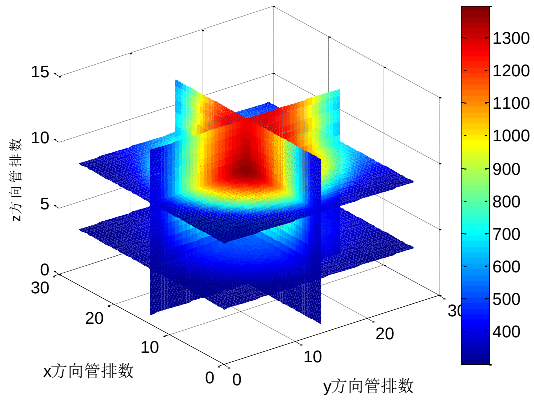
X Direction



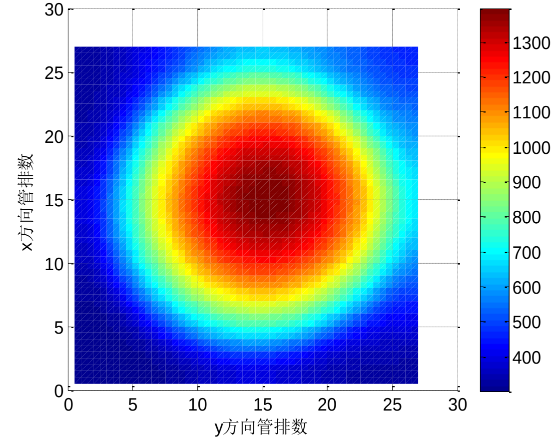
Y Direction

Pressure: 4 Mpa; Inlet Velocity of He: 30 m/s

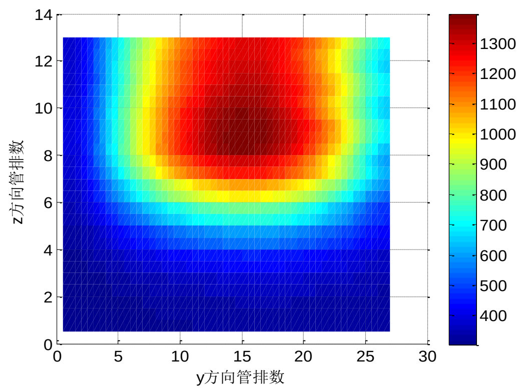
- **The highest temp of spallation target wall is 2083.9 K， reducing 116.5 K comparing to single model。**



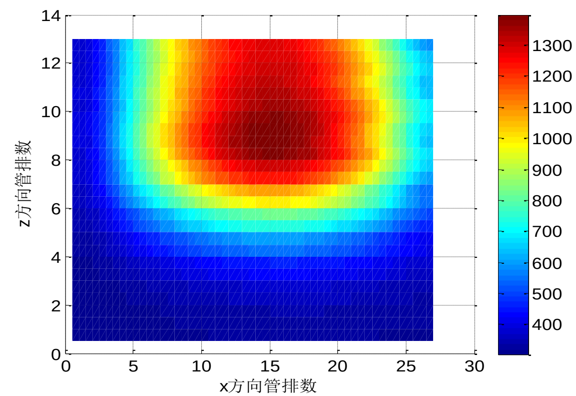
Temp Overview



Z Direction



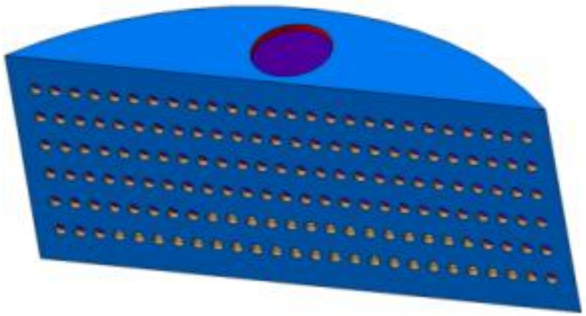
X Direction

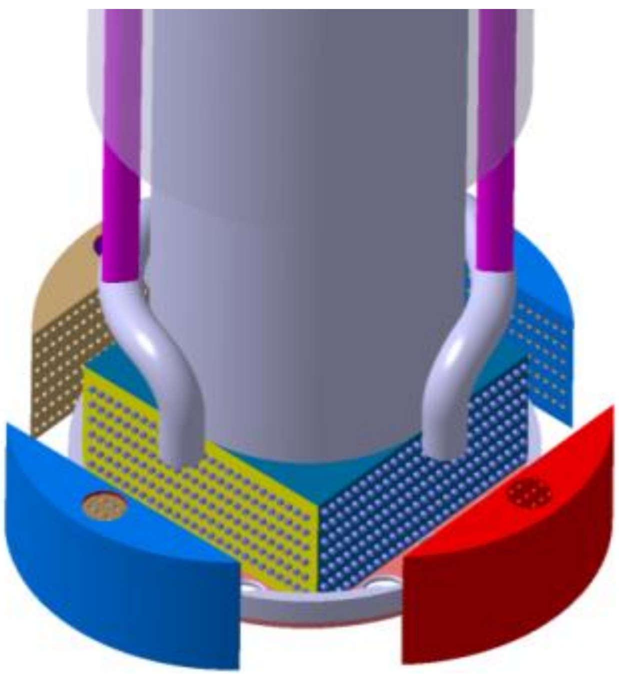


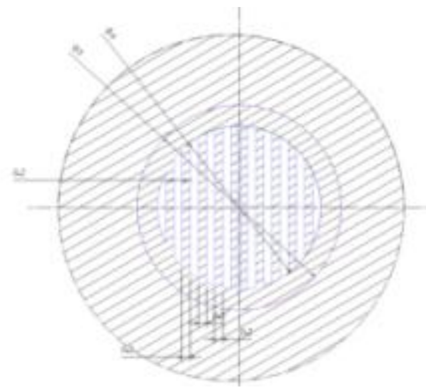
Y Direction

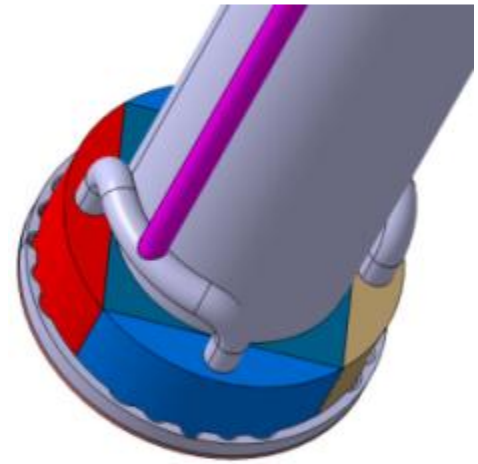
Pressure: 4 Mpa; Inlet Velocity of He: 30 m/s, Forced Heat Transfer Coefficient K=2

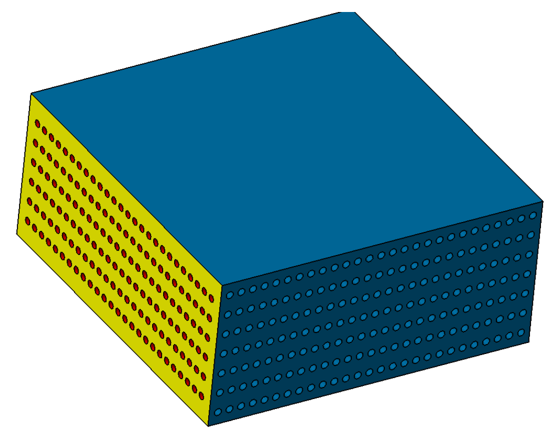
- **The highest temp of spallation target wall is 1397.2 K, reducing 686.7 K comparing to single model。**

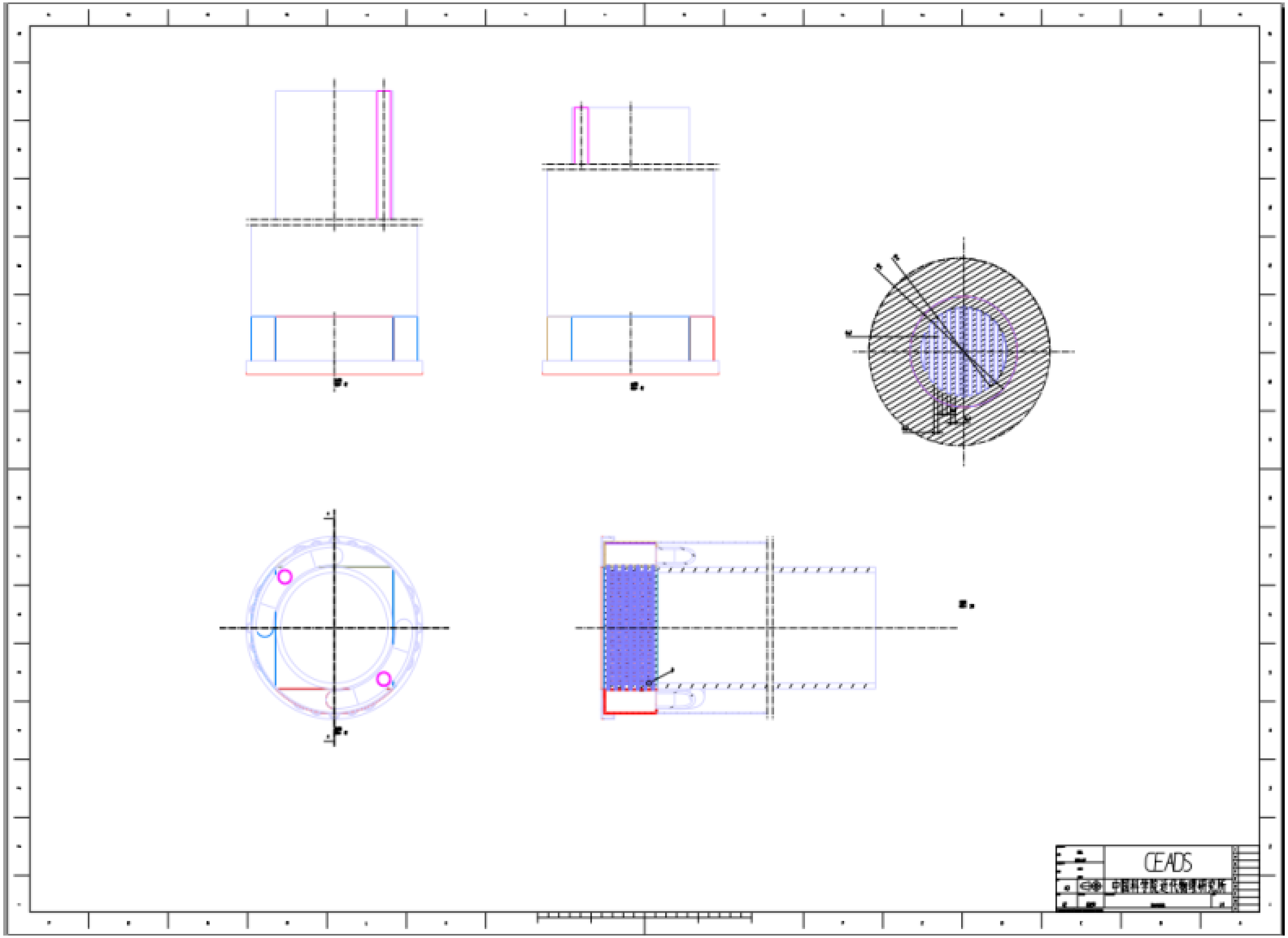








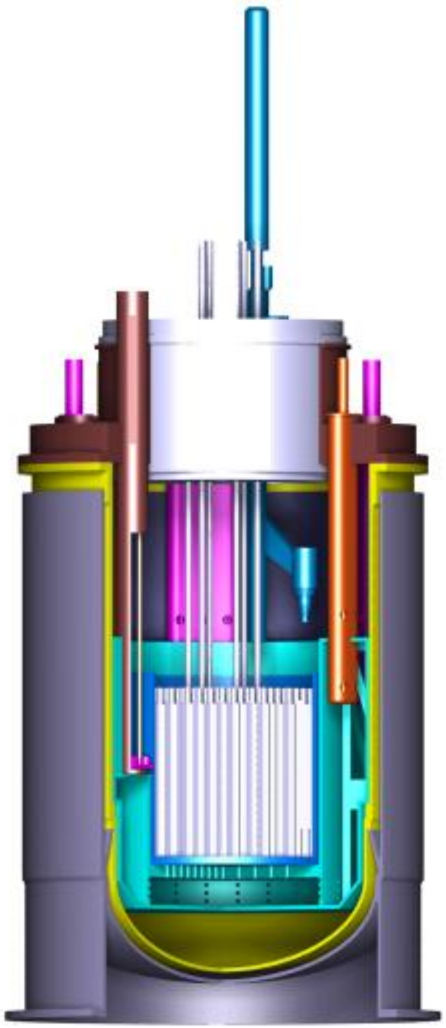



CEADS
中国科学院近代物理研究所

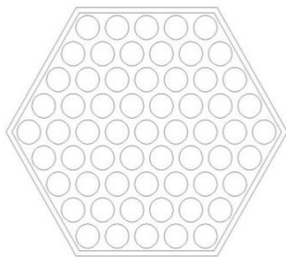
Sub-Critical Reactor

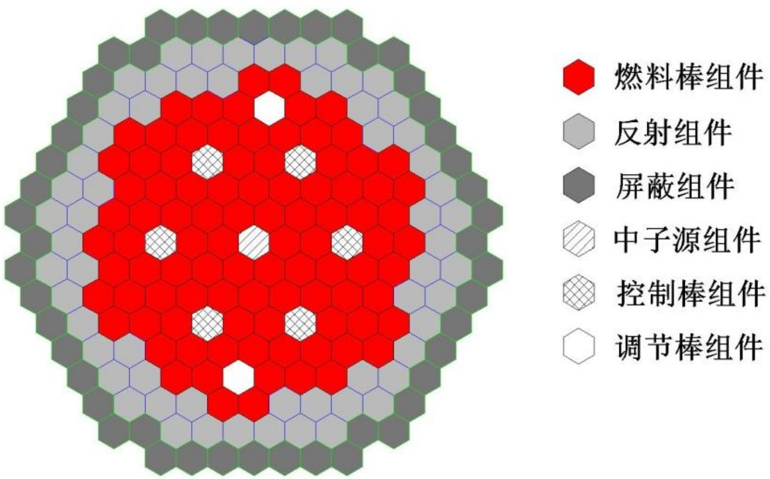
LBE Coolant Reactor

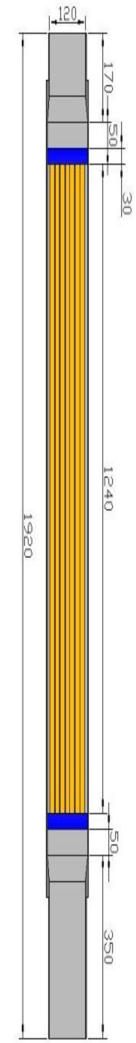
项目		参数
Type		Pool Type
Power		10MW
Reactor Core	Active Height	800mm
	Active Diameter	1,543mm
	Fuel	UO_2 (19.75%)
	燃料包壳	316Ti
	^{235}U	889kg
	Average Power	21.23W/cm
	Power Peak Factor	1.96
	Neutron Flux	7.93×10^{13}n/cm^2 s
Structure Material		316L
Outer Diameter of Main Vessel		4,420mm
Height of Main Vessel		6,300mm
Mass of LBE Coolant		~700t

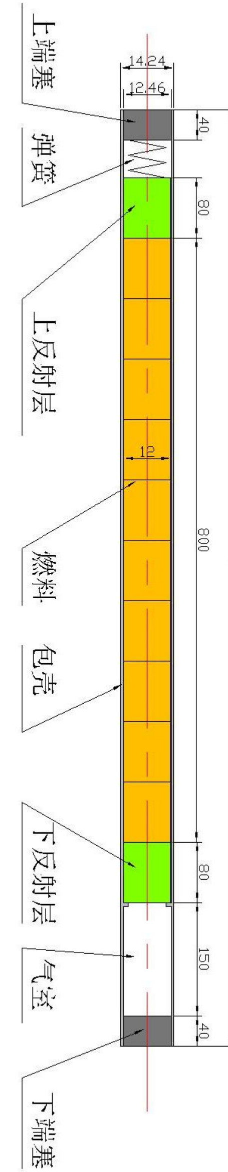


Nuclear Fuel Design



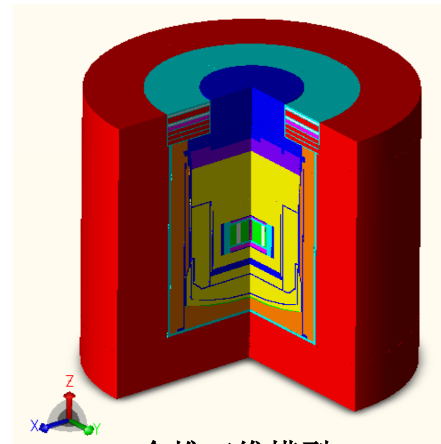




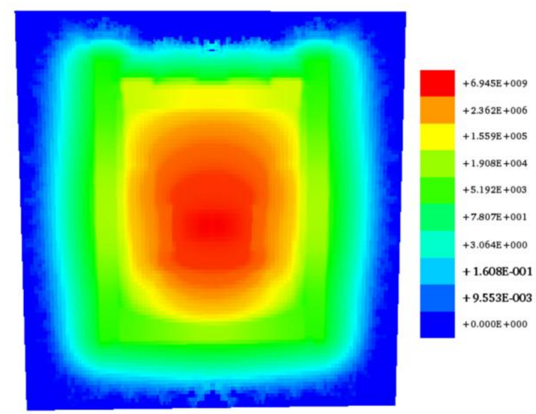


Neutronics

参数	结果
Initial Excess Reactivity	0.02056
Shutdown Margin/pcm	12022
Initial Neutron Flux/n/cm^2 s	7.93E+13
Power Peak	1.96
Fuel Mass /tHM	4.50
^{235}U /t	0.889
Active Diameter/m	1.543
Active Height/m	0.80
Doppler Coefficient/pcm/K	-5.078
Temp Coefficient/pcm/K	-46.52



全堆三维模型

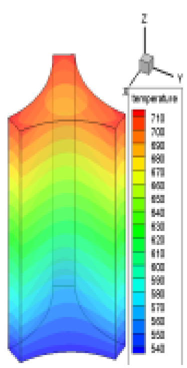


中子剂量场分布

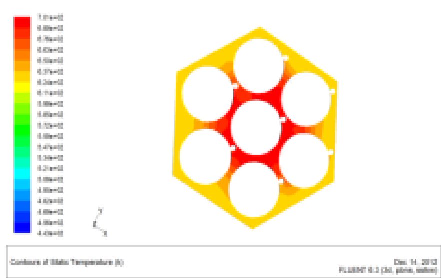
T-H Design

- Large Diameter
- Large Pitch

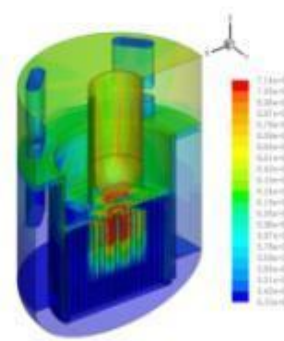
名称	参数
T-Power（MW）	10
Average Power Density for Pin（kW/m）	3.9
Inlet/Outlet Temp（℃）	260/390
Circulation Height（m）	2
Coolant Average Flow Rate（m/s）	0.17
Mass Flow Rate（kg/s）	529.5
Highest Temp for Fuel Cladding(℃)	462
Highest Temp for Fuel (℃)	660



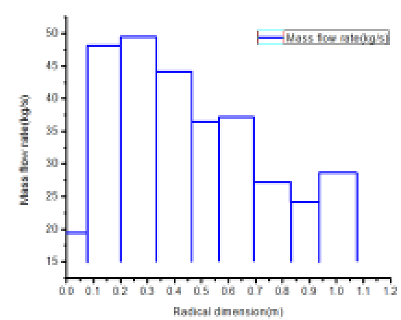
CFD for Coolant Channel



CFD for Bundle



CFD for Natural Convenient



Coolant Distribution

T-H Design

项目		设计方案
Primary Coolant System	Coolant	LBE
	Drive Mode	Natural Convection
	Operation Temp	280/393℃
	Auxiliary Heater	200kW
Secondary Circuit	Coolant	2MPa Water
	Drive Mode	Mechanical Pump
	Operation Temp	190℃ /204℃
Third Circuit	Coolant	Water
	Drive Mode	Mechanical Pump
	Operation Temp	28/35℃
	Hot Trap	Air Cooling Tower
Decay Removal System	Coolant	LBE
	Drive Mode	Natural Convenient
	Operation Temp	~279/357℃ （Normal Operation） ~182/192℃ （Shut-down Mode）
	Hot Trap	Air Cooling Tower

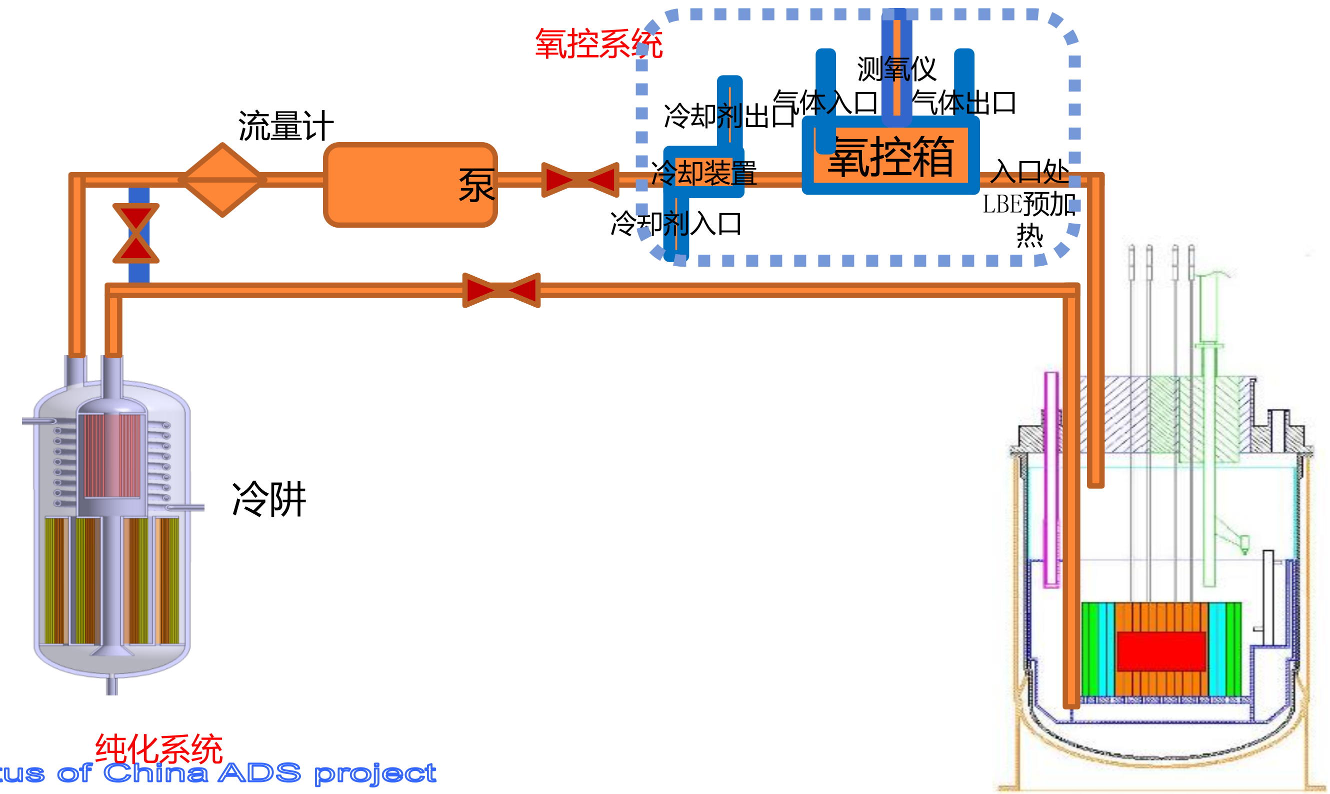
LBE Process System

❖ Purification System

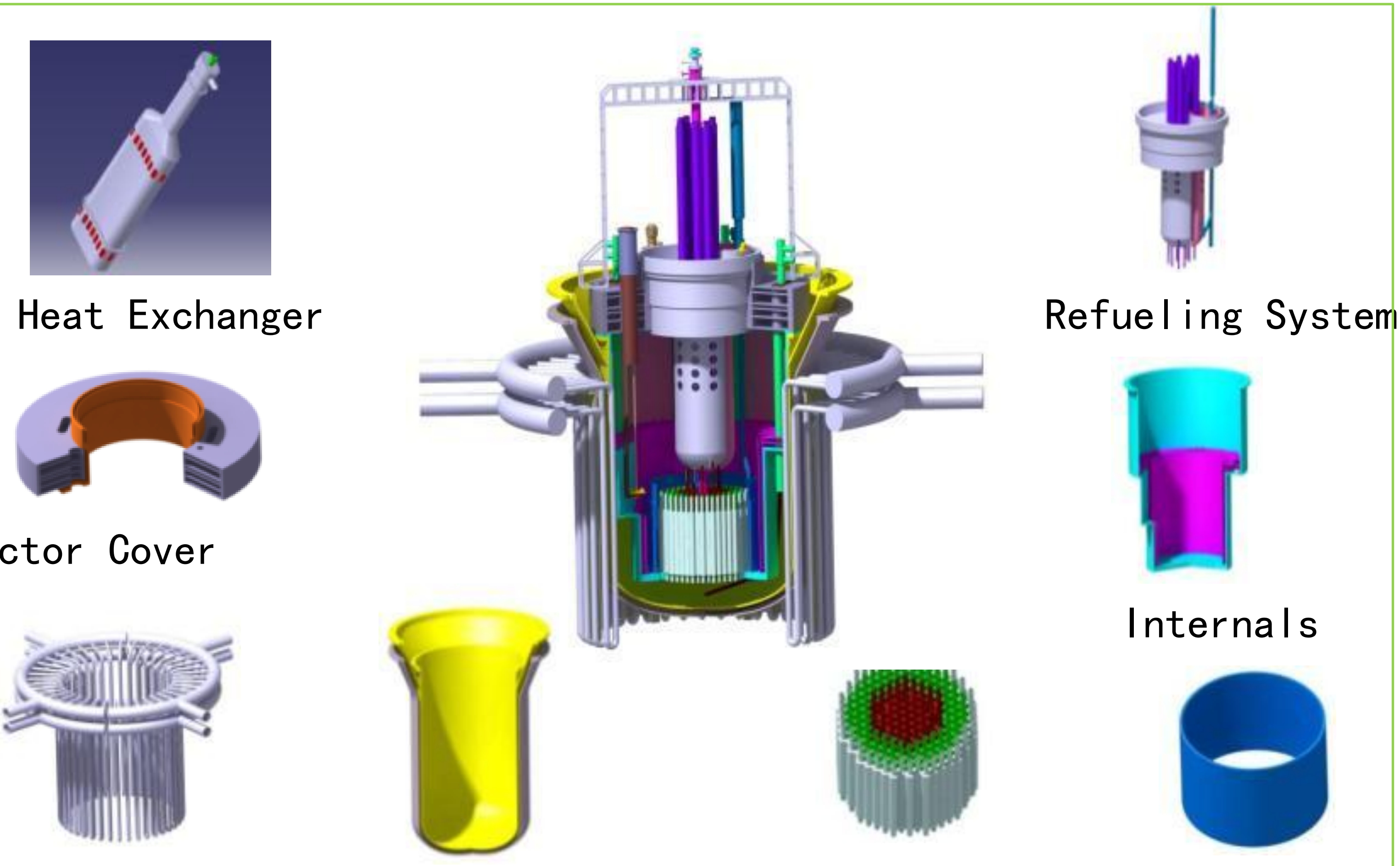
- Temp of Cold Trap 200℃
- Volume of Cold Trap=1~2% Reactor Core

❖ Oxygen Control System

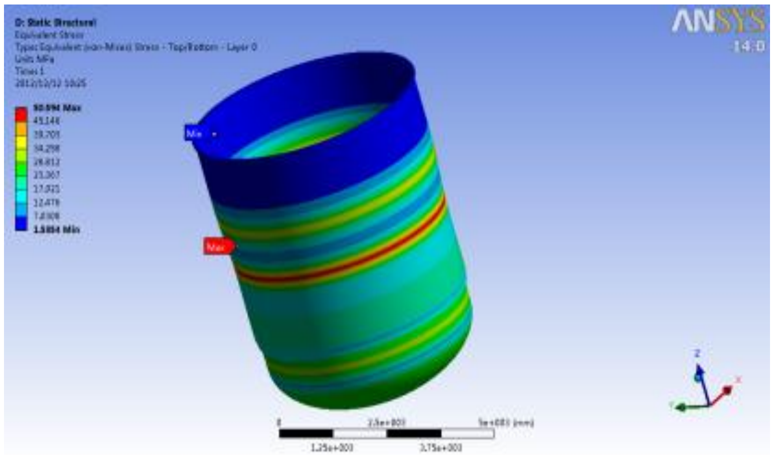
- Oxygen Control Box Heated to 550℃
- Top level in the system



Main Coolant System for LBE Reactor



Reactor Noumenon



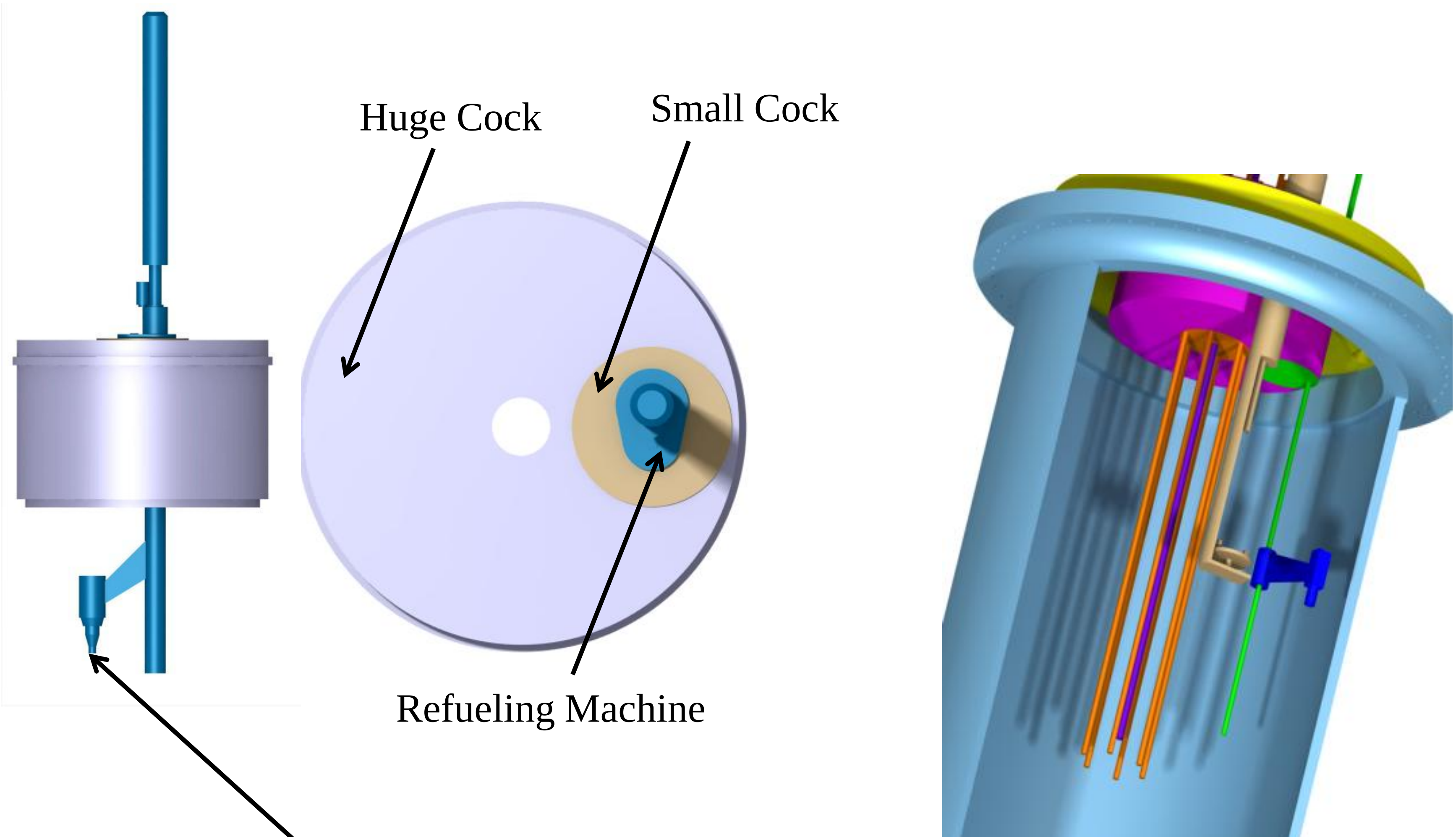
参数名称	单位	设计值
Main Vessel		
Outer Radius	m	4.38
Height	m	6.4
Safety Vessel		
Outer Radius	m	4.72
Height	m	7.22
Reactor Vessel Cover		
Outer Radius of Reactor Cover	m	4.4
inner Radius of Reactor Cover	m	2.88

- Main Vessel + Safety Vessel

•Double Pool Design;

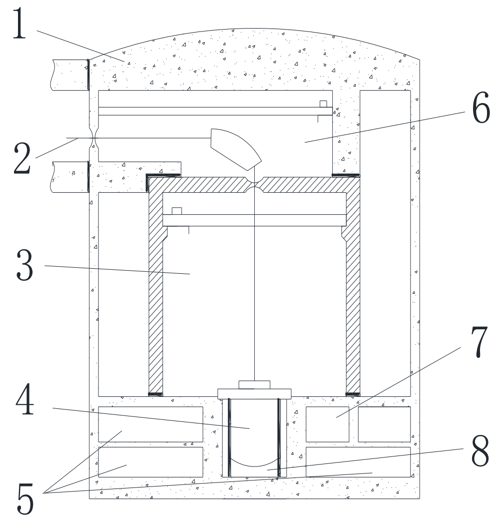
•Higher Inertia;

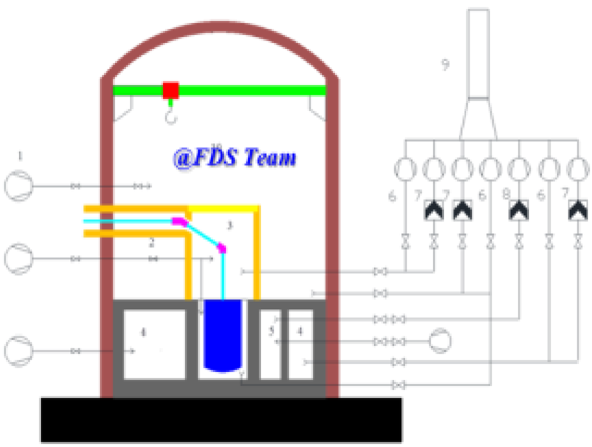
Double Plug Cocks Refueling System

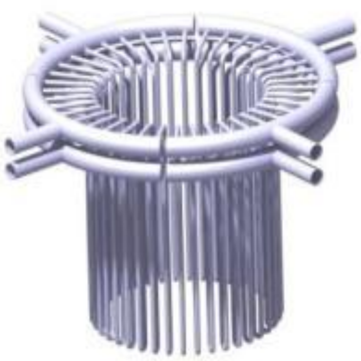


Engineered Safety System

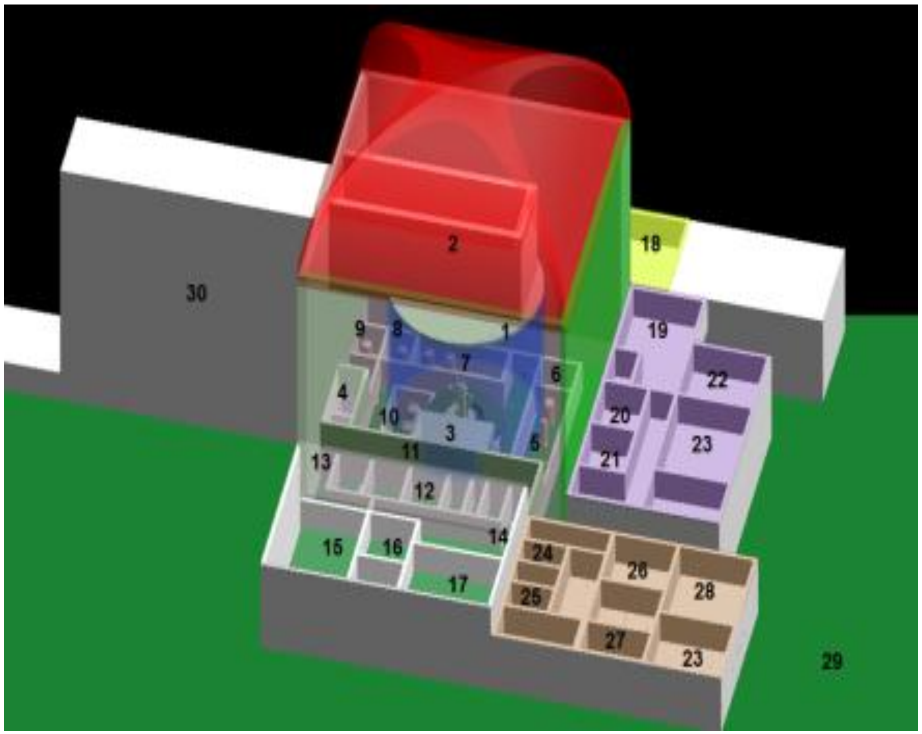
- Containment System
- Accident Heat Removal System
- Reactor Vessel Overpressure Protection System
- Safety Vessel

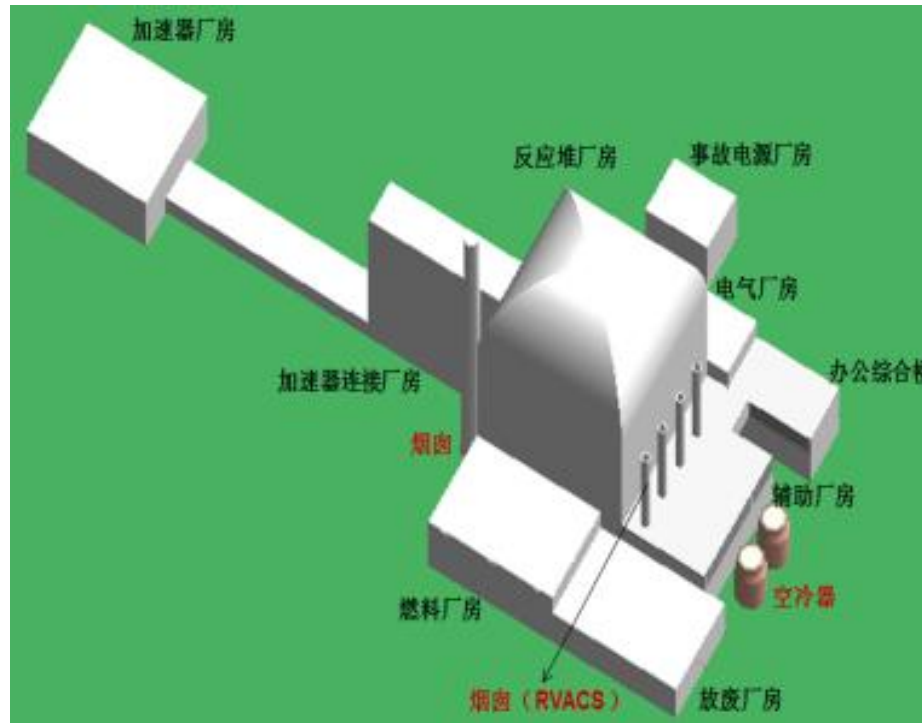






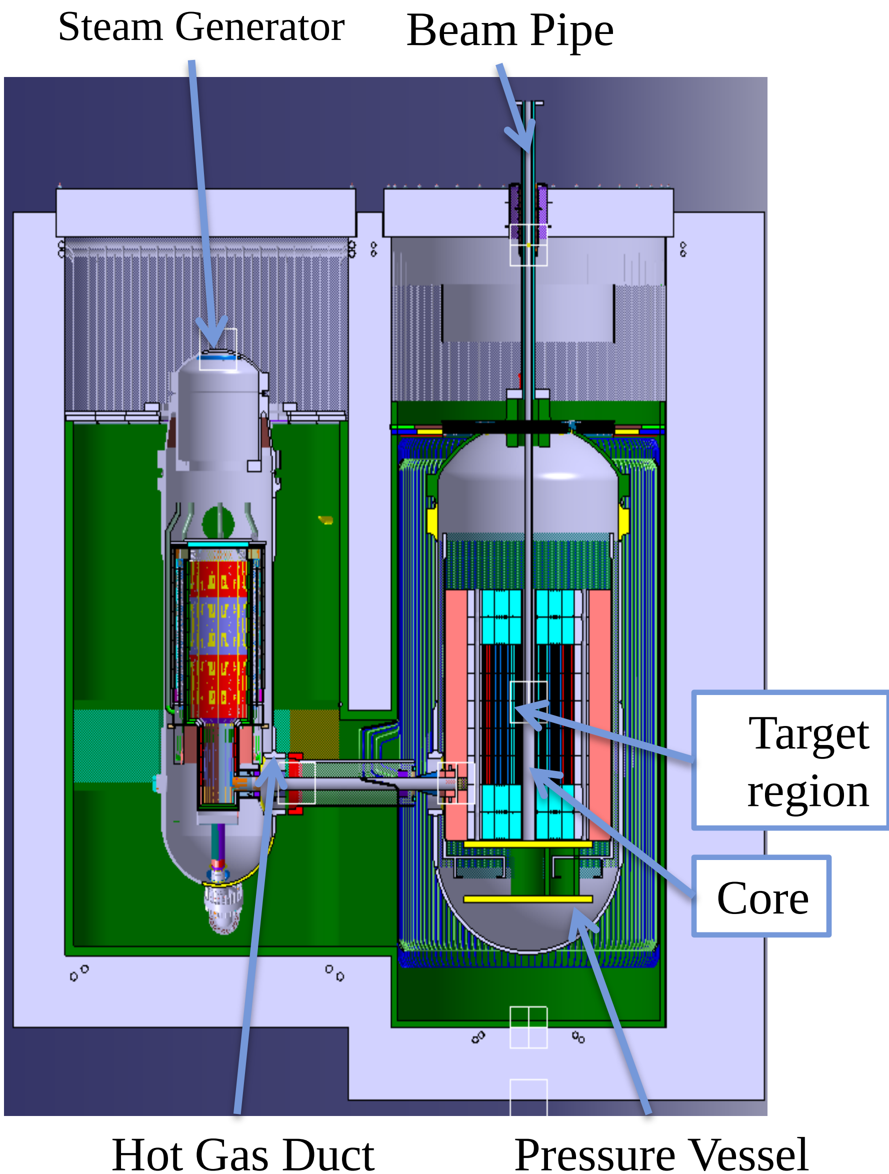
Reactor Building Layouts

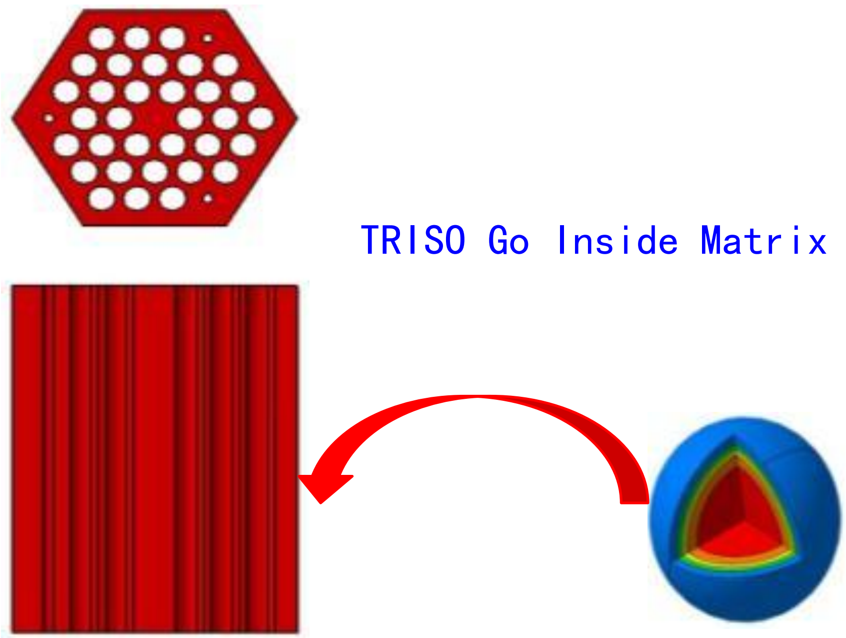


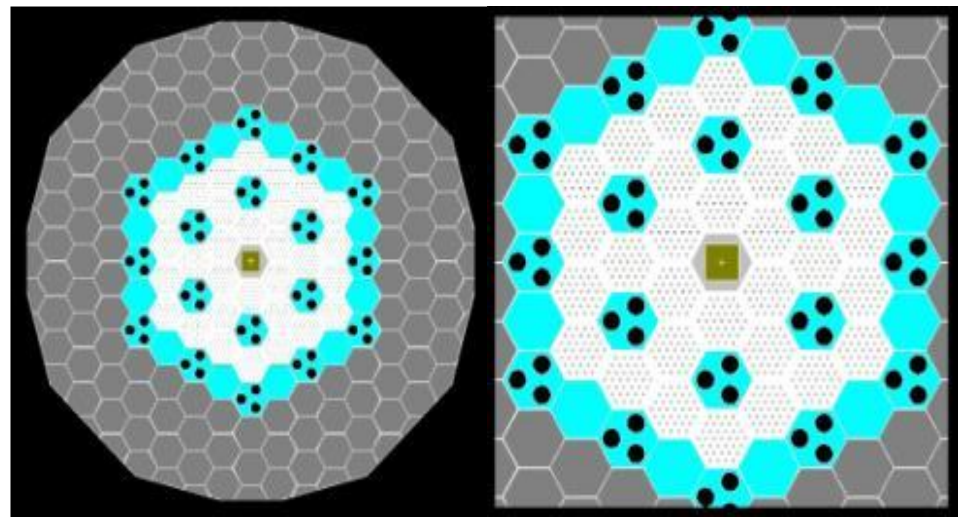


Gas Cooled Reactor

Accelerator	250MeV，4mA
Target	solid tungsten
Length, width, height	22cm、22cm、10cm
Fuel form	TRISO particles
Fuel in fast region	$(U\text{-}MA)O_2/SiC$
Number of fuel assembly layers	5
Total number of assembly layers	9
Assembly subtense distance/cm	35.8
Assembly interval/cm	0.2
Assembly height/cm	40
Number of assemblies in T/F region	6/24
Enrichment in T region	30%+MA
Enrichment in F region	1#10% 2#15%
Coolant	He
Coolant pressure	4MPa
Mass flow rate	12.5kg/s
Inlet/outlet temperature of the core	500k/654k





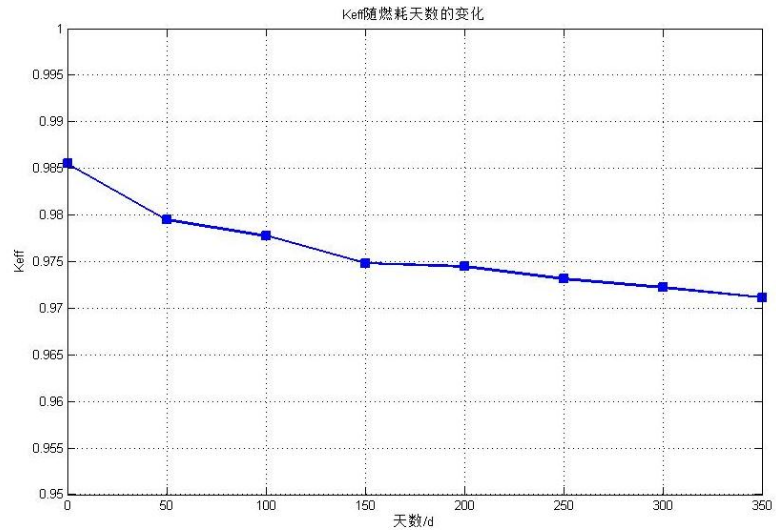


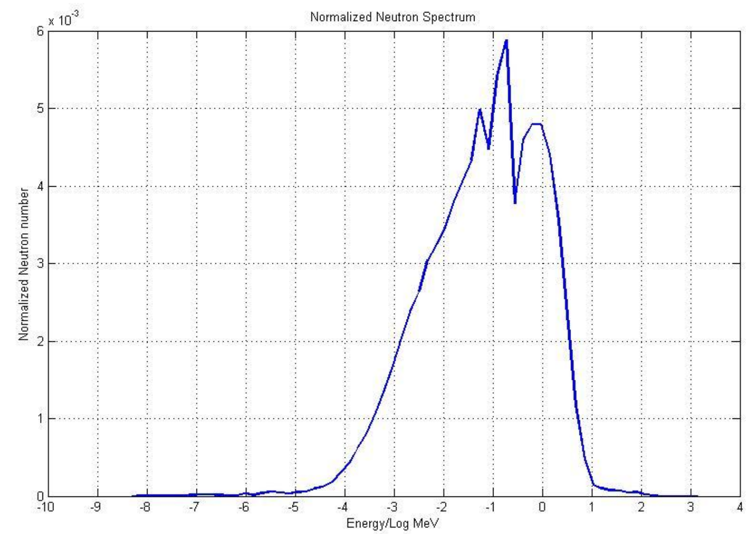
Transmutation Region UO2+MA，Enrichment 30%，Fuel Region 1# 10%，Fuel Region 2# 15%，Active Zone Height 200cm

时间/d	ψ	IP/mA	βeff/pcm	keff	功率峰因子
0	2.84	0.65	608	0.98549	1.3933
50	3.66	0.71	725	0.97948	1.3890
100	3.10	0.92	497	0.97776	1.3576
150	3.84	0.84	380	0.97480	1.3654
200	3.42	0.96	761	0.97446	1.3527
250	3.74	0.92	757	0.97314	1.3576
300	3.55	1.01	723	0.97220	1.3459
350	3.59	1.03	752	0.97114	1.3520

Keff Only1.5% in One Cycle

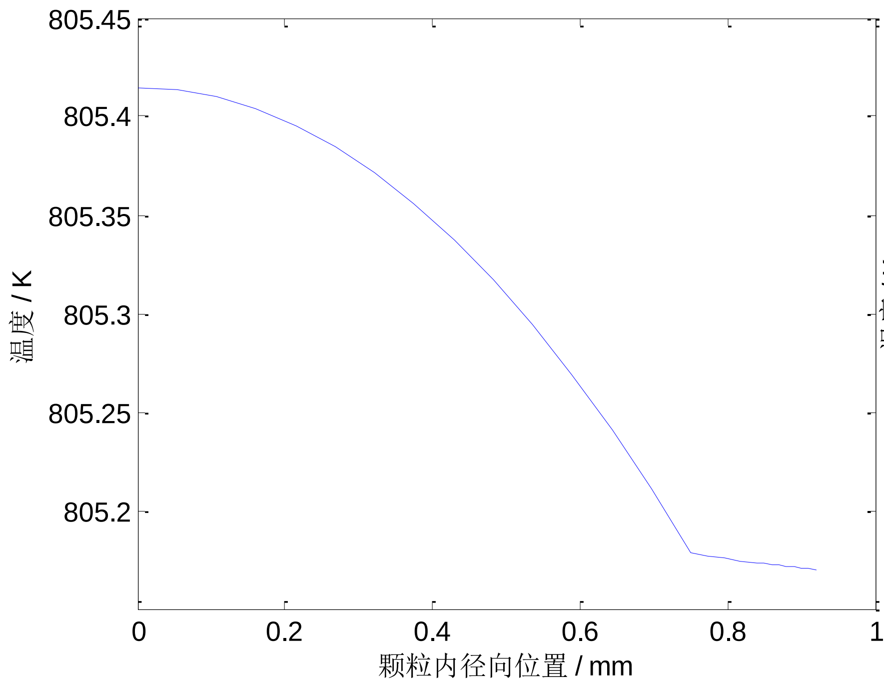
Steady With Depletion

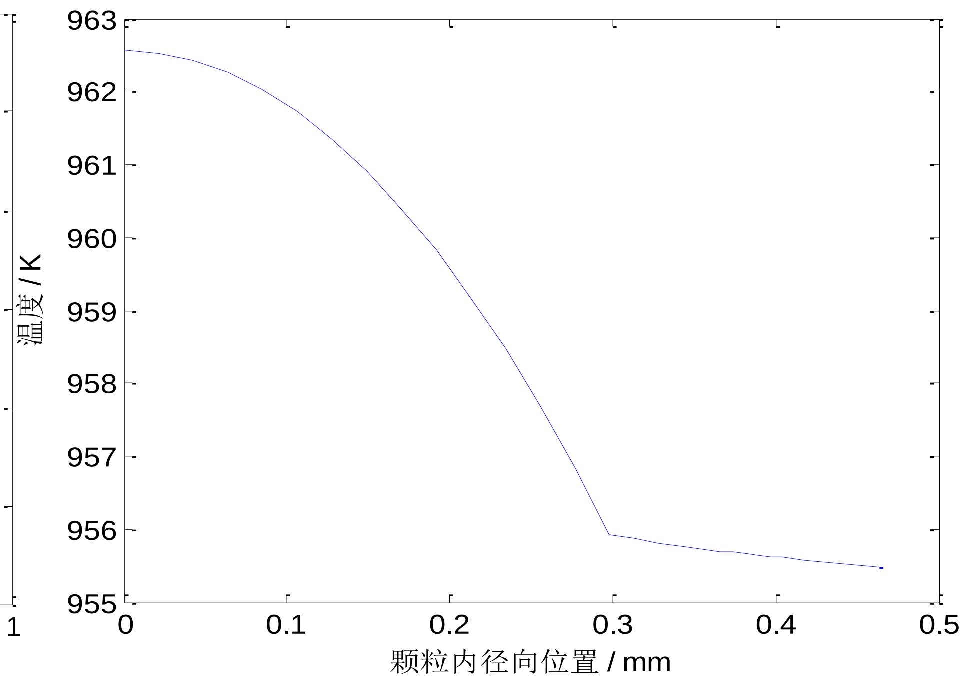




The most central Region

Neutron Energy Spectrum



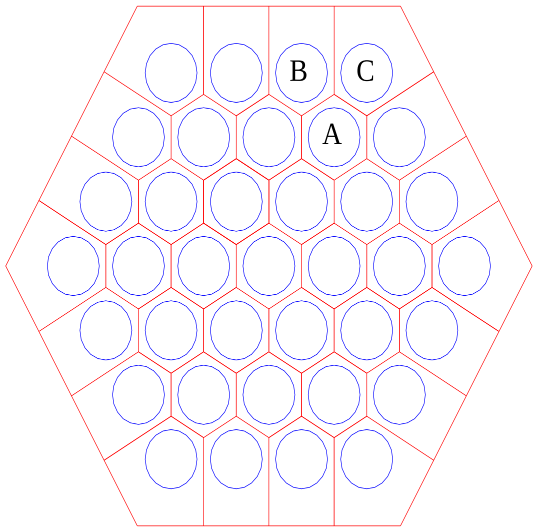


Transmutation Region Tem Distribution

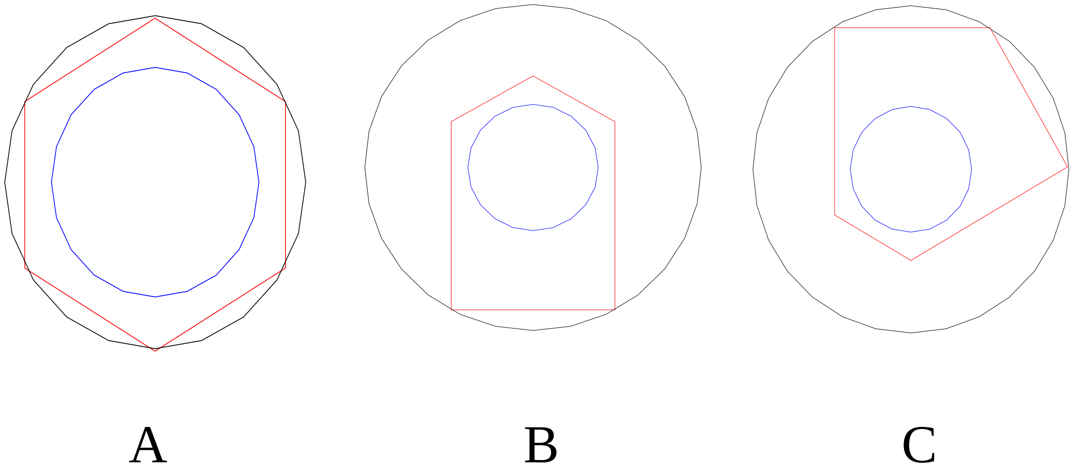
Temperature difference between inside and outside the particles is only 0.24 K the maximum temperature is 805.41 K,

Fuel Region Tem Distribution

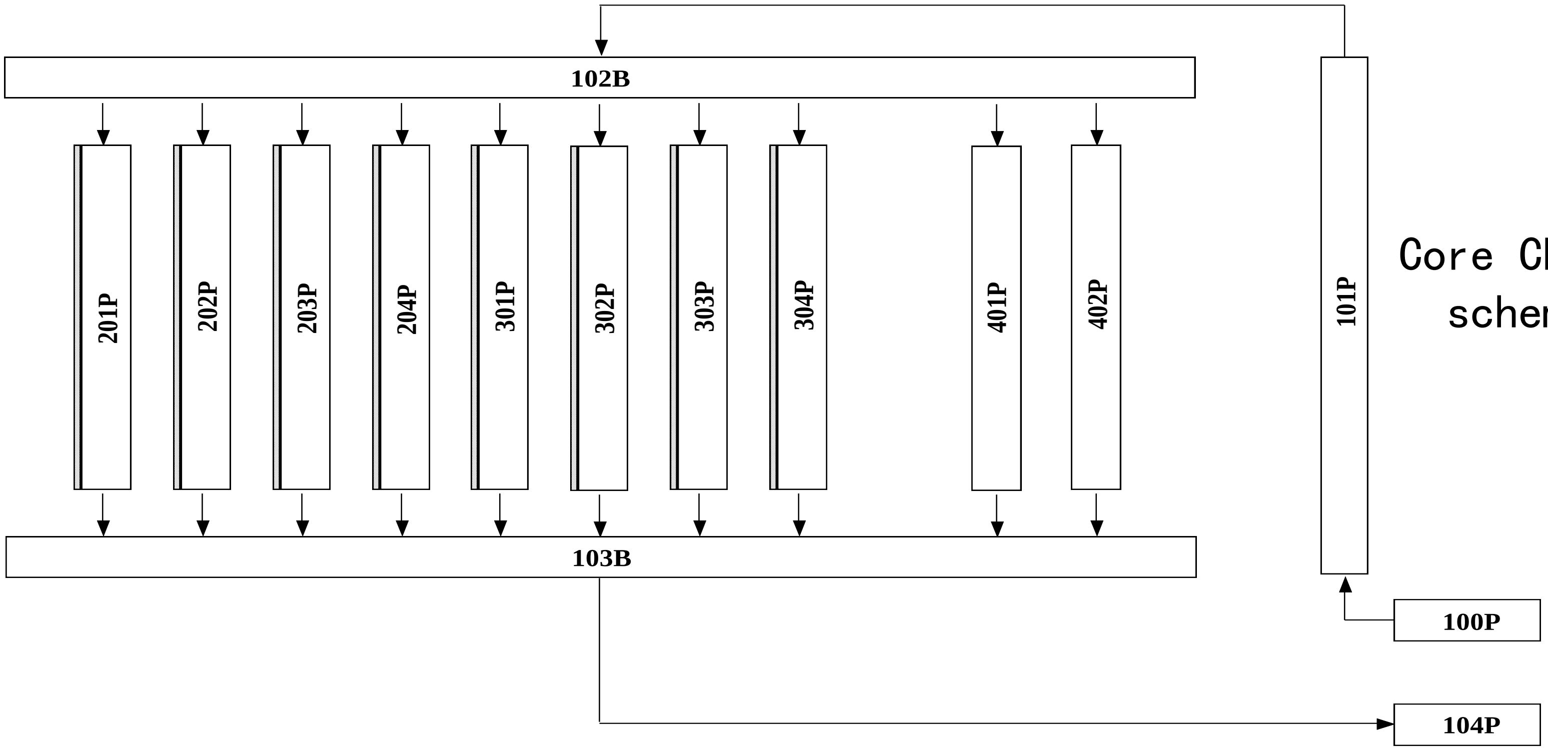
Temperature difference between inside and outside the particles is only 7.07 K, the maximum temperature is 962.56 K



Single Channel Model for One Assembly

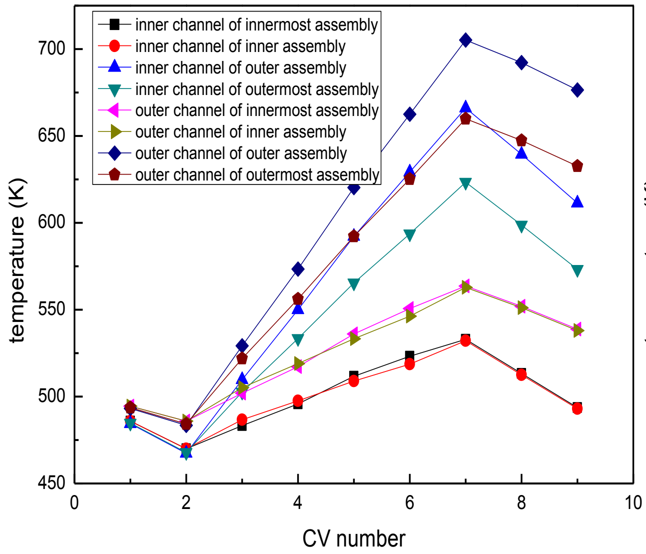


- Net quantity of heat produced in T & F region;
- Thermal isolation between each Assembly;
- Thermal isolation between each channel in the same assembly;

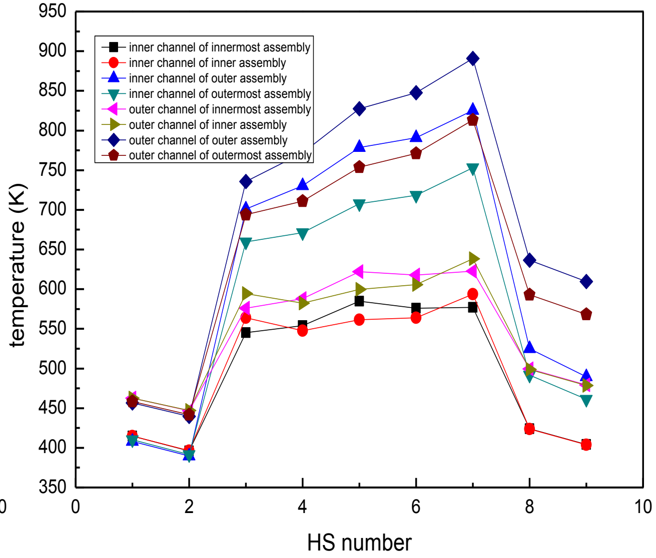


Core Channel Division schematic diagram

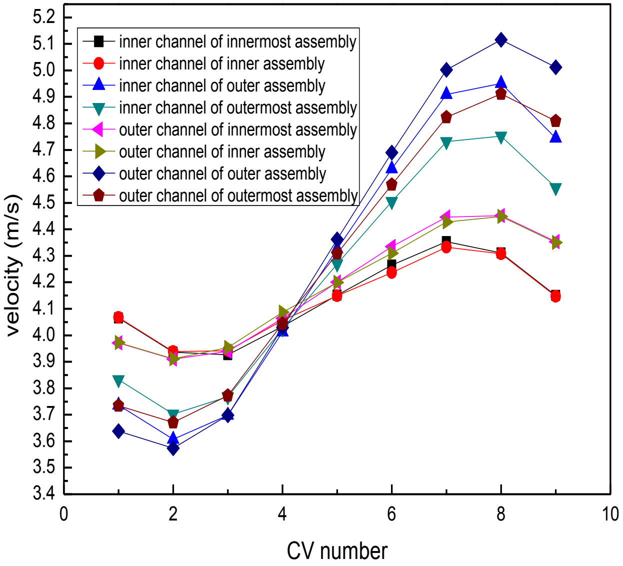
堆芯热工参数	数值
Thermal Power (MW)	10
Main Coolant System Pressure(MPa)	4.0
Core Inlet Temperature(℃)	250
Core Outlet Temperature(℃)	404
Mass Flow Rate(kg)	12.5



Temperature distribution in different coolant channel



Temperature distribution in different heat structure around the coolant channel



Coolant velocity in different coolant channel

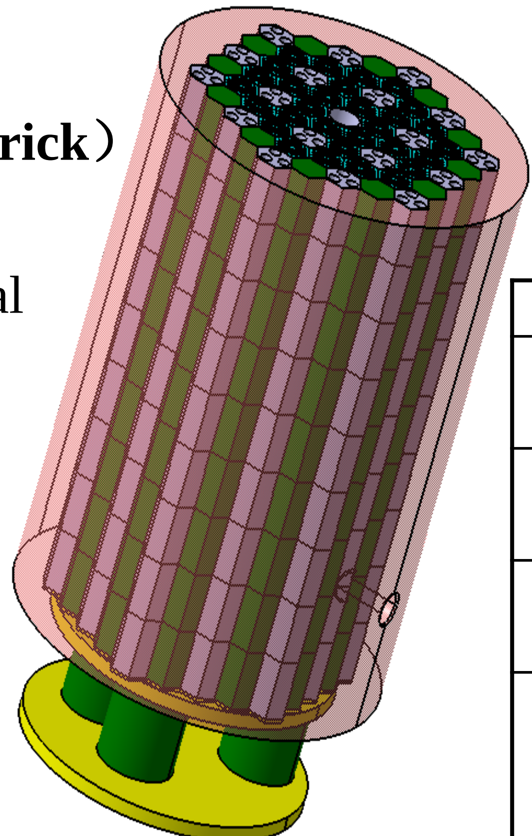
Reactor Internals=Ceramic & Metallic Internals

Ceramic Internals

（Graphite+Carbon Brick）

•Graphite—Reflector。

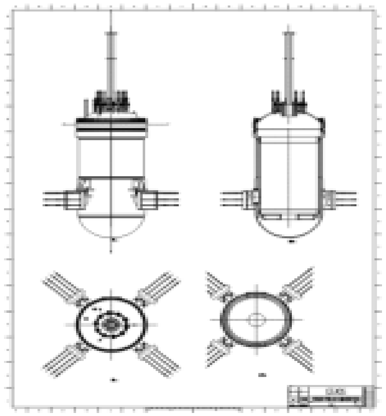
•Carbon Brick—Thermal Isolation



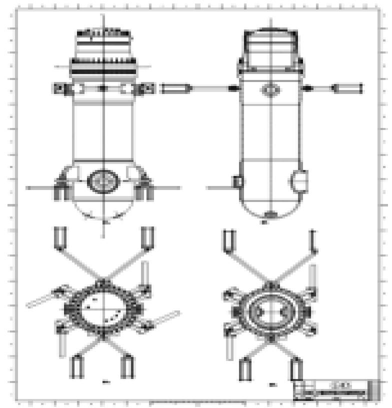
Metallic Internals: Support the reactor core

名　称	尺寸规格(mm)	材 料
Vessel	**Height11200 Inner Diameter 4500**	**12Cr2Mo1R**
Top Support	**Thickness 120 Diameter 4200**	**12Cr2Mo1R**
Bottom Support	**Thickness 120 Diameter 4200**	**12Cr2Mo1R**
Ceramic internals support roller	**Support roller (Diameter 150) Cover (Thickness 125)**	**40CrNiMo 42CrMo**

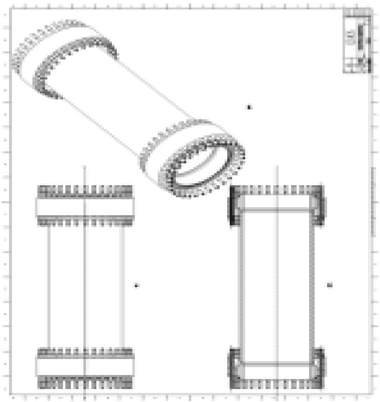
Main Coolant System Pressure Boundary



Reactor Pressure Vessel
(RPV)



Steam Generator Pressure Vessel
(SGPV)



Hot Gas Duct Pressure Vessel
（HDPV）

Function： Primary Coolant Pressure Boundary.

The most important safety barrier for the reactor 。

Operation Temp :4.0MPa； Design Temp: 350℃； Operation Temp: 250℃。

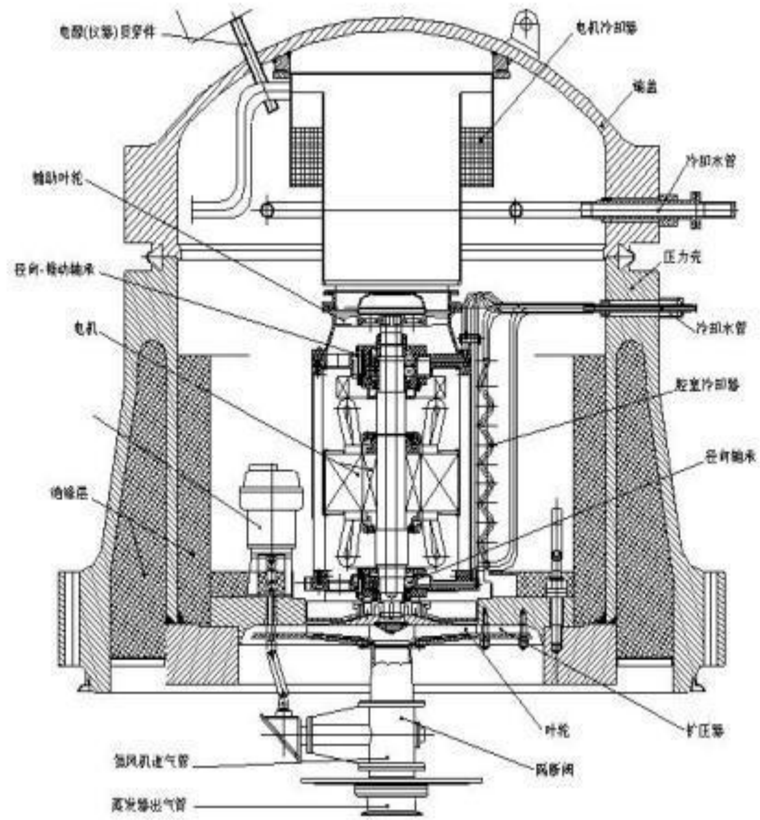
RPV： Inner Diameter 4200 mm， Height 11200 mm， Thickness150mm。

SGPV: Inner Diameter 2500 mm， Height 11400 mm， Thickness 50~100 mm。

HDPV: Length 3350mm， Inner Diameter 900mm， Larger Opening Flange on two side

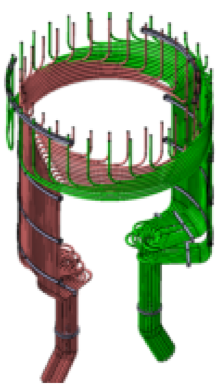
Main Coolant Helium Fan

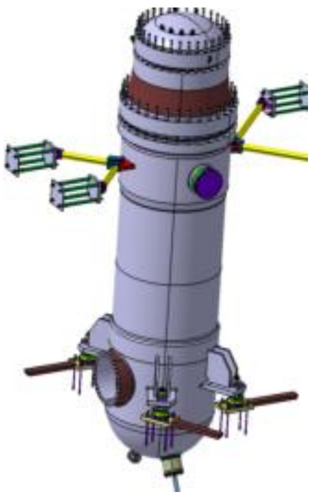
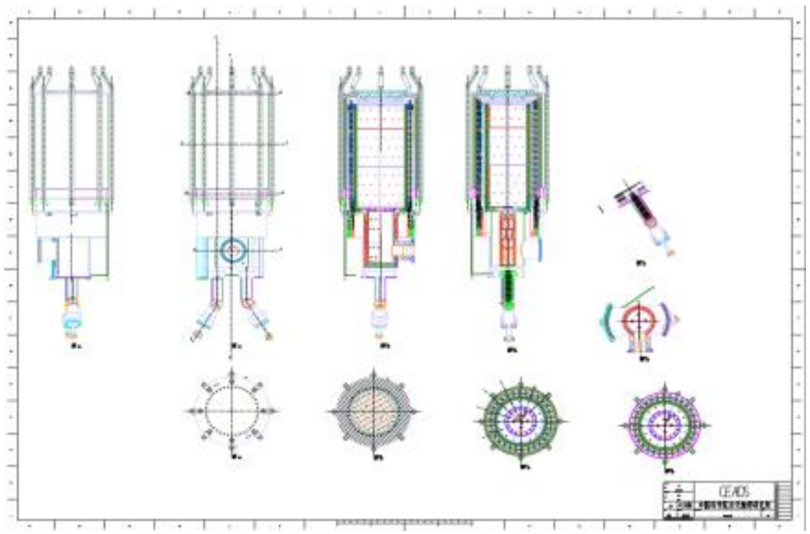
Para	Value
Temp	250 ºC
Pressure	4.0 MPa
Density	3.62 kg/m^3
Mass Flow Rate	12.5kg/s
Pressure Raise	0.06 MPa
Vane wheel type	Centrifugal
Speed	5000 rpm
Power	165 kW



主氦风机

Helix Tubes Steam Generator

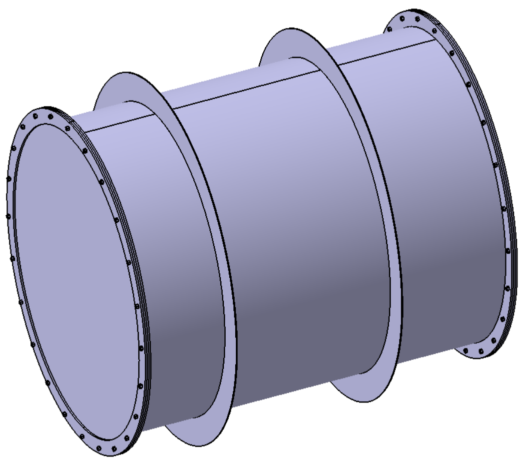


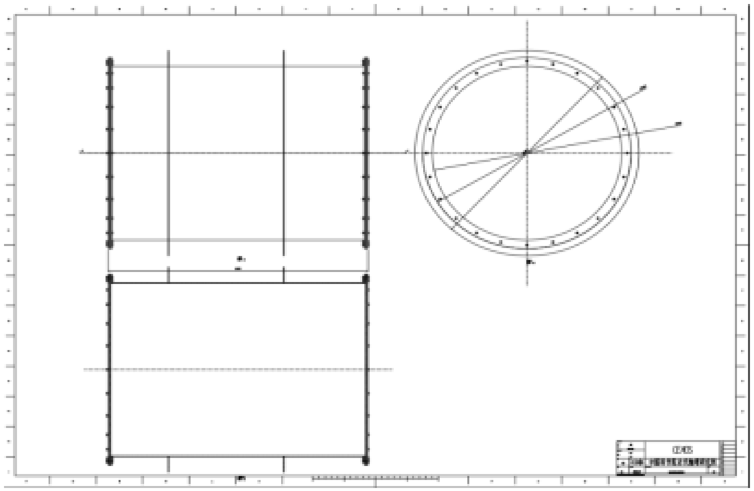



Constitution： Helix heat transfer tubes, Connection tubes, Central tube, Compensation tubes, Main feed water box, Main Steam pipe box.

Process: 404℃ Helium flows from the bottom to the top of the helix tube bundles , then rise the pressure by the main coolant pump and cold to be 250℃

Negative Pressure Ventilation Blasting Membrane

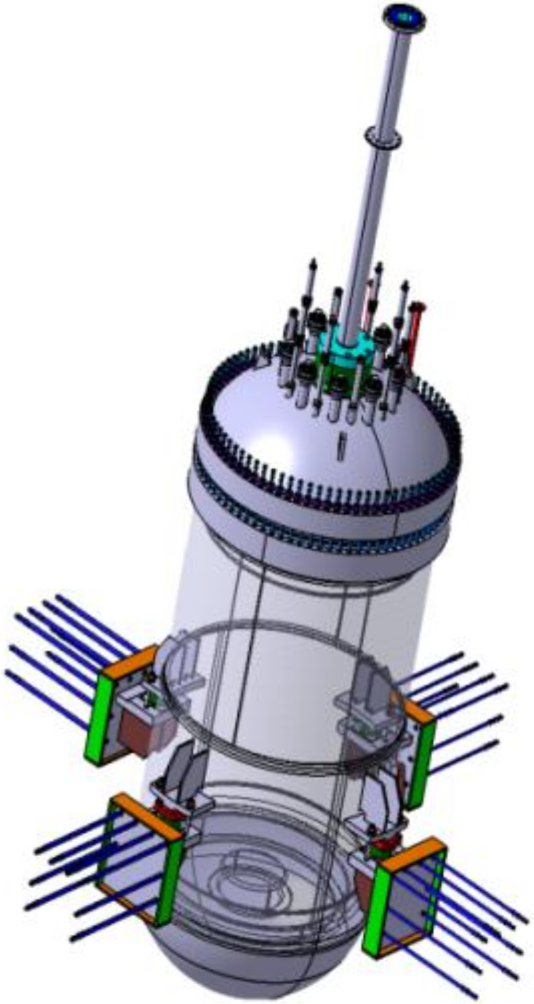


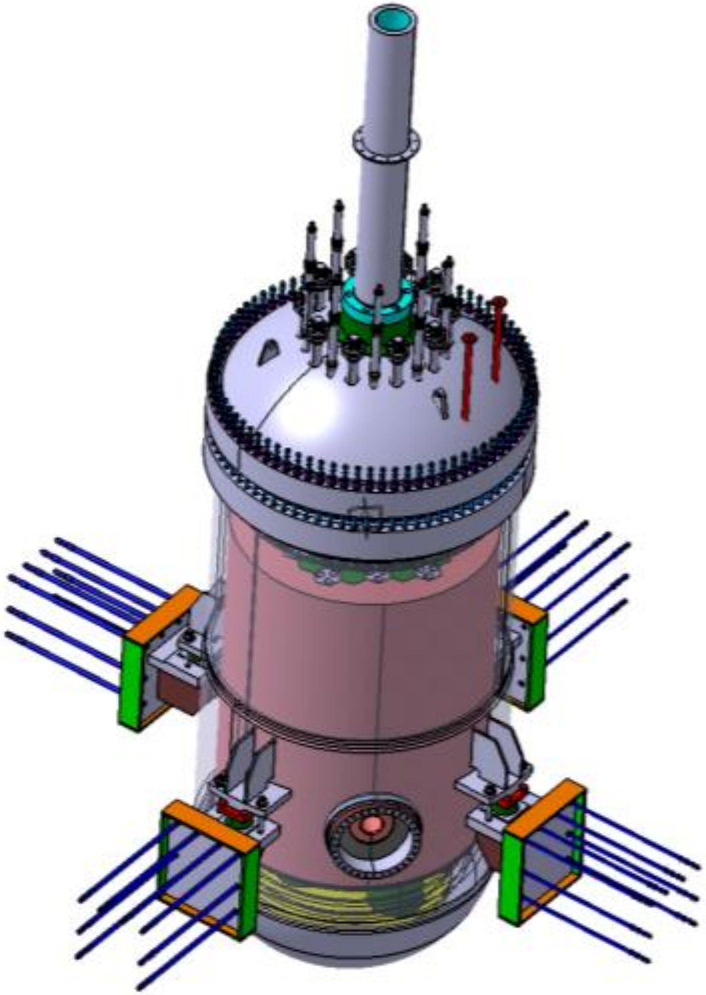


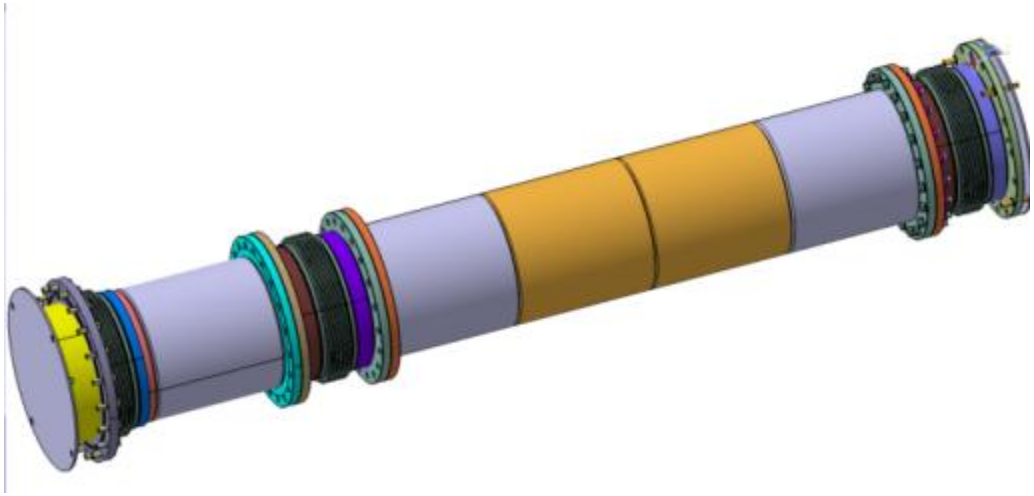
负压通风爆破膜

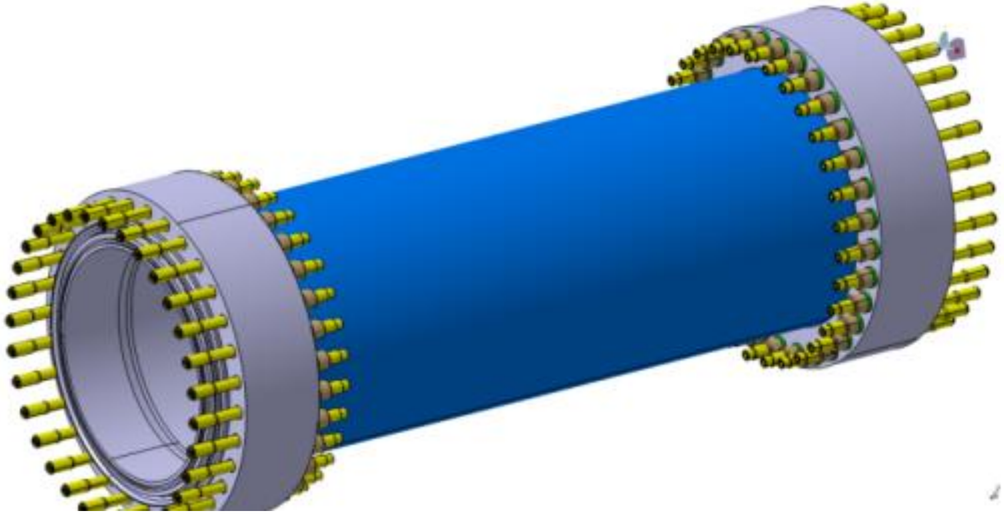
Function： Overpressure Protection for Primary Coolant System

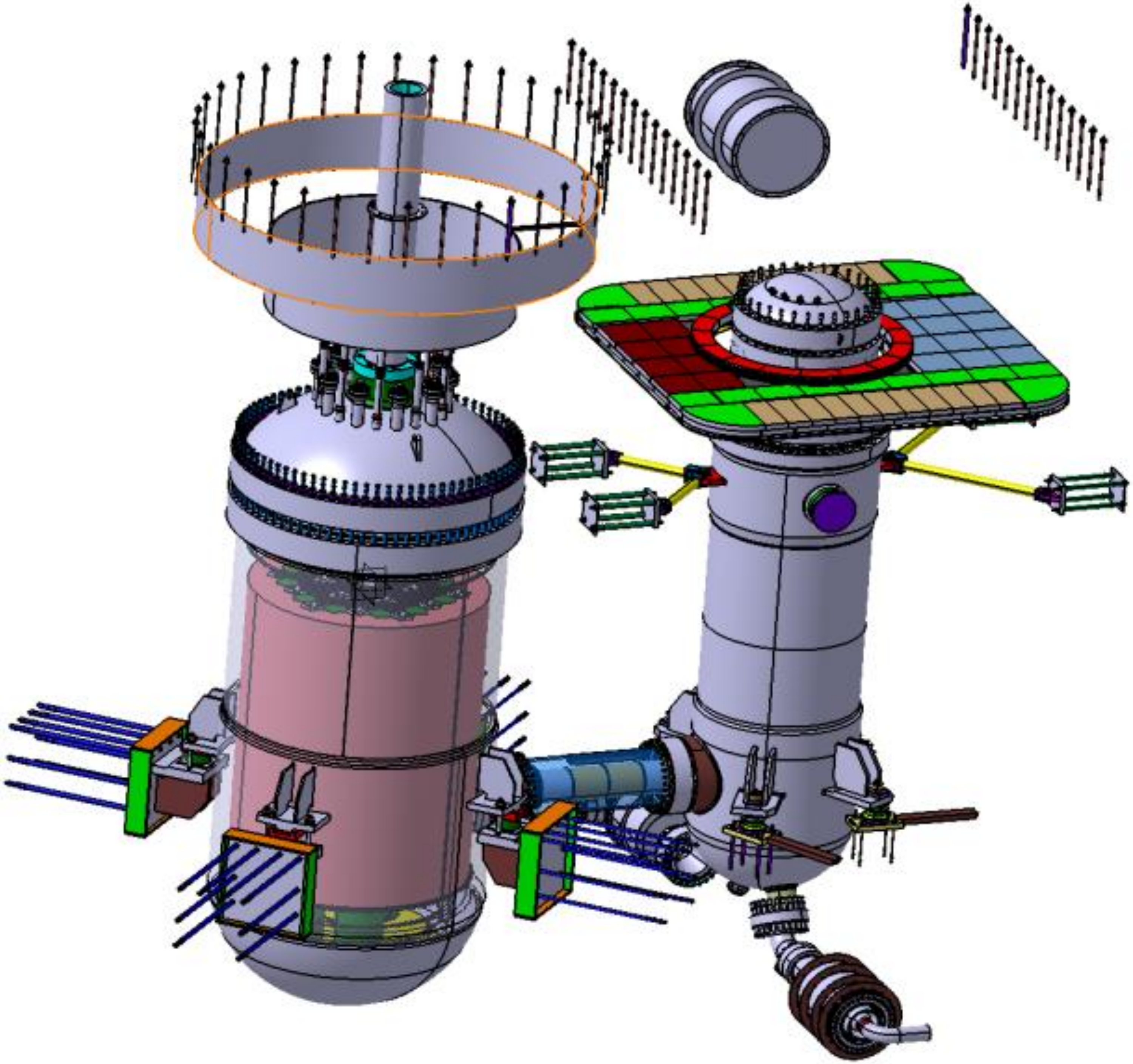
• Design Pressure : 0.127MPa。









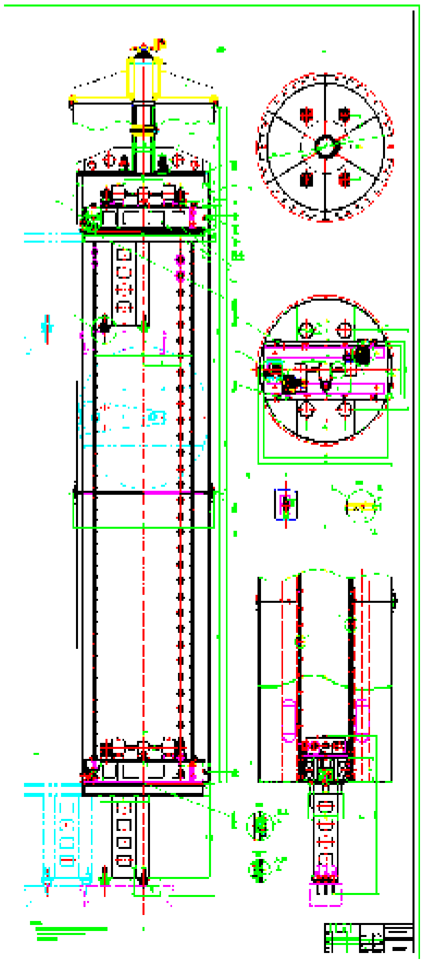


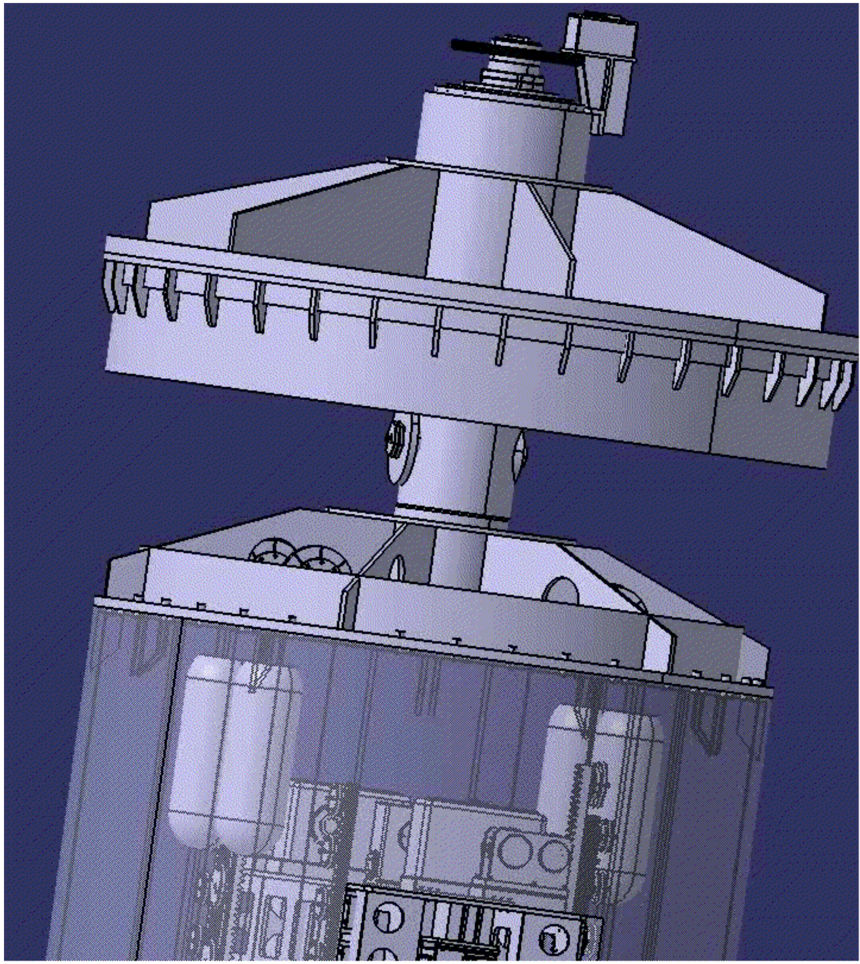
Auxiliary System——Refueling System

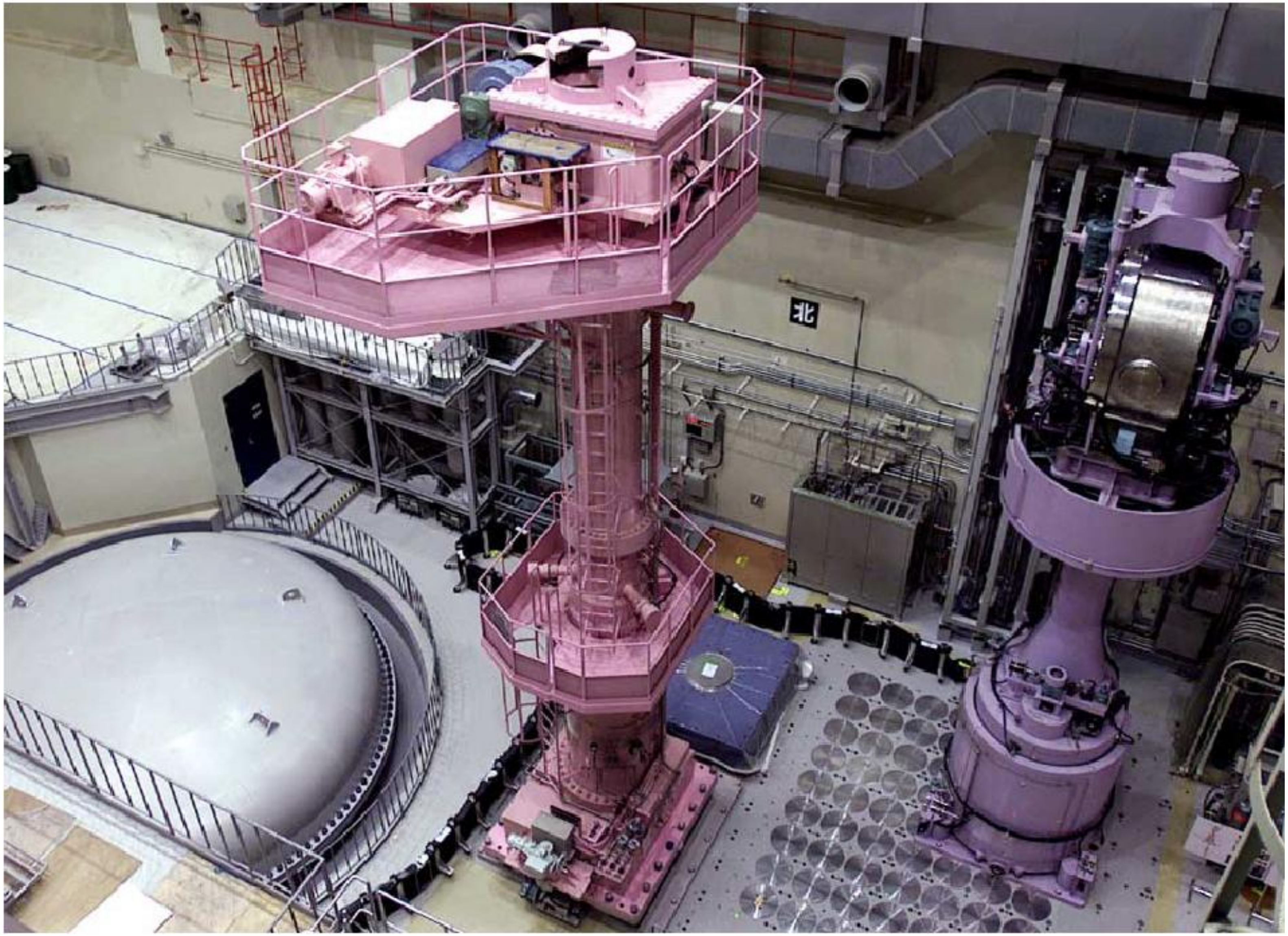
Function:

Refueling the fresh and spent fuel for the reactor core from the storage pool。

- **Shaft seal structure**



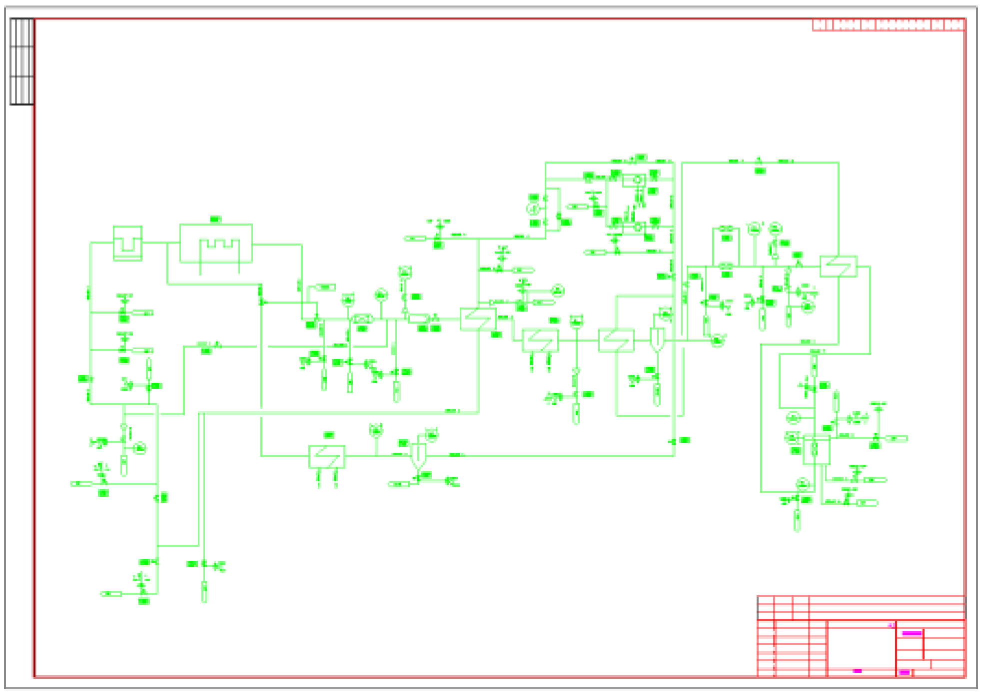



北

Auxiliary System-Helium Circulatory & Purification System

H_2	H_2O	CO	CO_2	CH_4	N_2	O_2
≤30	≤2	≤30	≤6	≤5	≤2	≤2

Impurity Content in Coolant Helium on Operation Condition(ppmv)

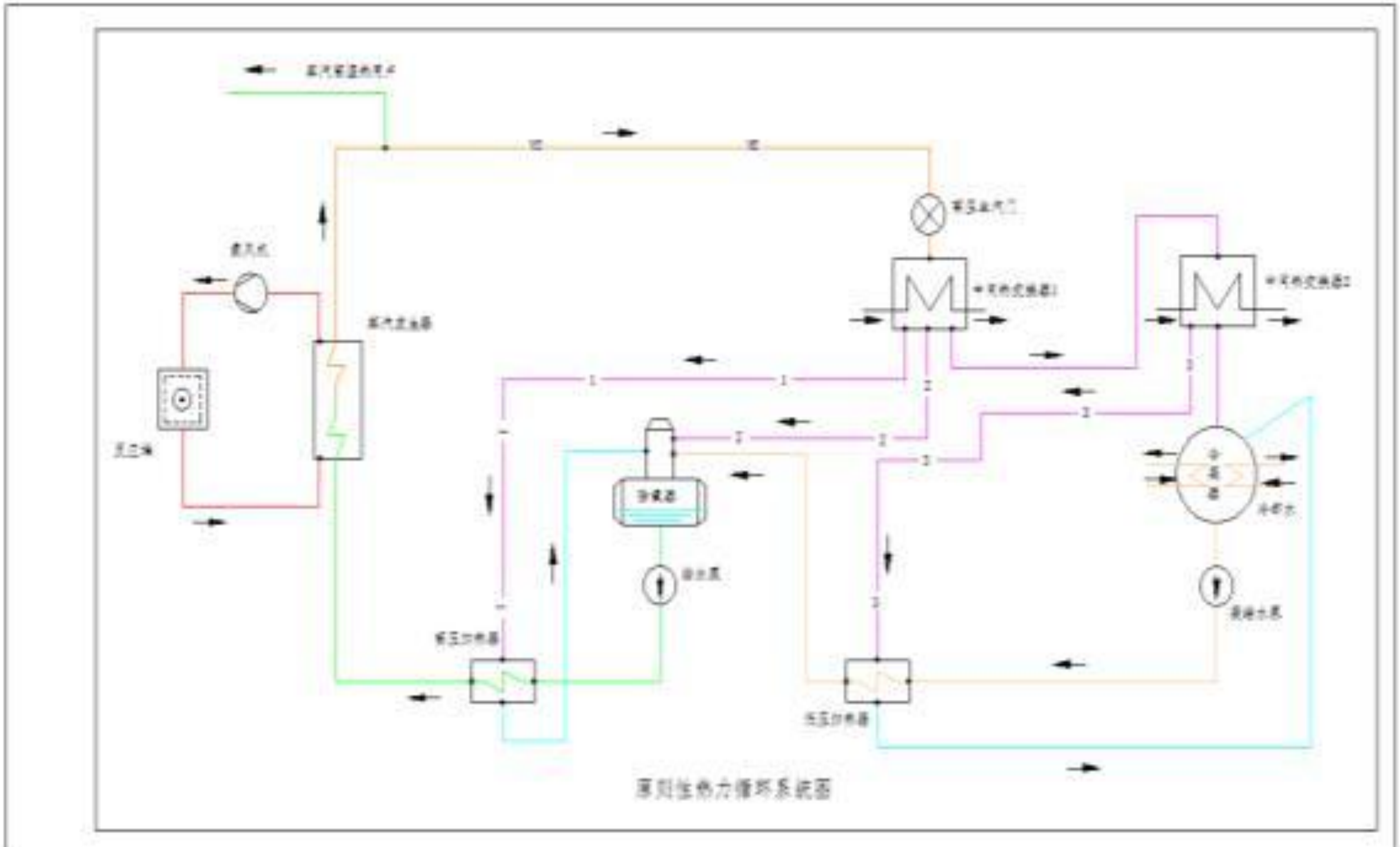


Helium Circulatory & Purification Flowchart

1. Remove Chemical Impurity(H_2O、O_2、CO_2、CO、H_2、CH_4、N_2), Radionuclide (Kr、Xe, T)and so on。
2. Purification System including:
   - Normal operation condition purification system
   - Accident condition purification system

Thermodynamic Cycle Parameters

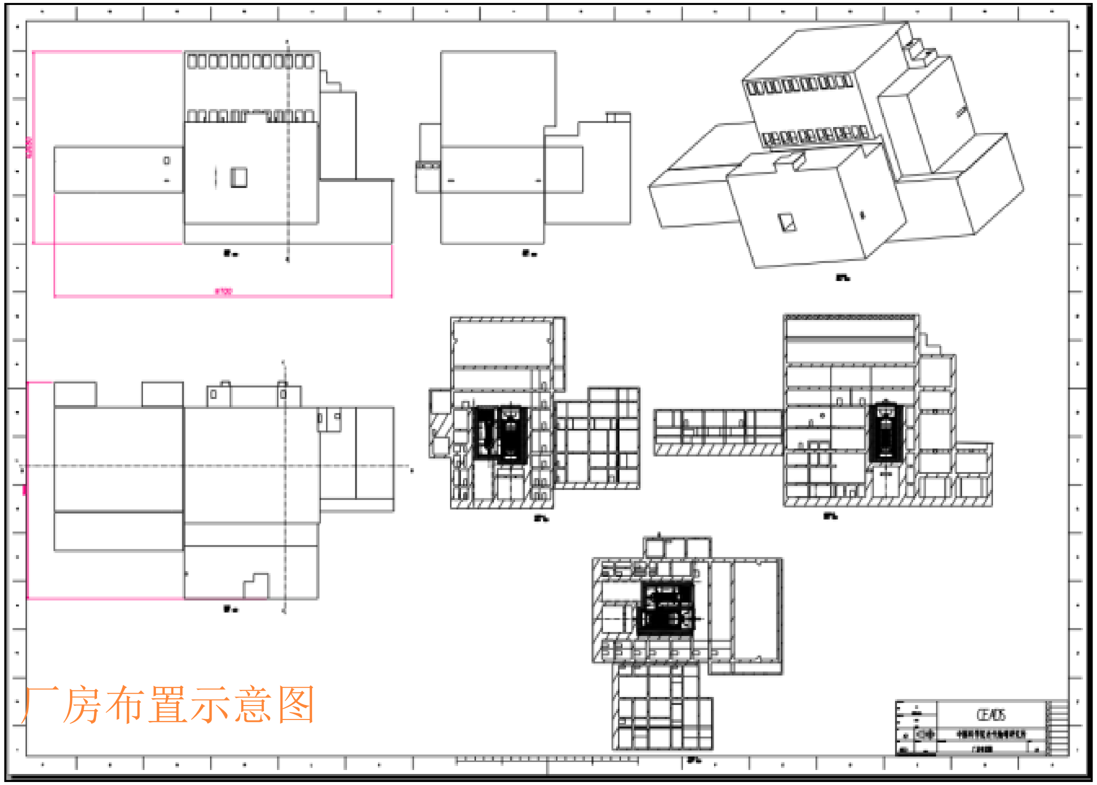
Helium Inlet Temp	**404℃;**	**Helium Outlet Tem**	**250℃**
Feed Water Mass Flow Rate	**5kg/s ;**	**Steam Outlet Pressure**	**4.1MPa**
Steam Outlet Temp	**270℃ ;**	**Feed Water Inlet Temp**	**224℃**



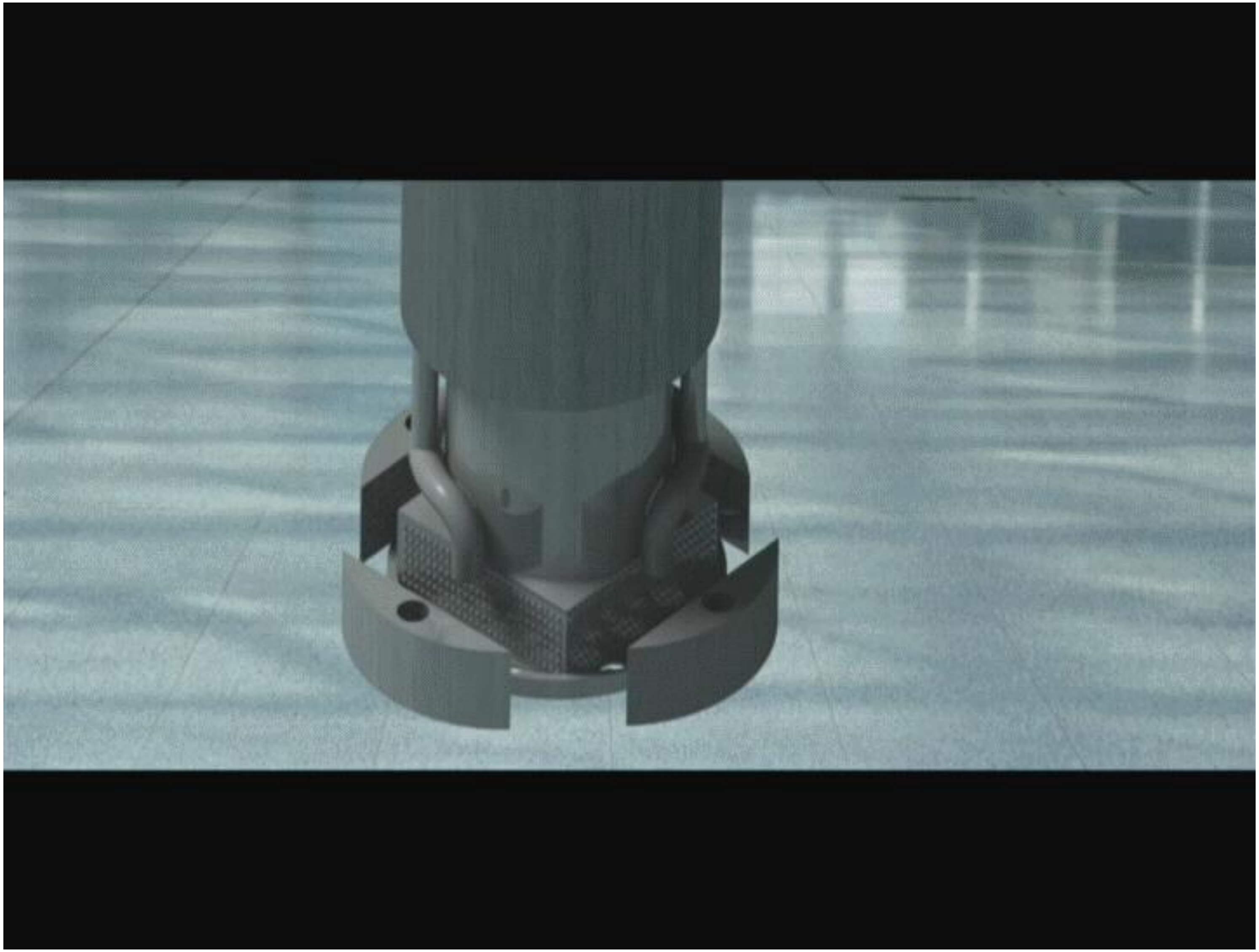
Thermodynamic Cycle Flowchart

Reactor Building

Floor Area 6007m²、Rooftop Elevation+62.65m



Shielding Concrete Cooling System



OUTLINE

I. Introduction
- Motivation
- ADS Roadmap in China
- New Site & Institute for C-ADS

II. Current Progress of C-ADS
- Overview of C-ADS
- Accelerator System
- Spallation Target
- Subcritical reactor

III. Open Questions on ADS

Open Questions on ADS

- Relationship of purpose & acceptable objective on ADS
- The role of nuclear fuel cycle——Future
- How to understand the reliability of the ADS
- Whether there are some opportunities to find new physics on ADS
- Industrial demo facility requirements
- …….

Welcome Collaboration !

THANKS FOR ATTENTION