



The Present Status and Future Potential Applications of RRs in CIAE, China

BEIJING

Notable Outer Suburbs



by

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- 2. Utilization of the existing RRs in CIAE**
- 3. The history and Current status of CARR**
- 4. Utilization plan for CARR**

1. General information of RRs in CIAE

- Heavy Water Research Reactor (HWRR),
- Swimming Pool Research Reactor (SPR) ,
- Miniature Neutron Source Reactor (MNSR) and MNSR-I,
- Several ZPRs

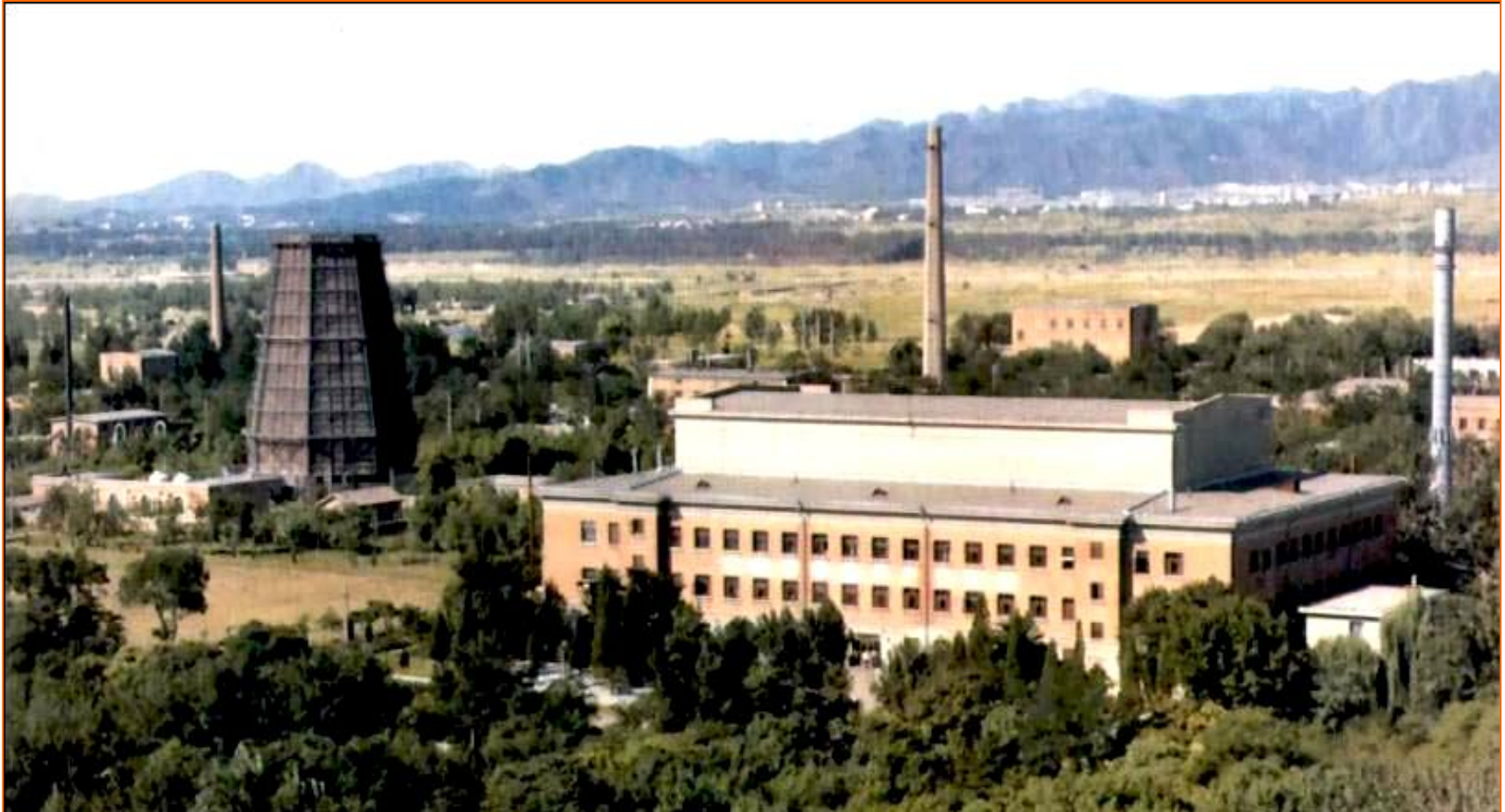
CARR and CEFRR are under constructed.

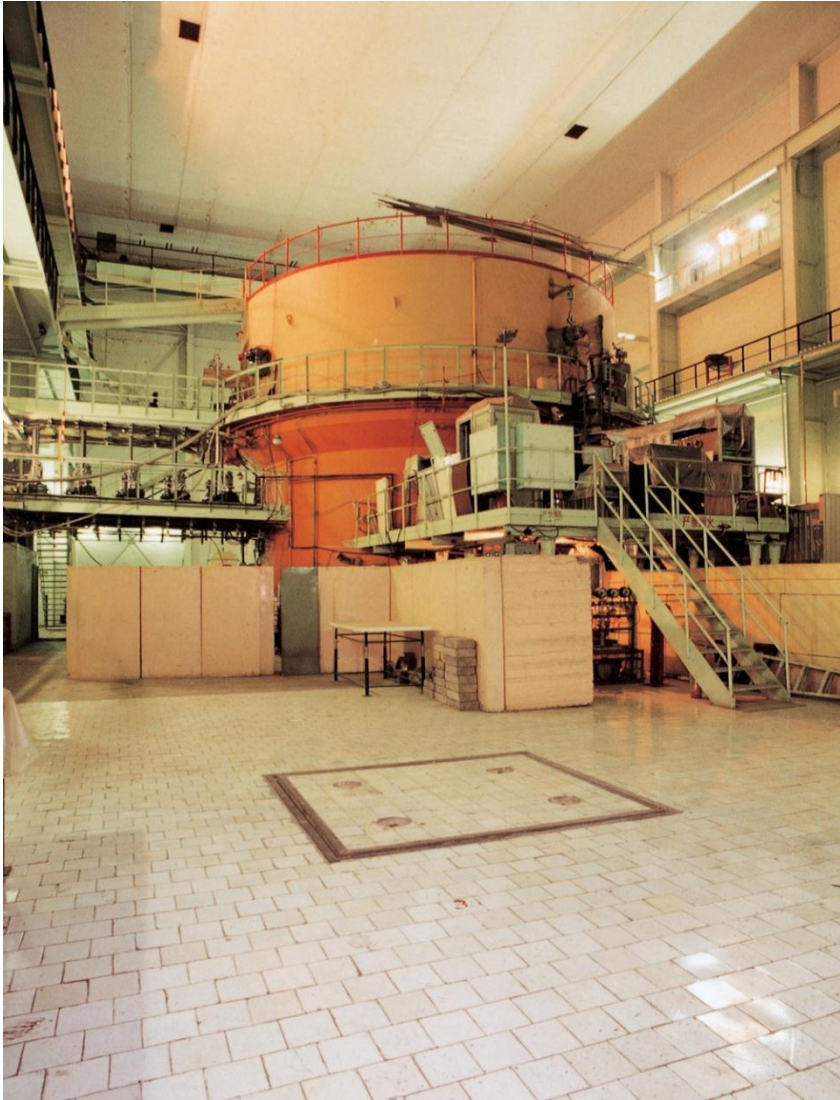
1. Existing RRs in CIAE



1.1 HWRR

The building of HWRR

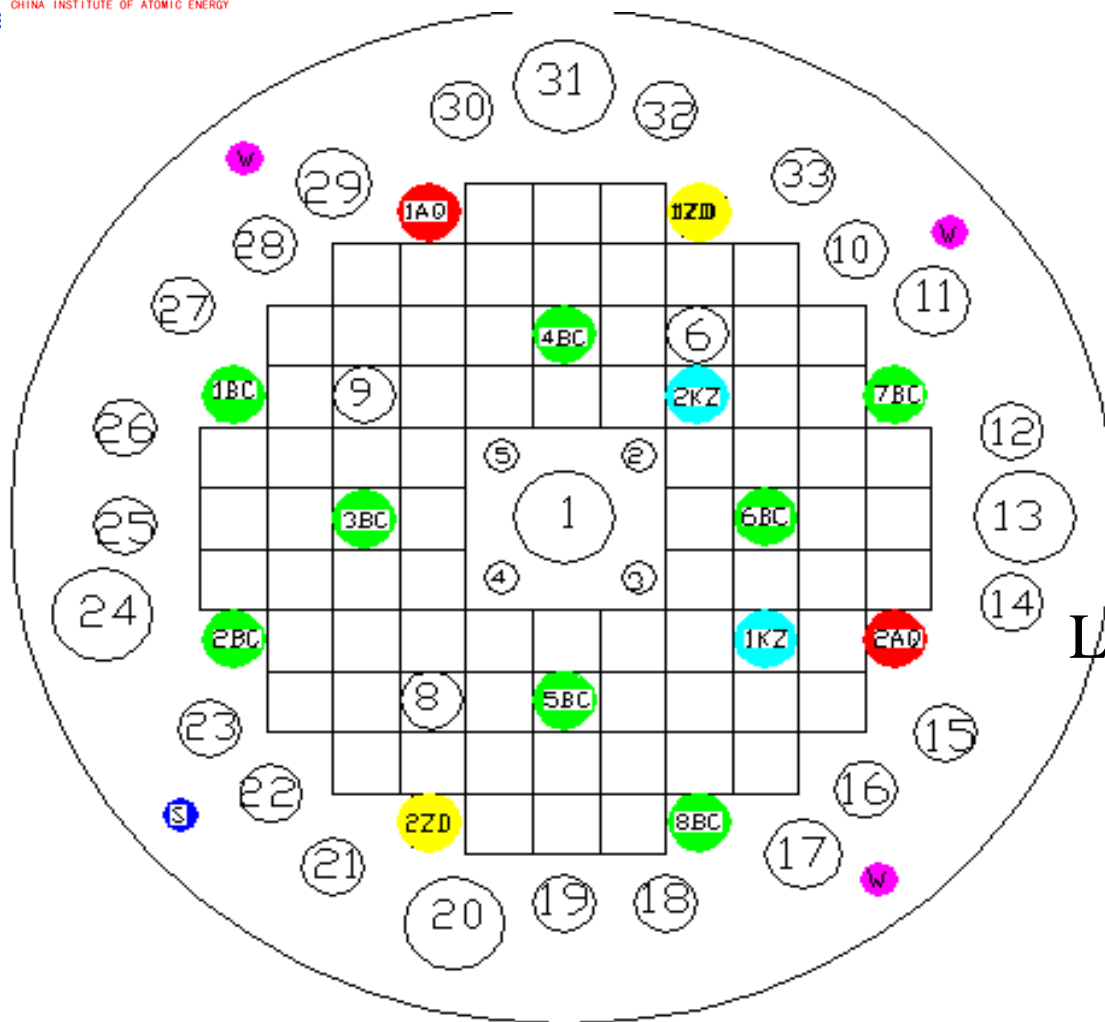




Heavy Water Research
Reactor (HWRR)

1.1 General information of HWRR

- 1st nuclear reactor in China
- Type: tank
- coolant and moderator : D2O
- Reflector: graphite
- First critical: 1958
- Modified : 1979 ~1982
- Closed: 2008



Layout of HWRR Core

“1AQ”“2AQ”: No.1、2 safety rod; “1ZD”“2ZD”: No.1、2 regulating rod;
 “1—8BC”: 1—8 shim rod; “1KZ”“2KZ”: No.1、2 standby safety rod;
 “①—⑨”: vertical channel; “W”: thermometer; “S”: water level gauge.

Parameters of HWRR

No.	Items	Value
1	Lattice, mm	92
2	Core height, mm	1000
3	Fuel	UO ₂
4	Cladding material	Zr-2
5	Number of fuel assembly	72
6	²³⁵ U enrichment, %	3.0
7	²³⁵ U weight, kg	7.682
8	Rated thermal power, MW	15 (10)
9	Largest thermal neutron flux, cm ⁻² · s ⁻¹	2.6 × 10 ¹⁴
10	Safety rods	4
11	Control rods (Regulating+ Shim)	2+8
12	Vertical irradiation tubes (core+ graphite)	32+34
13	Horizontal neutron beams	7

Utilizations of the HWRR

- Thermal Neutron Scattering (CNS facility)
- RIs Production (^{125}I , ^{131}I , ^{99}Mo , ^{119}Sn , ^{192}Ir , ^{60}Co , ^{210}Po , ^{198}Au , ^{131}Ba , ^{32}P , ^{153}Sm)
- PWR Fuel Element Irradiation (**QSNP Fuel Assembly test**)
- Neutron Activation Analysis (NAA)
- Neutron Transmutation Doping (NTD) of silicon (3~5 inches)
- Personnel Training

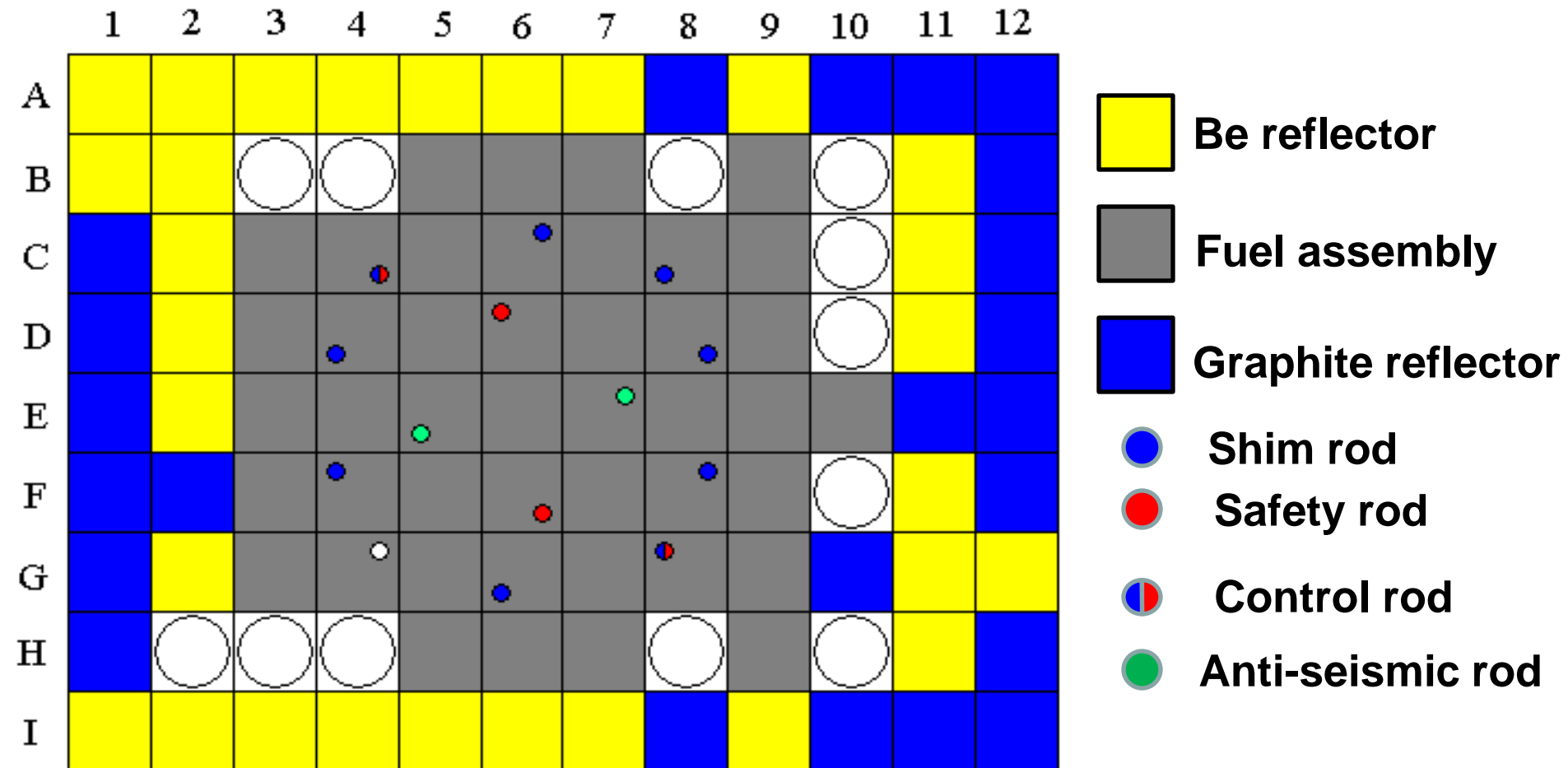
1.2 SPR

- **Type:** **swimming-pool**
- **coolant and moderator :** **H₂O**
- **Reflector:** **Be+graphite**
- **First critical:** **1964**
- **Opration:** **up to the present**

Main control room



Layout of SPR core



Parameters of SPR

Power	3.5 MW	
Max. thermal flux	5.2×10^{13} n/cm²·s	
Max. fast flux	1.4×10^{14} n/cm²·s	
FUEL	Loaded ~ 5.6 kg ²³⁵U	Max. No. of fuel assemblies, 44
Fuel element	Rod type, UO₂ and Mg dispersion, Aluminum cladding , ²³⁵U enrichment 10%.	
Core height	500 mm	
Swimming pool	7800mm (height) × 4500mm (length) × 2000mm (width)	
Control rod	11	2 safety rods, 2 regulating rods, 7 shim rods. regulating rod material is Cd, and the other is B₄C
Horizontal channel	5	1 thermal column , 1 tangential channel
Vertical channel	20	10 in core and 10 out core

SPR building



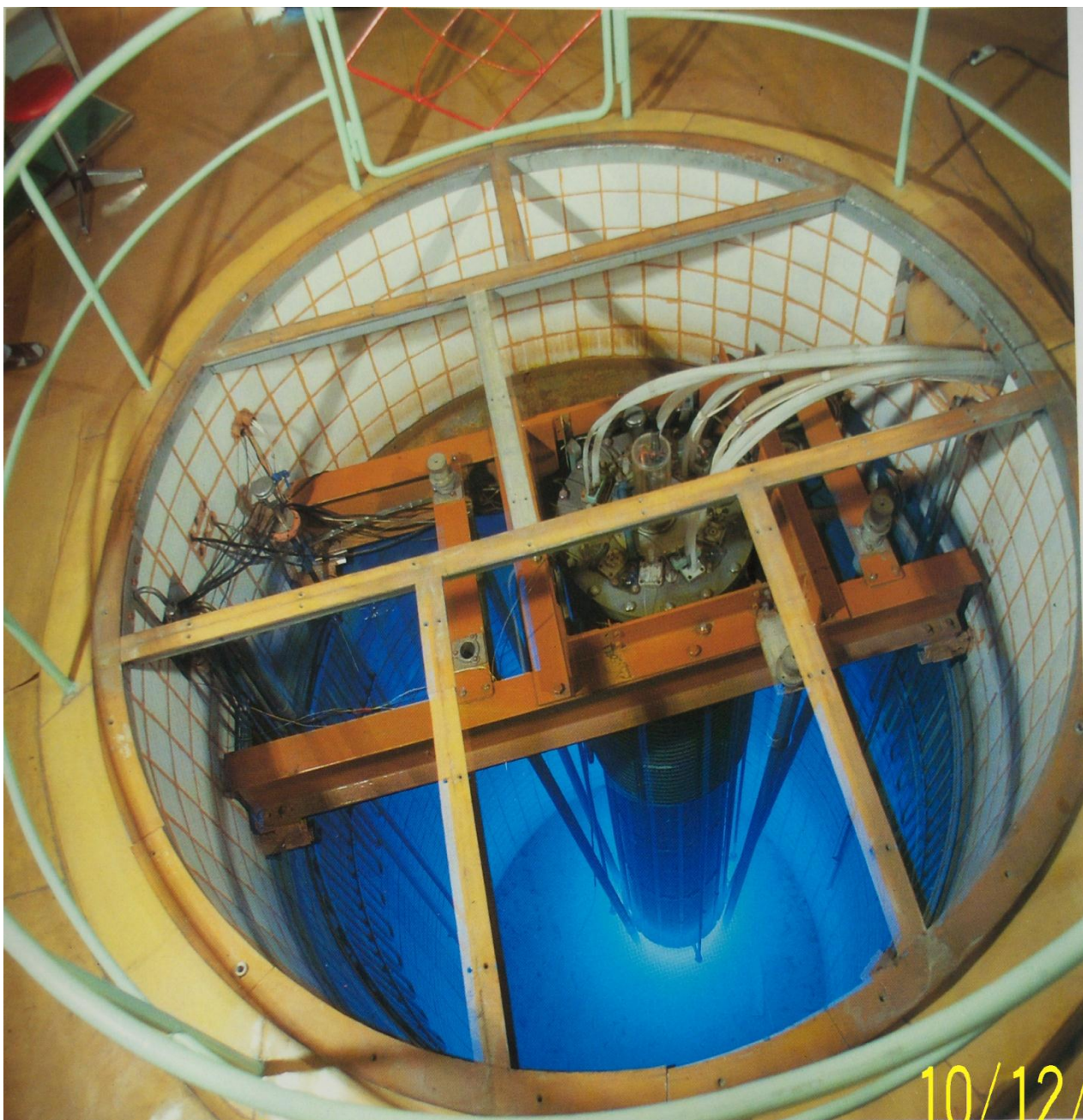
SPR control room

Applications of the SPRR

- The main applications are as follows:
 - fuel and material performance test;
 - The RIs and NTD silicon productions;
 - Gemstone coloration, medicinal irradiation;
 - NRG;
 - NAA;
 - Personnel or operator training
 - In-pile experiment and measurement's technique research etc.

1.3 MNSR

- **Type:** tank-in-pool
- **coolant and moderator :** H₂O
- **Reflector:** Beryllium(top/bottom and surrounding)
- **Features:** Simple, Super Safe, Saving
- **First critical:** 1985
- **Operation:** up to the present
- **A new MNSR (MNSR-I) was already critical at the end of last year**
improved in: from HEU to LEU
BNCT added,



10/12/

Main Parameters of MNSR-I

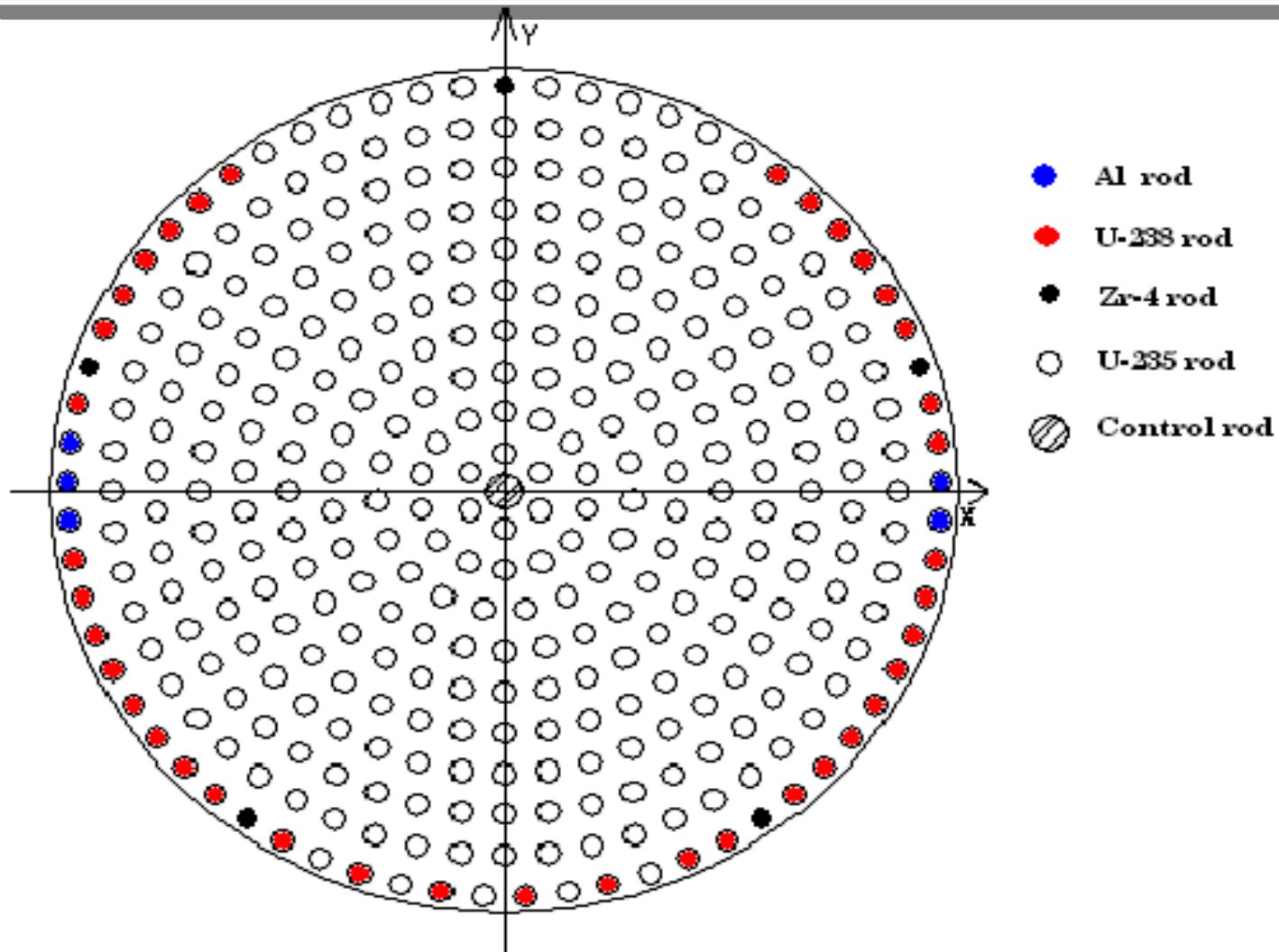
- Thermal power : 30 kW
- Thermal flux $1 \times 10^{12} \text{n/cm}^2 \cdot \text{s}$ (inner tube)
 $5 \times 10^{11} \text{n/cm}^2 \cdot \text{s}$ (outer tube)
- Core height: 258mm
- Critical mass: ~ 300 fuel elements
- ^{235}U enrichment (rod type): **12.5 wt%**
- Fuel type: UO_2
- Vertical tubes 5
- Horizontal tubes 2

Applications of the MNSR-I

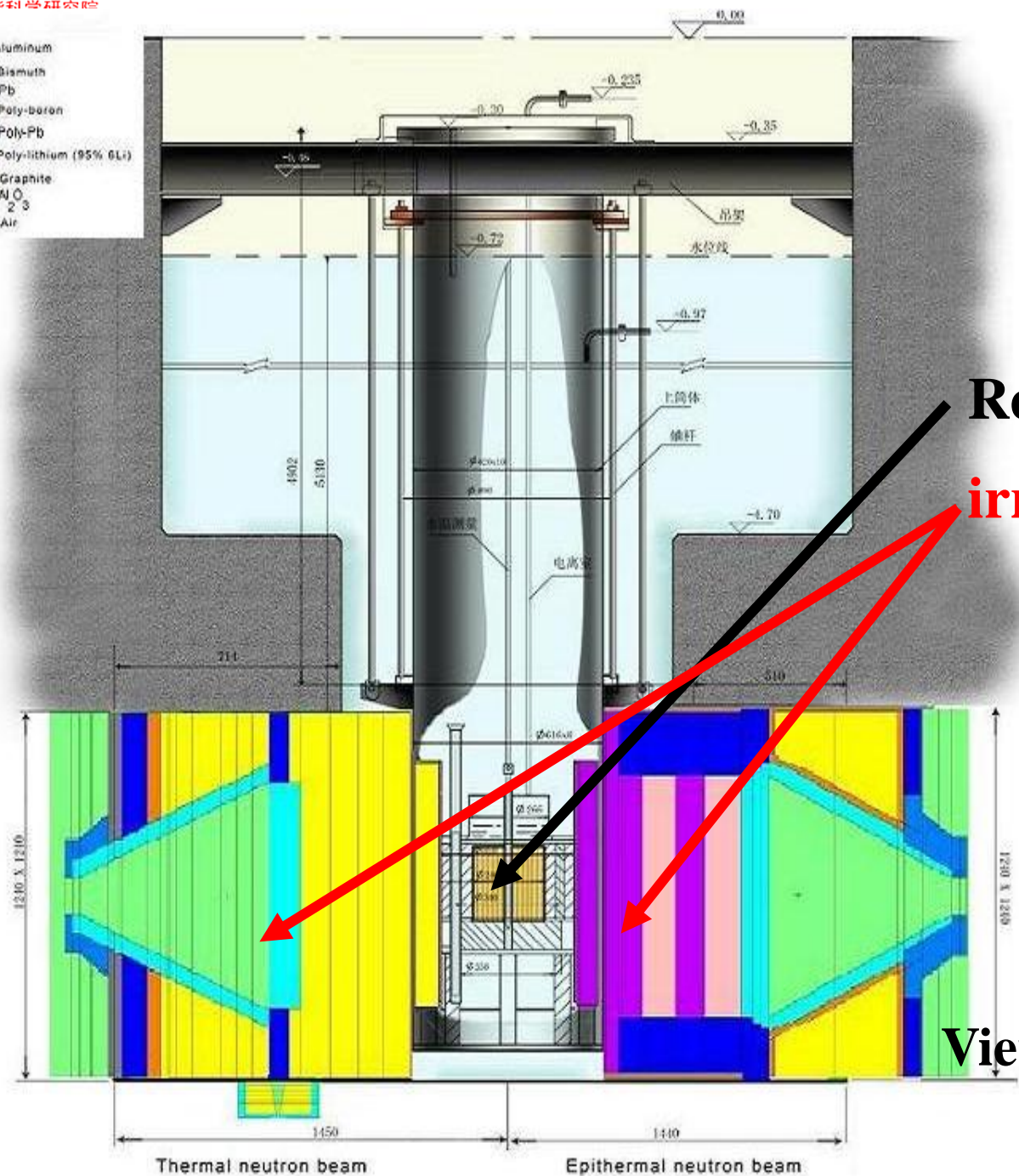
- ✓ BNCT
- ✓ NAA
 - ✓ Thermal neutron
 - ✓ Epithermal neutron
- ✓ Production of the RIs with short lived
- ✓ Research, education and training
- ✓ Detector test

- **The secret of the death of Guangxu Emperor (1871-1908) of Qing Dynasty** is resolved by NAA.
- **Analysis result: Arsenic poison**
- **It has a good advertise of the applications of RR.**

Loading lattice of MNSR-I



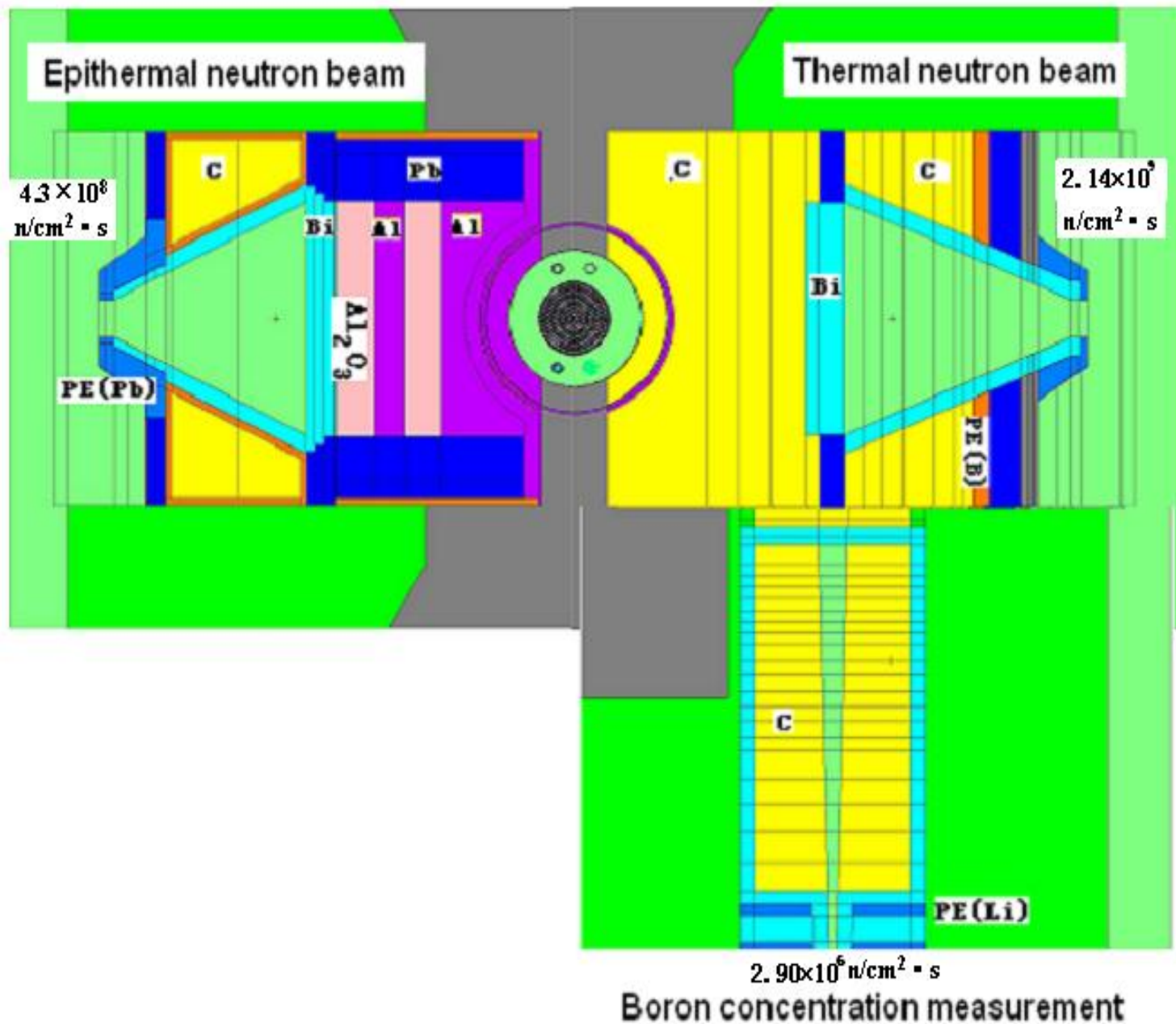
- Aluminum
- Bismuth
- Pb
- Poly-boron
- Poly-Pb
- Poly-lithium (95% 6Li)
- Graphite
- Al_2O_3
- Air



Reactor core

irradiation beam

View of MNSR-I



The figure of neutron beam equipment

Other (ZPR) facilities



ZPR Facility: HWZPR, FZPR, SZPR, USZPR, etc.

CARR project: ***China Advanced Research Reactor***



CEFR project: ***China Experimental Fast Reactor***

- Power: 65MWth and 20MWe, demo
- Fuel loading start at June 10, 2010
- Estimated critical date: July 20, 2010
- 79 FAs will be critical by calc.



2. Utilization of existing RRs in CIAE

utilization items	HWRR	SPR	MNSR
Fuel element and material Irradiation test	√	√	
RIs production	√	√	√
NAA	√	√	√
Silicon NTD	√	√	
Neutron Scattering	√		
Gemstone coloration		√	
Radiography	√	√	
Personal training	√	√	√

2.1 PWR Fuel Assembly Test Loop in HWRR



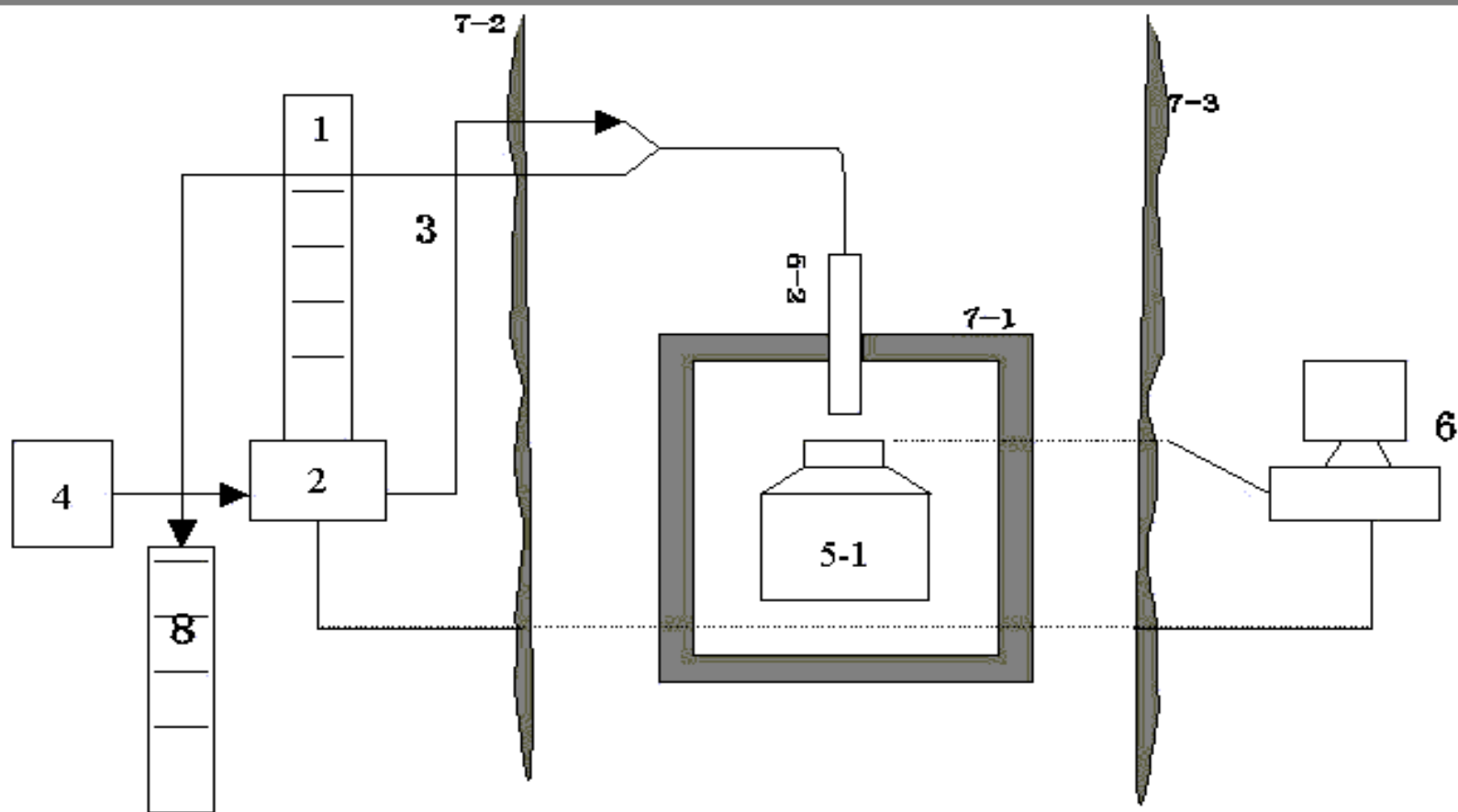
2.2 RIs Production

- more than 20 RIs have been irradiated, such as: ^{198}Au , ^{82}Br , ^{14}C , ^{51}Cr , ^{64}Cu , $^{55+59}\text{Fe}$, ^{153}Gd , ^{203}Hg , ^{125}I , ^{90}Y , ^{131}I , ^{32}P , ^{99}Mo , ^{35}S , ^{153}Sm , ^{46}Sc , ^{113}Sn , ^{60}Co , ^{58}Co , ^{192}Ir , etc
- 5 RIs are produced routinely, they are ^{131}I , ^{32}P , ^{153}Sm , ^{60}Co , ^{192}Ir

2.3 NAA

- **activities of NAA in CIAE can be traced back to the early 1960s**
- **NAA facilities for sample preparation, irradiation, measurement, automatic sample changer as well as computer software has been developed.**

A computer controlled automatic sample changer



- | | | | |
|-------------------------------|--------------------------------|-------------------|---------------------------|
| 1. Rack for sample sending; | 2. Converter; | 3. Tubing system; | 4. Compressed air system; |
| 5-1. HPGe Detector; | 5-2. Sample counting terminal; | | 6. PC Control system |
| 7-1. Lead Chamber; | 7-2. Reinforced concrete wall; | | 7-3. Common wall |
| 8. Rack for sample retrieving | | | |

A computer controlled automatic sample changer



Lead Chambers



A Gamma spectrometer and measurement System



2.4 Neutron scattering

- ☐ Powder neutron diffractometer
- ☐ Four circle diffractometer
- ☐ Triple axis spectrometer
- ☐ Double-chopper TOF spectrometer
- ☐ SANS spectrometer with a 64x64 elements ^3He position sensitive detector
- ☐ Be-filter wide angle detector spectrometer

research activities of neutron scattering

- ❑ Crystallographic and magnetic structures of **rare-earth-iron permanent magnetic alloys** were studied by neutron powder diffraction, and the studies are mainly focused on the R_2Fe_{17} and RFe_{12} series, the atom occupancies and magnetic moments of magnetic atom were obtained by the Rietveld analysis program.
- ❑ Powder neutron diffraction studies and measurement of neutron inelastic scattering spectra of **high-Tc superconductor**, such as Hg – 1223, $YBa_2(Cu_{1-y}Co_y)_3O_x$ and $YBa_2Cu_3O_{6+\delta}$.
- ❑ Small angle neutron scattering study of **biology sample** has been also done, e.g. The association effect for studies of Human Serum Albumin under different concentration of Zinc ion [Zn^{2+}].
- ❑ Single crystal structure analysis of **non-linear optical material** has been done on Four Circle Diffractometer, such as Deuterium (Hydrogen) L-Arginine Phosphate monohydrate D(H)LAP. In this investigation, the length of hydrogen bond and molecular structural formula have been determined .
- ❑ Lattice dynamics studies of **functional materials** (such as Invar alloys, shape memory alloys): Generalized phonon densities of states (PDOS) on amorphous $Fe_{90-x}Co_xZr_{10}$ ($x=10$ and 40) were measured by time of flight spectrometer at room temperature. The results show that the generalized PDOS below 17meV become soft at the Invar concentrations.

2.5 Education and Training

- ❑ NPP staff, especially for the new employee and operators;
- ❑ The students, including undergraduates, masters and doctors;
- ❑ Operators from other RRs
- ❑ Overseas engineers and technicians
- ❑ Support the Nuclear Industrial (organization, government officer, engineering of NPP)

Proverb: Old chicken with much more eggs!

Operation practice by the NPP operators under-supervising



3. The history and Current status of CARR

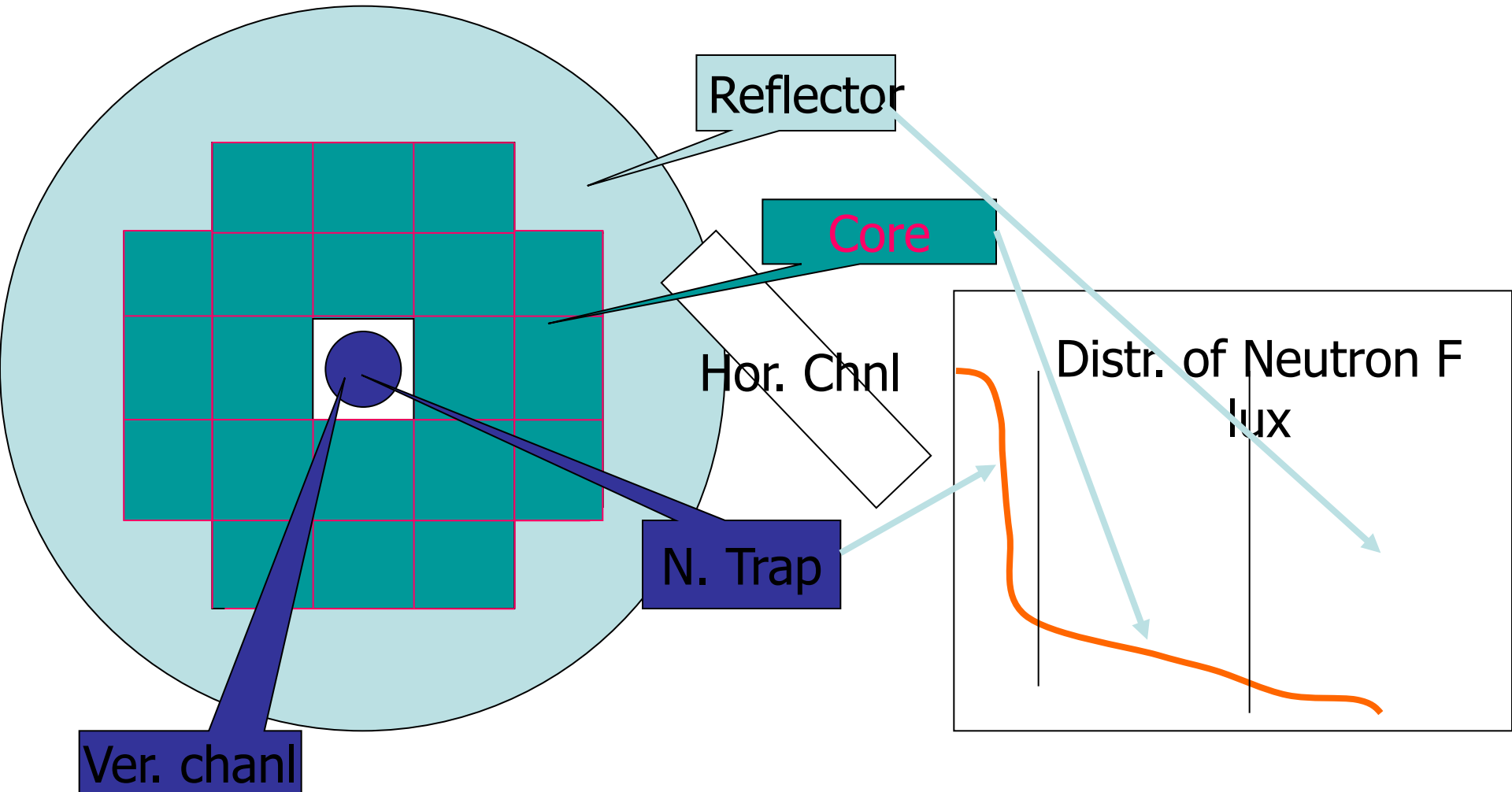


- The brief introduction to CARR
- The construction history of CARR
- The current status of CARR

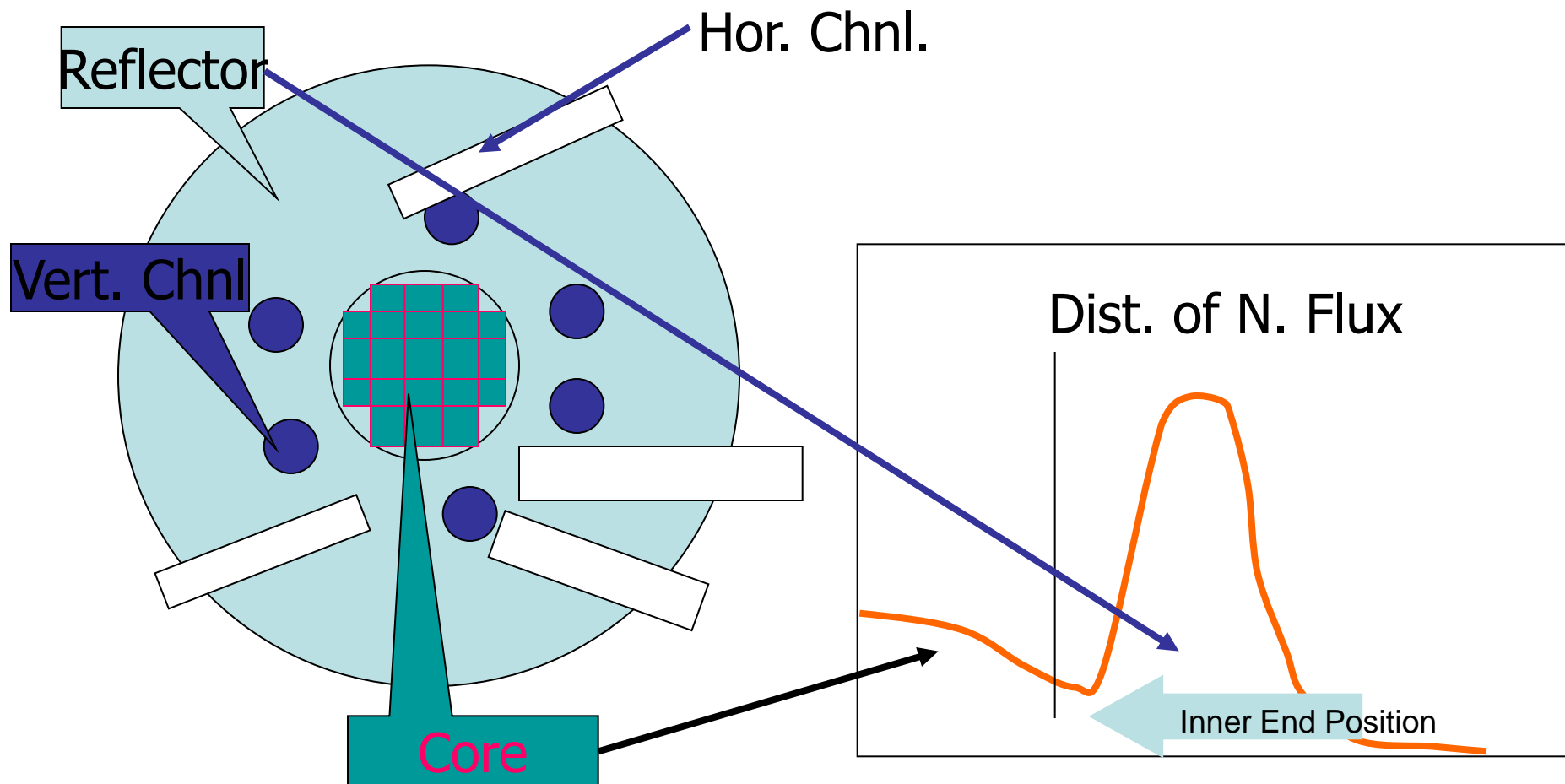
Brief introduction to CARR

- China Advanced Research Reactor (CARR) had approached its first criticality on May 13, 2010
- Pool-tank type
- Nuclear Power: **60 MW**.
- A **compact core** composed of 17 standard FAs and 4 control rods with FAs follower
- H₂O coolant, D₂O reflector
- Maximum thermal neutron flux:
 $8 \times 10^{14} \text{ n}\cdot\text{cm}^{-2}\cdot\text{s}^{-1}$ in reflector; $1 \times 10^{15} \text{ n}\cdot\text{cm}^{-2}\cdot\text{s}^{-1}$ in central FAs replacing by irradiation rig.

Neutron Trap Type



Inverse Neutron Trap



Brief introduction to CARR

- The MTR type FA
- U_3Si_2 -Al dispersion fuel
- ^{235}U enrichment: 19.75 wt%
- Uranium density of the fuel: 4.3 g/cm³
- Total loading of ^{235}U for a fresh core: 11.0kg
- Core height: 850 mm
- Vertical channels: 21
- Beam tubes: 9

Pipe of
hot-water layer

Tube for
Ionization chamber

Pipe of
Primary loop

Flow guiding tank

Heavy water tank

Decay tank

Pool gate

Concrete
shielding

Reactor pool

Safety rod drive
mechanism

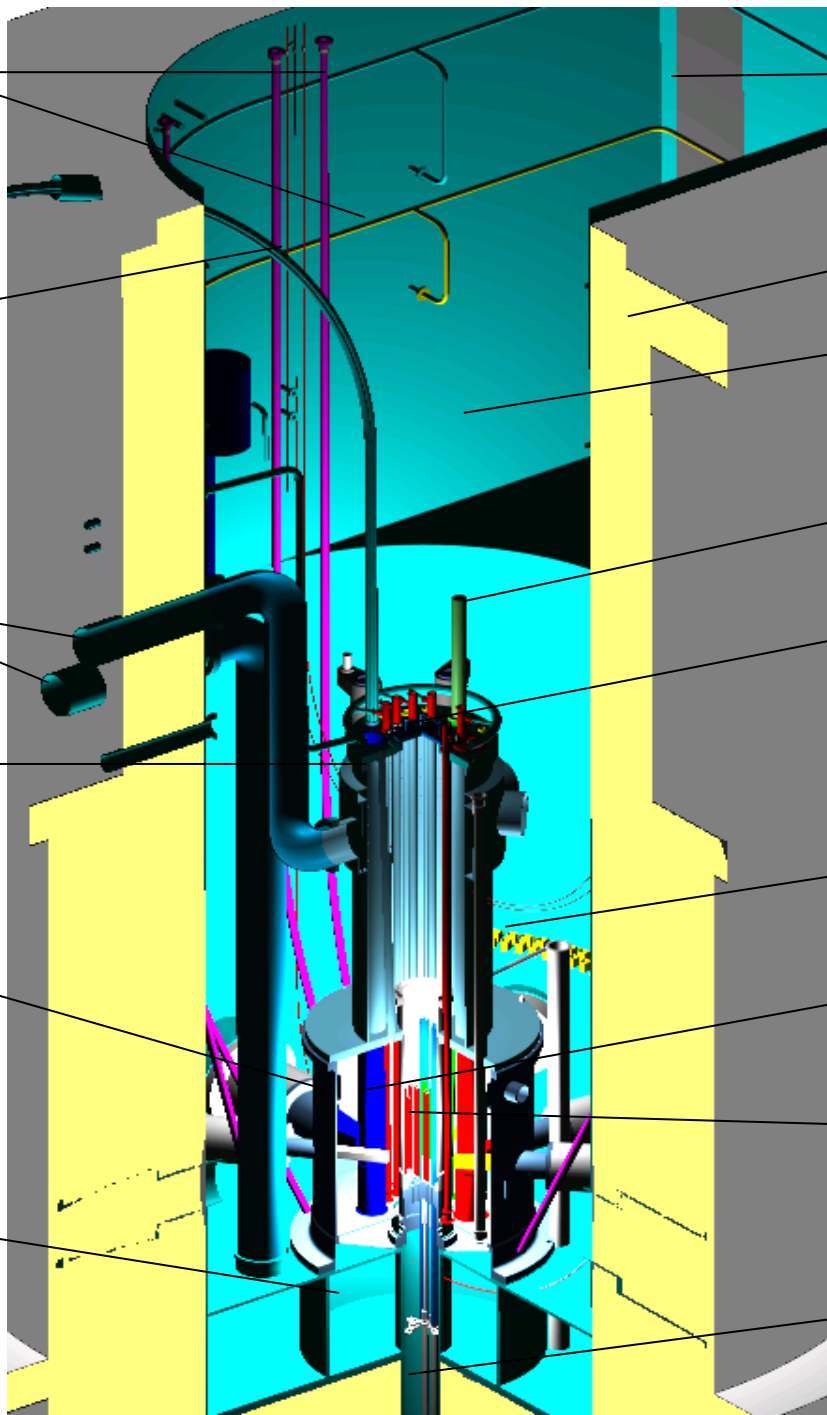
Vertical channel

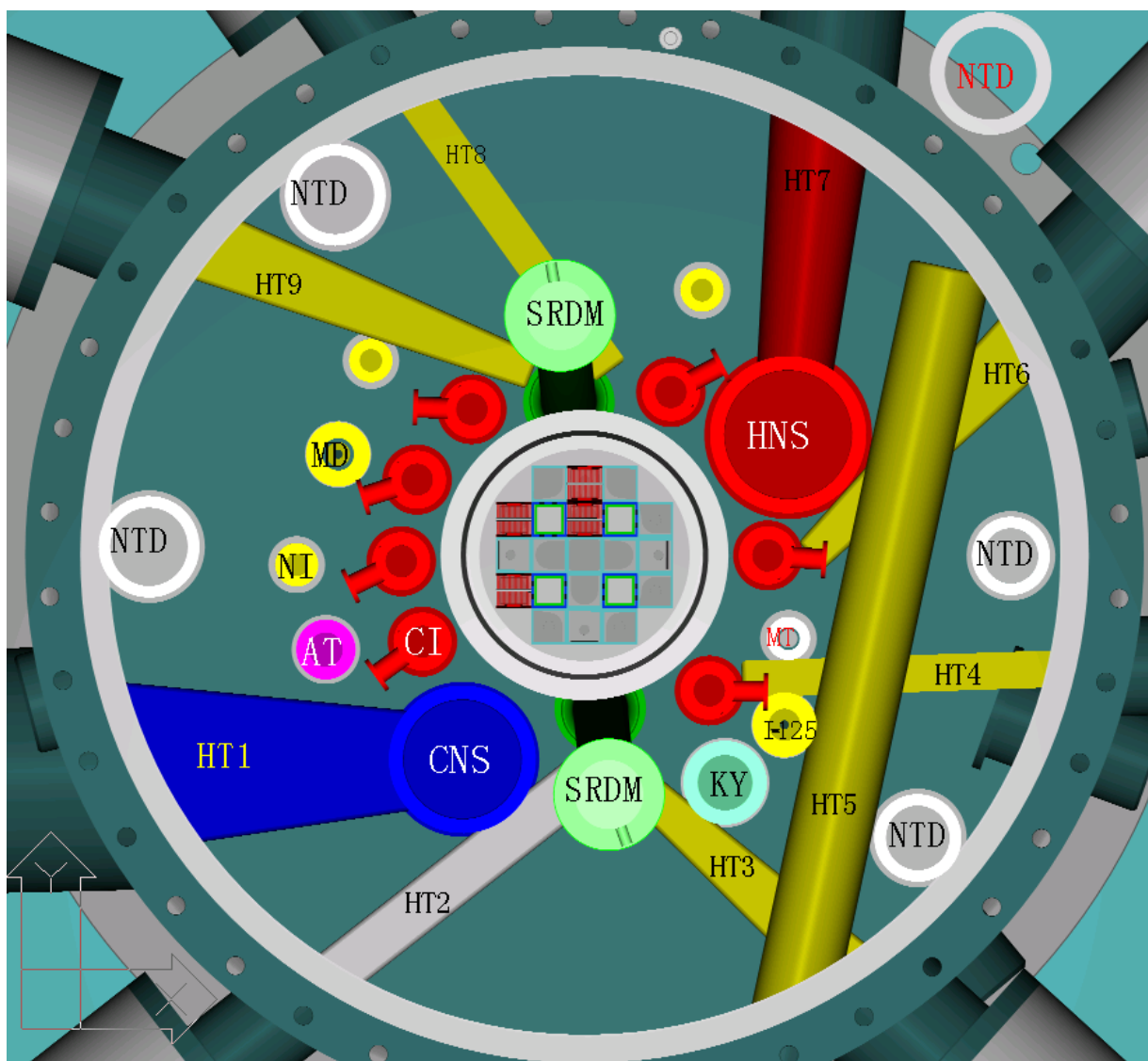
Storage shelves of
spent fuel assembly

Core vessel

Fuel assembly

Control rod drive
mechanism





Vertical channels:

CNS: Cold neutron source

HNS: Hot neutron source

CI: Water cooling RI

MT: Material irradiation

I-125: I-125 RI

KY: Fuel Test

NTD: NTD Silicon

MD: Mo-Tc generator

AT: NAA

NI: RIs

SRDM: Safety rod
drive mechanism

Horizontal beam tubes:

HT1: Cold neutron source

HT2: Multi-filtration

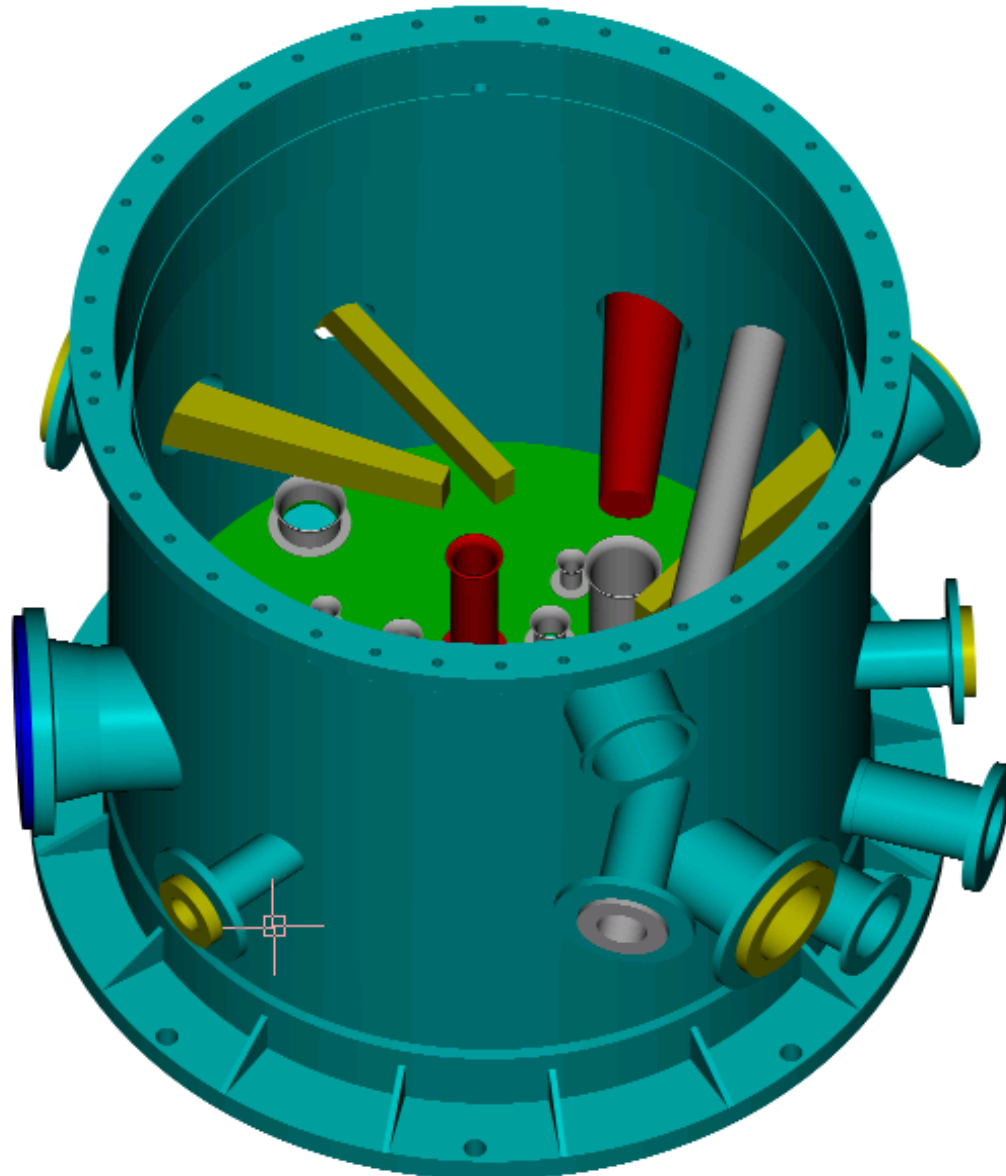
HT3/HT4/HT6/HT8/HT9:

Thermal beam tubes

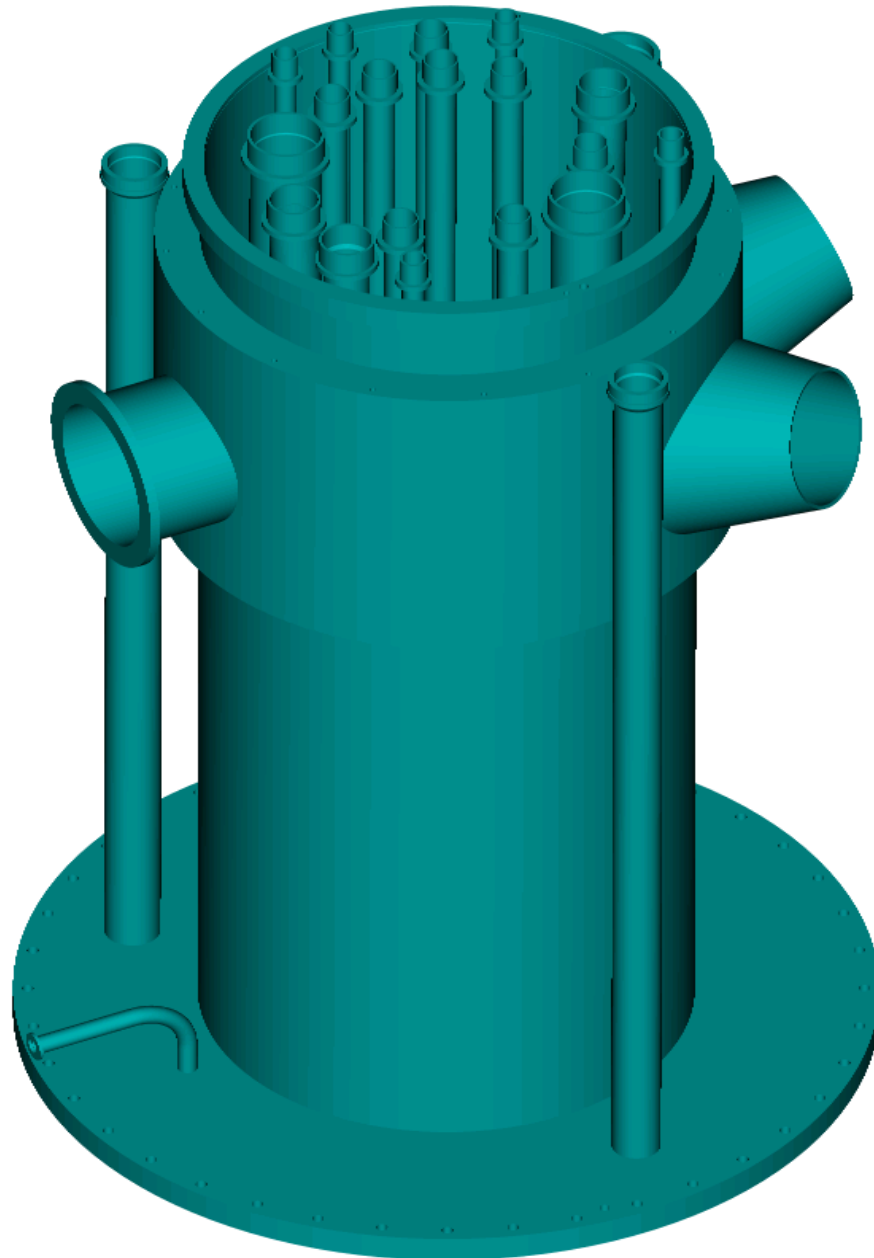
HT5: tangential beam tube

HT7: Hot neutron source

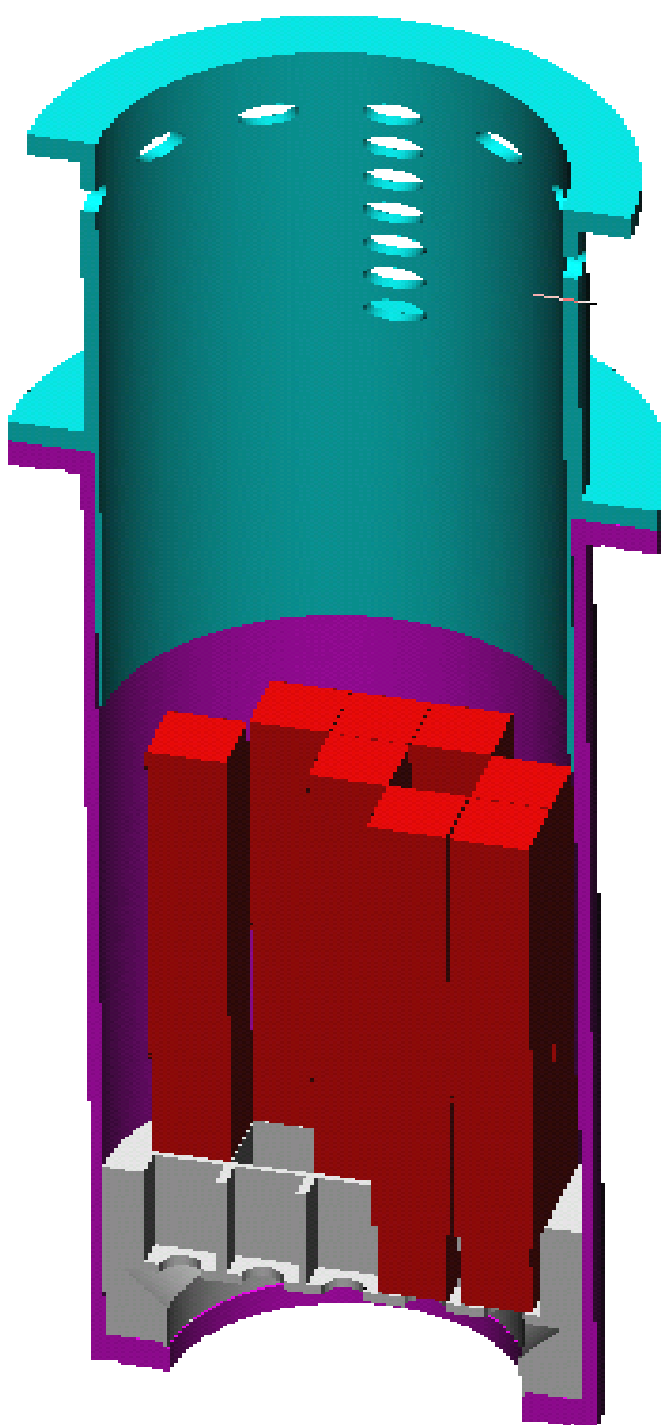
Heavy water tank



Flow-guiding tank



Core vessel



Main control room of CARR



Digital Control System of CARR



The construction history of CARR

- August, 2000, the formal approvemement from government.
- Dec. 2000, the start point (dig)
- August, 2002, the start ceremony
-

中国先进研究堆(CARR)工程开工

2002.8.26



Aug.26,2002, Ceremony of
CARR Project



Main structure of 05sub-item top cover finished



Installation for frame of Horiz. beam channels



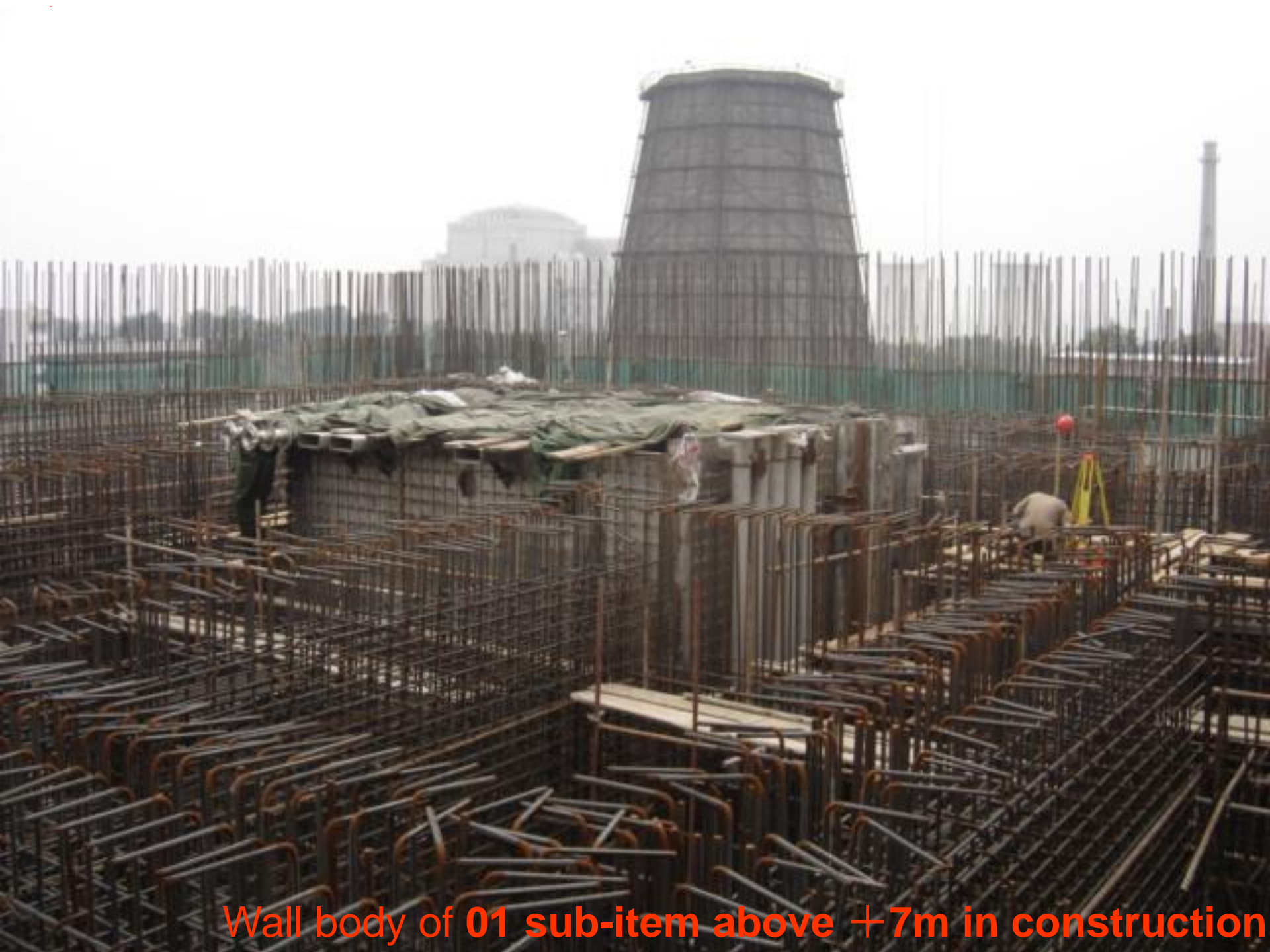
Hoisting of the steel liner



Steel liner set into place



Complete of steel liners welding



Wall body of 01 sub-item above +7m in construction





Low voltage cabinets set place in 03 sub-item(2005.7)



Medium voltage cabinet installation of 03 sub-item(2005.4)



Piping system installation of 03 sub-item(2005.7)



Tests on 6061 (T) Al core vessel(2005.7)



The guiding tank is being hoisted and ready for setting in position

The heavy water tank and guiding tank were installing





Construction of cooling tower base(2005.10)



Construction of hyperbola cooling tower +20m (2006.4)



Completion of hyperbola cooling tower 60m(2006.8)

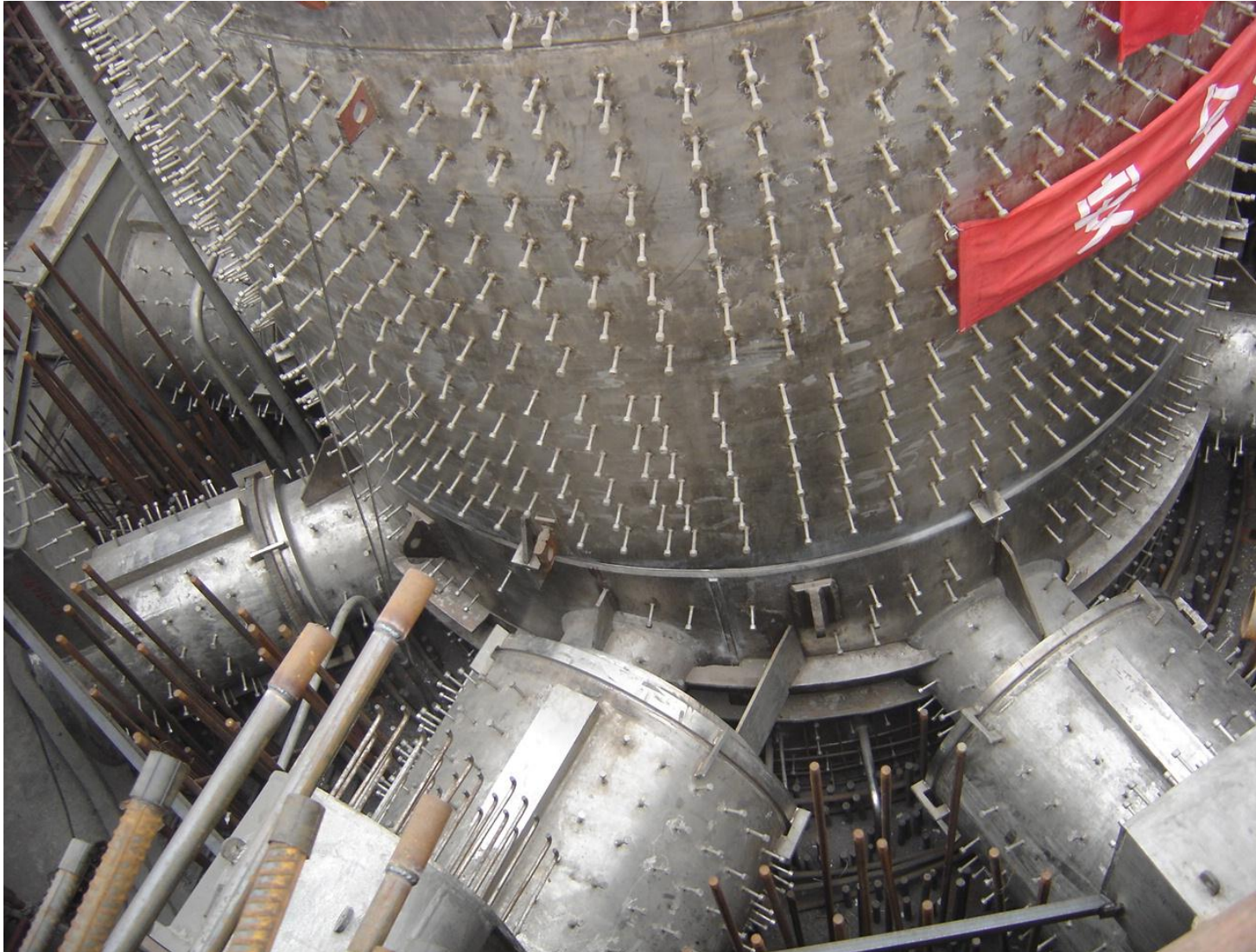


**Loading machine
tests in factory**



Round crane in Experimental hall

Reactor pool liner and beam tubes





Installation of secondary loop piping

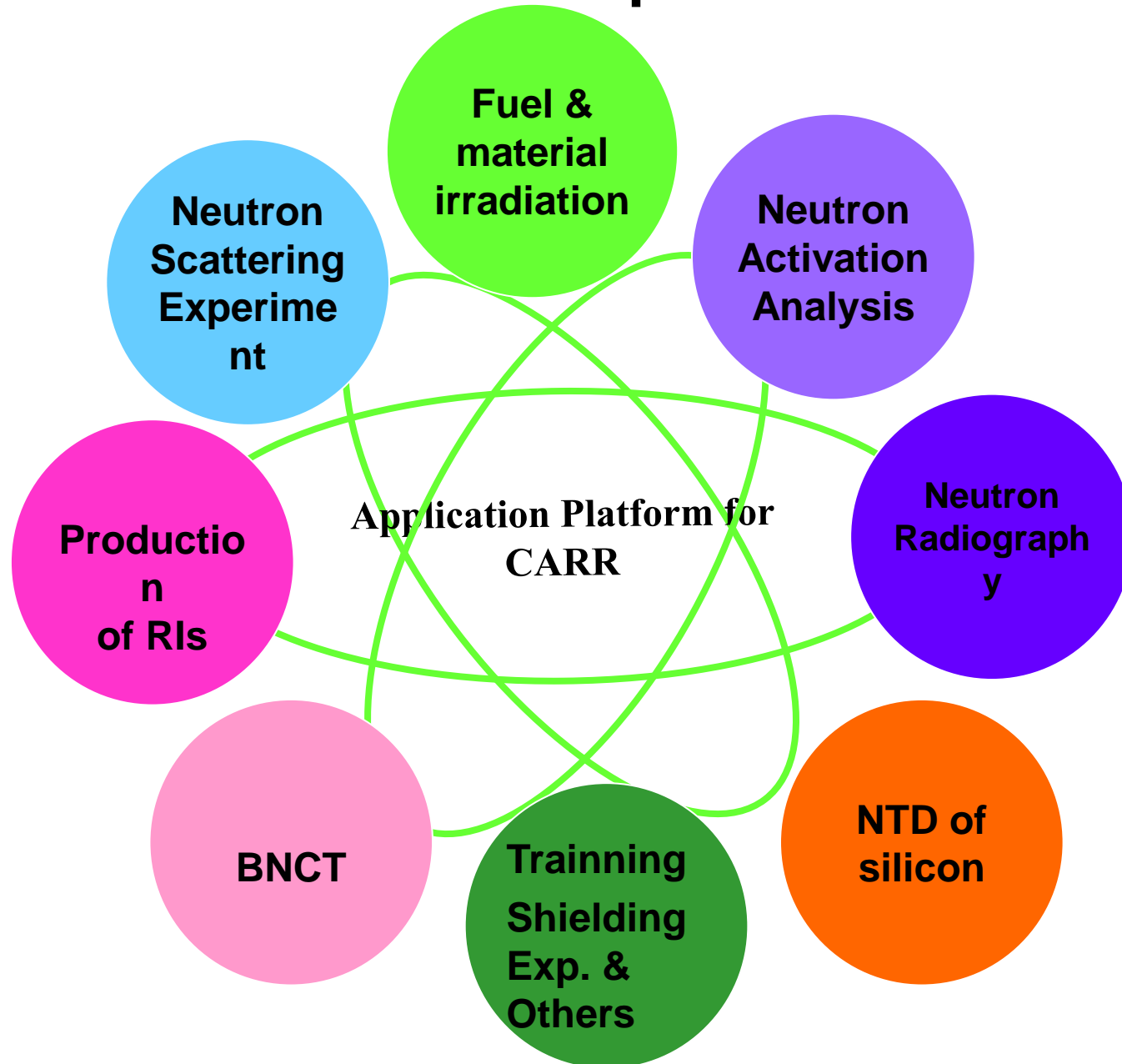


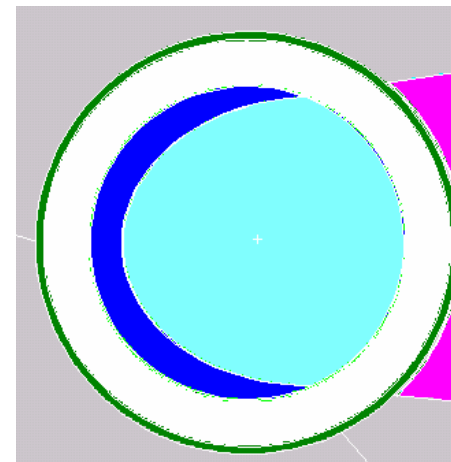
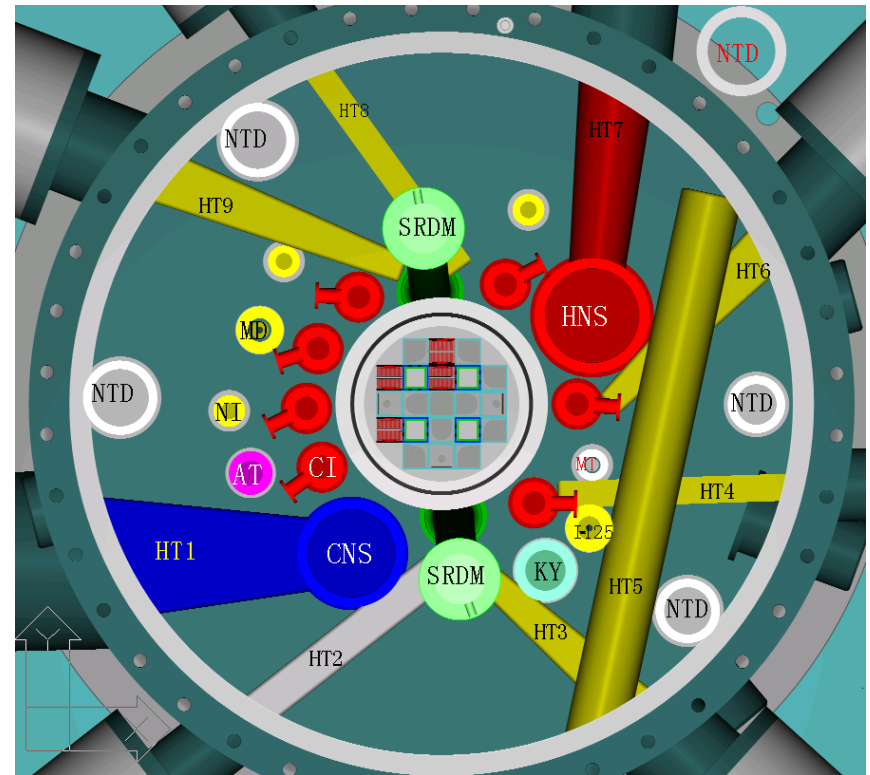
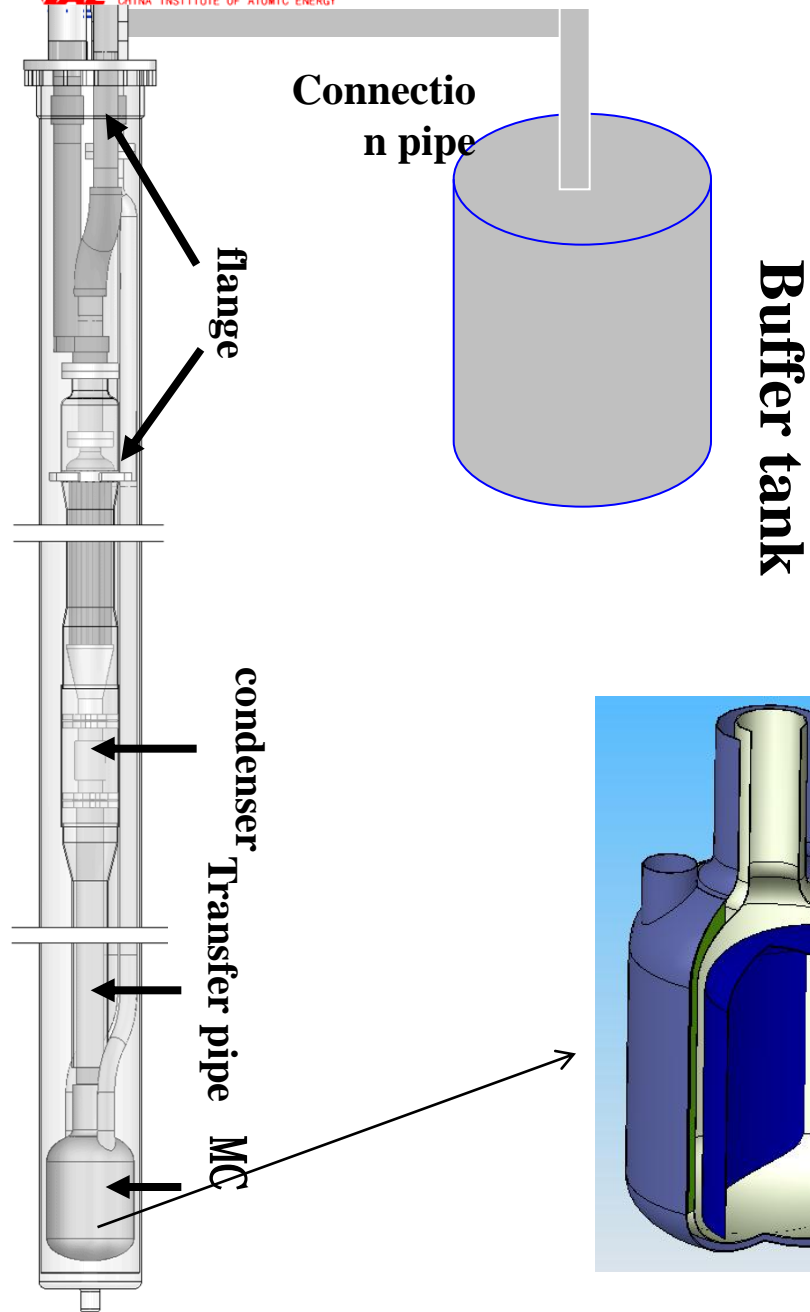
Ventilation stack seated

Next step-The reactor physics experiments

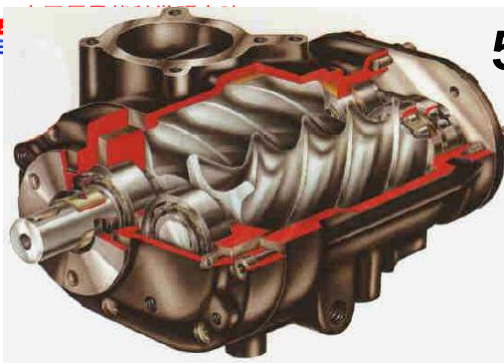
- Full fuel loading:
 - Reactivity: control rods worth; FA worth; kinetics parameters;
 - Neutron spectrum measurement;
 - Neutron distribution measurement, etc.
- With notable power:
 - Poison worth, control rods worth, temperature coefficient, power coefficient, and so on;
- Full power: to finish it at the end of this year.

4. The utilization plan for CARR

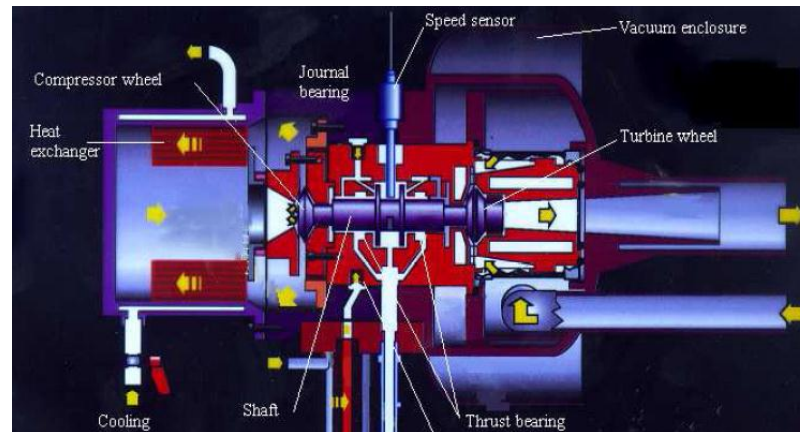
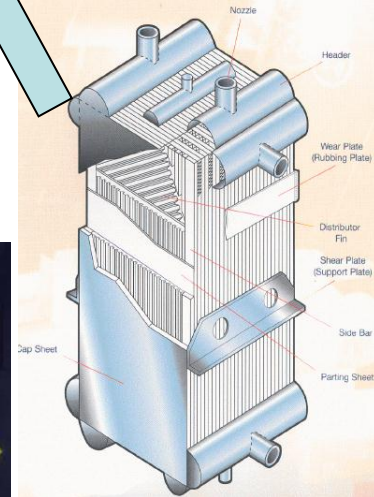
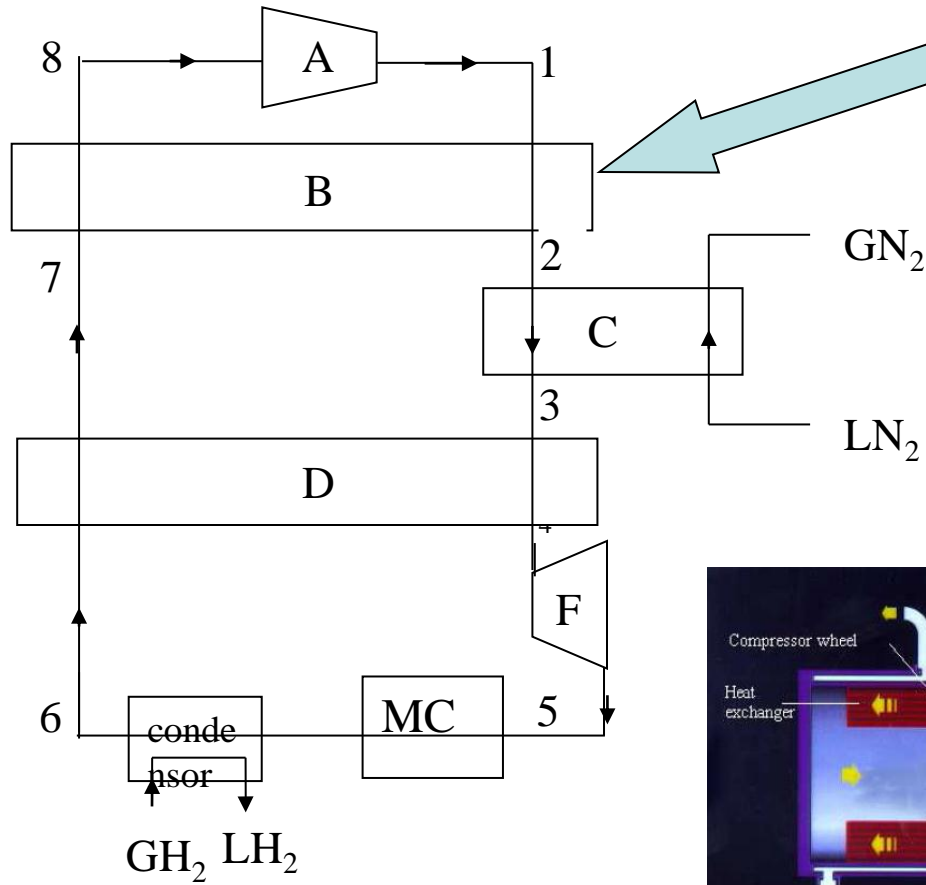




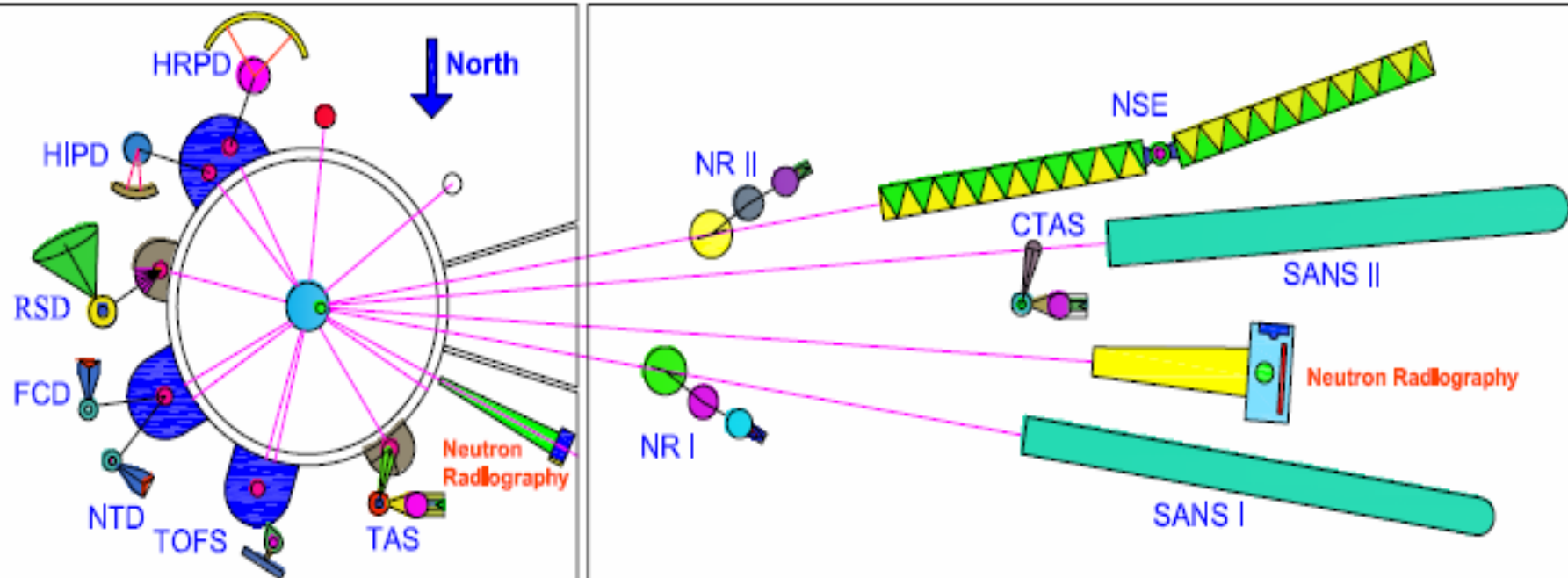
Liquid H2
@21K



5.5kW@14.5K



Sketch map of neutron scattering instrumentation



3.1 Neutron scattering experiment facilities (to be upgrade from HWRR)

- **Triple-axis spectrometer**
- **Four Circle Diffractometer**
- **Time of flight spectrometer**
- **Small Angle Scattering Instrument**
- **Powder Diffract Texture Gauge**

3.1 Neutron scattering experiment facilities (to be developed in the future)

- **High Resolution Powder Diffractometer,**
- **Horizontal Reflectometer,**
- **Diffraction Stress Gauge,**
- **Spin-Echo Spectrometer,**
- **Backscattering Spectrometer,**
- **Vertical Reflectometer,**
- **Cold Neutron Triple-Axis Spectrometer**
- **High Intensity Powder Diffractometer**

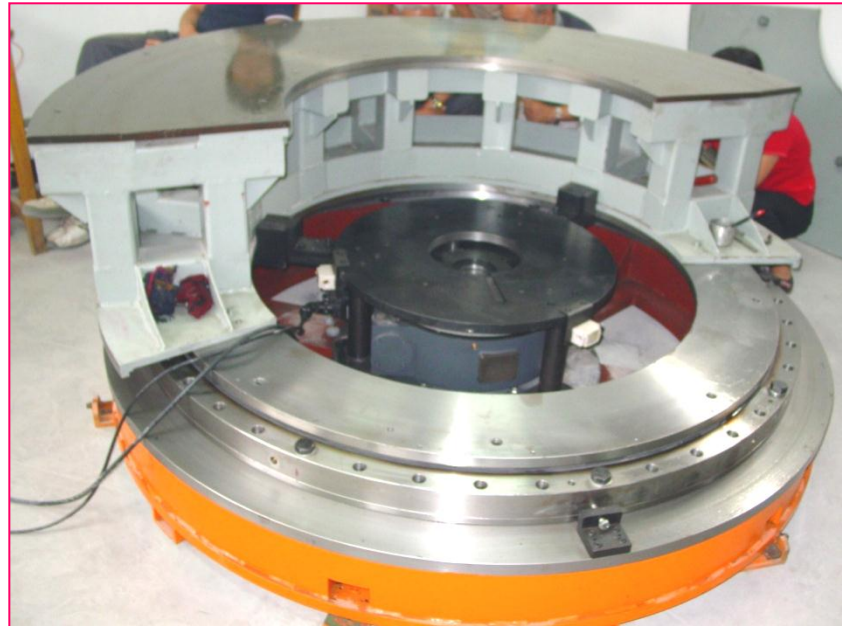
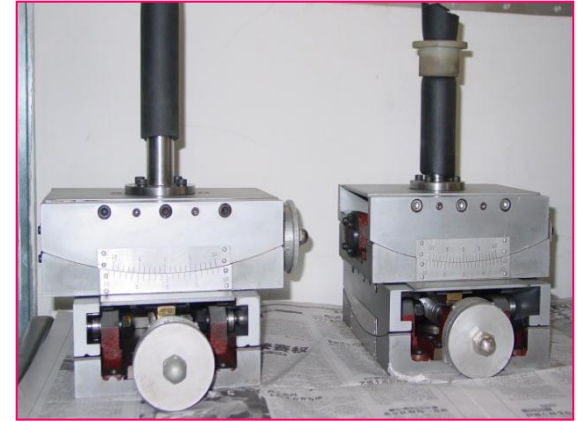
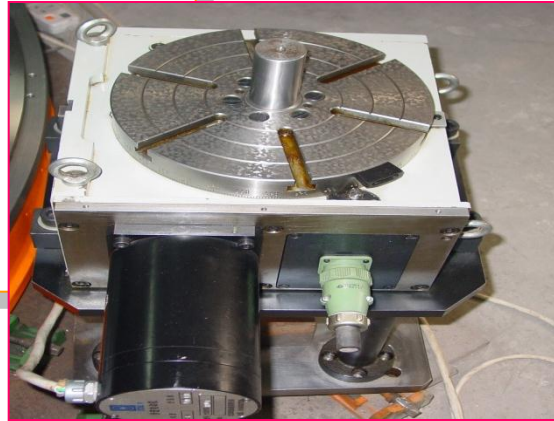
Photo of neutron physics experiment hall



Photo of neutron scattering hall

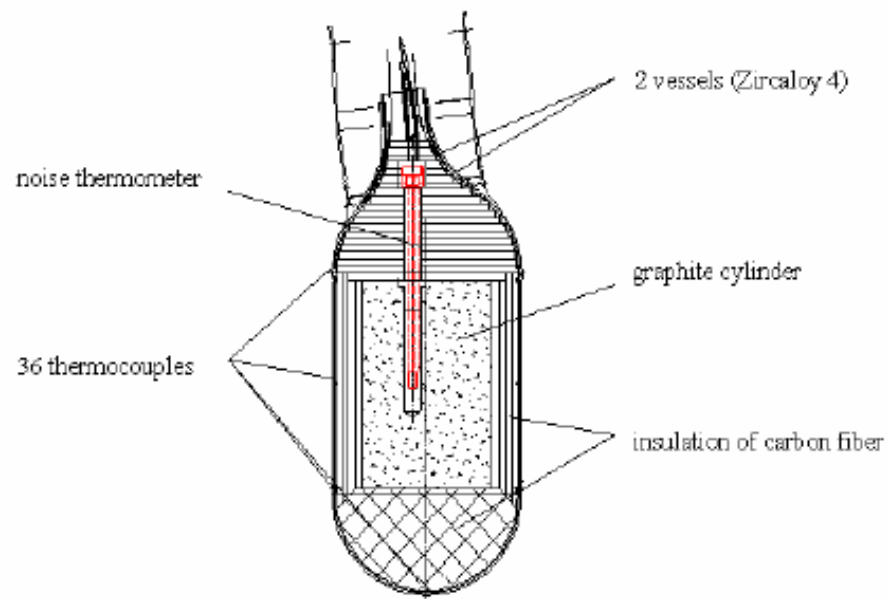
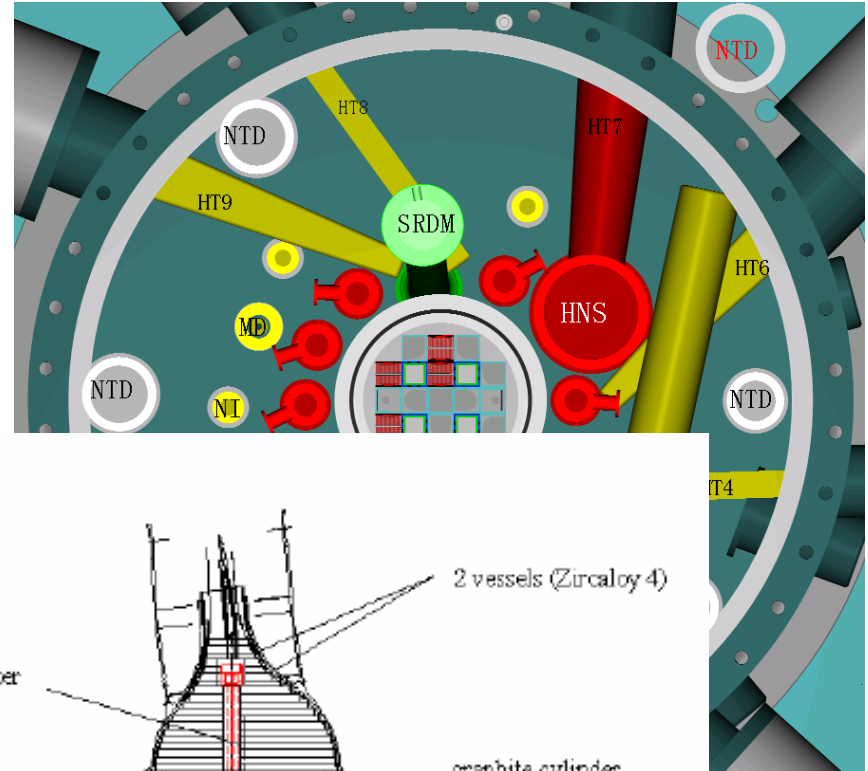


- Motion system Factory
Acceptance Test
June 2007



HNS

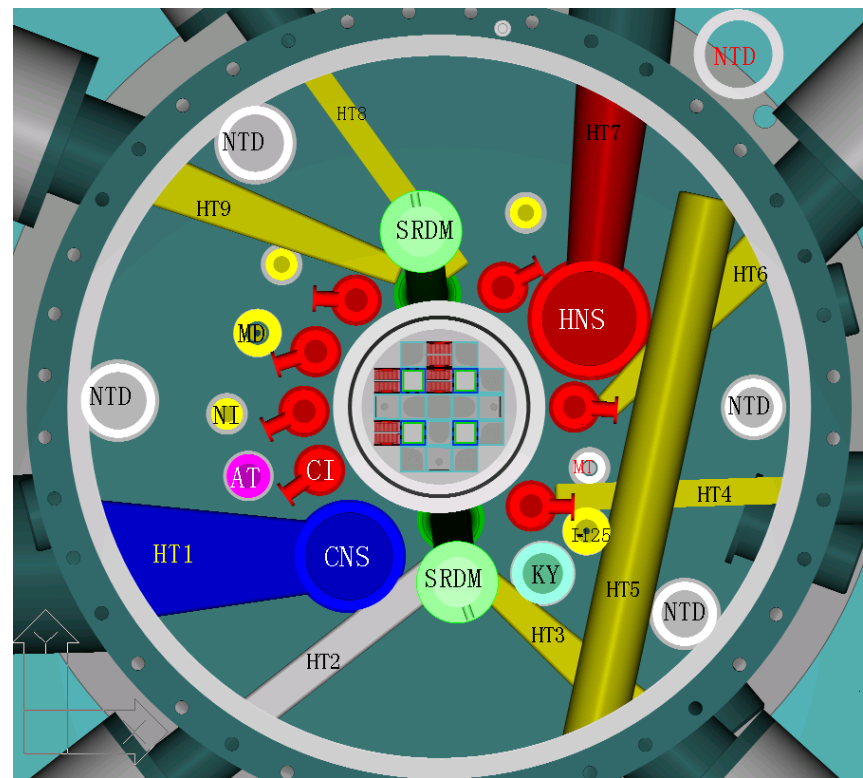
- inner diameter: 280mm
- Similar to FRM-II
- No design now



FRM-II

3.2 Radioisotope production facilities

- 12 Vertical tubes, different flux,
- ^{99}Mo , ^{131}I , ^{113}Sn , ^{125}I , ^{32}P , ^{92}Ir , ^{14}C , ^{35}S , ^{160}Ho and ^{198}Au , etc.
- CI cooling loop is constructed.
- I-125: interrupt circulation mode
- Partial satisfied the requirements from local market now by guess.

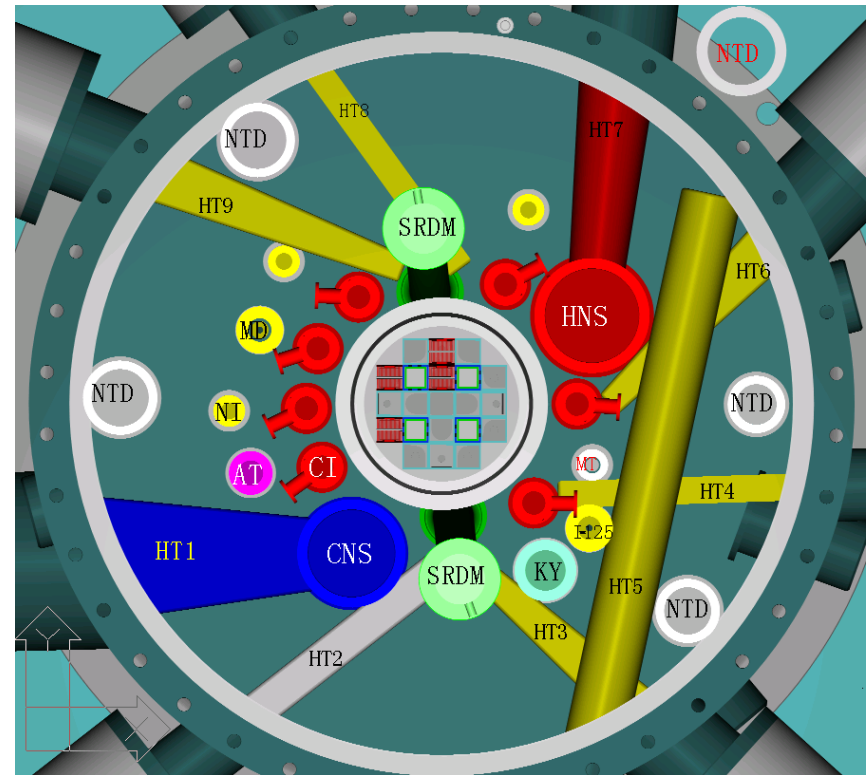


Ideal RIs production abilities

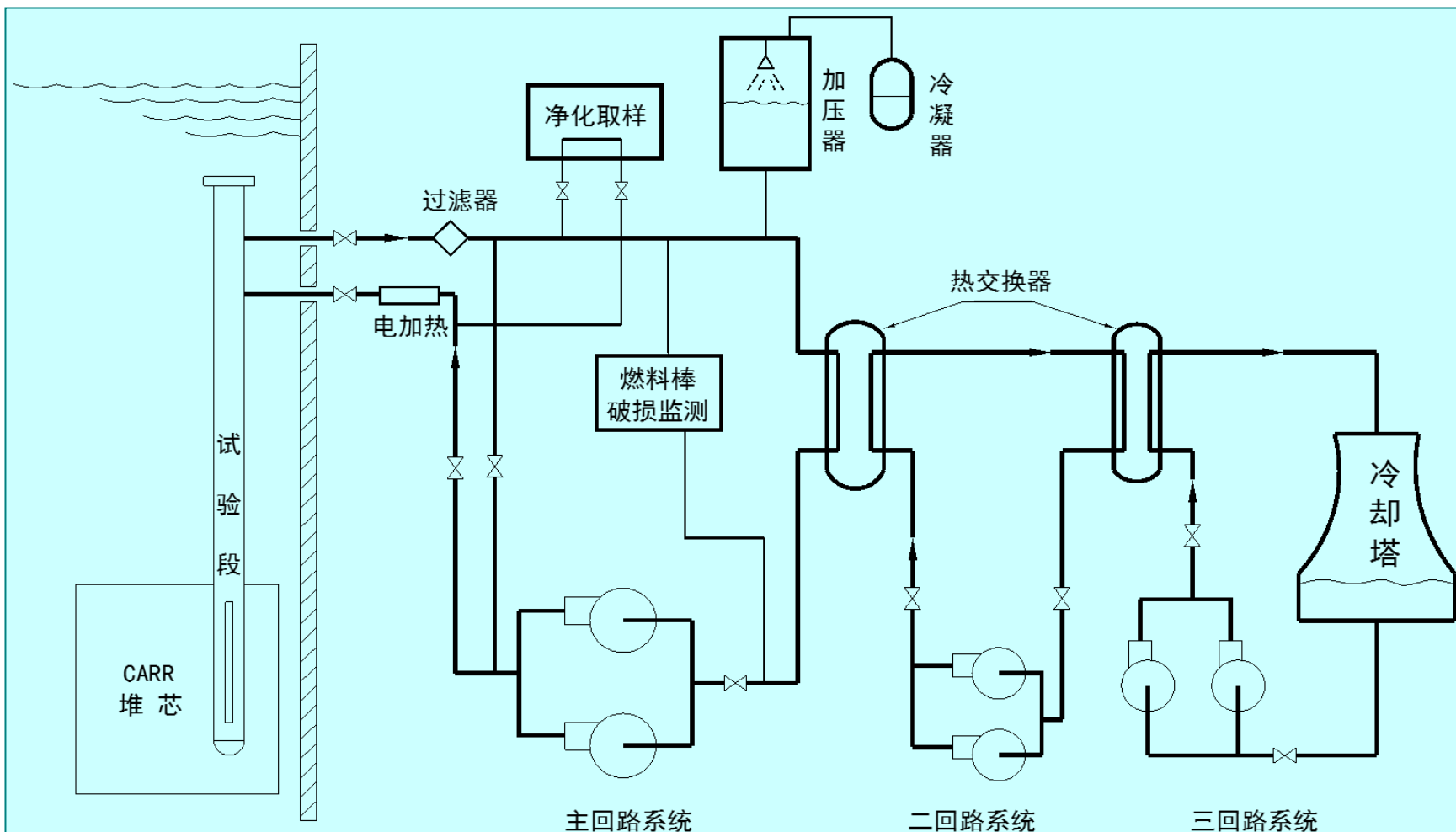
items	CIAE production without	CARR production, Ci/a
	CARR, Ci/a	
^{125}I	60	2717.8
^{131}I	2000	8363.5
^{32}P	100	256.5
^{153}Sm	1000	3828.0
^{131}Ba	15	44.2
^{89}Sr	10	20.2
^{113}Sn	4	9.6
^{166}Ho	0	8392.8
^{188}W	0	953.6 ?
Medical ^{192}Ir -1	4000~7500	21441.6
Indust. ^{192}Ir -2	2250	22023.4
Indust. ^{192}Ir -3	50000	31335.4
Indust. ^{60}Co		35130.2-CANDU NPP

3.3 Fuel & material irradiation test facility

- A high temperature and high pressure testing loop with ^3He gas-adjusting loop will be constructed in CARR.
- The performance tests, high burn-up test, water chemistry activity transport and corrosion test, and fuel integrity and qualification test, etc., could be conducted using this loop and relevant devices.
- Design pressure: 17.5MPa
- Design Temperature: 350C



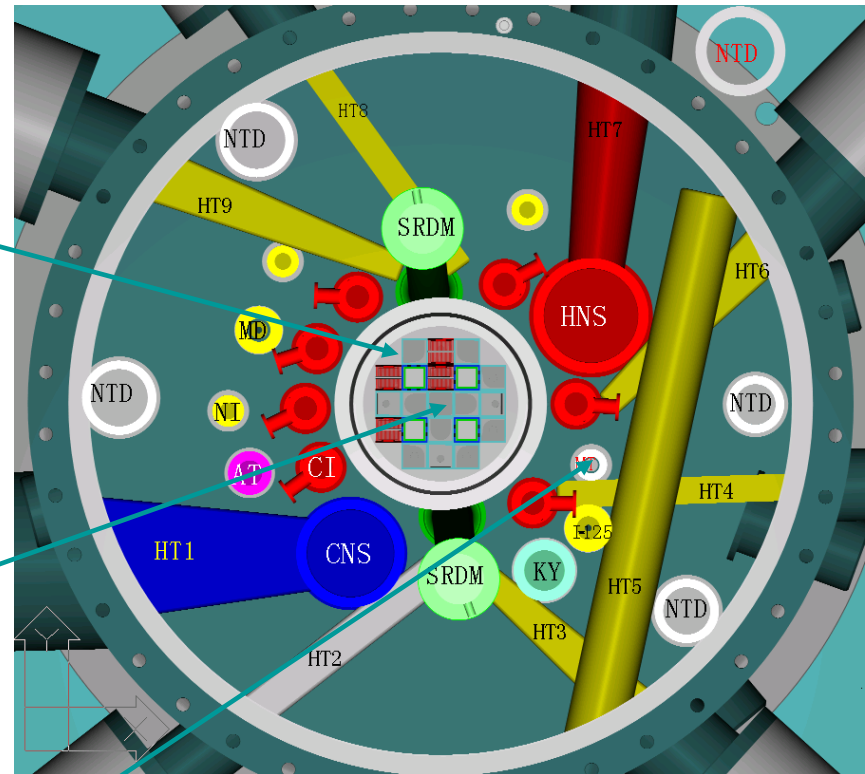
Sketch map of high pressure and temperature loop for fuel and material test



CARR堆内高温高压试验回路示意图

Material test

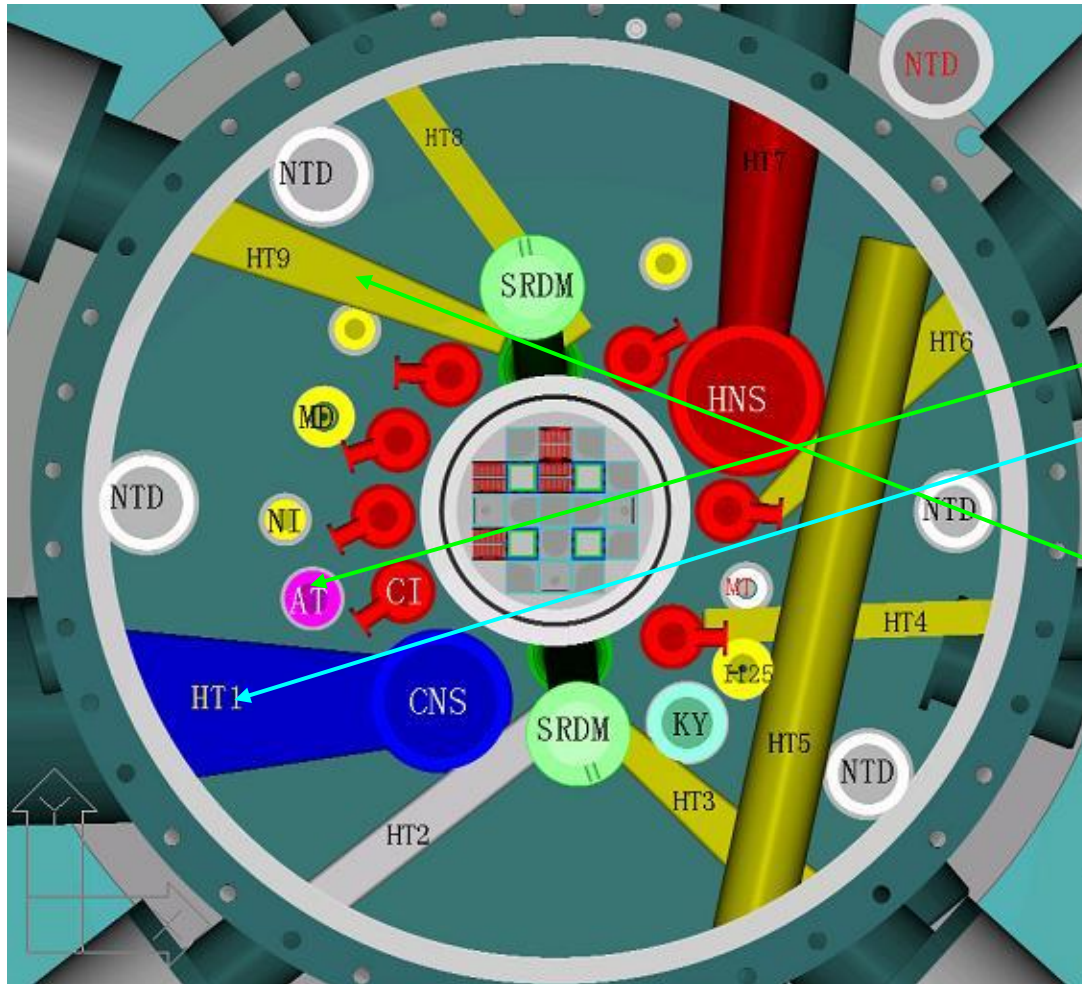
- 6 irradiation position
- 4 channels (inside core vessel, outside the fuel)
 - Distance from the core: 22cm,
 - Inner diameter: 3cm,
 - Light water cooling.
 - Unperturbed fast flux: 2×10^{14}
- Central FA position:
 - Withdraw FA
 - Replaced with irradiation Rig
 - N₂ or He cooling
 - Unperturbed fast flux: 8×10^{14}



3.4 NAA facilities

- >40 years experience in CIAE
- new advanced NAA facilities will be built.
- the sensitivity up to 10^{-6} ~ 10^{-9} gram for most chemical elements.
- Short-lived nuclide NAA System, Prompt Gamma Activation Analysis System (PGNAA), Cold Neutron on PGNAA and Neutron Depth Profiling System will be developed.
- The facilities can be used comprehensively in industry, agriculture, medical science, environmental science, geology and archaeology.

CARR Reactor Channel Layout



AT: NAA Channel

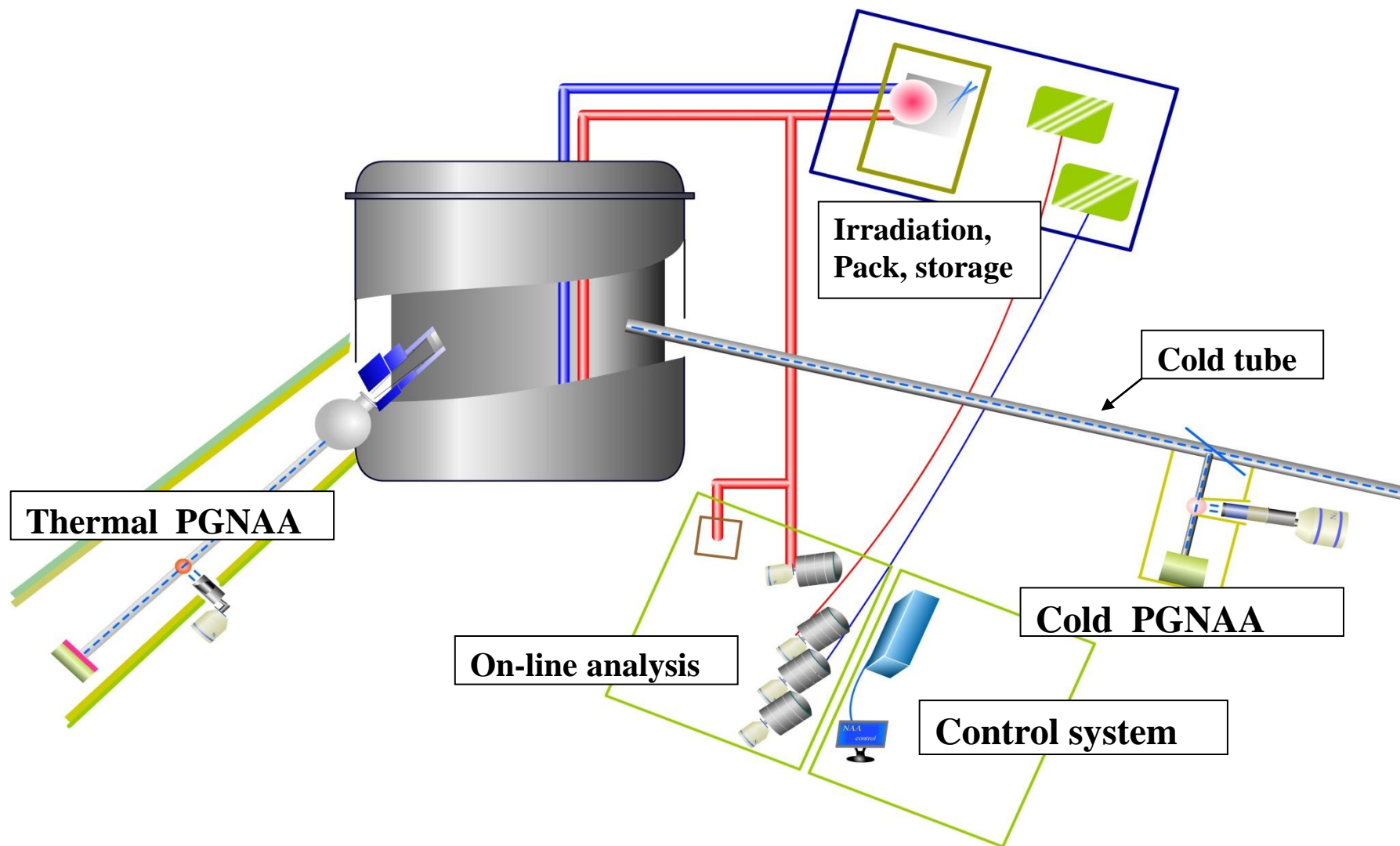
HT1:

**Cold neutron channel
(PGNAA)**

HT9:

**Thermal neutron channe
l (PGNAA)**

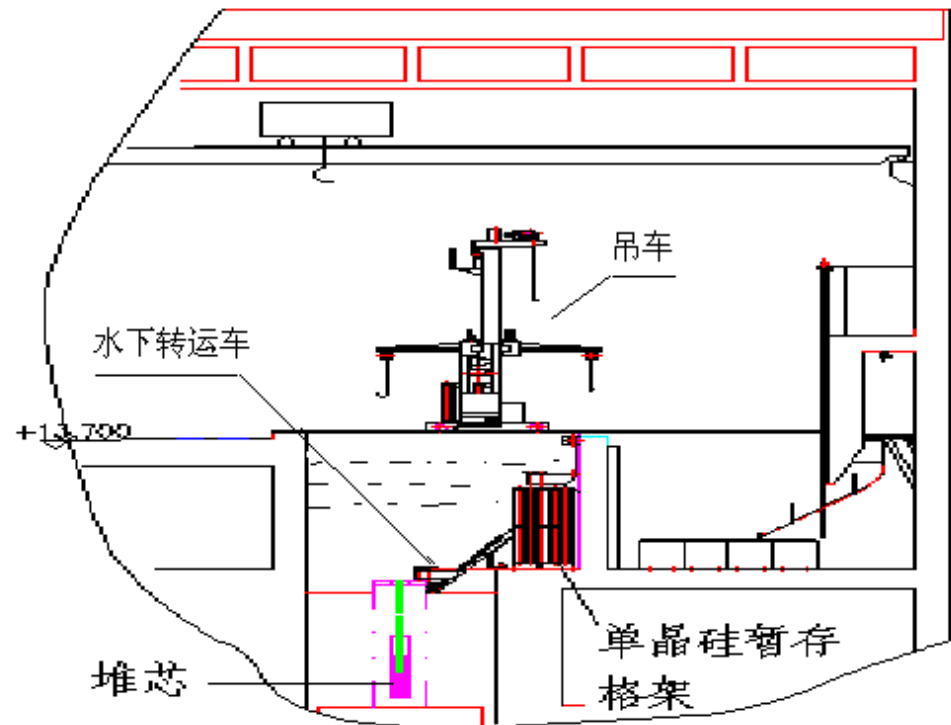
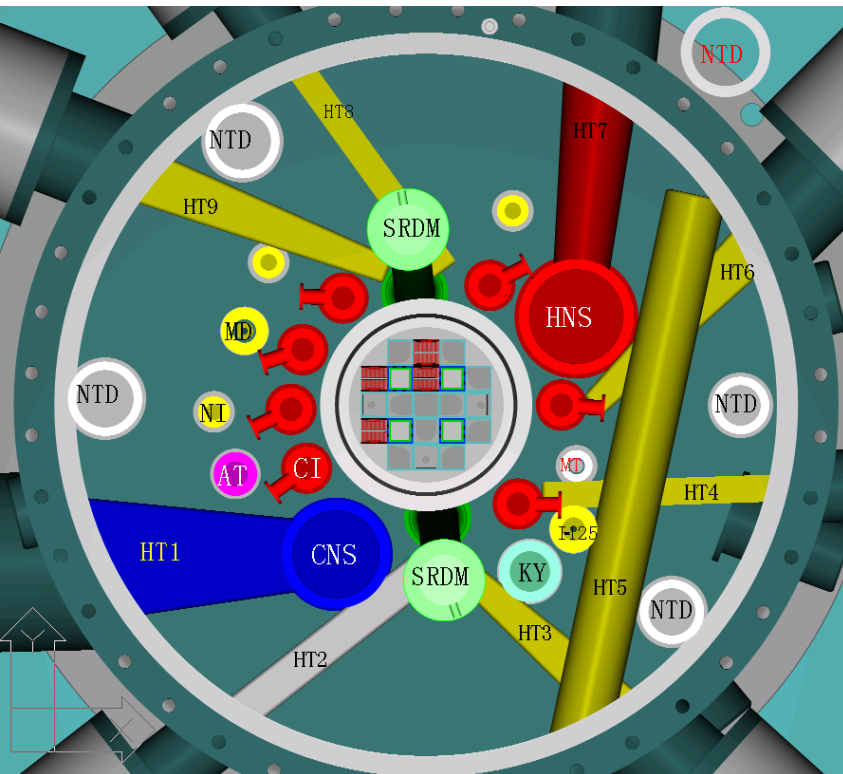
proposed NAA system in CARR



3.4 NTD silicon production facilities

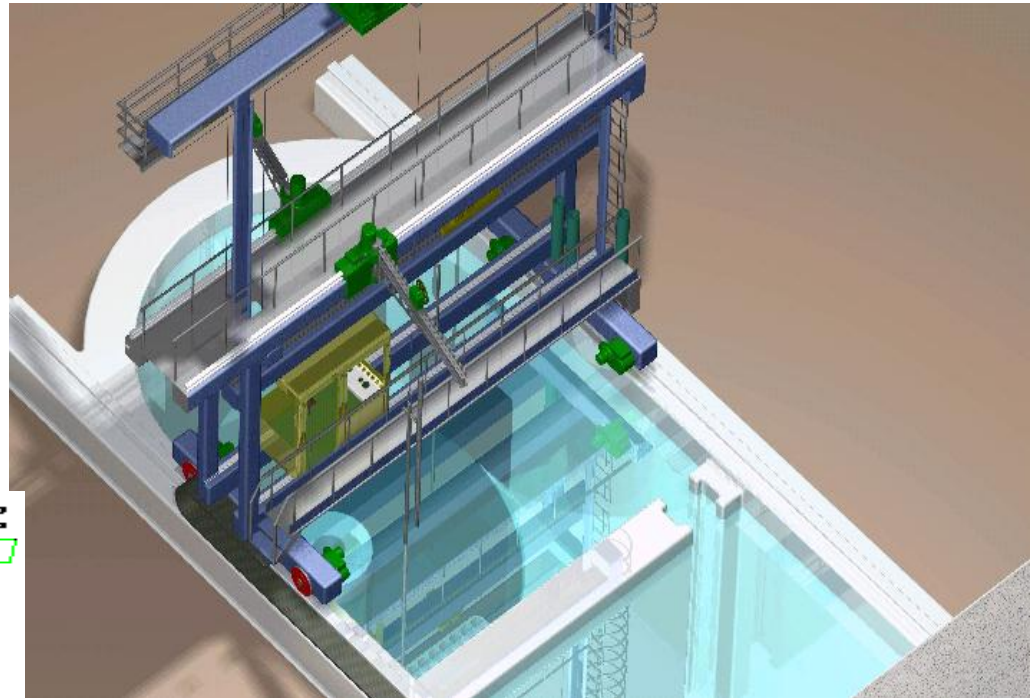
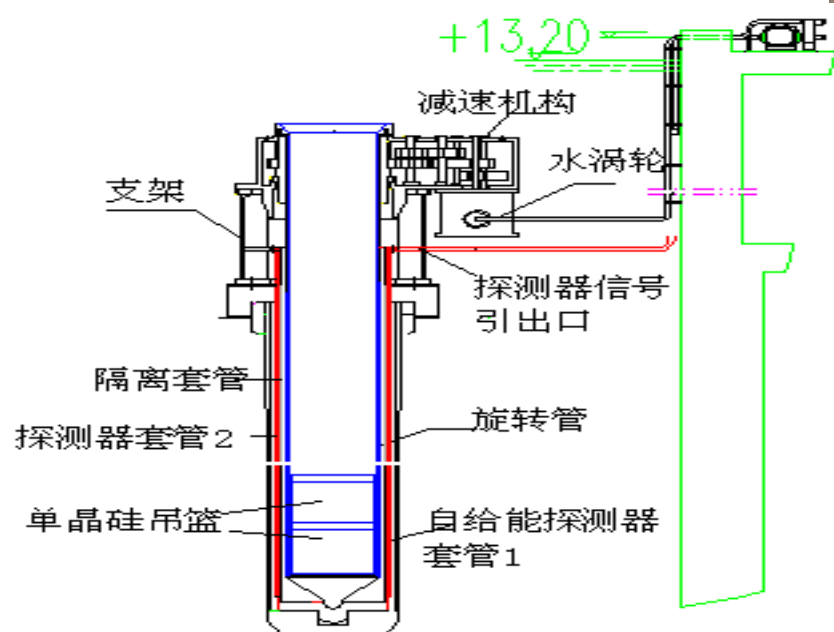
- There are five vertical holes for 3", 4", 5" and 6" Si ingots in CARR.
- Irradiation facilities will be designed for CARR, including:
 - ingot handling equipment in and out of the pool,
 - hydraulic drive mechanism, ingot storage rack during cooling,
 - electric property inspecting equipment,
 - annealing & cleaning equipment,
 - gamma spectroscopy system for fluence measurement, SPND, etc.,

Si Transfer System



Si-ingot Transfer Trolley

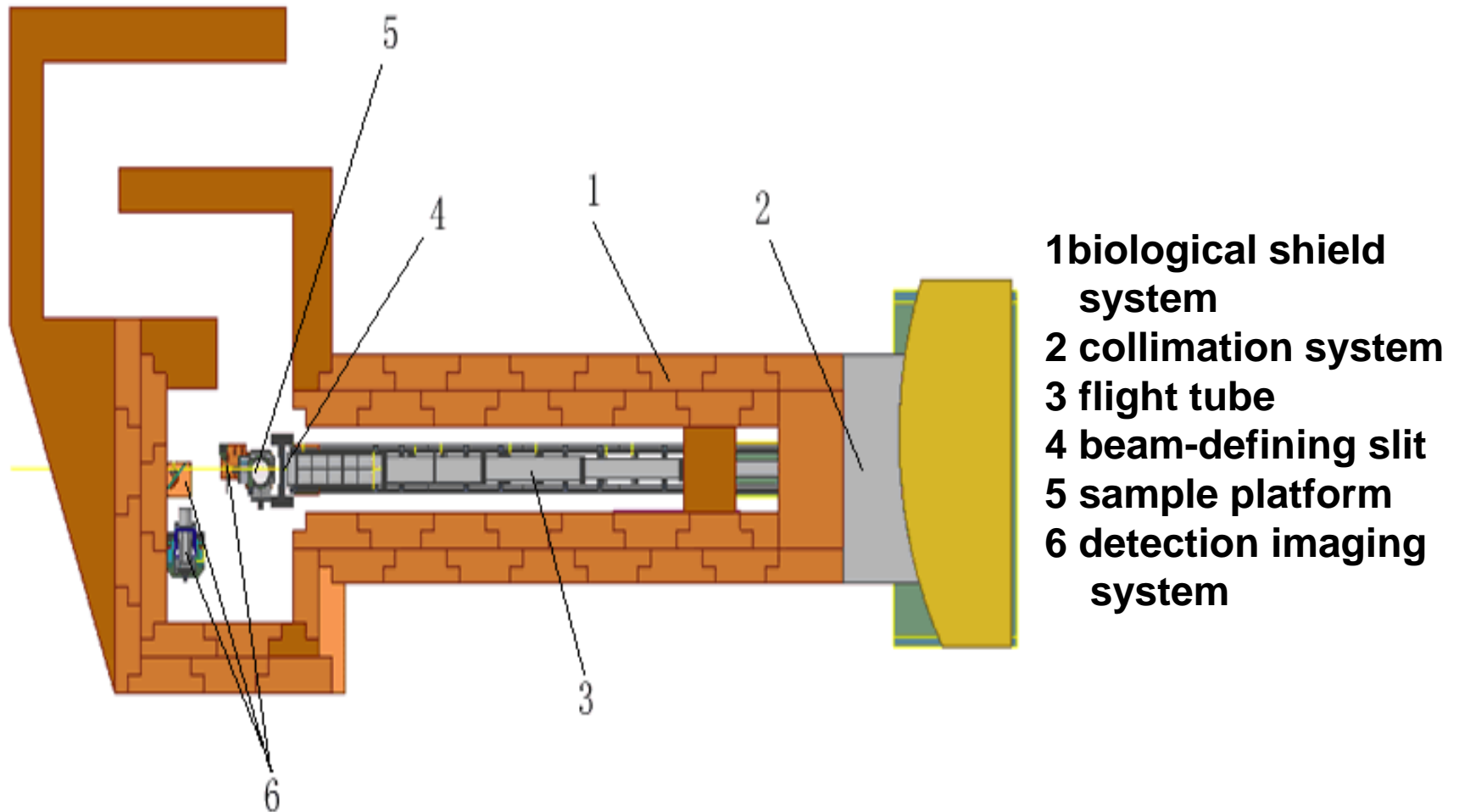
Irradiation Facility



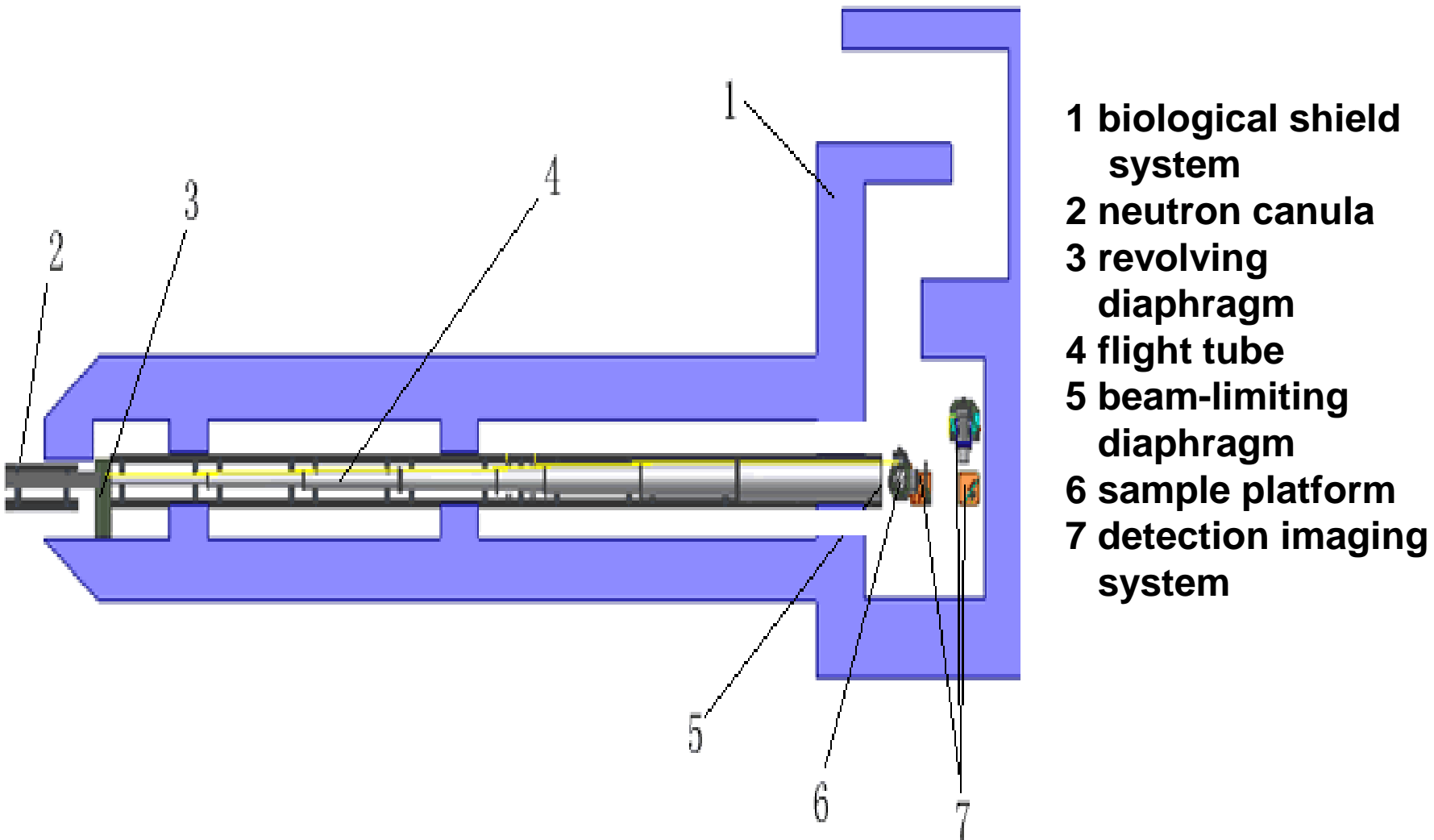
3.5 Neutron radiography facilities

- High Resolution Static Neutron Radiography System and High-frame-rate Neutron Radiography System will be developed.

proposed thermal neutron radiography facility in CARR



proposed cold neutron radiography facility in CARR



3.6 BNCT facility

BNCT facility with thermal/epithermal neutron beam and associated therapy equipments will be explored at CARR.

Hot cell in CARR building



Other hot cell group is very near CARR

Education and Training

- Simulator for CARR will be developed.
 - Every year, more than 500 new employee from NPP now.
 - Big development plan for NPP in China. High speed to construct.
 - 10 NPPs (28 units) under constructing now.
 - Now, <10GW, 2020, to 75GW, for reducing the discharging.
 - From 2% to 5%, nuclear energy/ total energy

(Graduate School of CNNC)

General Teaching Building



Training Building

Cost and income

- For CARR:
- ~20 M RMB/a (water, electricity, ..., salary)
- Fuel assembly cost: 70 M RMB/a
- Income: ?



Any suggestion is welcomed!

Thanks for your attention!