



INET

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Development of the industrial-scale HTR-PM and its preliminary application

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Outline

- R&D on commercial scale module and demonstration (HTR-PM)
- Qualification assessment and production of TRISO-coated particle fuel
- Deployment of multi-module plant
- Further R&D on HTR-PM and advanced application

Basic research

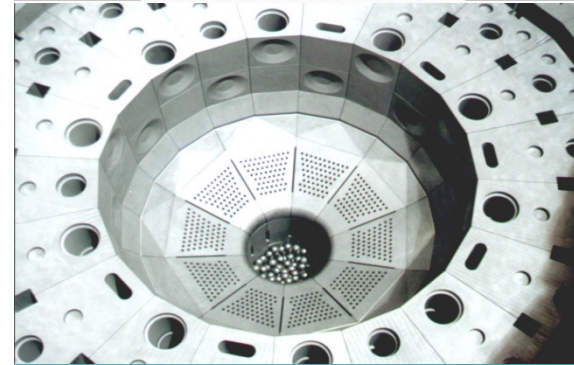
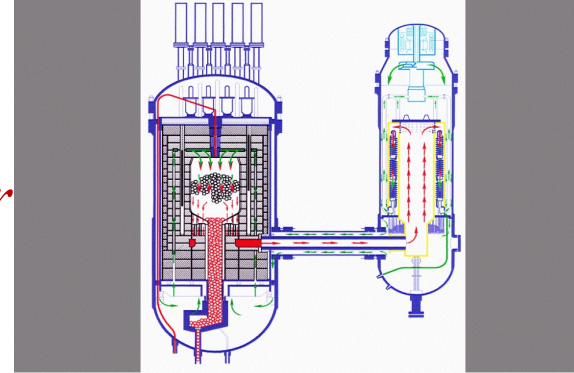
- 1980s, Basic research
- 1986, R&D on design and component technologies
- 1992 approved to construct the 10 MW high temperature gas cooled reactor – HTR-10

HTR-10

pebble-bed modular test reactor

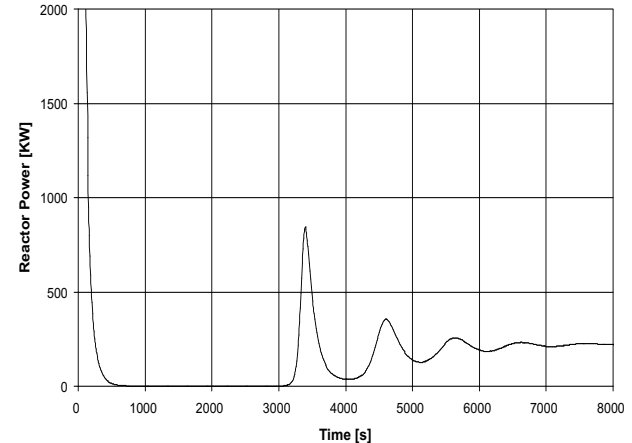
- 1995: Construction started
- 2000: First criticality achieved
- 2003: Full power operation

Reactor Power MWth	10
He Pressure MPa	3
Reactor Inlet Temp. °C	250
Reactor Outlet Temp. °C	700
Fuel Elements Number	27000



Safety Tests on HTR-10

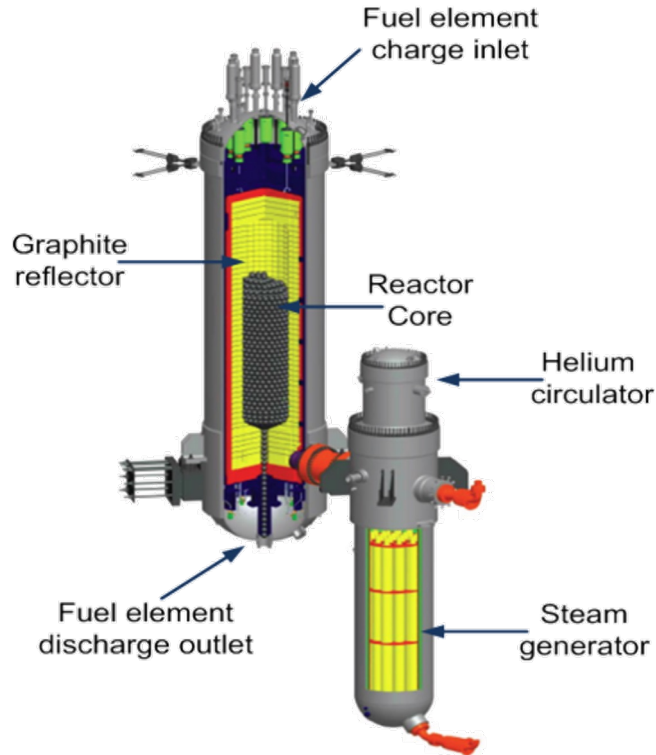
- ◆ Loss of helium flow
- ◆ Turbine trip
- ◆ Loss of off-site power supply
- ◆ Helium blower trip ATWS
- ◆ Reactivity insertion ATWS
- ◆ Helium blower trip without closing outlet cut-off valve



R&D on commercial scale module

- 2003~2006, Establishment of **EPC Company, owner, site selected**
- 2006 HTR-PM Demo listed as a major project in the *national science-technology development program*
- 2006, the overall technical design approved
- 2008, the overall implementation plan of the project approved

Overview of HTR-PM module

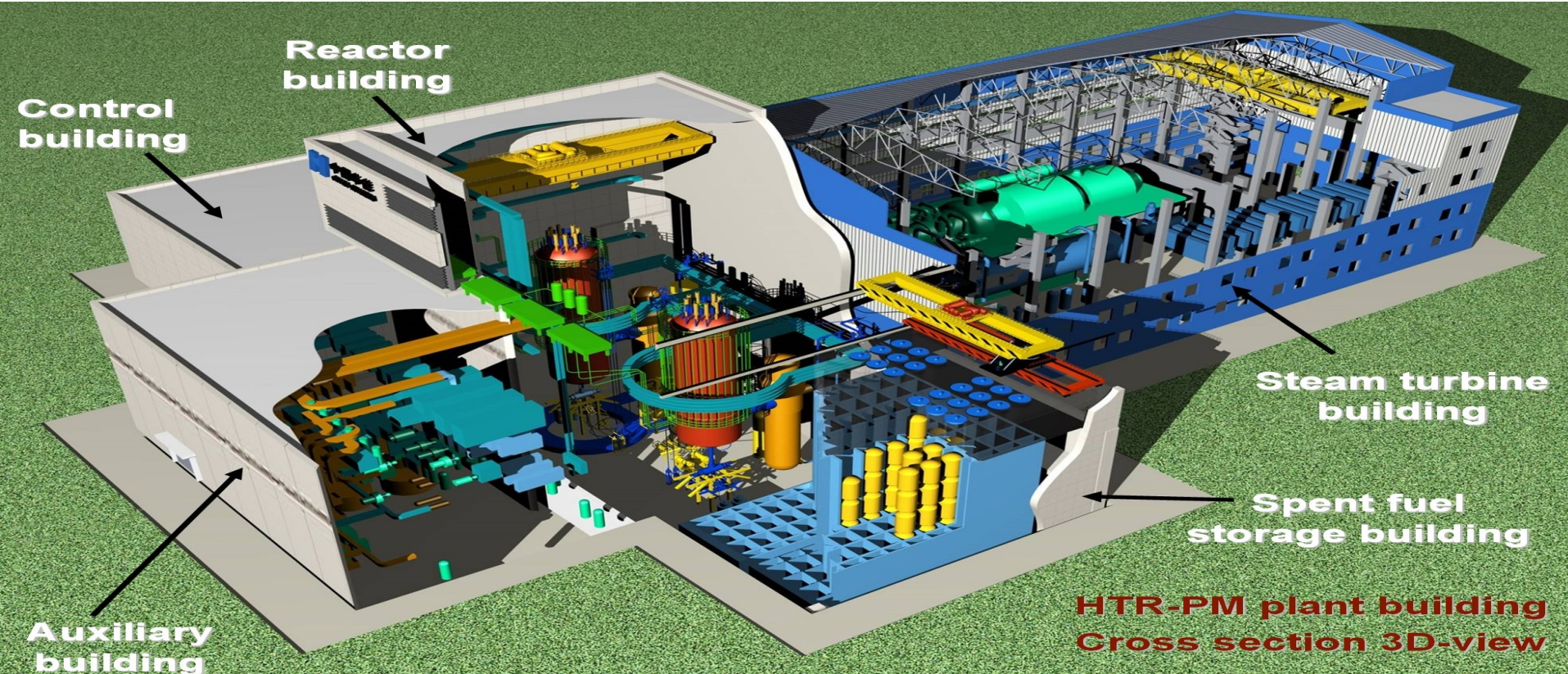


Plant electrical power, MWe	200
Core thermal power, MW	250
Number of NSSS Modules	2
Core outlet temperature, °C	750
Core inlet temperature, °C	250
Steam pressure, MPa	13.2
Steam temperature, °C	567

- **High Temperature**
- **Inherent Safety**
- **Modular**

Industrial Scale pebble-bed module

Isometric View of HTR-PM Demo Plant



Two reactor modules connected to one steam turbine

Key components

- ❑ RPV
- ❑ Blower
- ❑ SG
- ❑ Core internals
- ❑ Control rod system
- ❑ Small Absorber Sphere system
- ❑ FHSS
- ❑ Helium purification
- ❑ Dry spent fuel storage

■ Focus:

- Industrial scale-up
- Availability , Reliability, Maintainability, etc.
- Cost-effective

Engineering Laboratory *for components*



A large-scale helium loop established

Large-scale helium loop

- Power: 10 MW
- Temp.: 750 °C
- Pressure: 7 MPa
- Media: helium

Full-scale Tests, helium conditions

- Steam generator, one of the 19 units
- Helium circulator
- Fuel handling system
- Control rods driving system
- Small absorber balls system
- Helium purification system

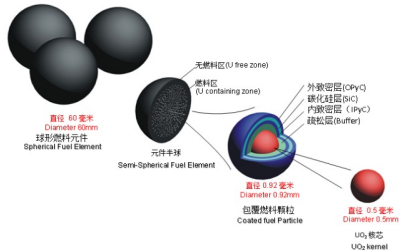
Totally 16 large-scale tests

R&D Strategy of TRISO fuel

Four key phases of efforts completed:

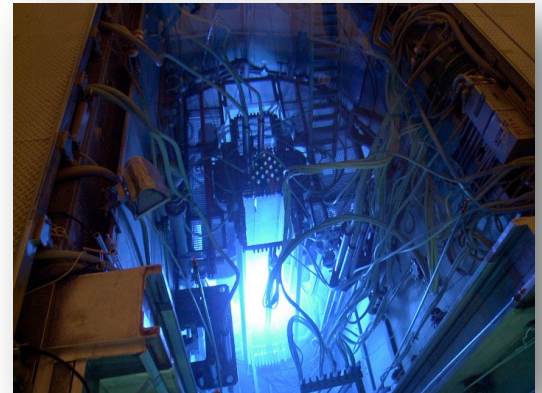
- ✓ Technologies and components in scale-up fuel fabrications
- ✓ Industrial scale prototype/demo production facilities
- ✓ Irradiation testing and post-irradiation examinations
- ✓ Larger-scale fuel production lines

Through the research, design, processing, installation, commissioning and production operation of key components, the key processes and components are finalized.



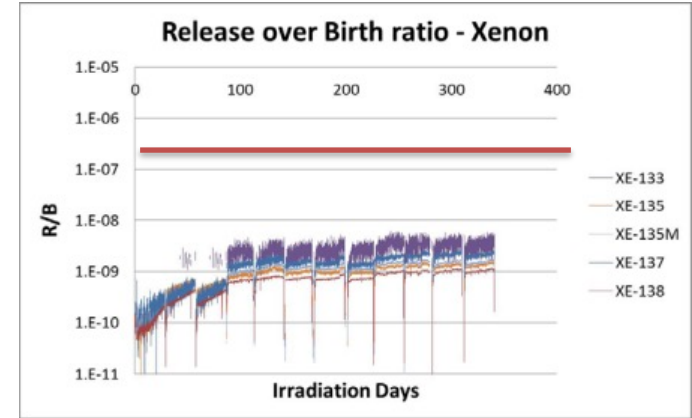
Irradiation test of TRISO fuel

- INET demo production facility, 100,000/a, 2010
- Irradiation test of fuels, Petten, The Netherlands,
 - From 2012 to 2014



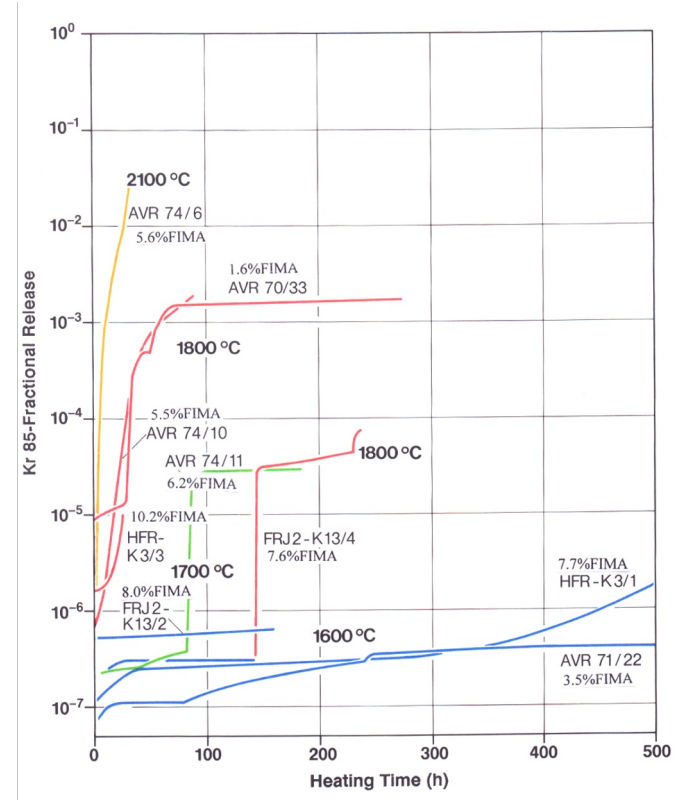
Results of Irradiation tests

- ✓ 5 randomly selected sample pebbles were irradiated in HFR
- ✓ Conditions: Helium temp, 1150°C; Burnup, ~110,000 MWD/tU
- ✓ No TRISO particles fails. The matrix graphite material is very clean and has very low impurity content.
- ✓ Irradiation tests prove the best quality of fuel pebbles.



Heating tests and PIE

- ✓ 2016-2018, irradiated pebbles were heated up and examined in ITU, Karlsruhe, Germany.
- ✓ PIE further prove the best quality of fuel pebbles.



Fuel Production

- Industrial scale fuel plant, 300,000/a, Baotou, CNNC plant
 - 2013, started construction
 - 2016, started production



Milestones of HTR-PM demo

- 2012/12: FCD
- 2015/6: nuclear island construction finished
- 2016-2019: main component installation
- 2020/7: commissioning
- 2021/09: first criticality
- 2021/12: connected to grid
- 2023/12: commercial operation

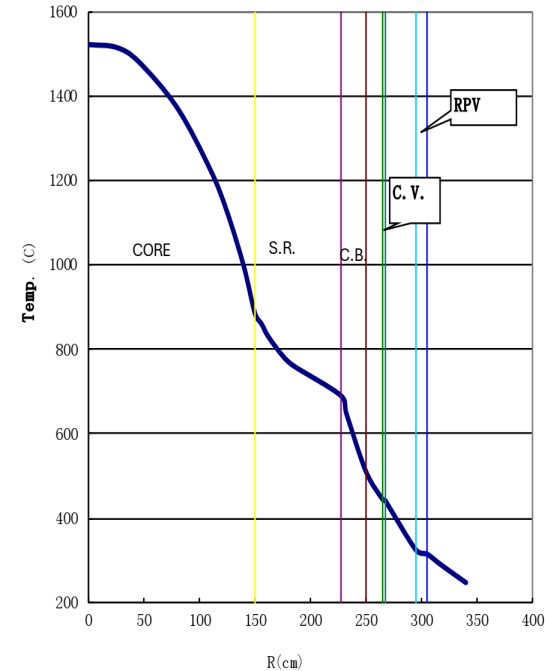
HTR-PM Demo Plant



The world's first pebble bed modular HTGR demonstration plant

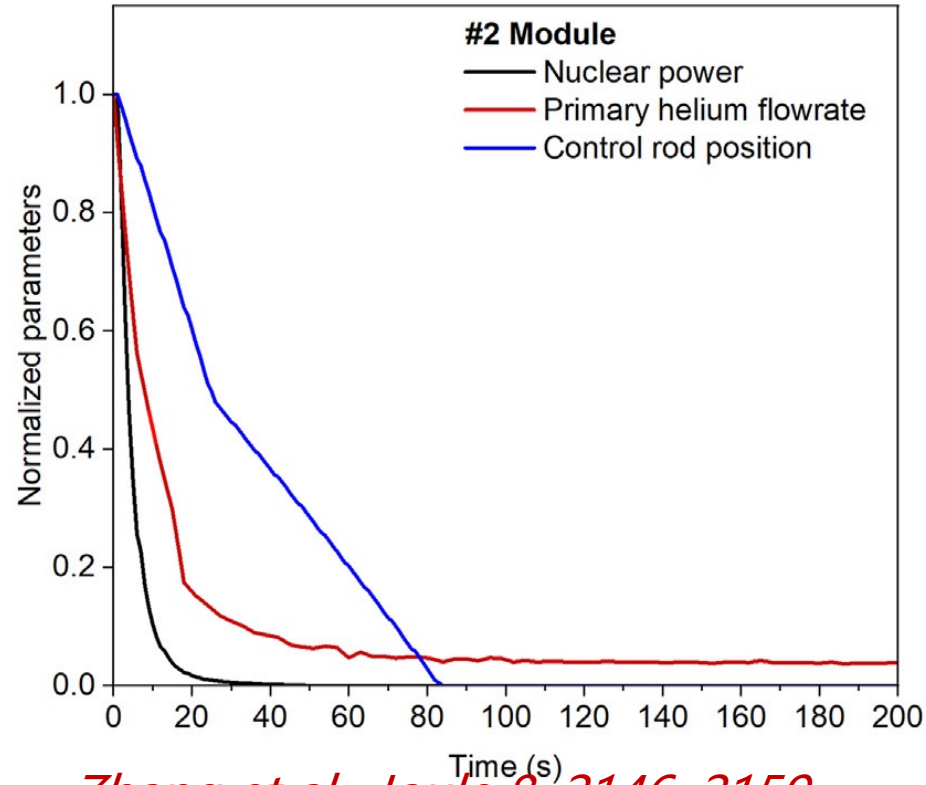
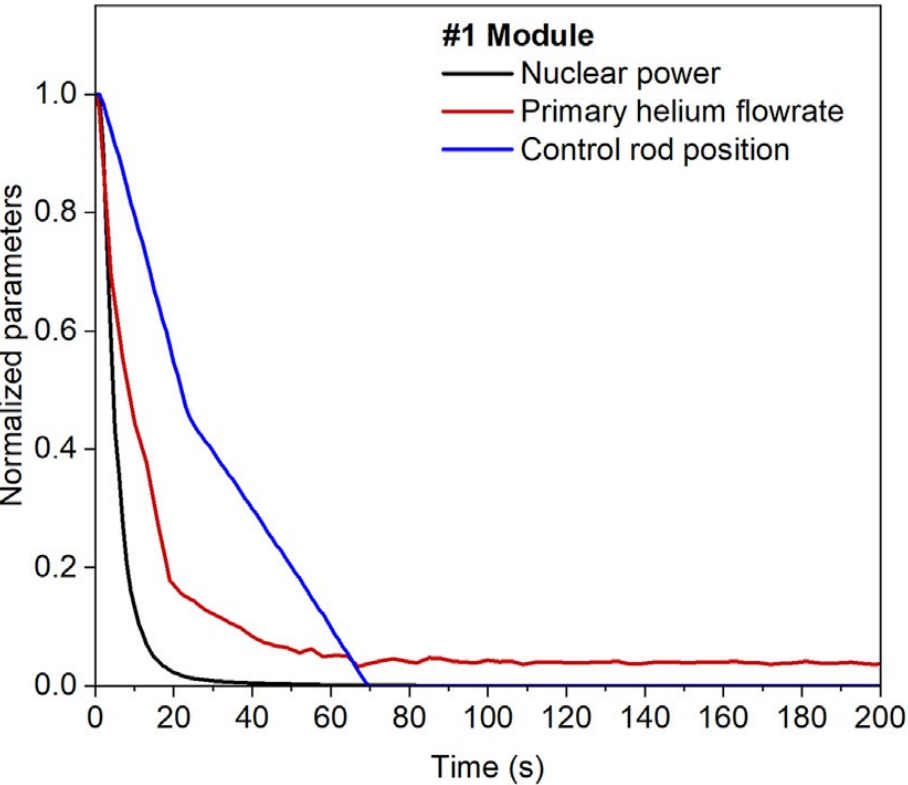
Tests

- ◆ Safety tests were conducted on two modules with a power of 200MWth.
 - ◆ Normal electricity power was switched off.
- ◆ Result: the reactors were naturally cooled down without intervention of humans and emergency core cooling systems.
- ◆ *Tests confirmed that commercial-scale reactors could be cooled down naturally.*



Simulation result of DLOFC

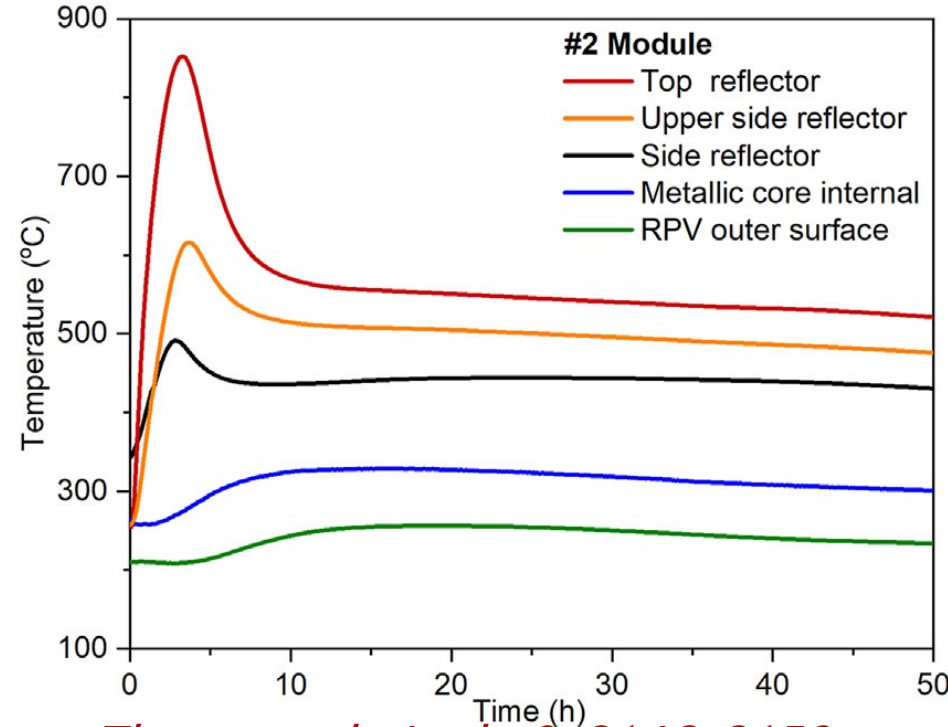
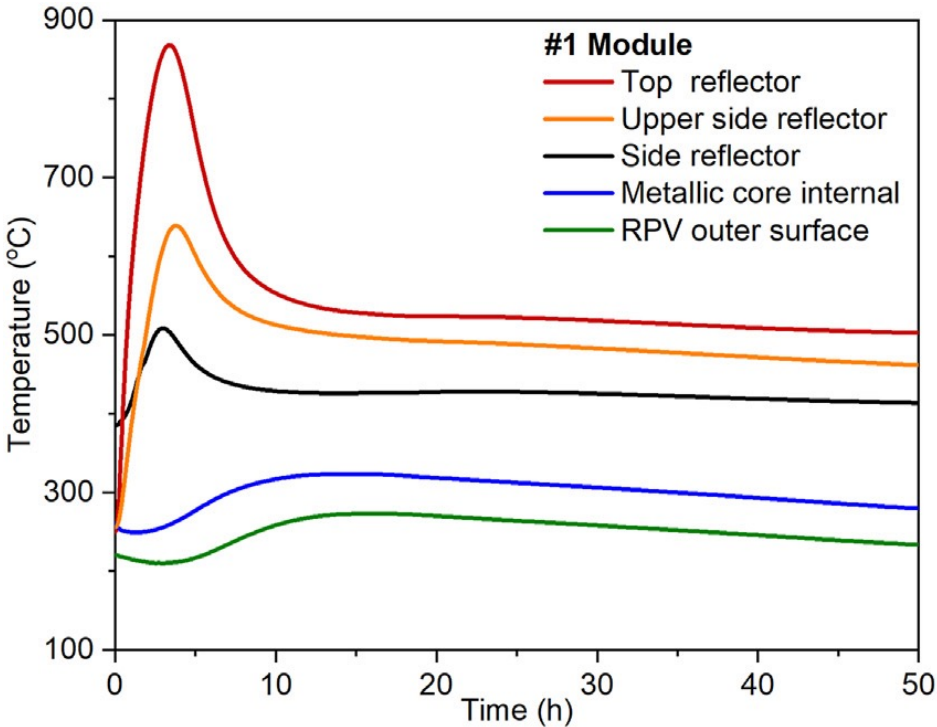
Safety Test Results (1/3)



Zhang et al., Joule 8, 2146–2159

Responses of power, helium circulator speed, and control rod position

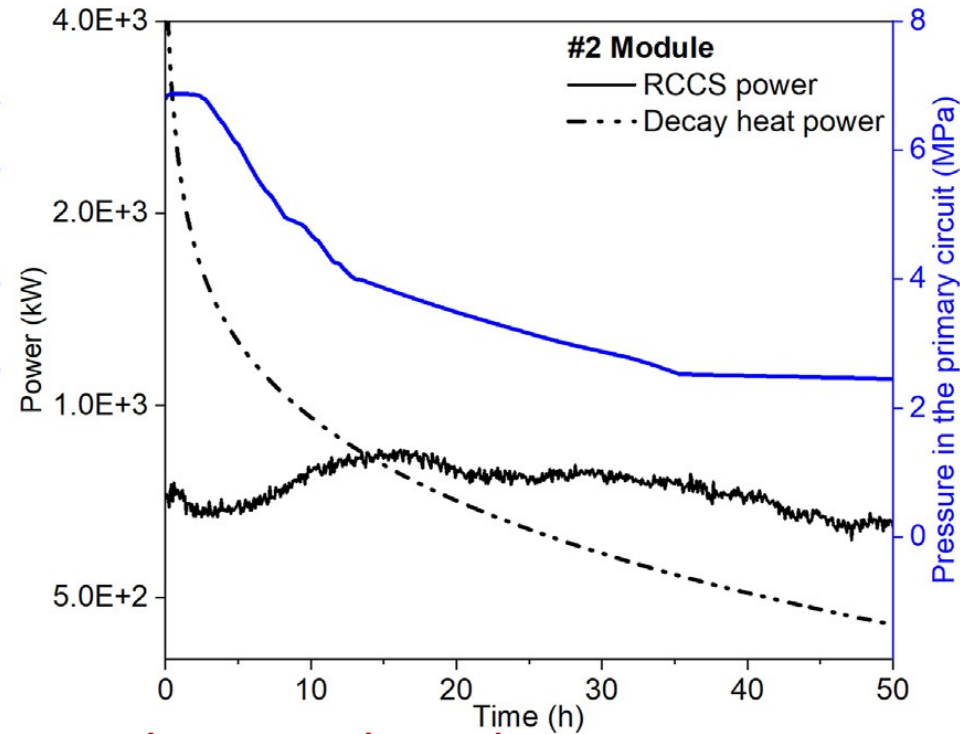
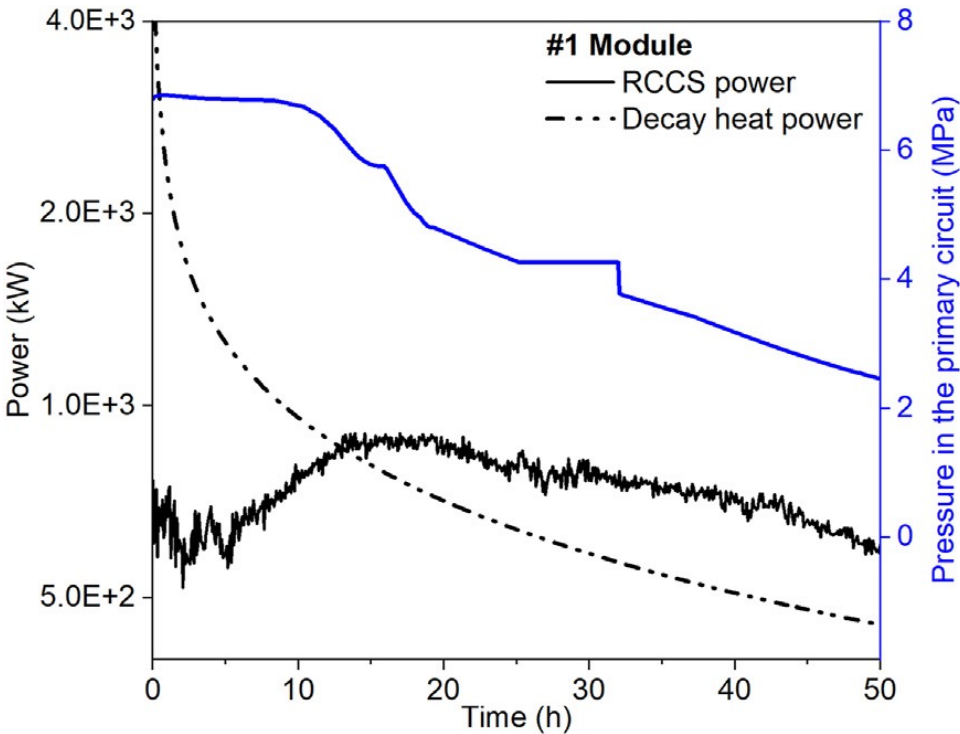
Safety Test Results (2/3)



Zhang et al., Joule 8, 2146–2159

Temp of the top /side reflectors, metallic core internal, and RPV

Safety Test Results (3/3)



Zhang et al., Joule 8, 2146–2159

Responses of decay-heat power, RCCS power, and primary pressure

Nuclear power deployment in China

■ Current Capacity in China:

- 56 units approved for construction,
- 64 units in operation.

■ *Actively, safely and orderly develop nuclear power -- the basic policy*

Year	Units	Reactor type
2019	6	2 x CAP1400, 4 x HPR1000
2020	4	4 x HPR1000
2021	5	4 x VVER, 1 x ACP100
2022	10	6 x CAP1000, 4 x HPR1000
2023	10	10 x HPR1000
2024	11	4 x CAP1000, 6 x HPR1000, 1 x HTR-PM600S
2025	10	2 x CAP1000, 8 x HPR1000
2026	8	6 x HPR1000, 2 x CAP1400

Deployment opportunities for HTR-PM

- The potential to play a key role in the nuclear power expansion, aimed at comprehensive utilization scenarios
 - Decarbonize power and industry through steam/electricity cogeneration
 - Replace fossil fuel generation
 - Work flexibly alongside renewables and energy storage.
 - Power the energy-hungry data centers, etc.
- Challenge: economic competitiveness

HTR-PM600

A multi-module power plant design

- 6 Modules + one steam turbine, 650 MWe
- HTR-PM600 vs HTR-PM Demo Plant:
 - same safety features,
 - same major components,
 - same operating parameters,
- Standardization

Jiangsu Xuwei Nuclear heat application

- Two Hualong One PWR units + one HTR-PM600S unit, approved
- Nuclear reactor-steam turbine generator set-heating system - collaborative operation mode
- Mainly provides industrial heating, with surplus energy used for power generation



Safety review and licensing

HTR-PM

- HTR-10's licensing experience of PSAR, FSAR, commissioning and Testing
- HTR design criterion, design criterion of key systems were documented and reviewed by the licensing authority
- Important licensing criterion, codes, standards, safety goal, key issues foreseeing in the licensing were documented, reviewed and accepted by the licensing authority
- Extensive licensing experience, Chinese licensing authority licensed various technologies.

HTR-PM600S

- PSAR under review
 - More PSA used based F-C curve
 - Optimized classification of SSCs

R&D on HTR w/ elevated temp

◆ Temp: 900-950 °C

- ◆ Nearly same core structure, slightly less power
- ◆ Extended qualification of fuel performance
- ◆ Key component development, such as IHX

◆ Application Scenario

- ◆ HT process heat application
- ◆ Hydrogen Production: *methane steam reforming, H₂O splitting by chemical process, HTSE*
- ◆ Gas turbine power generation

Summary

- Completed the journey from key technology to experimental reactor and then to demonstration project.
- The multi-module HTR-PM to supply steam for the chemical park was launched.
- Improve the economic competitiveness of multi-module units for large-scale deployment
- *To increase the reactor outlet temperature to lay the foundation for applications such as hydrogen production*