VHTR System

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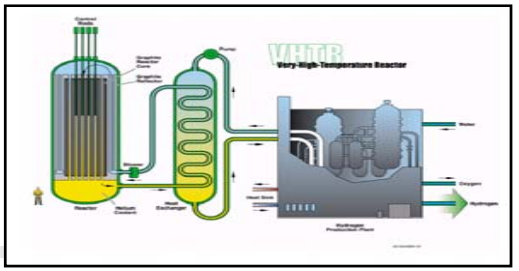
Outlines

- ***What's VHTR?***
- ***How about VHTR?***
- ***What are main R&D topics?***
- ***How to collaborate in GIF?***
- ***VHTR prospects***

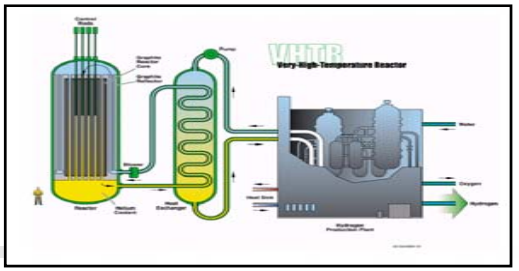
What's VHTR?



Very High Temperature Reactor

- ***Very high temperature reactor (VHTR) can produce very high temperature outlet***
  - ***Much higher than other NPPs***
  - ***Currently 700-950 ° C***
  - ***Next step: >1000 ° C***
    - ***According to definition in GIF Technical Roadmap Update 2014 (TRU)***
    - ***From viewpoint of application, no big difference between 950 ° C and 1000 ° C***
    - ***From viewpoint of technical challenge, big difference***

What's VHTR?



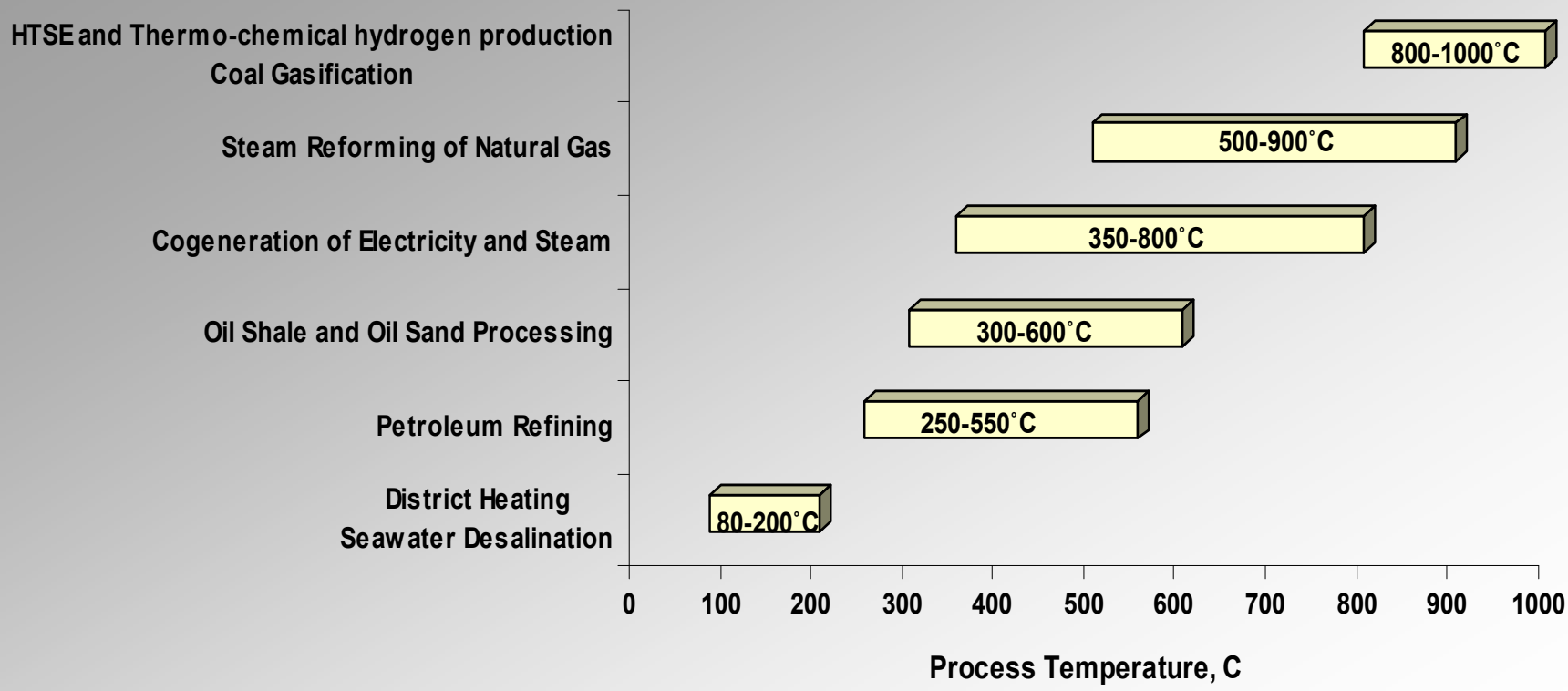
Very High Temperature Reactor

- ***VHTR maintains excellent inherent safety feature***
  - ***Even in the case of lost of all coolant, without active counter measures, no fuel failure, no core melt, no large release of radioactive into environment***

What's VHTR?

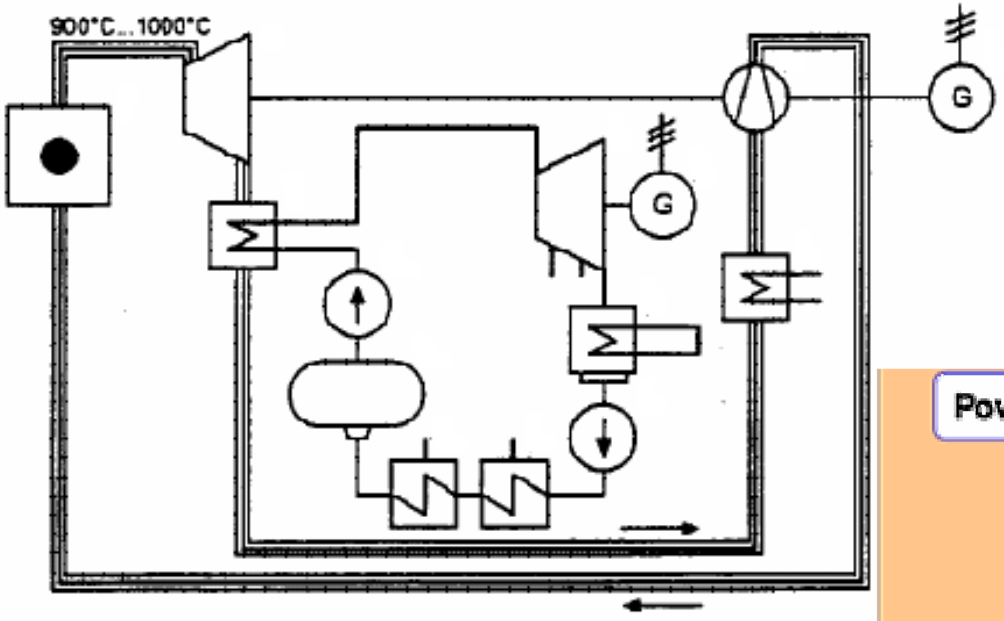
- ***VHTR is excellent for***
  - ***Electricity generation with higher efficiency***
  - ***Wide range of process heat application***
    - ***By steam, cogeneration***
    - ***By helium, hydrogen production***
  - ***Site can be close to end user, because of safety***
  - ***So, VHTR can expand the range of nuclear application, besides electricity***

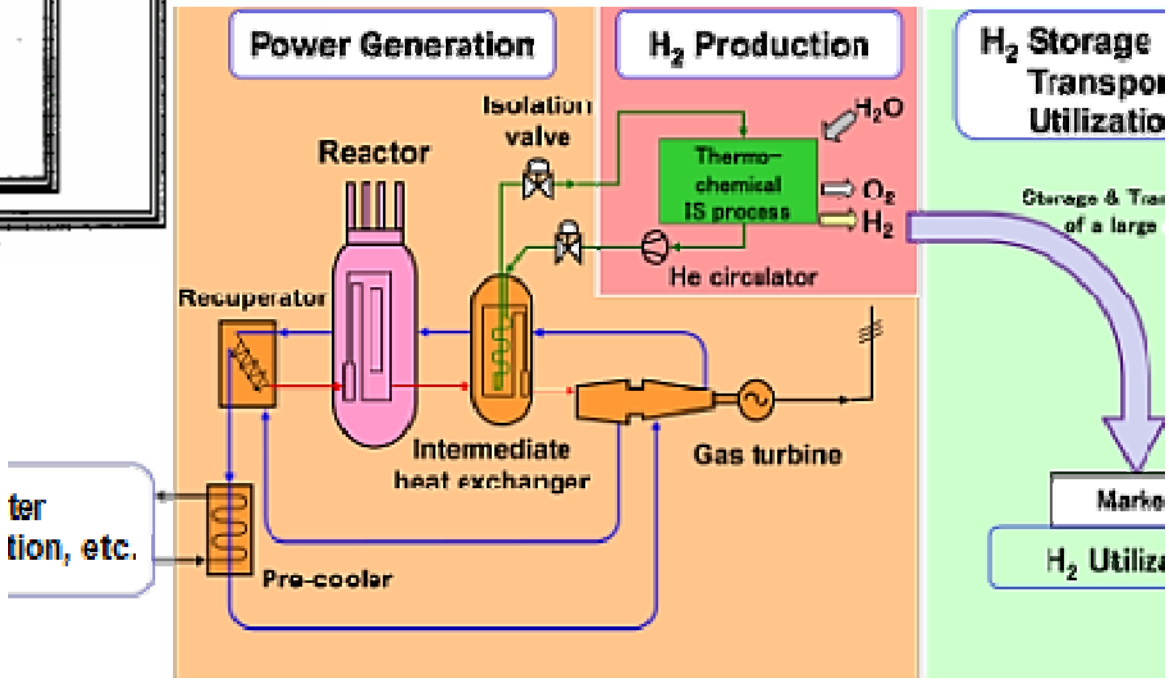
Temperature vs. process applications



Courtesy: Phil Hildebrandt, Battelle Energy Alliance, Global Petroleum Conference, June 11, 2008

H_2 + Electricity + Steam + Desalination: flexible combination



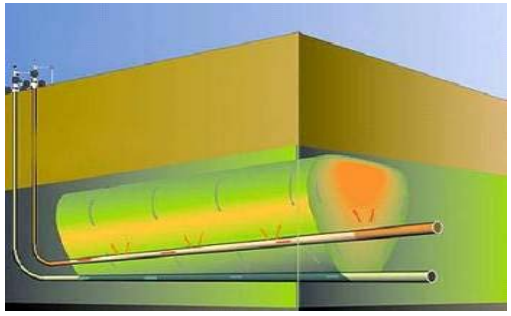


Process heat and Cogeneration- Big market

- *(Petro) Chemical Industries*
- *Coal Liquefaction*
- *Hydrogen production*
- *As well as electricity generation and desalination*

Hydrogen Production

Petrochemical, ammonia, fertilizer Production

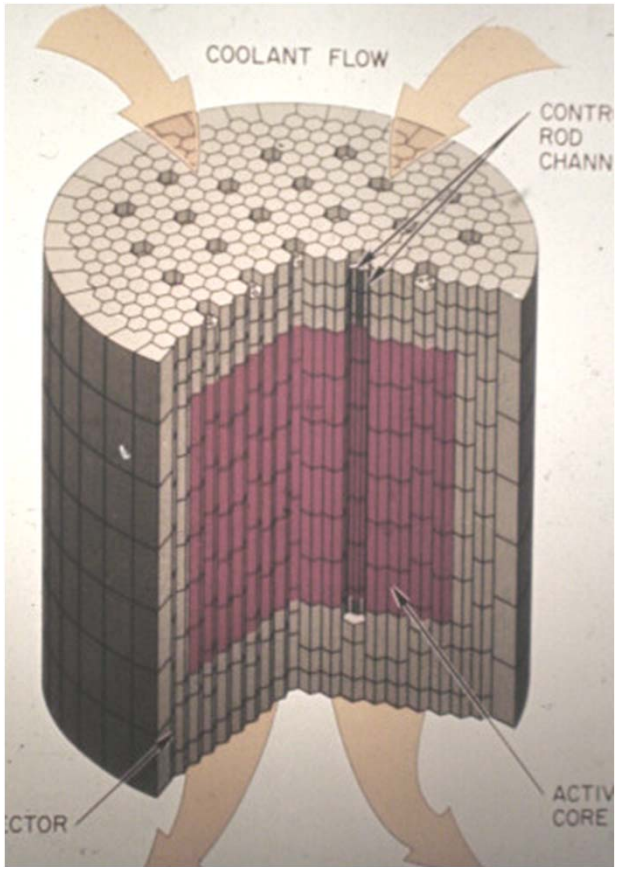


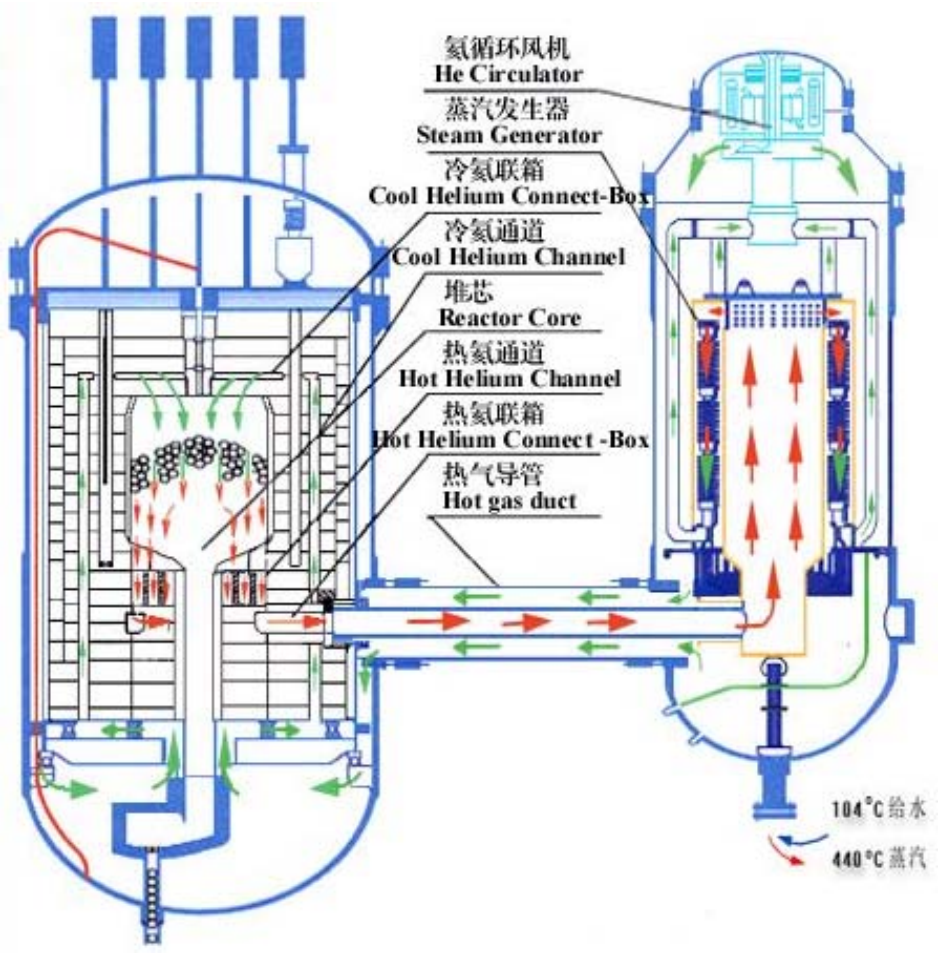
Hydrocarbon recovery

Coal-to-Liquids

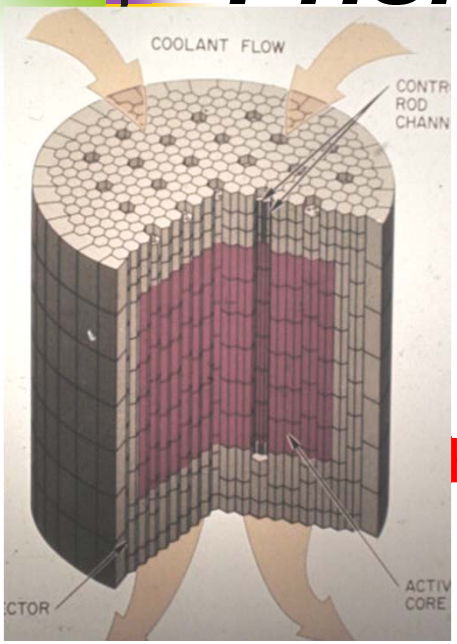
What's VHTR?

- With two typical design
  - Pebble bed
  - Prismatic



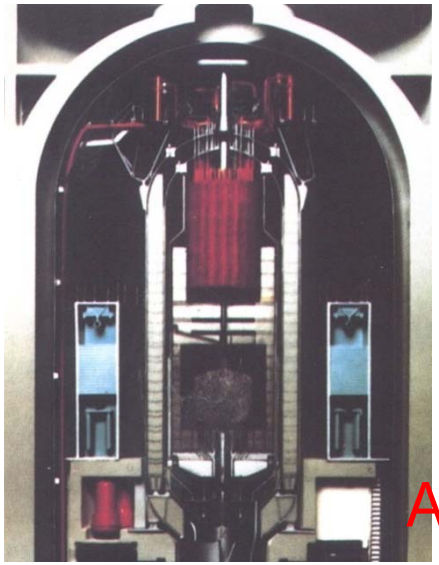


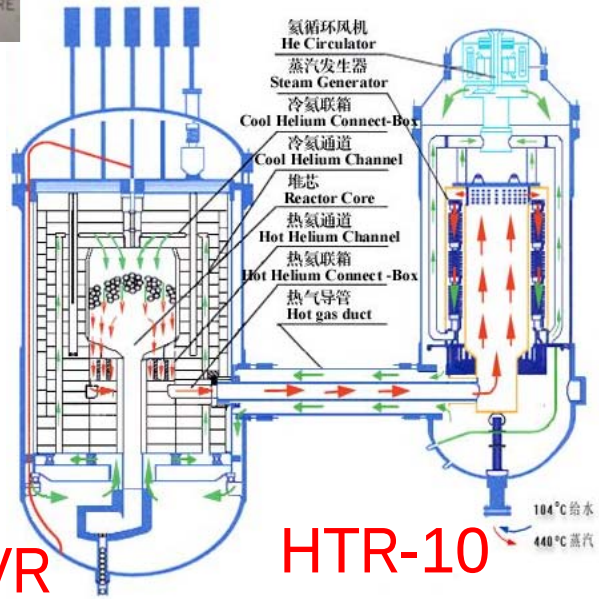
Prismatic & Pebble



HTGR vs. coal stove

HTGR





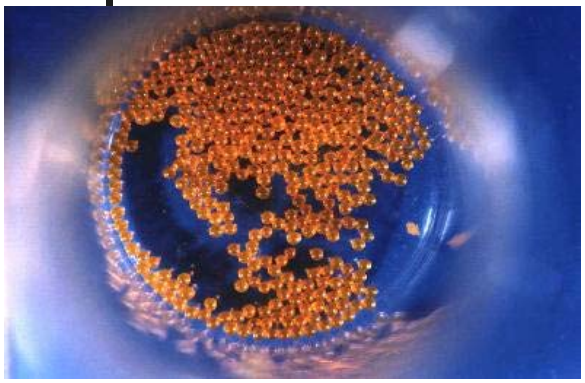
AVR

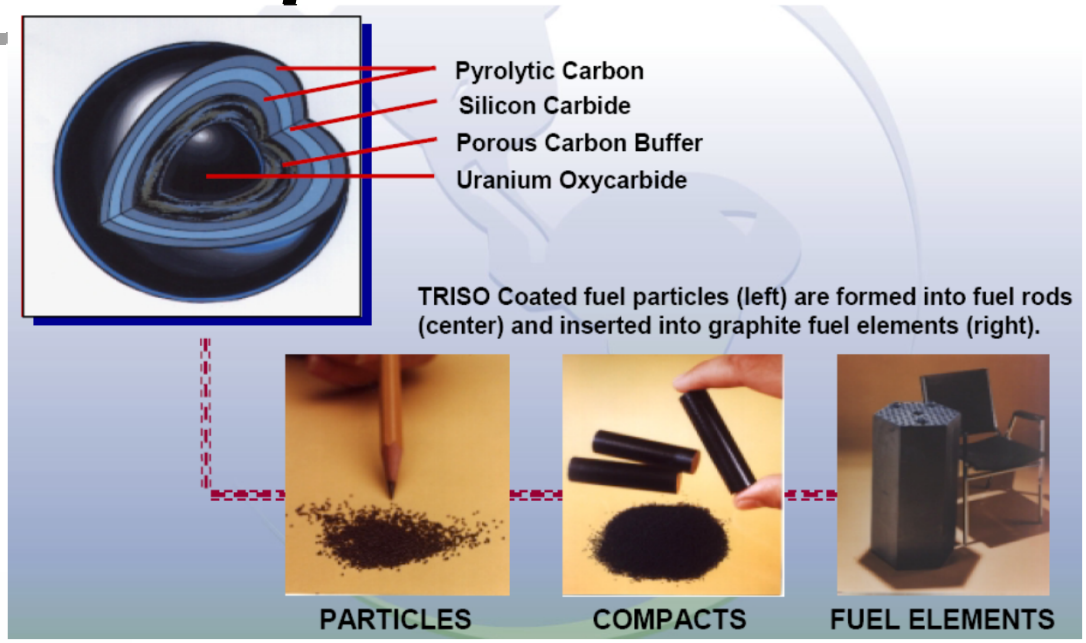
HTR-10

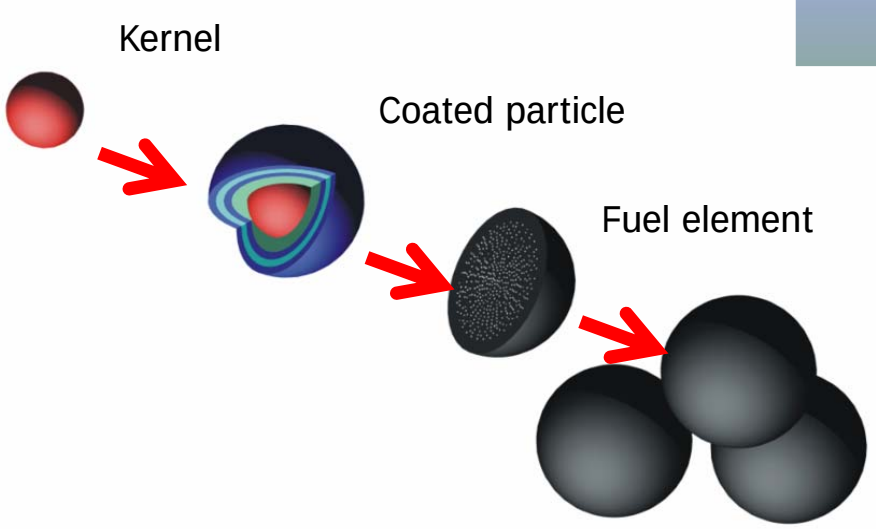
What's VHTR?

- **Same technology:**
  - **TRISO fuel: Accident tolerant fuel**
    - **Confine the fission product in normal and accident condition**
  - **Ceramic core structure**
    - **Withstanding high temperature**
  - **Inert coolant Helium**
  - **Properly designed core structure**
    - **For natural dispersal of decay**
    - **Low power density**

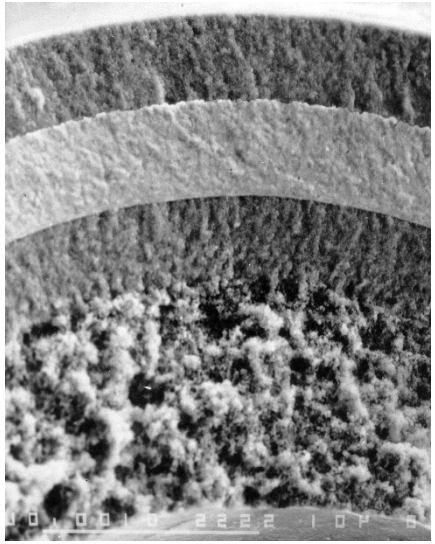
TRISO coated particle fuel for HTGR, pebble and prismatic





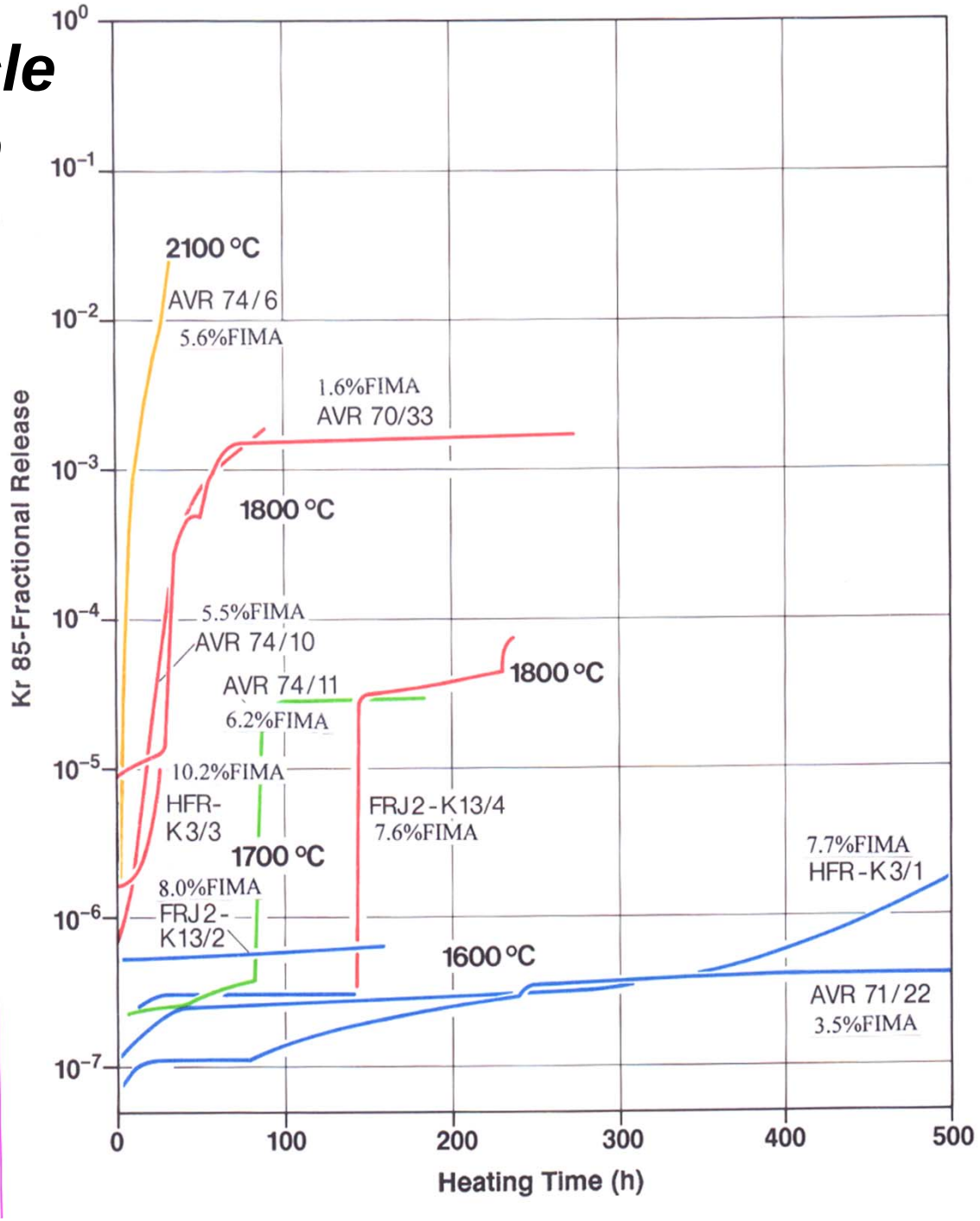


Coatings of fuel particle



TRISO particle performance

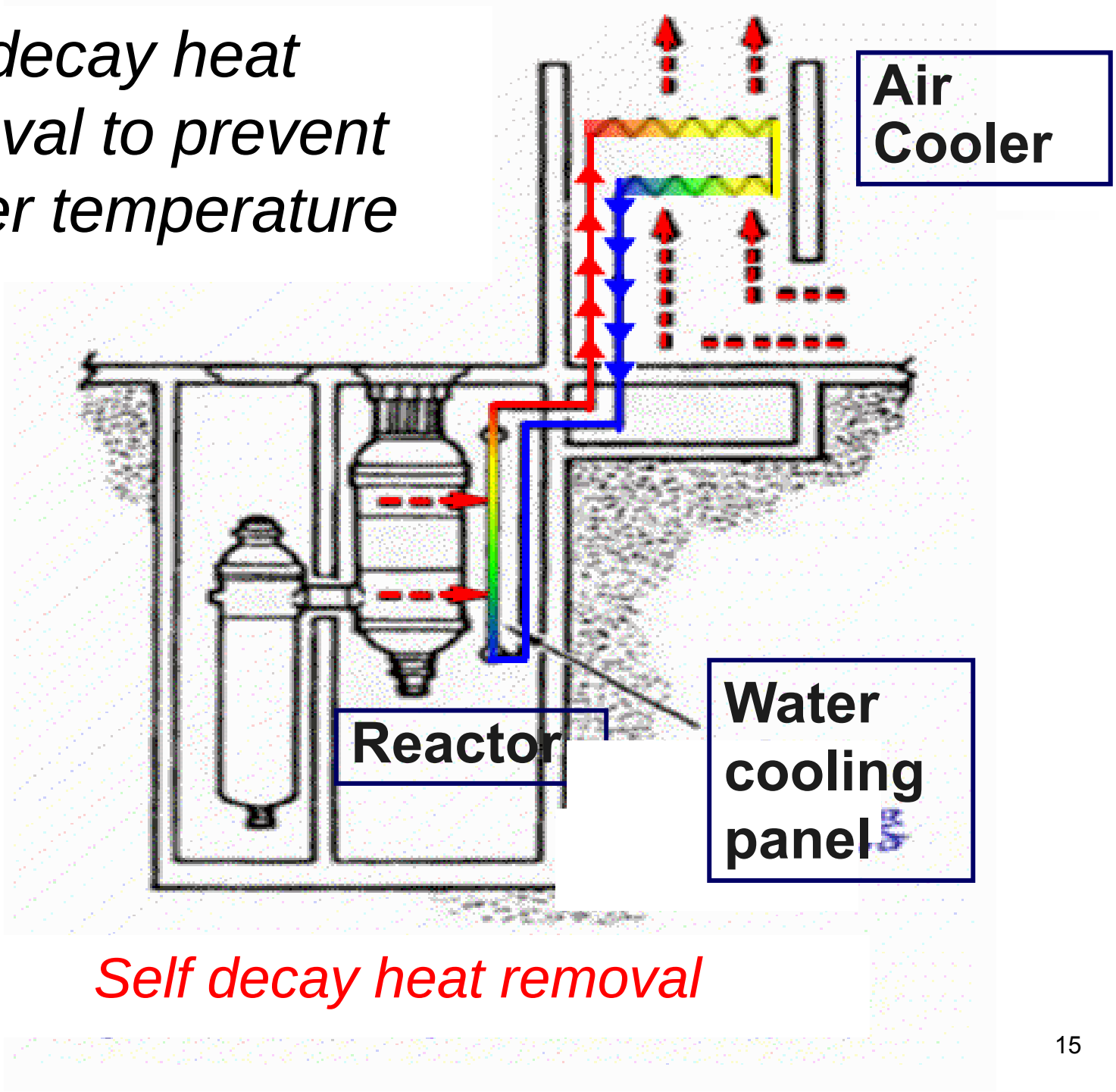
- *Very low failure rate even at very high temperature*
- *Failure without common cause*
- *Achieved since 1980s*
- *Even better performance today: higher temperature, higher burnup*



US recent fuel results are showing significant margin relative to designer specifications

	MHTGR Prismatic	HTR MODUL Pebble	AGR Results
Manufacturing Defect Level			
Heavy Metal Contamination	**2×10^{-5}**	6×10^{-5}	**2 to 5×10^{-5} (depending on batch)**
SiC Defects	**1×10^{-4}**		**3 to 6×10^{-5} (depending on batch)**
In-service Performance Requirements			
Incremental Full TRISO Failures (Normal Operation)	**2×10^{-4}**	1.6×10^{-4}	**$< 1 \times 10^{-5}$ (AGR-1) 4.2×10^{-5} (AGR-2)**
Incremental SiC Failures (Normal Operation)	-----	-----	**2.6×10^{-5}**
Incremental Full TRISO Failures (Accidents)	**6×10^{-4}**	6.6×10^{-4}	**7.3×10^{-5}**
Incremental SiC Failures (Accidents)	-------	------	**2.4×10^{-4}**

Self decay heat removal to prevent higher temperature

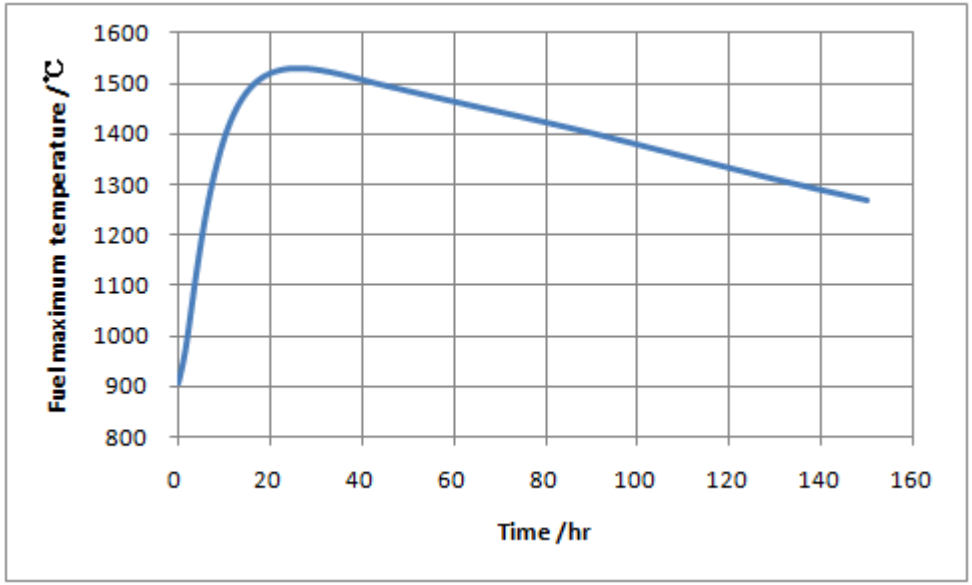


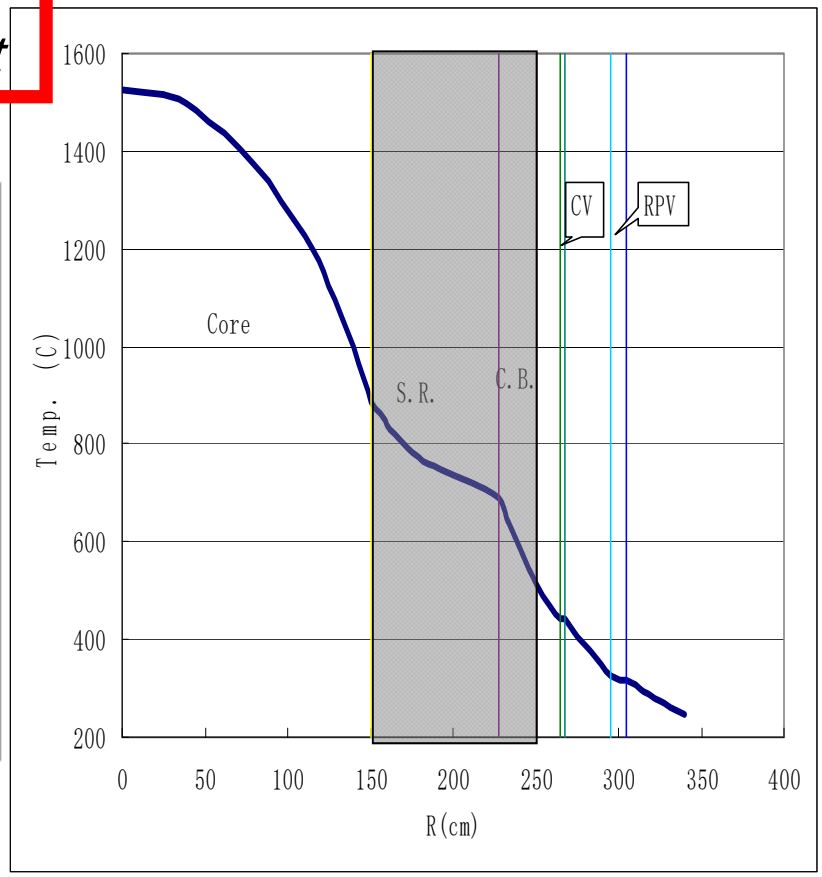
Self decay heat removal

Temperature distribution after DLOFC accident

Even in case of total lost of coolant,
After long time,
Fuel in small percentage, in short time will be in high temp, but less than limit

No other reactor can assume to lost all of coolant!





How about VHTR?

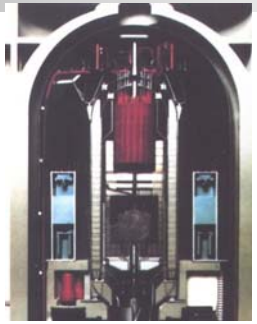
- Two stages of development
  - 700-950 ° C outlet
    - Technical mature: 950 ° C is demonstrated in AVR & HTTR already
    - Large market: electricity, process heat
    - Main tasks: demonstration, optimization, deployment
  - 1000 ° C outlet
    - Need more R&D
      - Improve fuel performance,
      - Develop material to use this high temperature

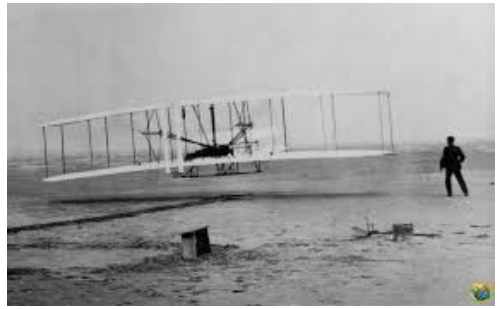
How about VHTR?

- *VHTR have many experiences*
  - *Components: Gas cooled reactor, HTGR*
  - *TRISO fuel: HTGR*
  - *System design/inherent safety: modular HTGR*
  - *Process applications: non-nuclear industry*
  - *Operation experience and performance optimization:*
    - *More are required*

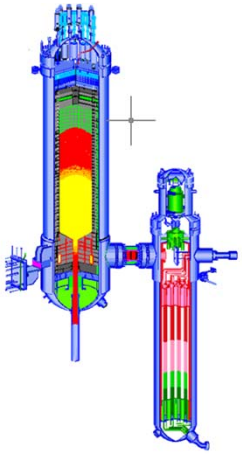
How about VHTR?

- *Early HTR (AVR, FSV, …)*
  - *Like plane of Wright Brothers*

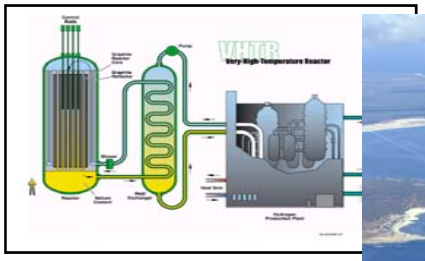




- *Current VHTR (HTR-PM, NGNP, …)*
  - *Like Boeing 787*

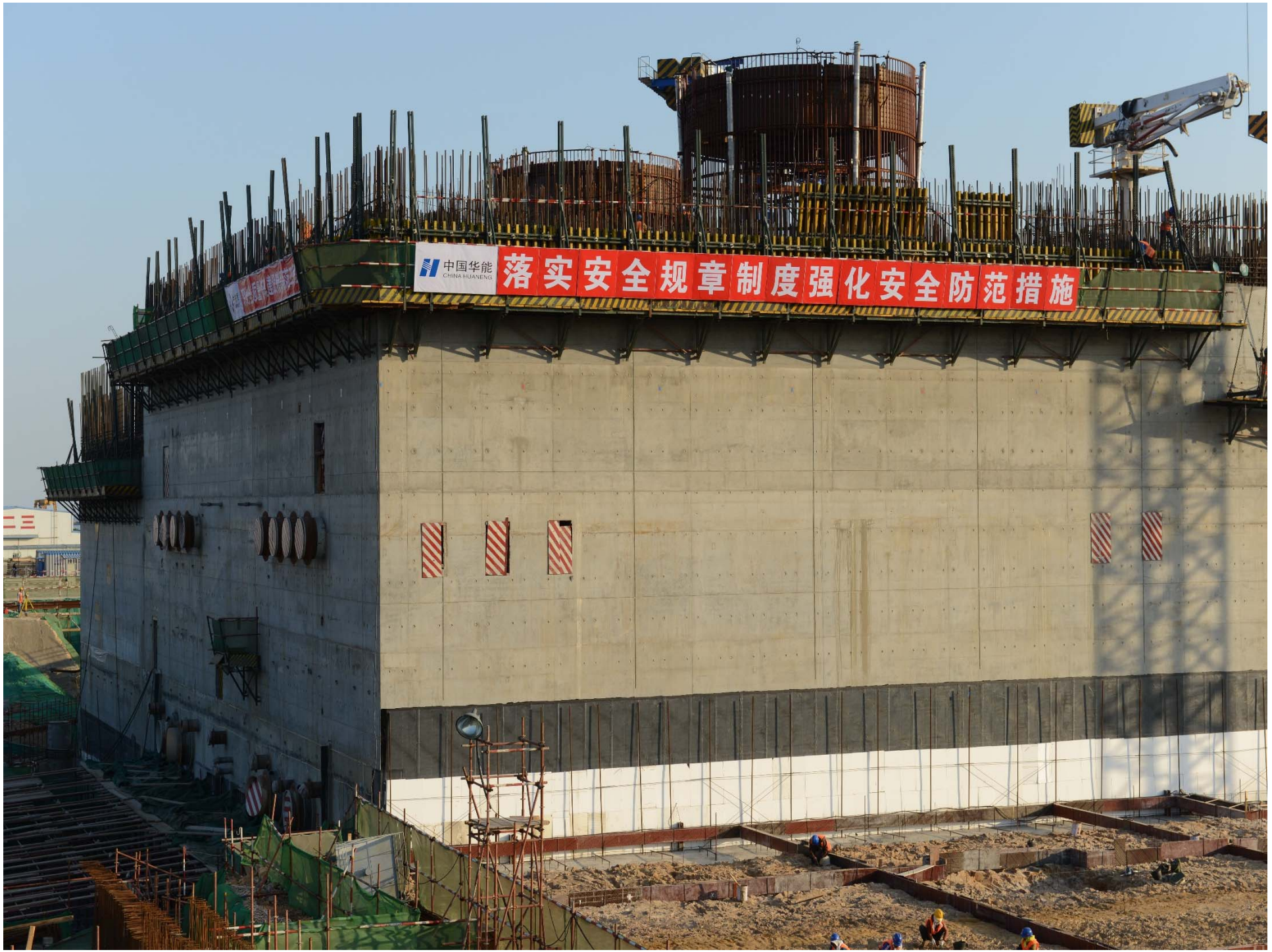


- *VHTR for 2nd stage*
  - *Like X47B*

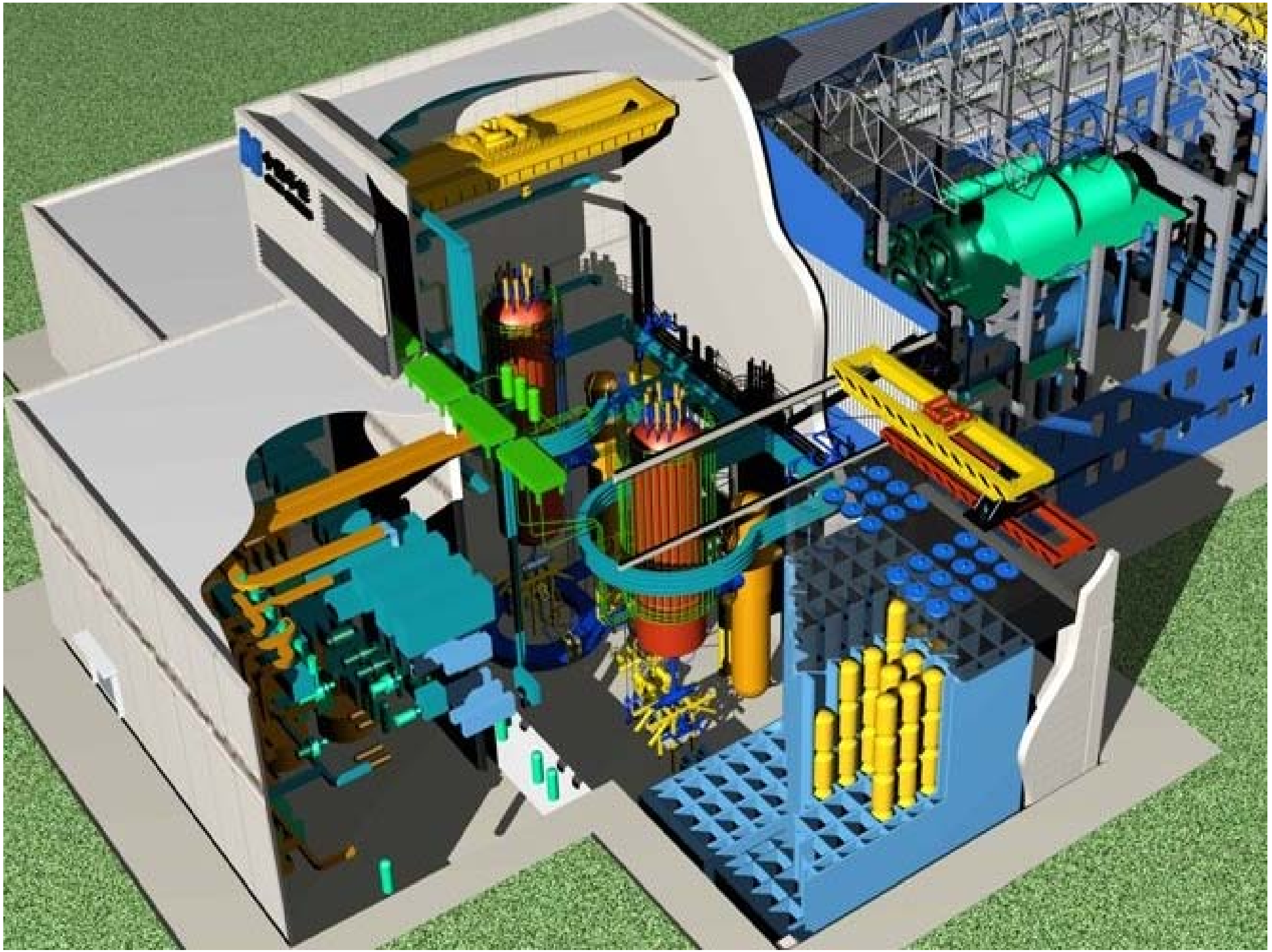


How about VHTR?

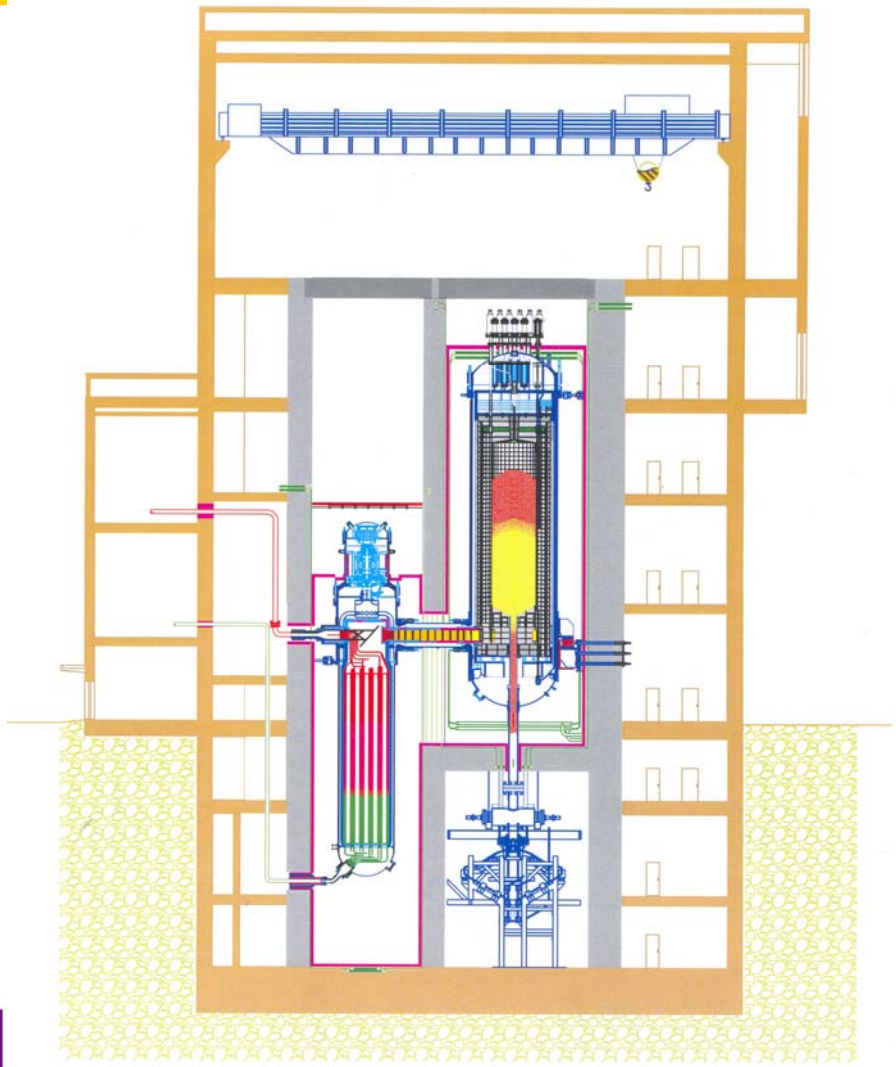
- ***VHTR of 1st stage enter the demonstration phase already***
  - ***HTR-PM from China is under construction***
  - ***Meet current market demands***
  - ***Many designs are available***
    - ***NGNP, GT-MHR, MHTGR in USA***
    - ***GT-HTR-300 in Japan***
    - ***HTR-MODUL***
    - ***PBMR***
    - ***…***

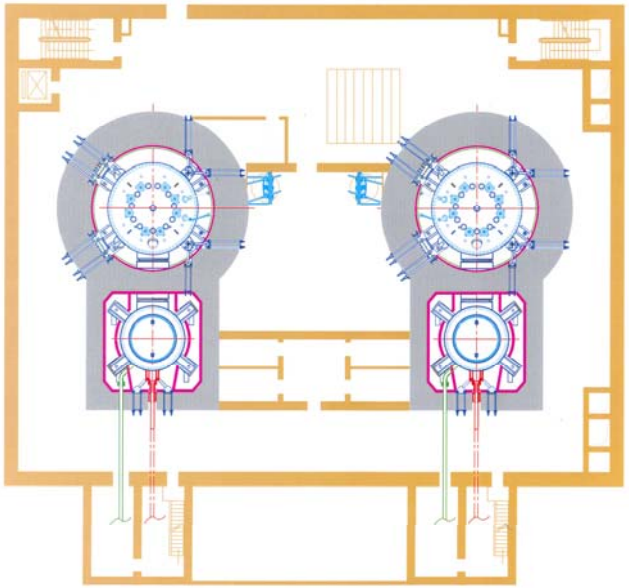

中国华能
CHINA HUANENG
落实安全规章制度强化安全防范措施

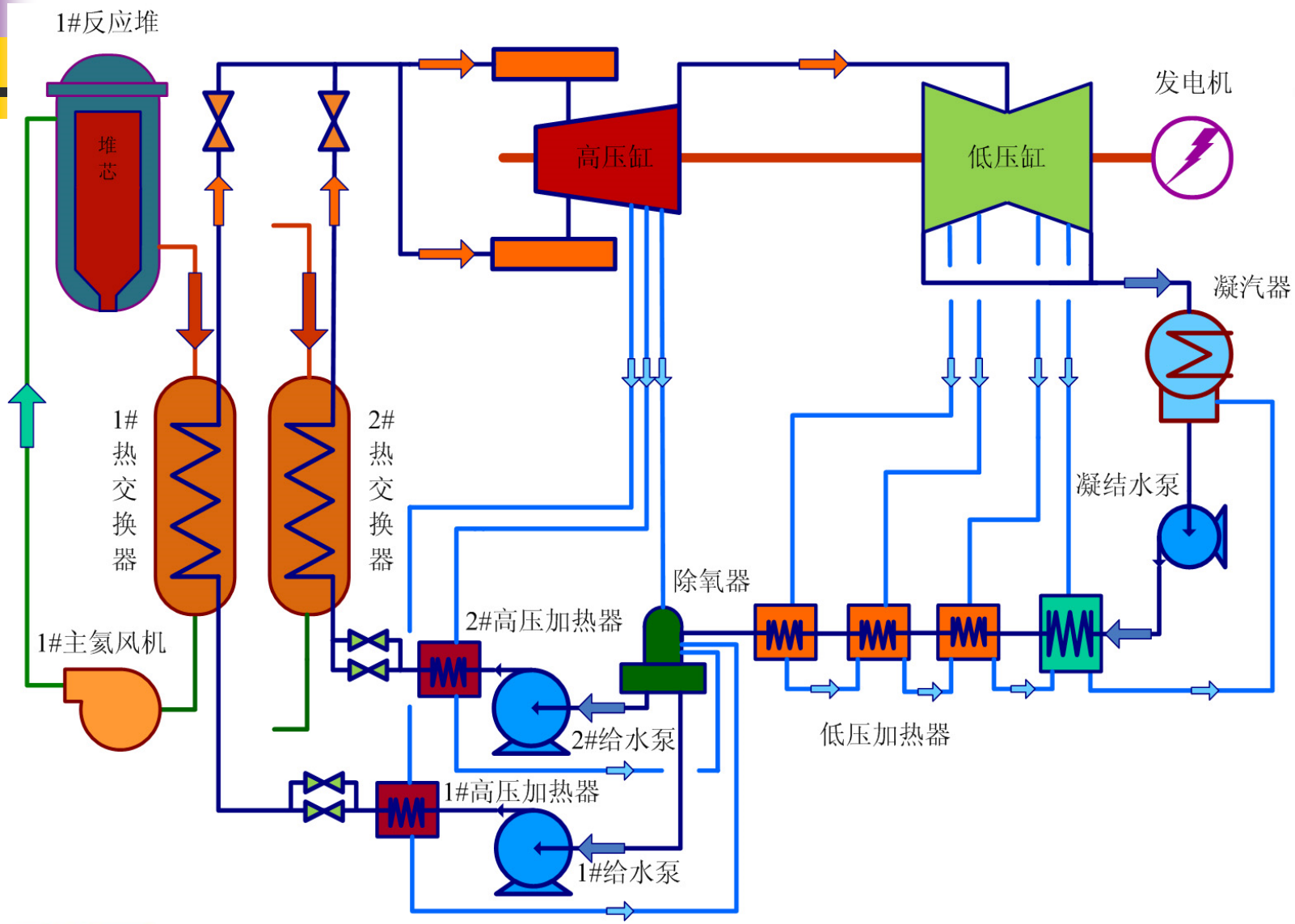
HTR-PM demonstration plant



Twin reactors configuration



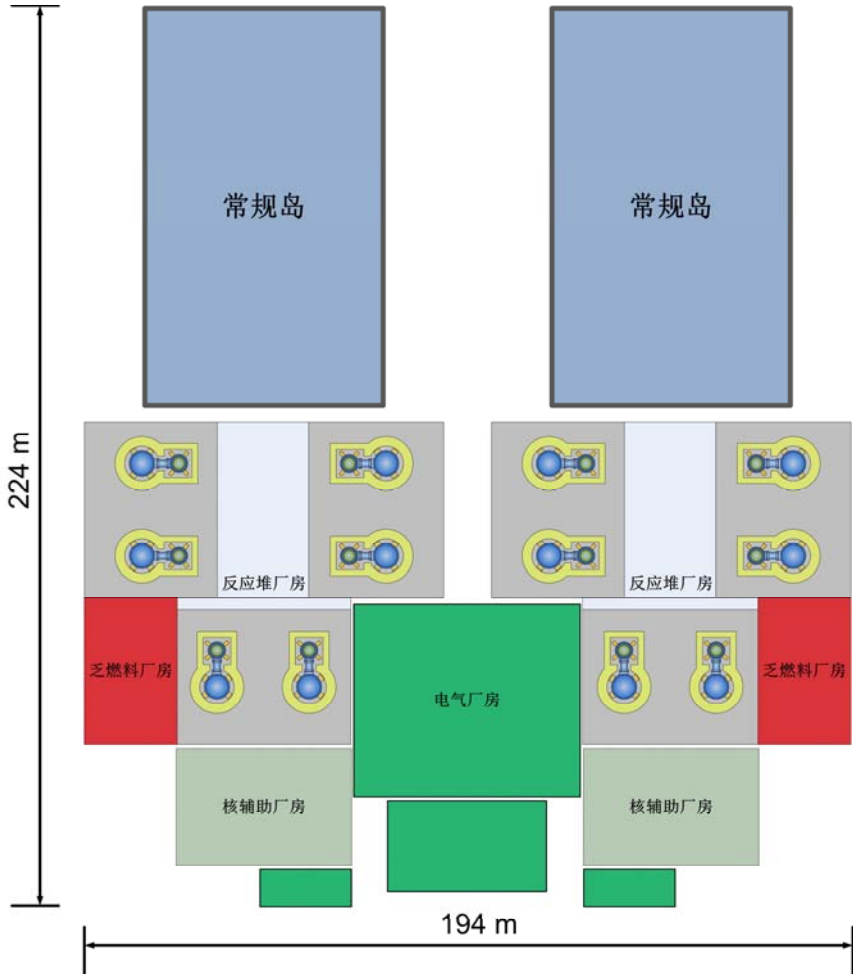




2 reactors, 2 SGs, with 1 turbine

Multi-module plant: HTR-PM600 as commercial plants for next deployment

- *6 reactor modules (250MWt, 250/750℃, 7.0MPa each) connecting to 1 steam turbine (13.25Mpa, 566 ℃), provide a 650 MWe nuclear plant.*
- *Almost same components and techniques as HTR-PM*
- *Co-generation of electricity and steam.*
- *Nearly the same site footprint of PWR plants.*
- *Capital costs improvement is expected.*



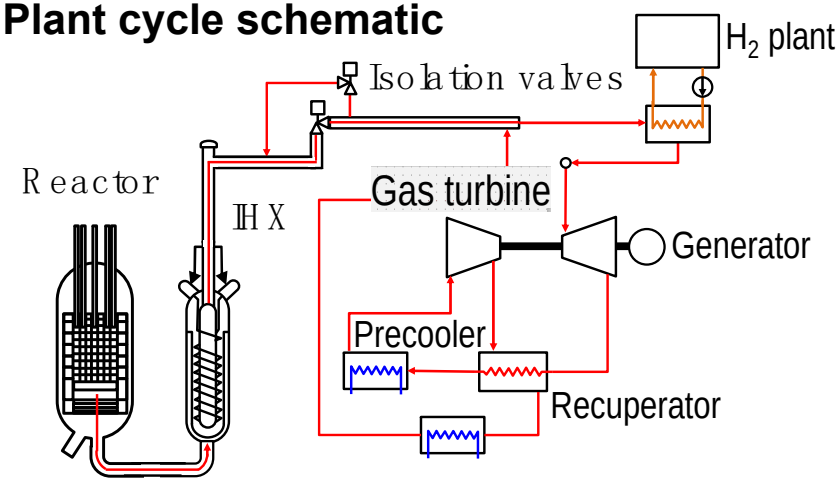
Other design with gas turbine and H_2 production

HTTR-GT/H2 Test (System Design Outline)

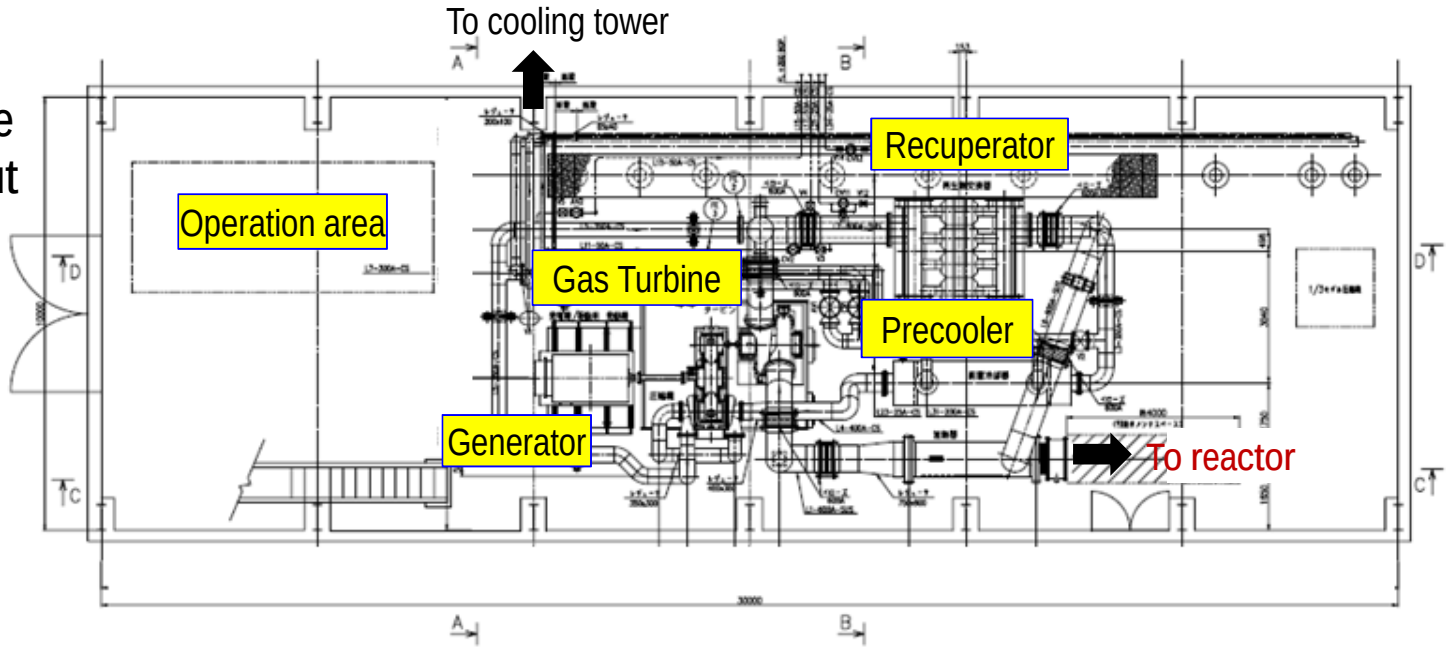
Major specification

Thermal power (IHX)	**10 MWt**
IHX heat supply temperature	900 °C
Gas turbine inlet temperature	650 °C
Gas turbine pressure ratio	1.3
Hydrogen plant power	1 MWt

Plant cycle schematic



Gas turbine Plant layout



What are main R&D topics?

- Improve VHTR in 1st stage (700-950 ° C)
  - Qualify fuel and material
  - V&V computation code
  - Process heat application: Hydrogen production, chemical industry, coupling between nuclear and application
- Development for VHTR in 2nd stage(1000 ° C)
  - Develop new material for IHX
  - Develop new coating for TRISO fuel

What are main R&D topics?

- R&D grouped into 4 PMBs
  - Fuel and Fuel Cycle (FFC)
  - Material (MAT)
    - Metal, Graphite, Ceramic
  - Hydrogen Production (HP)
  - Computational method verification and benchmarks(CMVB)

  - SIA (System Integration Assessment)

What are main R&D topics?

- FFC:
  - Qualification of TRISO fuel
  - Improve TRISO fuel
    - Current SiC coating, new ZrC coatings
  - Fuel cycle: Disposal of once-through fuel and graphite
- MAT:
  - Qualify & develop Metal, Graphite, C/C and SiC/SiC composite
    - Pressure vessel materials, Heat utilization systems materials(Steam generator/IHX), core structure

What are main R&D topics?

- Hydrogen Production
  - I-S, HTSE, Cu-Cl
  - Develop & use industrialized material
- CMVB:
  - For neutronics, T/H, safety, system simulation, FP chemical, mechanical, …
  - Code to code benchmarking
  - test rigs
  - data from reactor (AVR, FSV, HTR-10, THTR,…)

How to collaborate in GIF?

- *VHTR system structure*
  - *SSC*
    - *7 members: China, Euratom, France, Japan, Korea, Switzerland, United States*
    - *SSC chair/co-chair: Michael Fuetterer (EU) / Carl Sink (US)*
      - *Newly elected in May 8, 2015*
  - *PMBs*
    - *4 active PMBs*

How to collaborate in GIF?

- *4 active PMBs:*
  - *HP: CA, CN,EU,FR,JP,KR,US*
    - *Chair/co-chair: Francois Le Naour (FR) / Sam SUPPIAH(CA)*
  - *FFC:CN,EU, FR, JP, KR, US*
    - *Chair/co-chair: David PETTI (US) / LIU Bing (CN)*
  - *MAT: CN, CH, EU, FR, JP, KR, US*
    - *Chair: William R. CORWIN (US)*
    - *3 workgroups: Metals, Graphite, Ceramics*
  - *CMVB : CN, EU, JP, KR, US*
    - *Chair/co-chair: SHI Lei (CN)/Hans Gougar (US)*

How to collaborate in GIF?

- **Collaborate**
  - **FFC**
    - **Fuel manufactured in members are irradiated and examined in EU & USA**
    - **CARBOWASTE from EU are available for GIF**
  - **MAT**
    - **All experiment data is collected in ORNL database**
    - **Crosscutting with other systems: joint meeting**

Prospects for VHTR

- ***Fuel cycle***
  - ***Waste can be treated: CARBOWASTE***
  - ***Spent fuel can be reprocessed, compatible with current reprocessing***
  - ***Spent fuel is suitable for final disposal***
    - ***Larger volume, less(or same) decay heat, because of high burnup***
  - ***Capable for different type of fuel: U, Pu, Th, MA, …***
    - ***Synergy with preprocessing strategy, and other type NPPs***

Prospects for VHTR

- **Economical**
  - **? Large components & Small power size**
  - **! Market flexibility for small reactor**
  - **Cost mainly depend on plant size**
    - **Large unit/plant with multiple reactors can improve economy**
    - **For example: Chinese design HTR-PM600**
  - **Cost for high safety / performance**
    - **What's your choice? Porsche vs. Volkswagen vs. Motor . All can drive you.**
    - **Or Wright's Plane, Boeing 787, X47B?**

INET

What's your choice?

Porsche racing car

Normal car

Motor cycle

Prospects for VHTR

- ***Highlights of VHTR:***
  - ***High efficiency***
  - ***Versatile applications: electricity, cogeneration, process heat,…***
  - ***Inherent safety***
  - ***Relatively mature***
    - ***HTR-PM is under construction already***

Prospects for VHTR

- ***VHTR have a bright future***
- ***Safety is the key factor for nuclear***
- ***Process heat application has large market***
- ***HTR-PM project will promote VHTR***

- ***I am proud of VHTR, and VHTR SSC***