IGORR 22nd conference, Mito, Ibaraki, Japan
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Overview of CARR operation and applications

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CHINA INSTITUTE OF ATOMIC ENERGY

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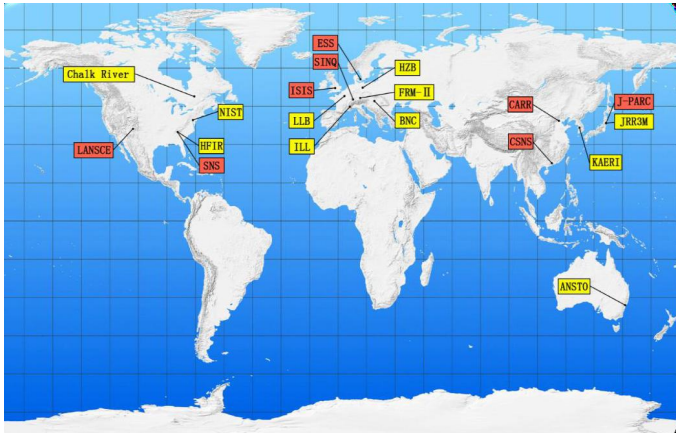
01 Introduction



CARR: A safe, reliable and multipurpose research reactor with high performance.

Main milestones of CARR construction

2002
Construction start

May 2010
First criticality

March 2012
72-hour test at full power

April 2012
Commissioning completed

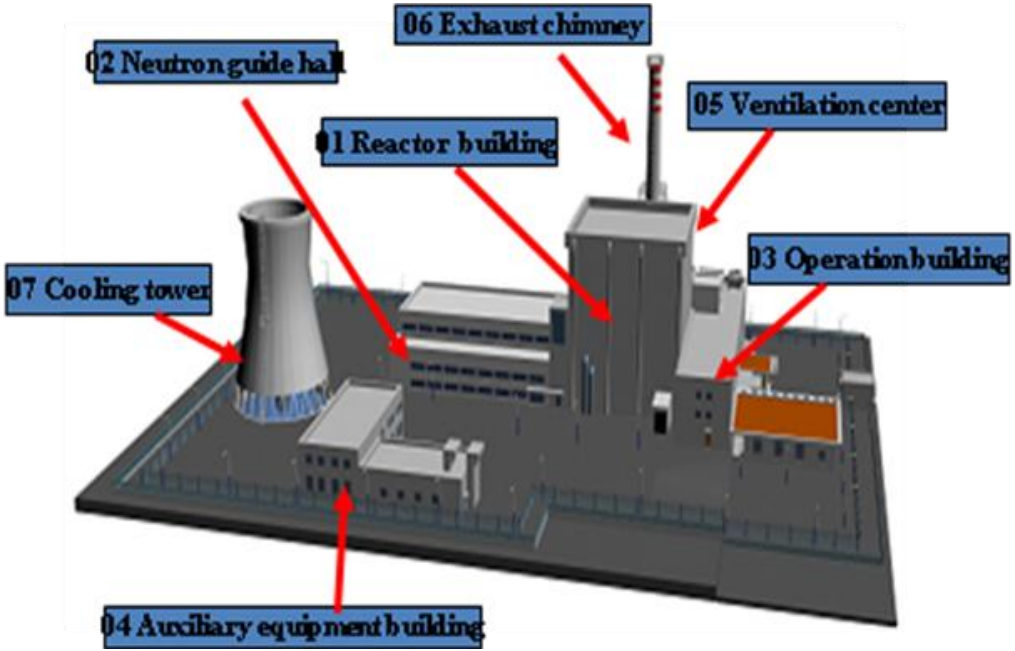
2017
CNS commissioning

02 Main features and parameters

Basic information of CARR

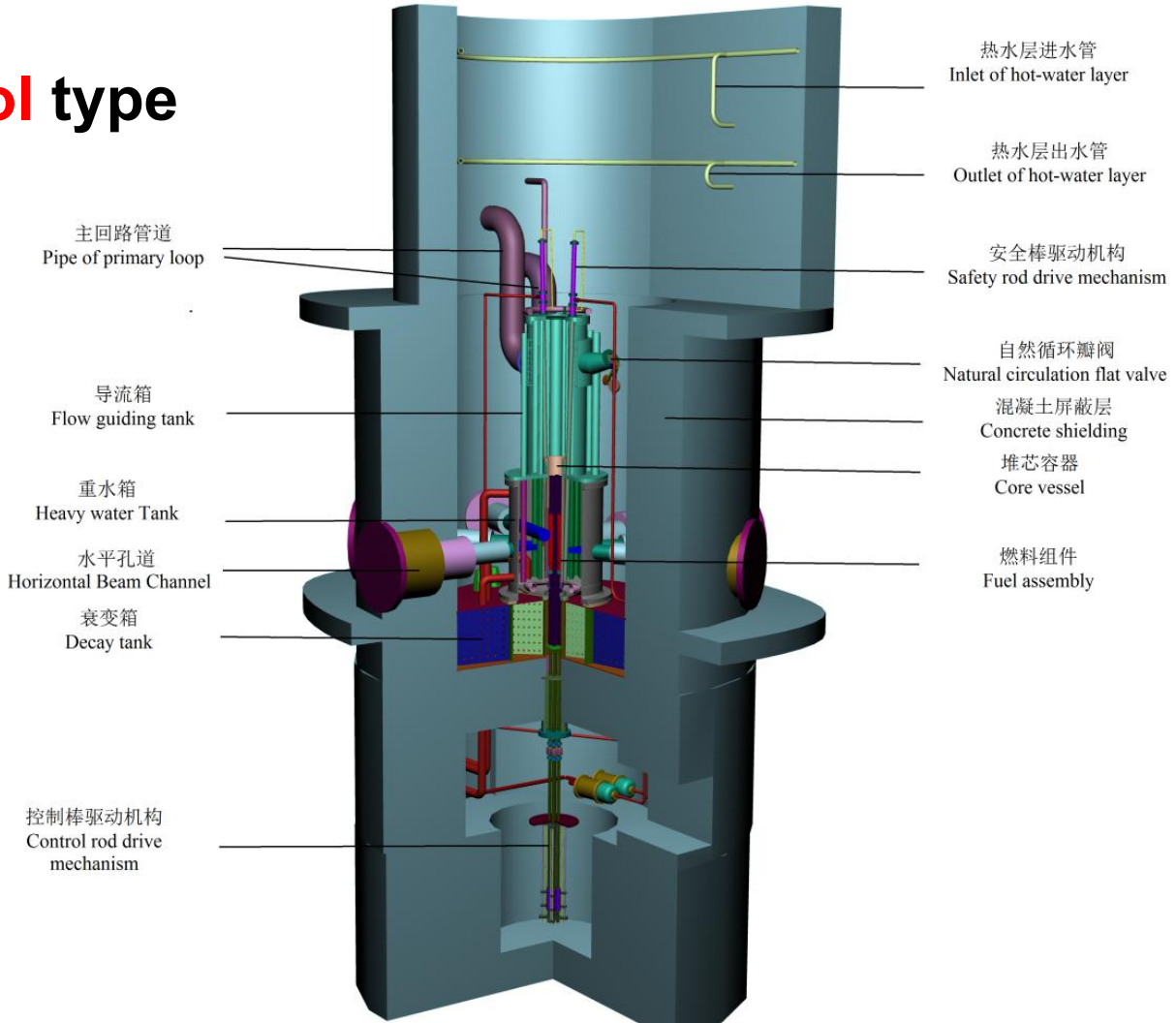
5 parts:

- Reactor building
- Neutron guide hall
- Operation building
- Auxiliary building
- Ventilation center
- Cooling tower



Reactor: Tank-in-Pool type

- Coolant:H2O
- Moderator:D2O
- reactor pool:15m deep
- Spent fuel pool
- Capacity:700 tons
- Water: De-mineralized
- Decay tank
- CRDM: below reactor



Reactor: Tank-in-Pool type

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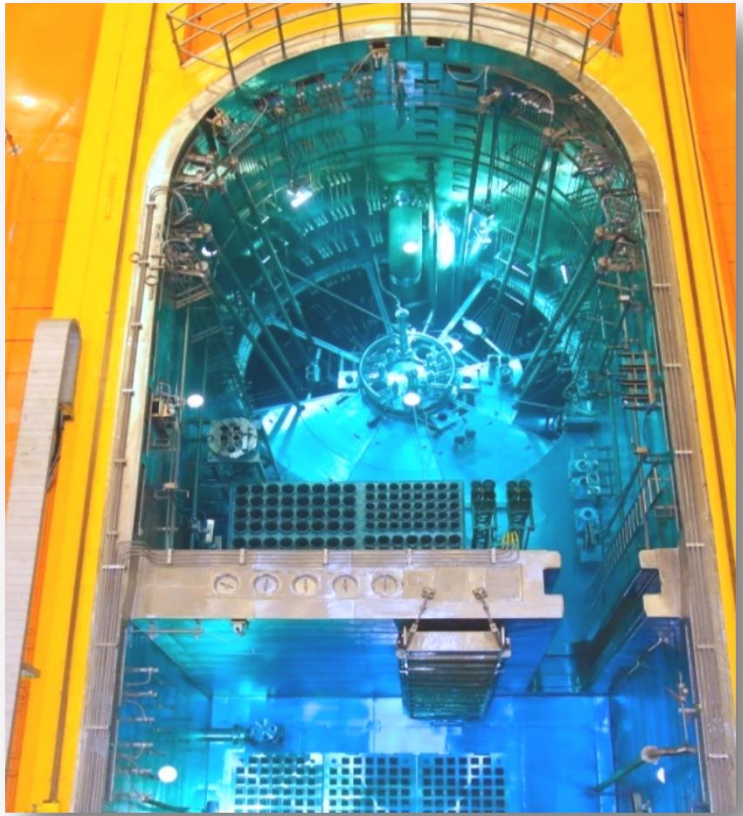
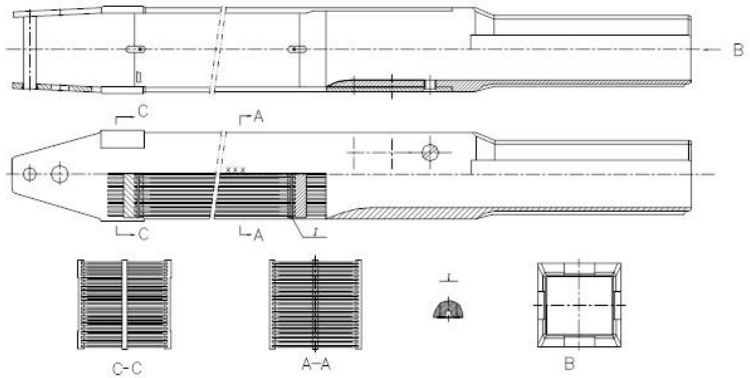
- Standard FA: 17
- Follow-up FA : 4
- Type: plate
- Fuel meat:

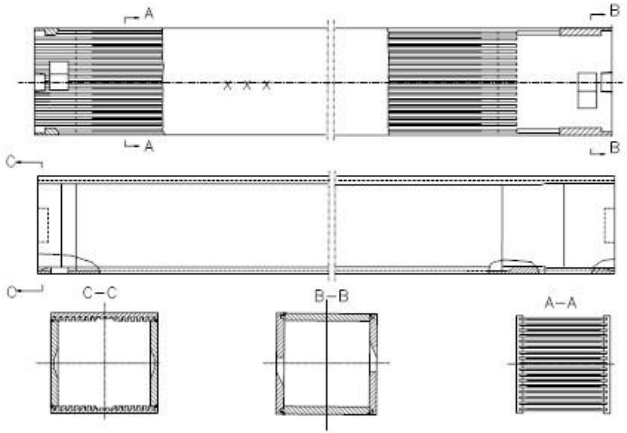
  U_3Si_2 Dispersed in Al
- ^{235}U enrichment: 19.75wt%
- Cladding : 6061-O alloy



Fuel assembly: Plate type



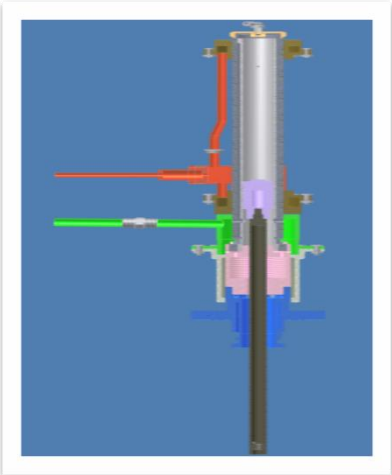
Standard FA



Follow-up FA

Control rods

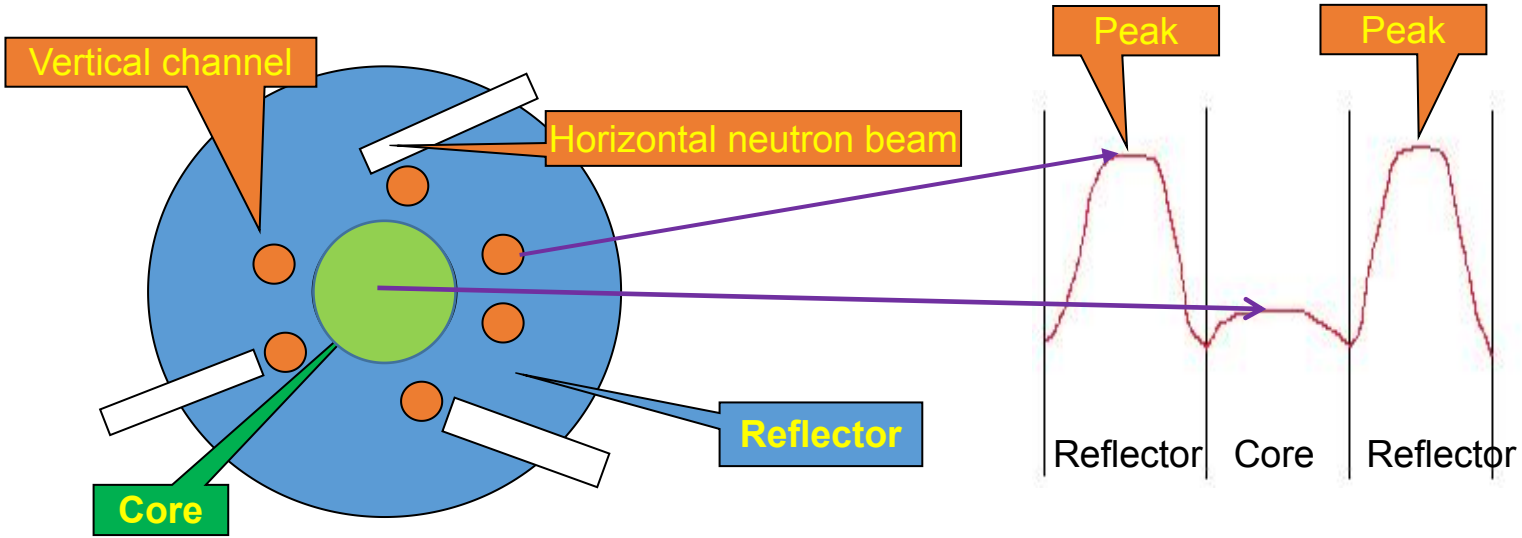
- Neutron absorber: Hf
- Two drive mechanisms with different principles.



Safety rod (2)
Hydraulically driven

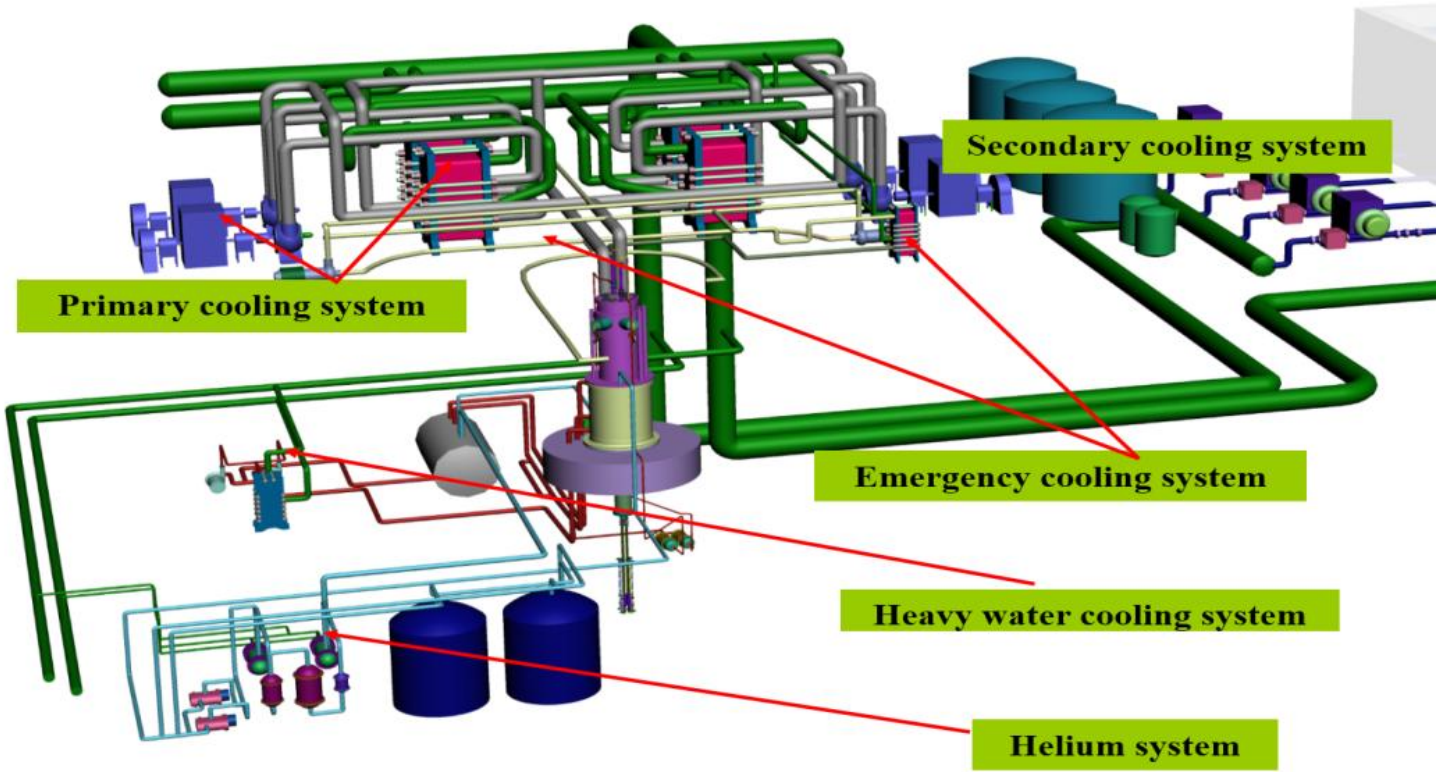
Control rod (4)
Magnetically driven

Inverse neutron trap

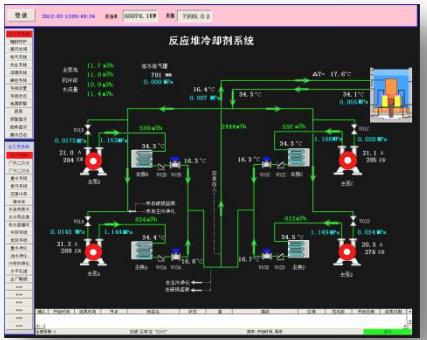


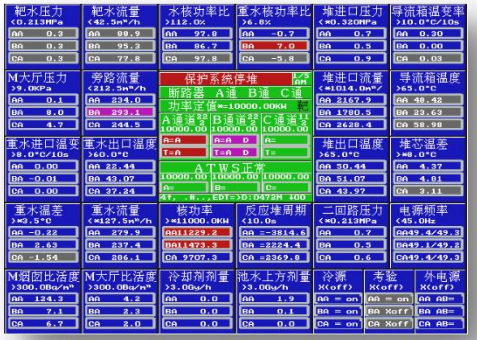
- Reactor core: compact (ID459)
- Fission neutrons: highly sub-moderated in core, mainly moderated in D2O
- Thermal neutron flux: peak in D2O tank (ID2 200)
- Large space: vertical channels, horizontal channels, applications

Main loop systems



Digital I&C system and protection system

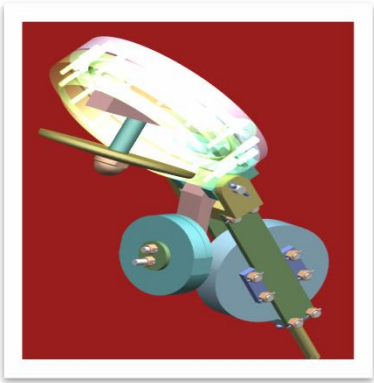




Reliable residual heat removal

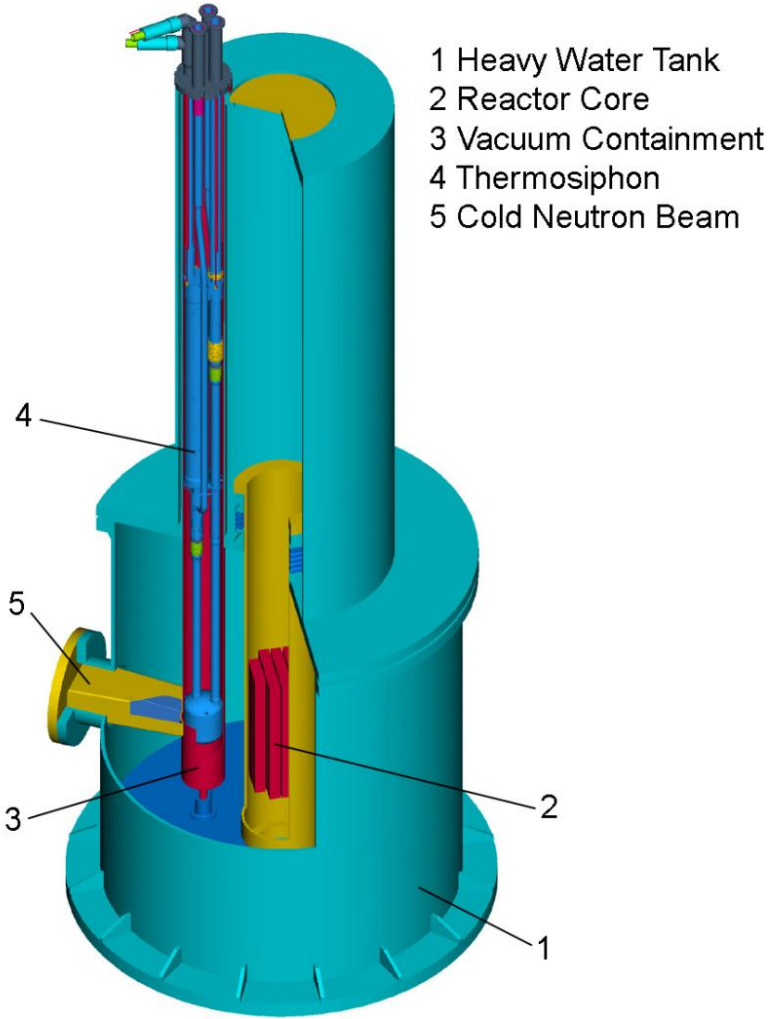
Main pump with **flywheel**

ECCS



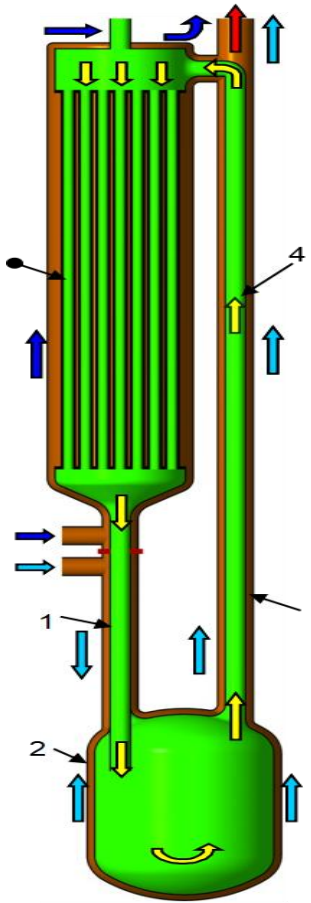
Passive **flap valve**

Cold neutron source



Cold neutron source

Parameter	Approximate Value
Reactor power	60 MW
Moderator type	Liquid Deuterium
Moderator circulation / cooling	By natural circulation of a liquid deuterium thermosiphon cooled by helium
Moderator volume	11.2 L
Thermosiphon volume	24.6 L
Heat removal capacity	6 800 W (in NO mode)
Vacuum Containment design pressure	4 MPa (reflected wave peak pressure)



Hot cell

Main parameters

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Parameters	Specifications
Reactor type	Tank-in-Pool, inverse neutron trap
Reactor Power	60MW
Coolant	Light water
Moderator and reflector	Heavy water
Max. thermal neutron flux in vertical channel	$1\times10^{15}n/cm^2s$
Fuel assemblies	21
Standard fuel assemblies	17
Follow-up fuel assemblies	4
Fuel type	Plate
Material of Fuel Meat	U_3Si_2 dispersed in Al
^{235}U enrichment	19.75wt%
Cladding material	6061-O alloy
Control rod material	Hf
Safety rods	2
Compensation rods and regulation rods	4
Horizontal experimental neutron channels	9
Vertical experimental neutron channels	25
Design life	30y

03 Operation and maintenance

Operation

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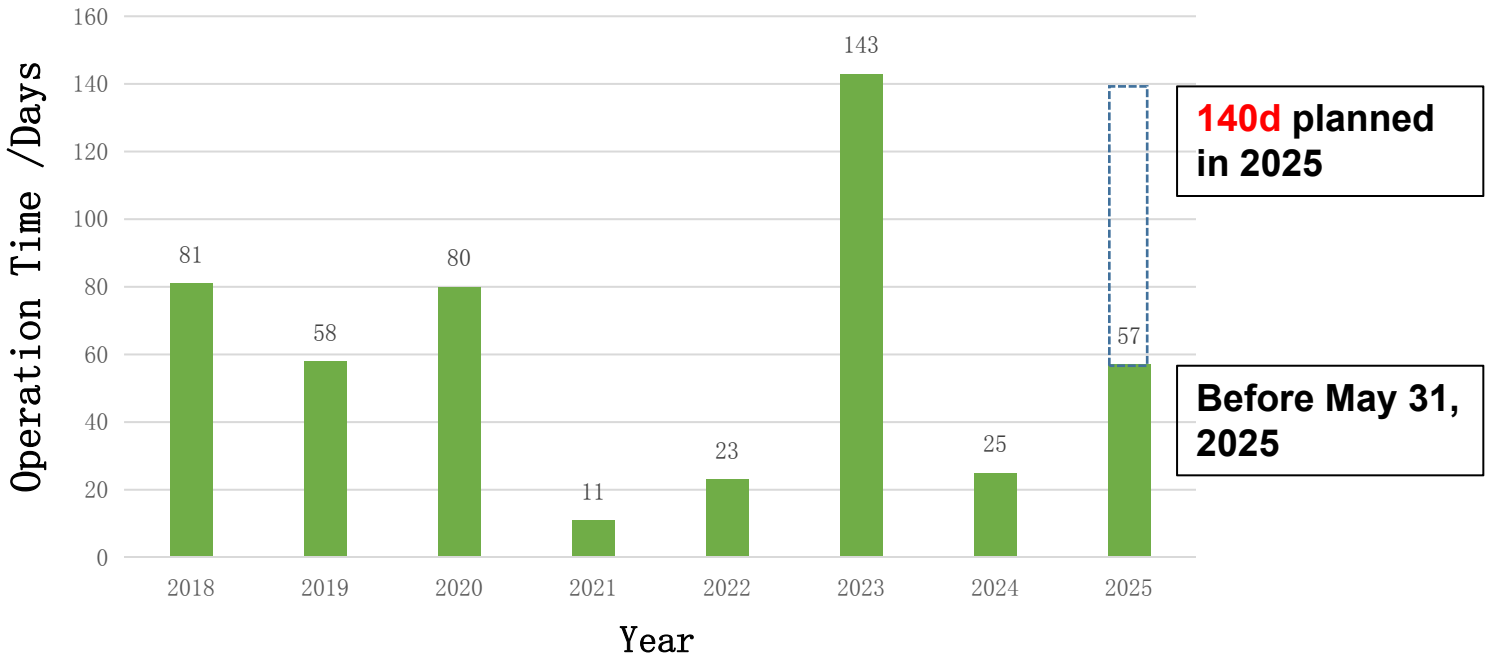

Operators

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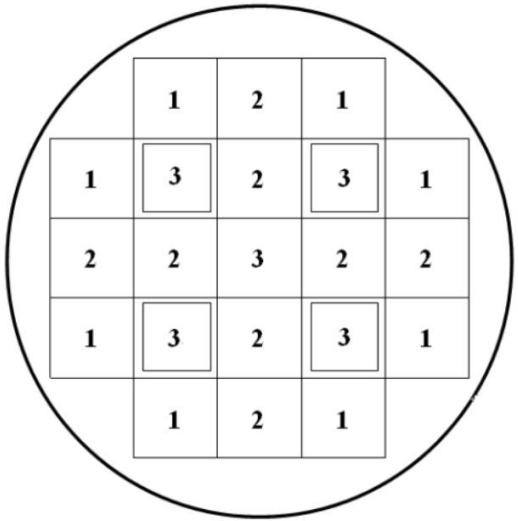
- At present, there are 25 operators with operator license, including 14 senior operators (6 shift leaders) and 11 operators .
- During routine operation, there are 5 shifts with 1 shift leader, 2 operators and 1 site operator for each shift at main control room.
- In addition, 1 or 2 CNS operators for each shift at CNS control room.
- More operators are needed for long period and stable normal operation.

Refuelling



- At equillibrium core loading, 2 types of refuelling modes.

a) 8 FAs:
8 S-FAs in Zone 1 to be discharged.

b) 13 FAs:
8 S-FAs in Zone 1 + 1 S-FA, 4 F-FAs in Zone 3 to be discharged.

2 types of refuelling modes are conducted in turn so that the reactor core loading will be the same after 2 refuelling cycles.

Refuelling

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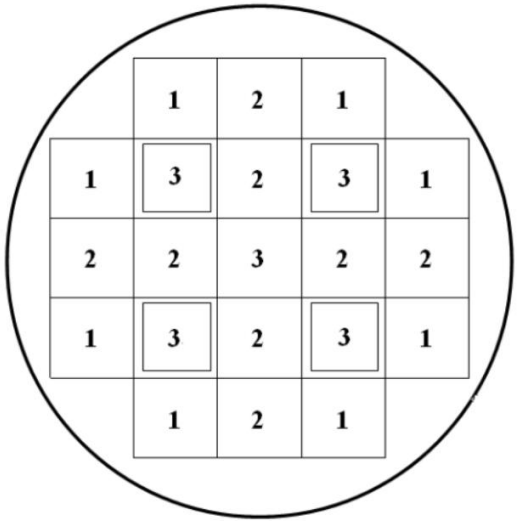
The refuelling cycle is 25 FPD.
so far, refuelling has been completed 6 times.



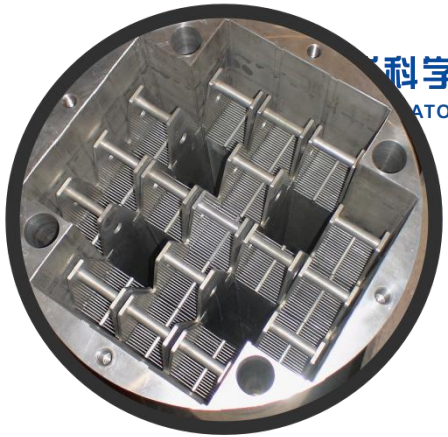
- **Cycle N: 8 FAs**

Discharged: 8 S-FAs in Zone 1
Shifted: 8 S-FAs in Zone 2 moved to Zone 1
Loaded: fresh S-FAs in Zone 2

- **Cycle N+1: 13 FAs**

Discharged: 8 S-FAs in Zone 1 + 1 S-FA, 4 F-FAs in Zone 3
Shifted: 8 S-FAs in Zone 2 moved to Zone 1
Loaded: fresh 8 S-FAs in Zone 2 + 1 S-FA, 4 F-FAs in Zone 3

Refuelling



Periodic inspection and examination

- Programme for periodical inspection and examination is developed and implemented.
- Plan for periodical inspection and examination in each year is developed and implemented.
- As a result, safety related systems and equipment are in normal conditions meeting the requirements of OLC.

Maintenance (1)

Preventive maintenance has been implemented and improved.

- **Programme for preventive maintenance is developed and implemented.**
- **Plan for preventive maintenance in each year is developed and implemented.**

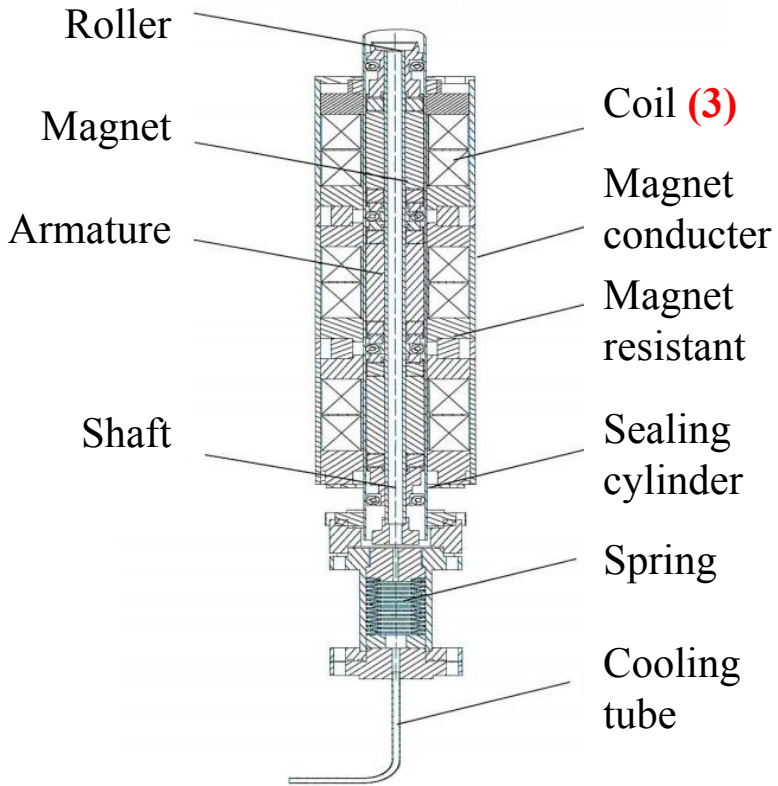
Maintenance (2)

Equipment management has been strengthened.

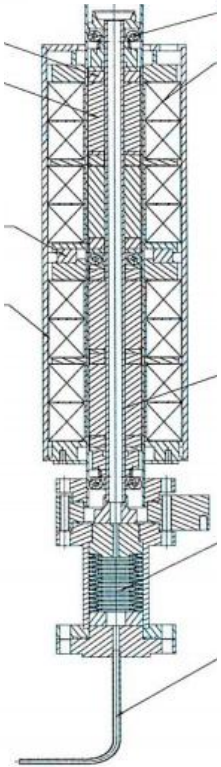
Some important modifications have been carried out, such as:

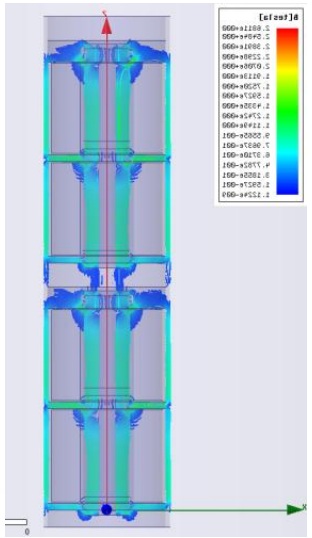
- **Control rod drive mechanism**
- **Hydraulic loop of safety rod drive mechanism**

Maintenance (3) • Control rod drive mechanism



Before

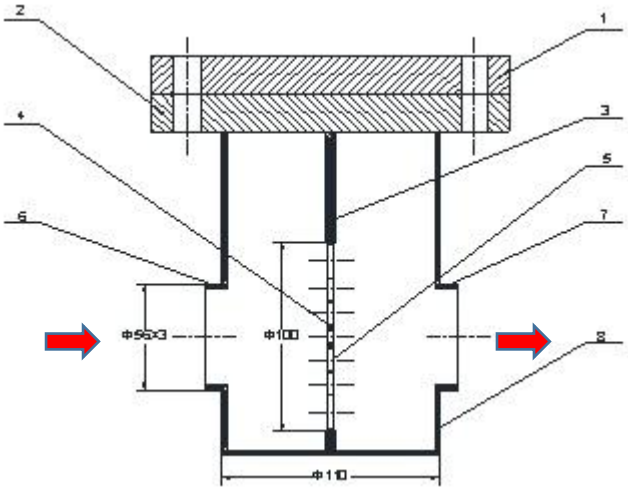




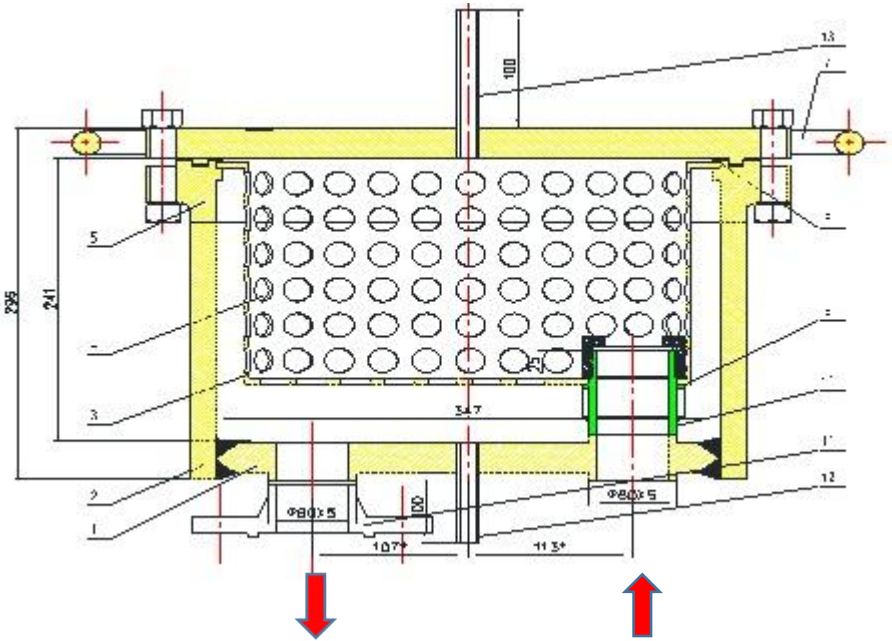
After

Maintenance (4)

- **Hydraulic loop of safety rod drive mechanism**

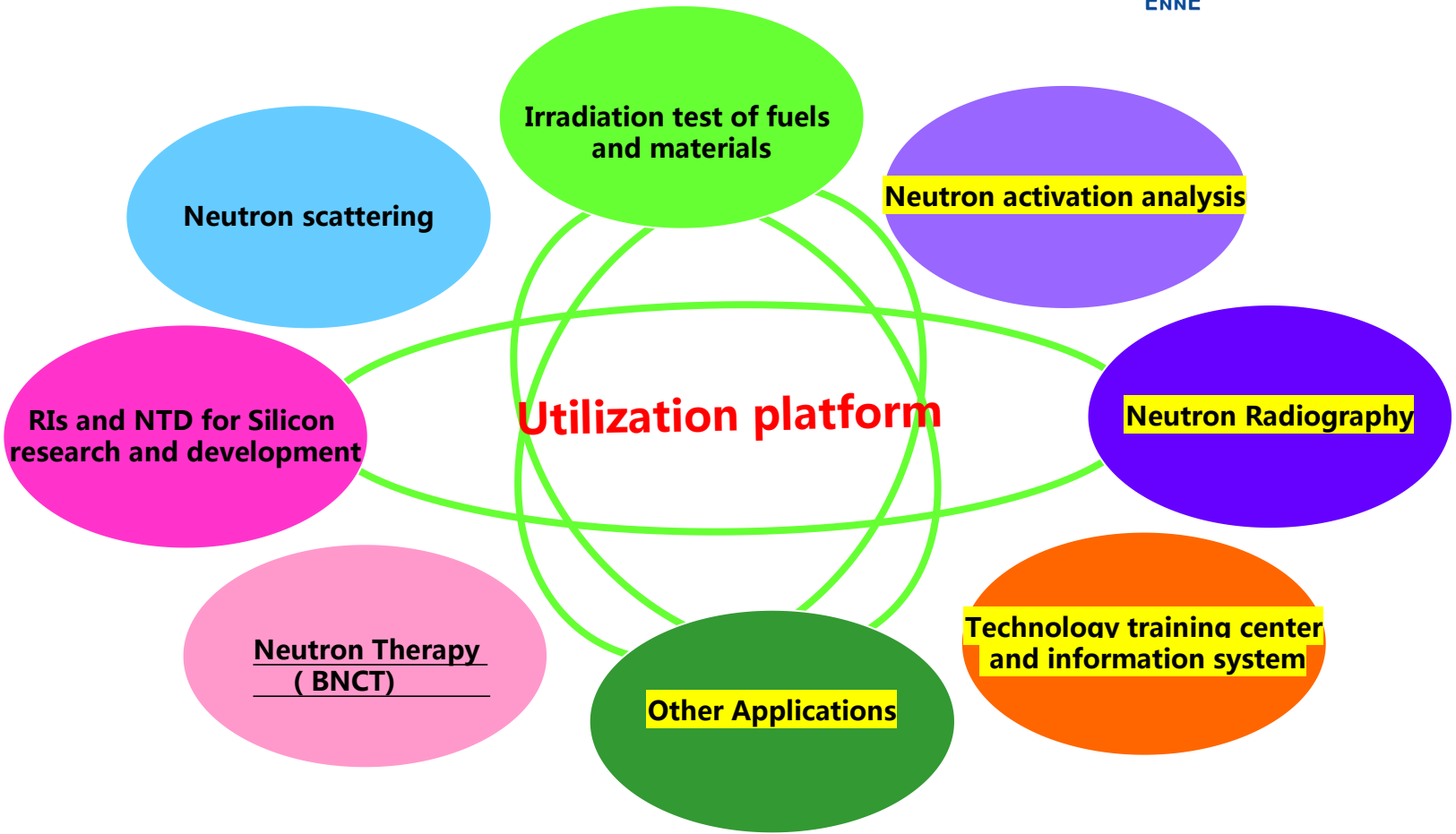


Before



After

04 Applications and outcomes


Irradiation test of fuels and materials
Neutron scattering
Neutron activation analysis
RIs and NTD for Silicon research and development
Utilization platform
Neutron Radiography
Neutron Therapy (BNCT)
Other Applications
Technology training center and information system

Channels for utilization

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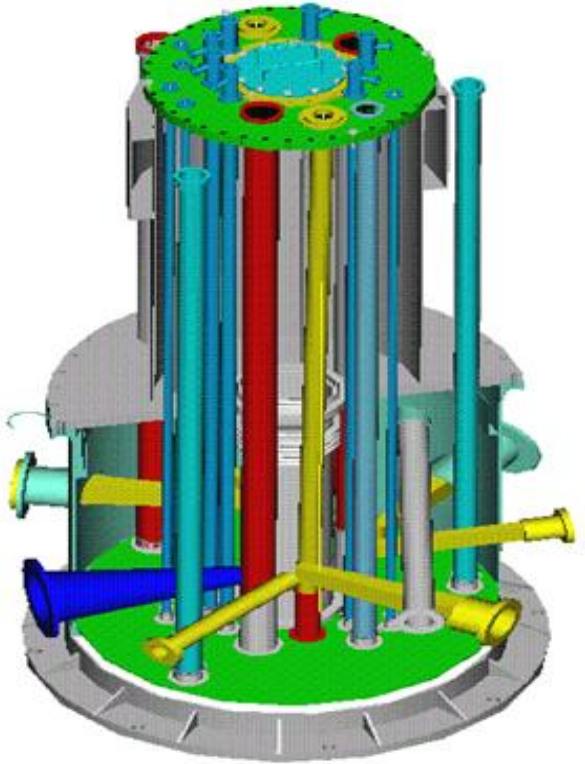
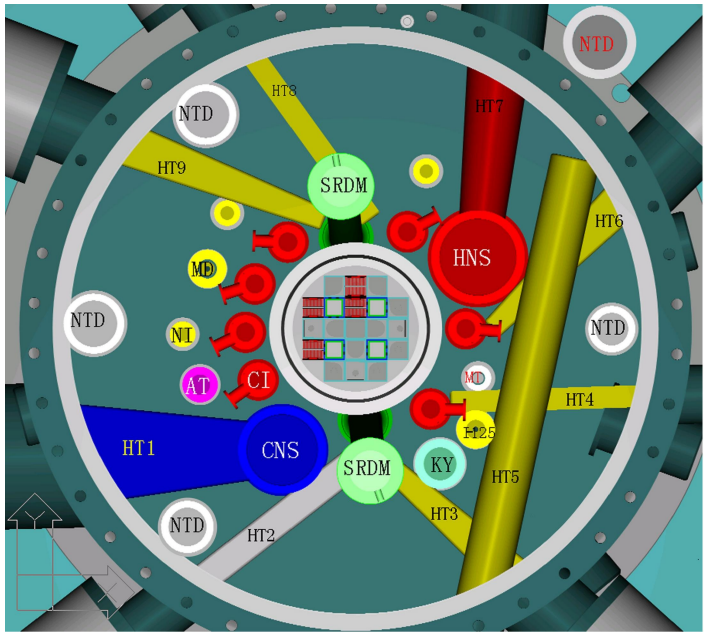
Type	Qty	Application
Vertical Channels	**25**	RI, Mo-99, I-125, NDT-Si, fuel and material irradiation and test, NAA, Cold Neutron Source
Horizontal Channels	**9**	Neutron scattering, neutron imaging, NAA, nuclear pumped laser, ISOL (cold neutron, thermal neutron)

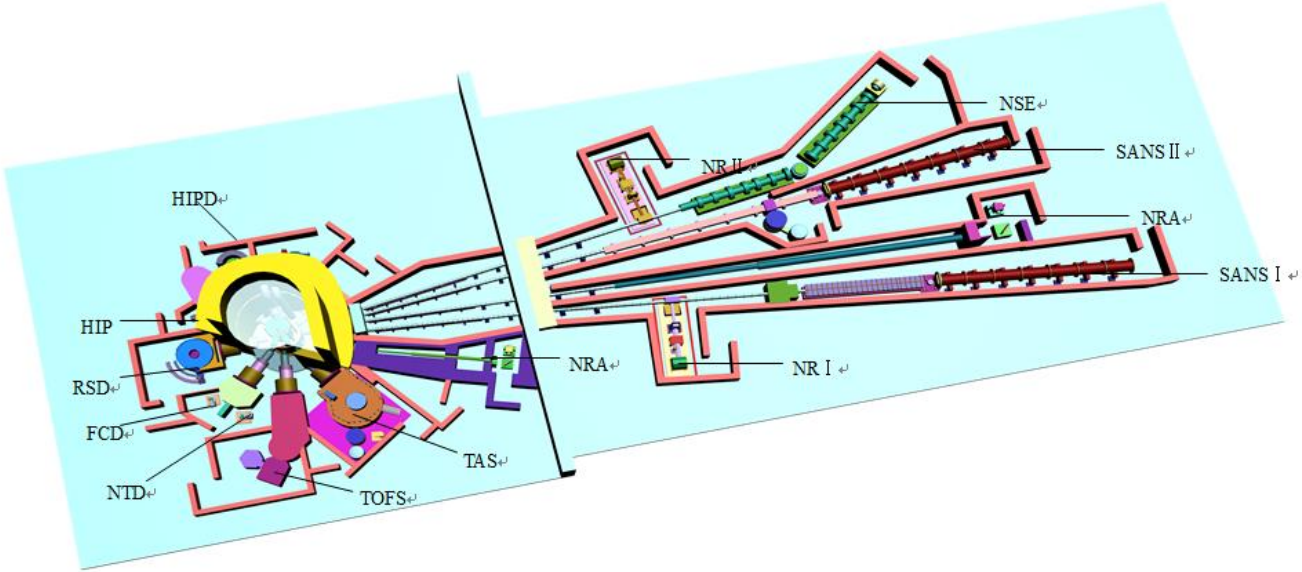


Vertical channels (1)



CI：RI production tube with cooling loop, 7
I-125：I-125 production tube
KY：Fuel test tube with cooling loop
NTD：NTD silicon tube, 5
MD：Mo-99 production tube, 2
AT：NAA tube
NI：RI production tube, 3
HT1：Cold Neutron Source Beam Tube
HT2：Multi-filtration Neutron Beam Tube
HT3、HT4、HT8、HT9:Thermal Neutron Beam Tubes
HT5：Long Tangential Beam Tube
HT7: Hot Neutron Source Beam Tube
CNS：Cold neutron source tube
HNS：Hot neutron source tube
SRDM：Safety Rod Drive Mechanism, 2

Horizontal channels (1)



NRA: Neutron Radiography Equipment
SANS: Small Angle Neutron Scattering Diffractometer
NSE: Neutron Spin Echo Spectrometer
CTAS: Cold Neutron Triple Axis Spectrometer
NR: Neutron Reflectometer

TAS:Triple Axis Spectrometer
TOFS: Time of Flight Spectrometer
NTD: Neutron Texture Diffractometer
FCD: Four Circle Diffractometer
RSD: Residual Stress Diffractometer
HIPD: High Intensity Powder Diffractometer
HRPD: High Resolution Powder Diffractometer

Horizontal channels (2)

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High Resolution Powder Diffractometer

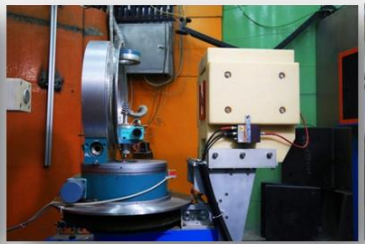

High Intensity Powder Diffractometer


Residual Stress Diffractometer

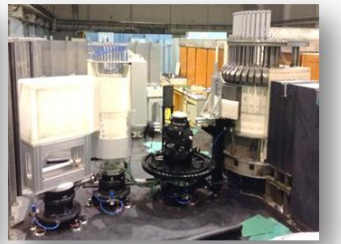

Multi Axis Crystal Spectrometer


Engineering Neutron Diffractometer

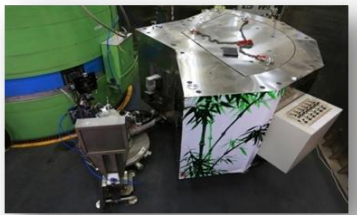

Texture Diffractometer


Four Circle Diffractometer


Triple Axis Spectrometer


Cold Triple Axis Spectrometer


Thermal Neutron Imaging


Triple Axis Spectrometer


Reflectometer

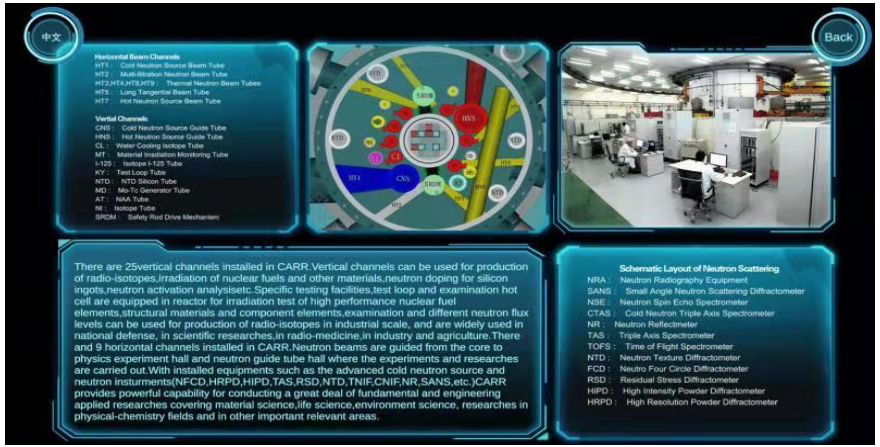

Small-Angle Neutron Scattering

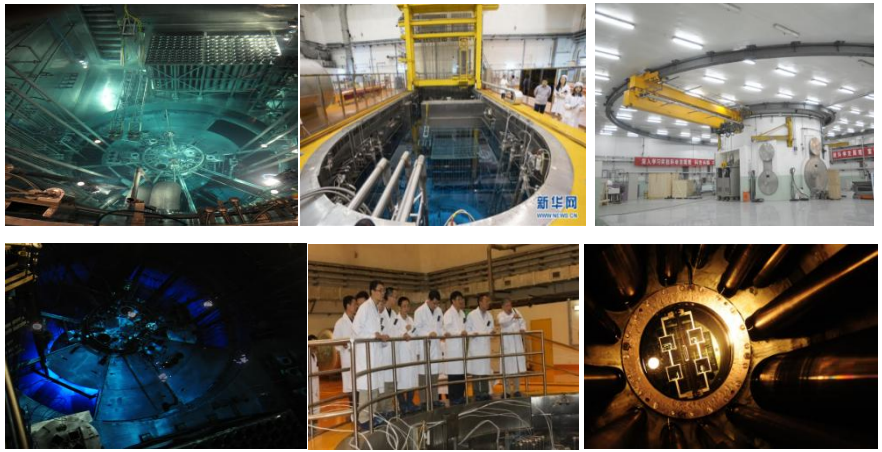

Neutron Depth Profile


Cold Neutron Imaging

Outcomes 1

Education and training





CARR is an important platform for public education of nuclear science. The public can have zero distance access to the reactor, enter the reactor hall and physics experiment hall. They can watch the reactor pool, cheronkov radiation and experimental devices.

Outcomes 2: Vertical channels (1)

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Limited but important irradiation and tests have been conducted through vertical channels.

- **C-14**
- **I-125**
- **Tests of tritium breeder for ITER**
- **Tests of nuclear detectors**

Outcomes 2: Vertical channels (2)

- C-14

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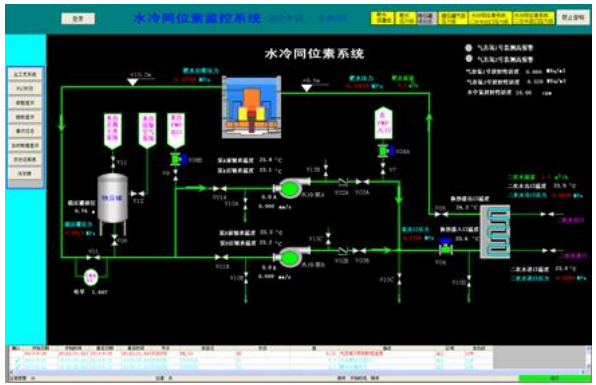
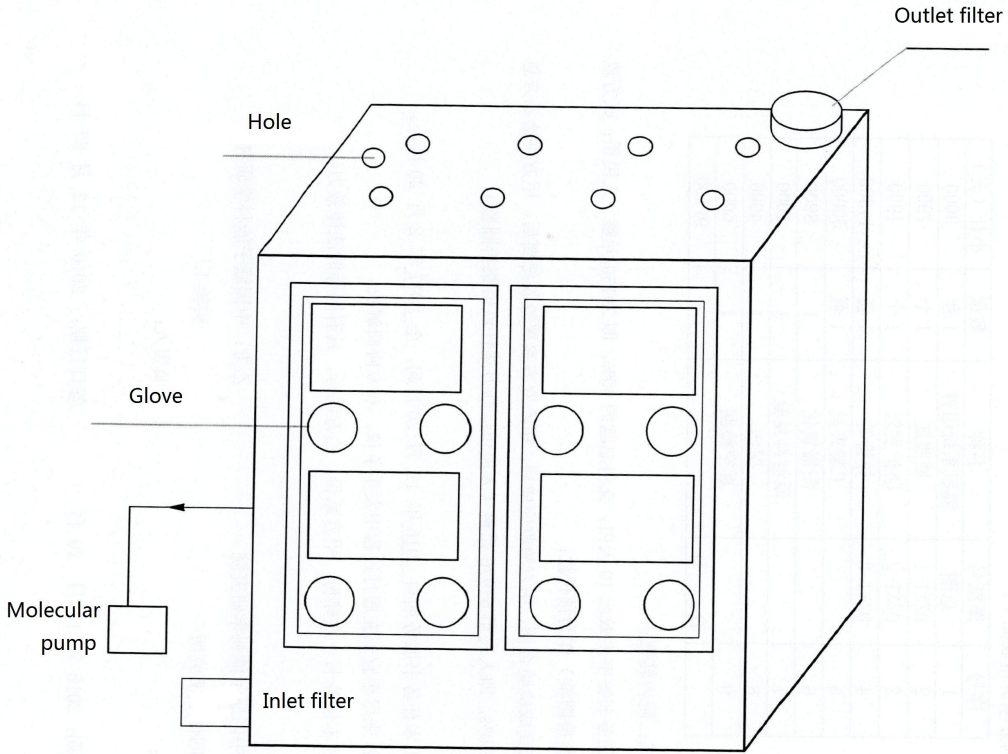


Outcomes 2: Vertical channels (3)

- I-125



Outcomes 2: Vertical channels (4)

- Tests of Online tritium production test for ITER

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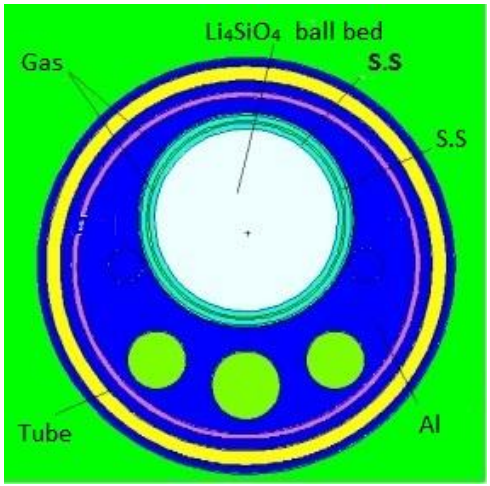

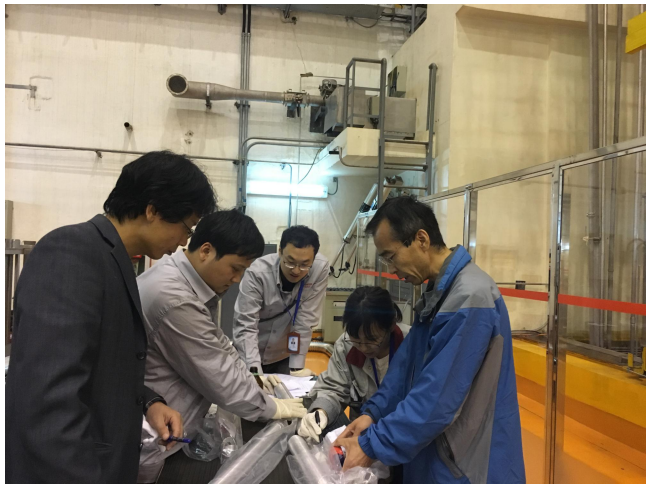

Outcomes 2: Vertical channels (5)

- Tests of Online tritium production test for ITER

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An ITER online tritium production test circuit was established, and corresponding research work was carried out on the heat transfer and effective thermal conductivity of solid breeding ball bed, tritium production, etc.

Further online tritium production study for ITER is planned to be carried out at CARR.

Outcomes 2: Vertical channels (6)

- Tests of nuclear detectors

Outcomes 3: Horizontal channels (1)

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Many studies have been conducted through horizontal neutron beams, both for industry application and fundamental studies.

- Measurement of residual stress in wheel of high speed train
- Measurement of residual stress inside superalloy components for aircraft engines
- Neutron imaging on the internal structure of Han Dynasty arrows head
- NAA of lunar samples
- Neutron diffraction on cathode material for sodium battery
- Flexible nature of NSP13 protein in solution

Outcomes 3: Horizontal channels (2)

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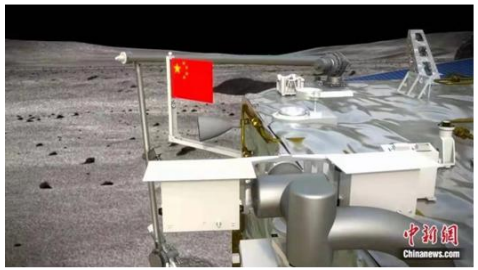
Neutron Activation Analysis lunar samples

Over 40 elements were quantified, and provide important data for related researches.



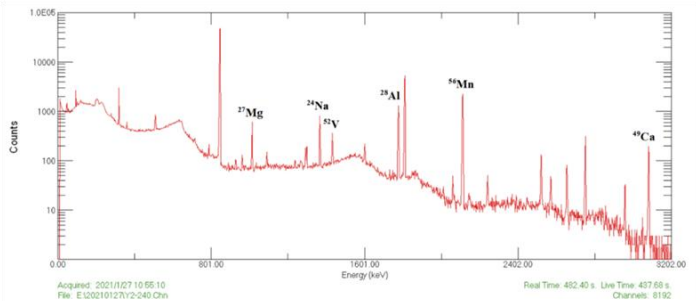


Figure 1. Spectrum of gamma rays for the short-time irradiated sample CE5C0800YJFM003. The spectrum was obtained using an HPGe detector combined with a digitized multichannel analyzer (MCA). The sample CE5C0800YJFM003 was irradiated for 300 s in the MNSR at the CIAE and counted for 437.68 s (live time) at a decay time of 17.25 min.

Chang’ E-5 lunar sample

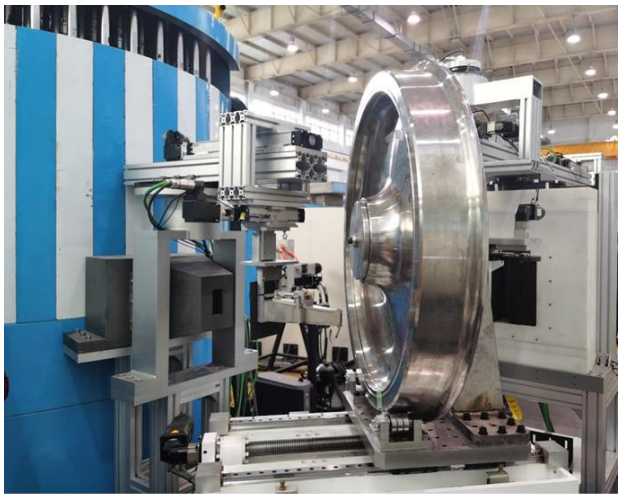
Chang’ E-5 lunar sample; lunar meteorite ;

- **Important new data for related research**
- **Concentrations of more than 40 elements**

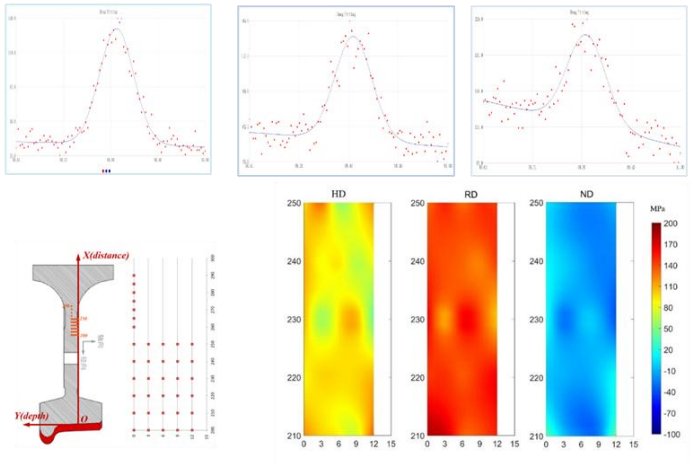
Outcomes 3: Horizontal channels (3)

Residual Stress in wheel of high-speed train measured non-destructively using neutron diffractometer at CARR

The results is important for the manufacturing of wheel, and helpful for assuring the safety the train.



Depth up-to 4cm
Gauge volume 3mm*3mm*3mm



Outcomes 3: Horizontal channels (4)

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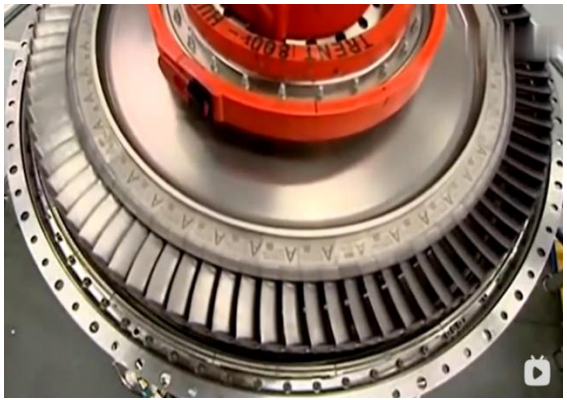
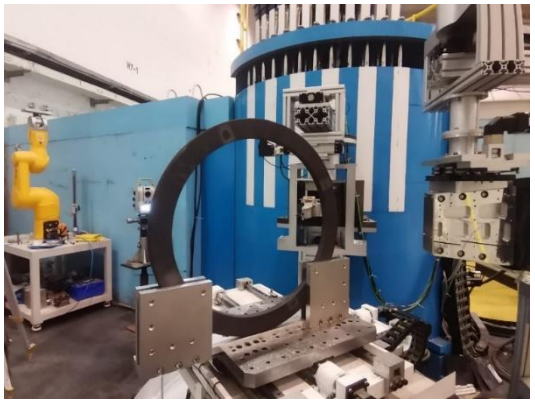
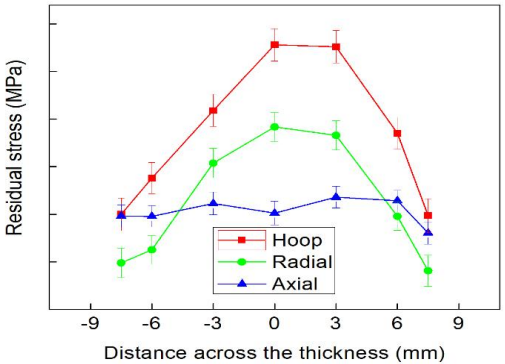
Residual stress inside superalloy components for aircraft engines



Superalloy annular component



Neutron Experiment



Neutron results

Outcomes 3: Horizontal channels (5)

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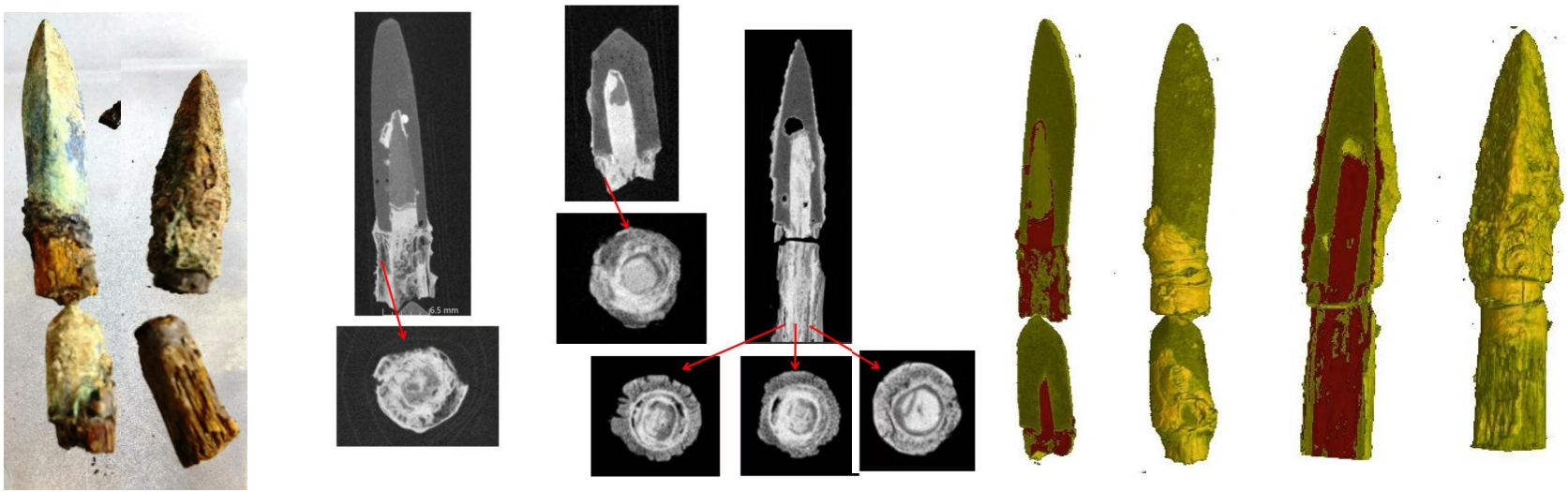
Neutron imaging on the internal structure of Han Dynasty arrows head



Understand manufacturing process, better protect the cultural relics.

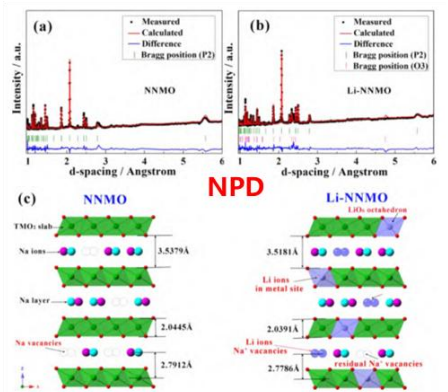
Outcomes 3: Horizontal channels (6)

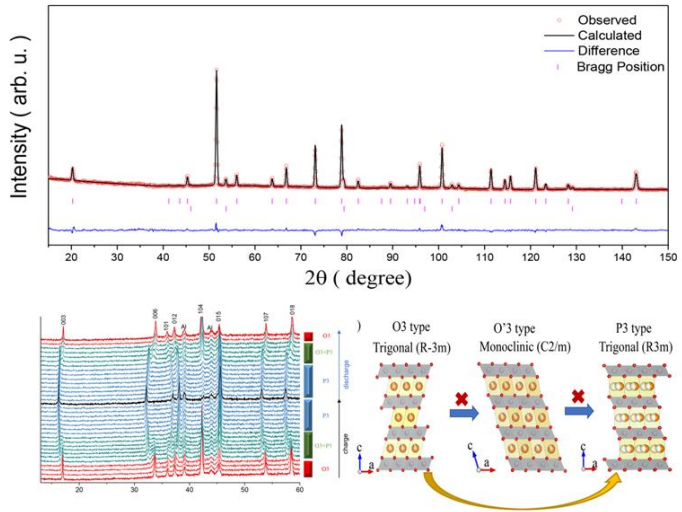
Neutron diffraction on cathode material for better Batteries

Crystal structure, where Li or Na ions occupy

The results is valuable for the design of new battery materials.

Capacity and cycling life





- Hao GUO et al., Chemical Engineering Journal, 2021,413,12874
- Zheng-Yao Li et al., ACS Appl. Energy Mater. 2022, 5, 1, 1126–1135

Outcomes 3: Horizontal channels (7)

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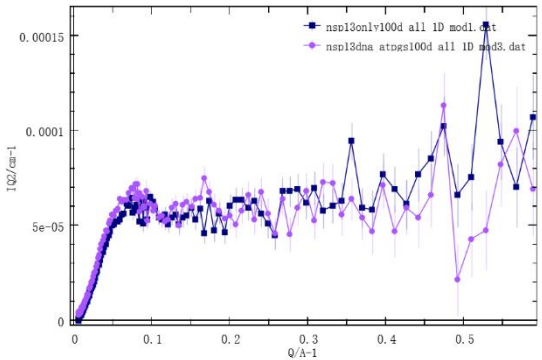
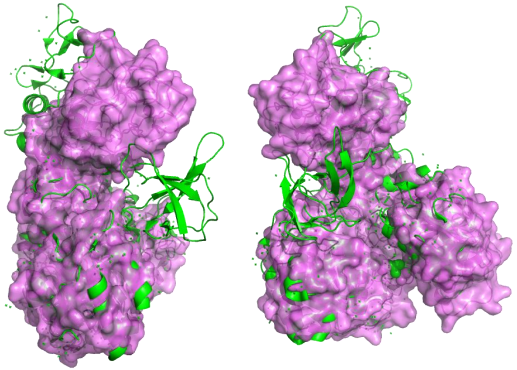
Flexible nature of NSP13 protein in solution by Small Angle Neutron Scattering

Life science and health



SANS data



Solution structure of NSP13

05 International cooperation

CARR Application Research Center was established for promotion of cooperation on CARR applications in 2013.

CARR also cooperates with many domestic universities and research institutes.

CARR has also participated in international cooperation. So far, CARR has cooperated with ~50 international organizations, universities and research institutions, such as IAEA, IGORR, PSI, JULICH, JAERI, ANSTO.

- **Hosting international meeting on safety of research reactors**
- **Hosting IGORR12 in 2009, Beijing**
- **Carrying out studies**
- **Establishing a mechanism for mutual visits and academic exchanges**

2024 marked the 40th anniversary of China's accession to the IAEA.

During the past 40 years, China has engaged in the building of an open and inclusive environment for internatioanal cooperation, worked together with its global partners toward technological innovation and development in the nuclear sector,and delivered solid outcomes to mankind from relevant technoligical advancement.

During IAEA 68th General Conference in 2024, China hosted a side event on **Open for Future: CNNC R&D Facilities**. At this event, CNNC annouced that it will open **12** research and development facilities including reactors for different applications, facilities for testing, qualification and simulation. **CARR** is one of the facilities and at the first of the list.

List of 12 R&D facilities:

- **China Advanced Research Reactor (CARR)**
- **Swimming Pool Reactor (49-2 SPR)**
- **Minjiang Test Reactor (MJTR)**
- **Miniature Neutron Source Reactor (MNSR)**
- **HL-3 (Tokamak device)**
- **Beijing Rare Isotope Beam Facility (BRIF)**
- **Beishan Underground Research Lab (Beishan URL)**
- **Nuclear Reactor Thermohydraulic facilities**
- **Containment thermohydraulic test facility (PANGU, 盘古)**
- **Containment structural performance test facility (XUANWU，玄武)**
- **Nuclear environment simulation facilities**
- **Equipment qualification facilities**

06 Summary

- CARR is a multi-purpose RR with high performance.
- Operation performance has been gradually improving.
- A great number of experiments and irradiation have been completed.
- Valuable outcomes have been generated.
- International cooperation has been carried out well.
- Further cooperation will be expanded in the future.

Welcome to visit, understand and share CARR.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Thank you for your attention!