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The Production of Hydrogen with Nuclear Energy
Part 3: Nuclear Process Heat Reactors

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The Production of Hydrogen with Nuclear Energy

Part 3: Nuclear Process Heat Reactors

Karl Verfondern
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Joint IAEA – ICTP Advanced School on "Development and characterization of materials for hydrogen-based energy systems: Role of nuclear technology"
June 13-18, 2011, Trieste, Italy

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Part II

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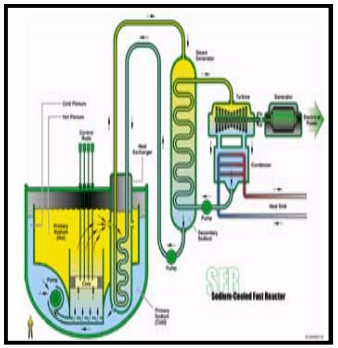
- Gen-IV Reactor
- High Temperature Gas-Cooled Reactor
- Process Heat HTGR
- Intermediate Heat Exchanger

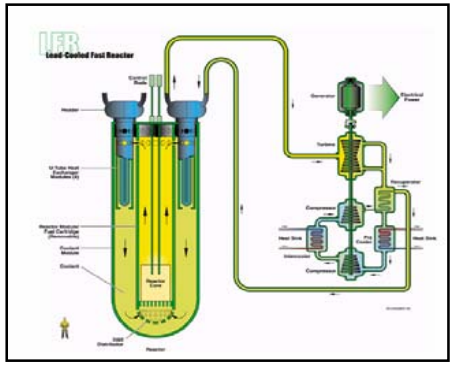
Improvements for Future Nuclear Reactors

- **Safety improvements by innovative technologies**
- **Competitive cost**
- **New approaches for waste minimization & disposal**
- **Reduction of proliferation risk**
- **Improvement of public acceptance**
- **Extension of applications (electricity, heat, hydrogen)**
- **Conservation and extension of expertise & competence**

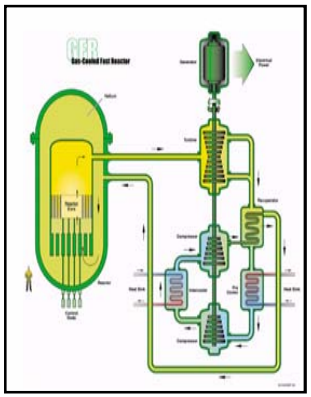
Gen-IV Nuclear Reactor Systems



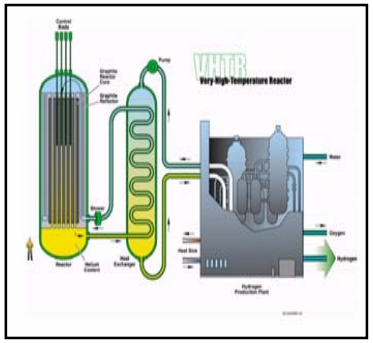
Sodium Fast Reactor



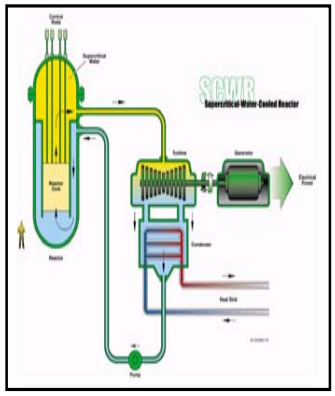
Lead Fast Reactor



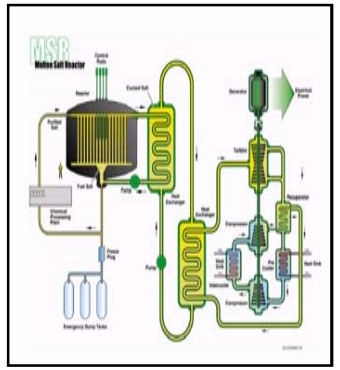
Gas Fast Reactor



Very High Temperature Reactor



Supercritical Water Reactor



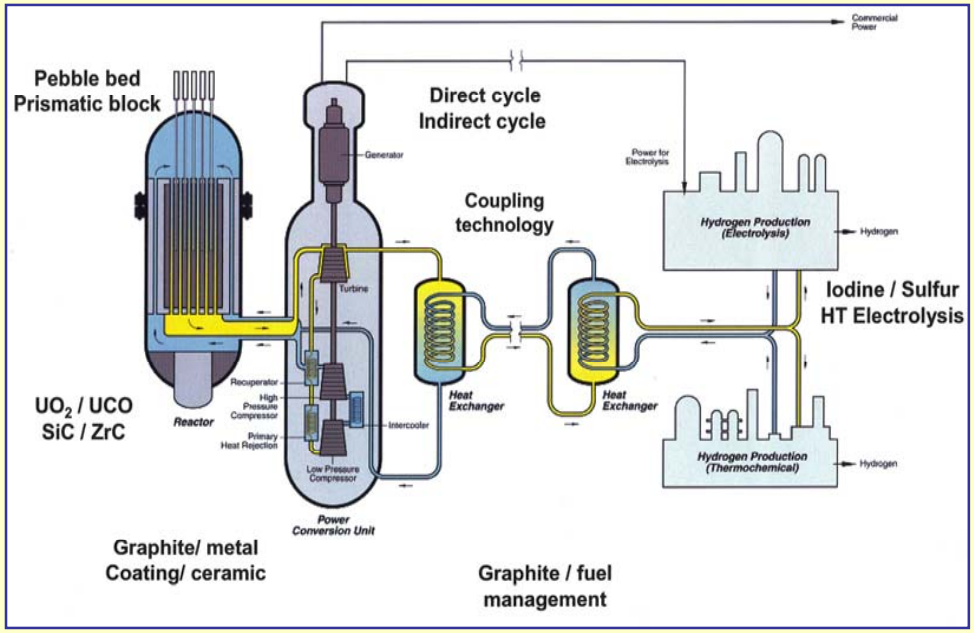
Molten Salt Reactor

Very High Temperature Reactor (VHTR)

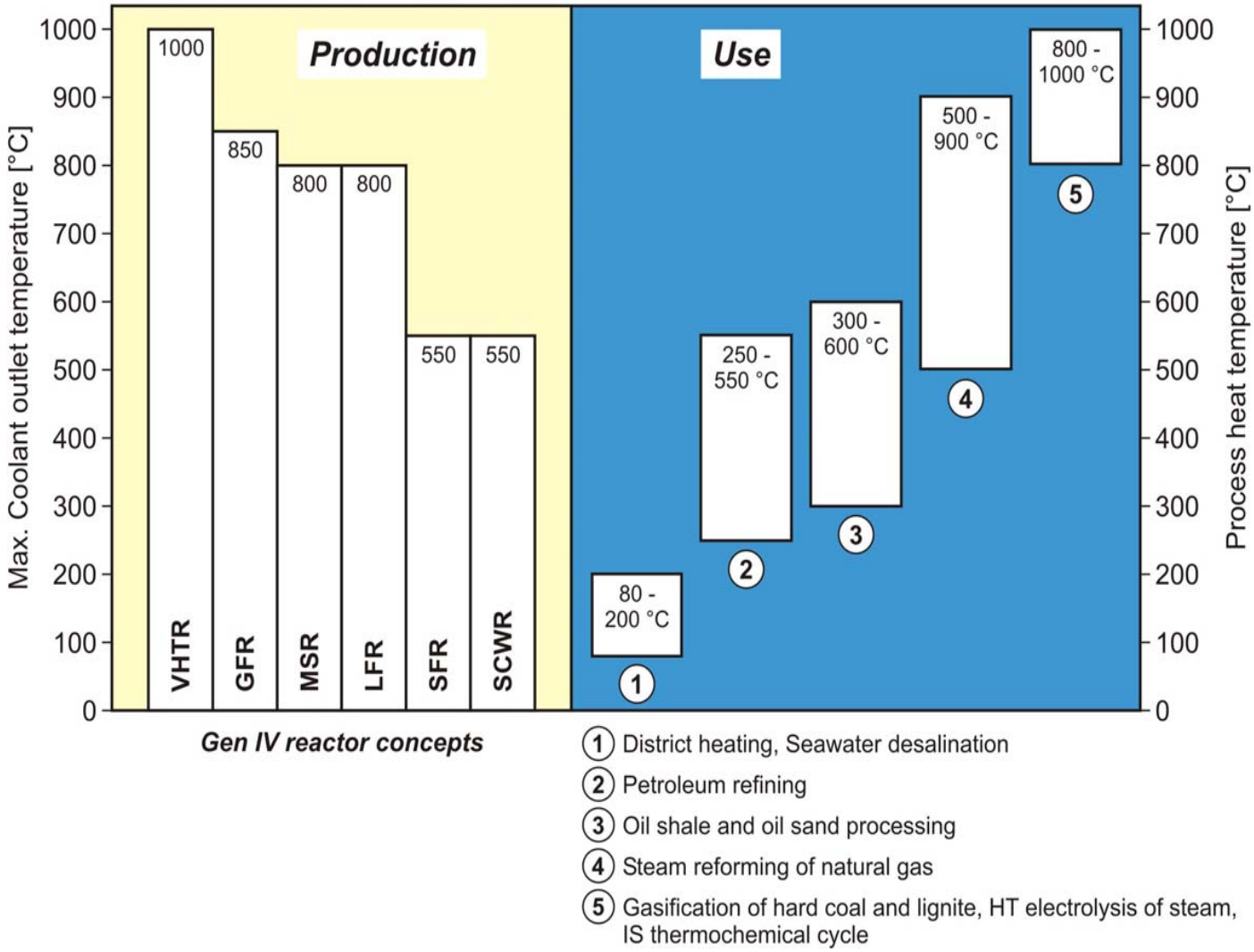
- **Nearest-term option of a Gen-IV system;**
- **To deliver electricity, process heat & steam for CHP & H_2 (or other fuels) production;**
- **Demonstration plant to be operational by about 2015-2020.**

GenIV Nuclear Reactor: VHTR

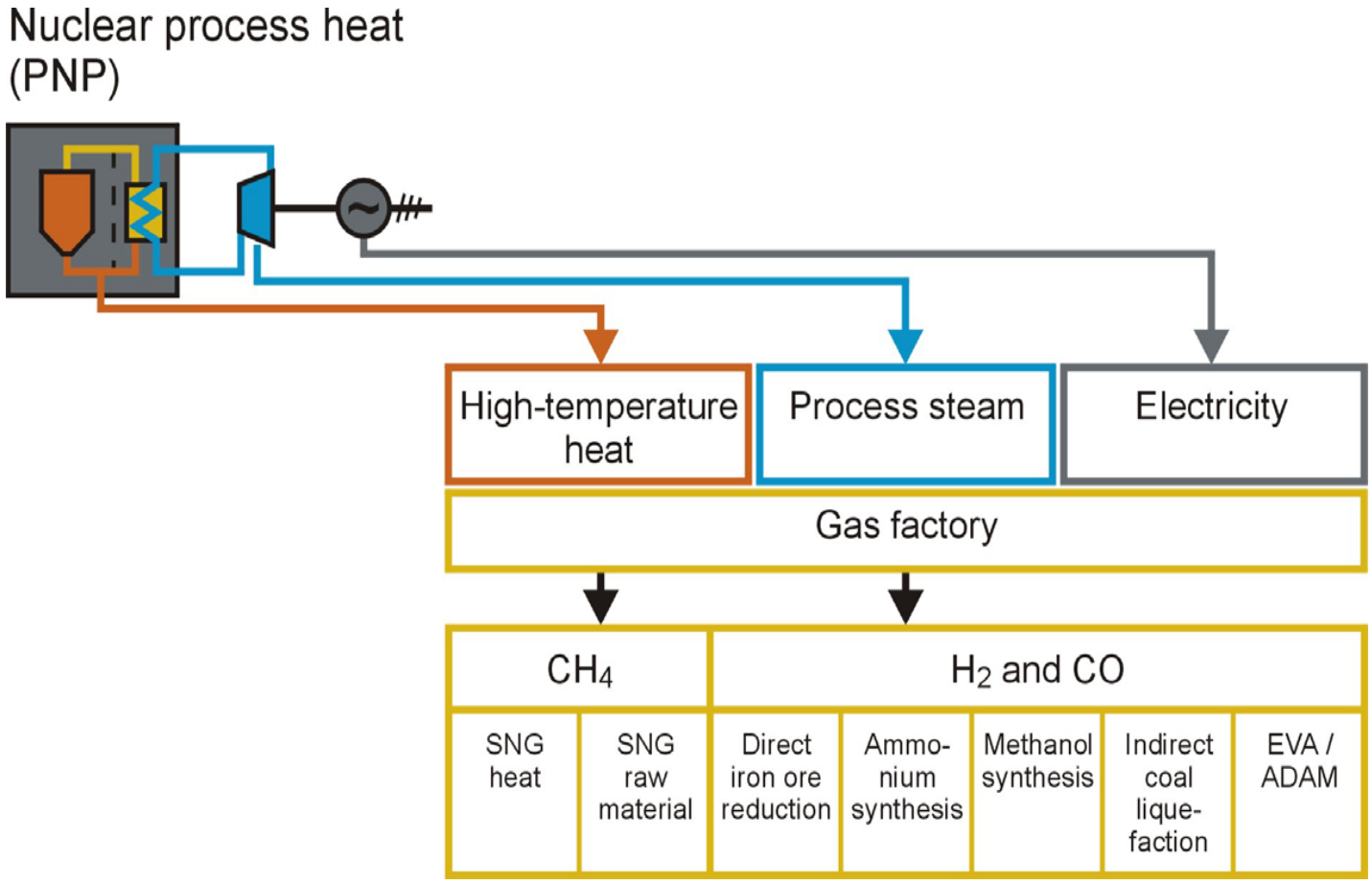
- 400-600 MWt for electricity and process heat production;
- Helium-cooled, graphite-moderated, thermal neutron spectrum;
- Gas outlet temperature of 900-1000 °C;
- IHX for heat transfer to H_2 production plant or gas turbine.



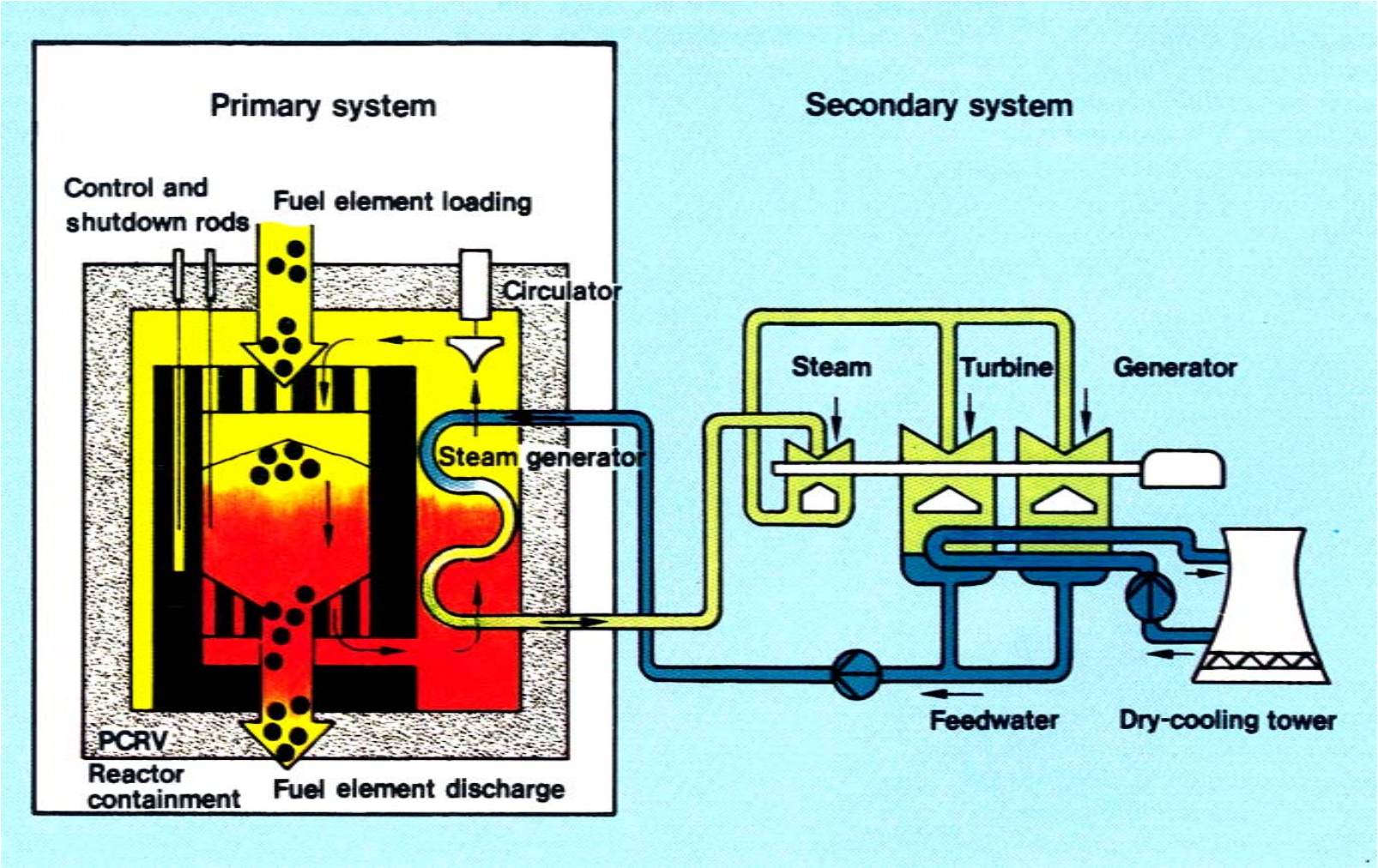
Temperature Ranges Provided and Required



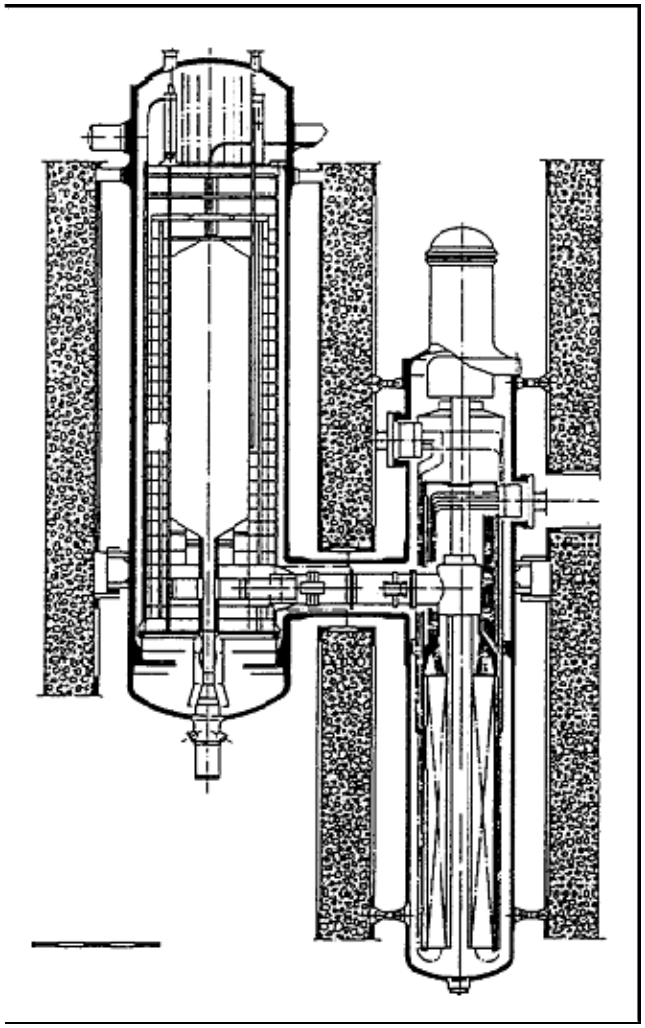
Nuclear Process Heat Applications

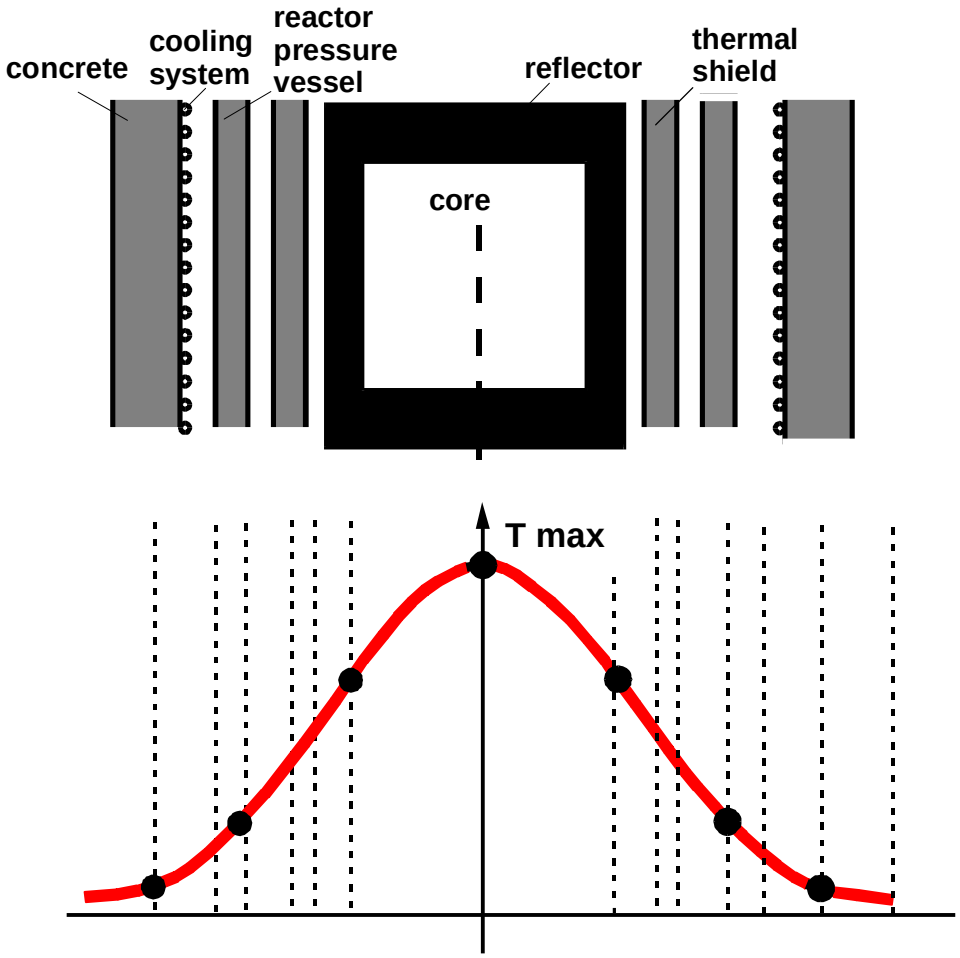


Steam Cycle HTR with Pebble Bed Core

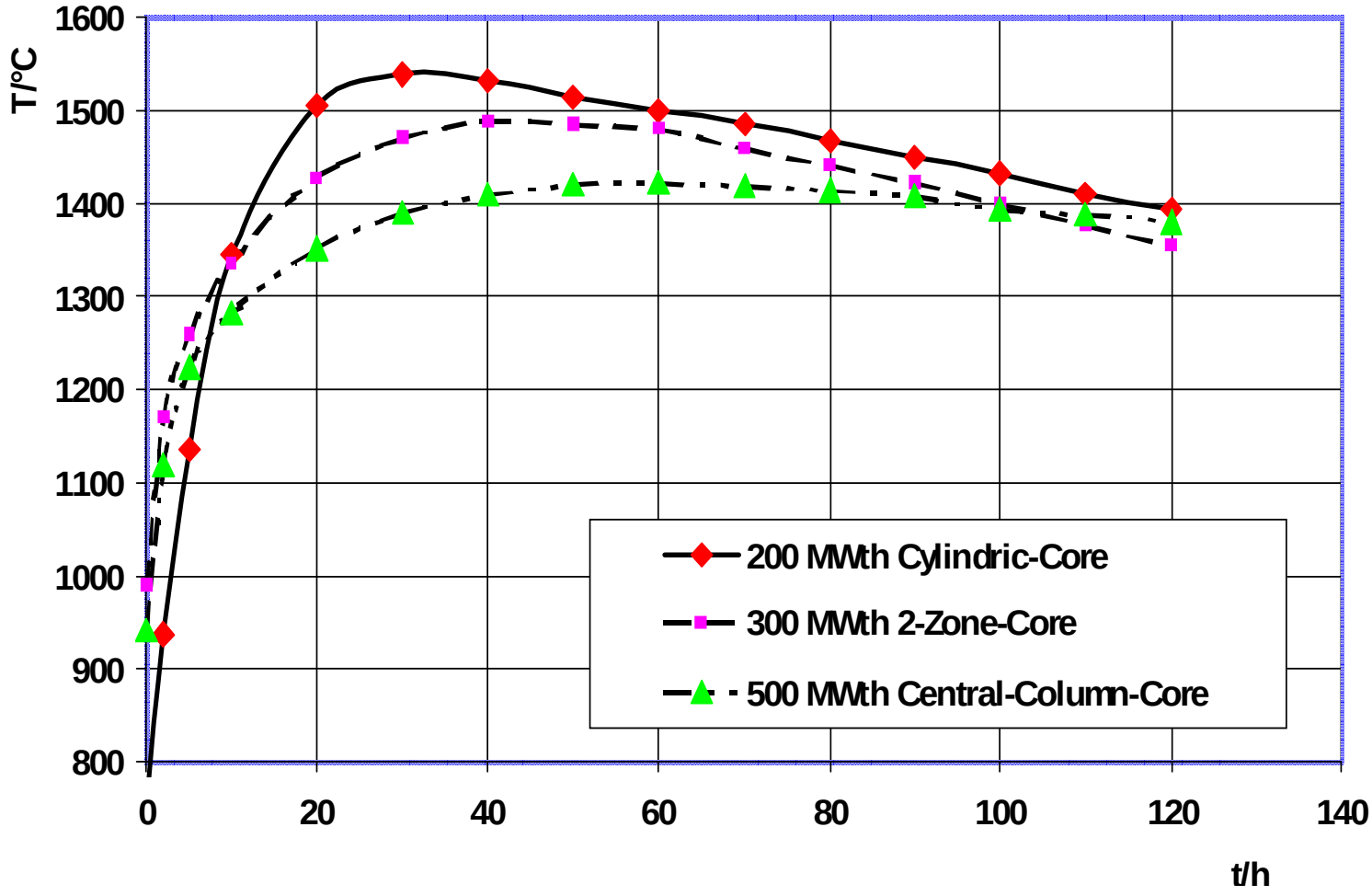


200 MWt HTR–Modul by INTERATOM

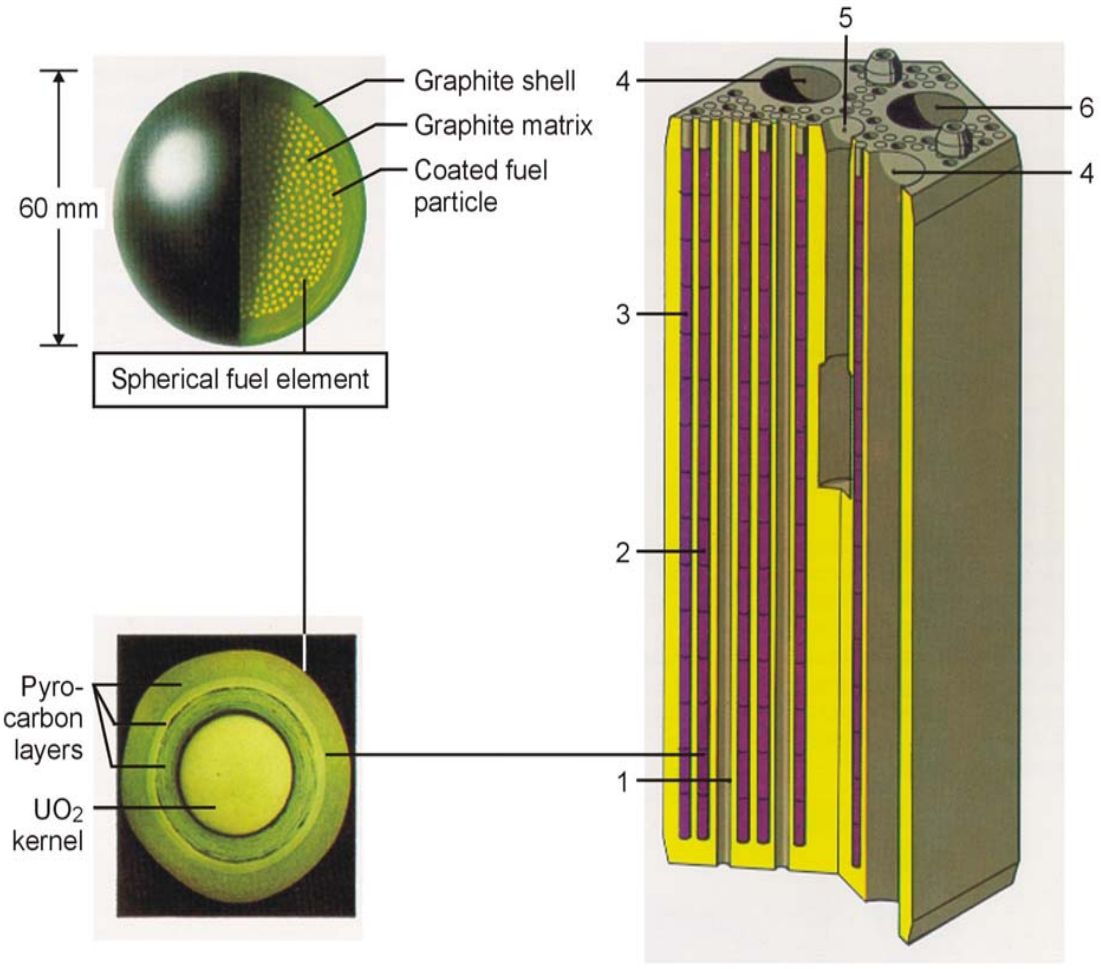




Fuel Temperatures during DLOFC Event



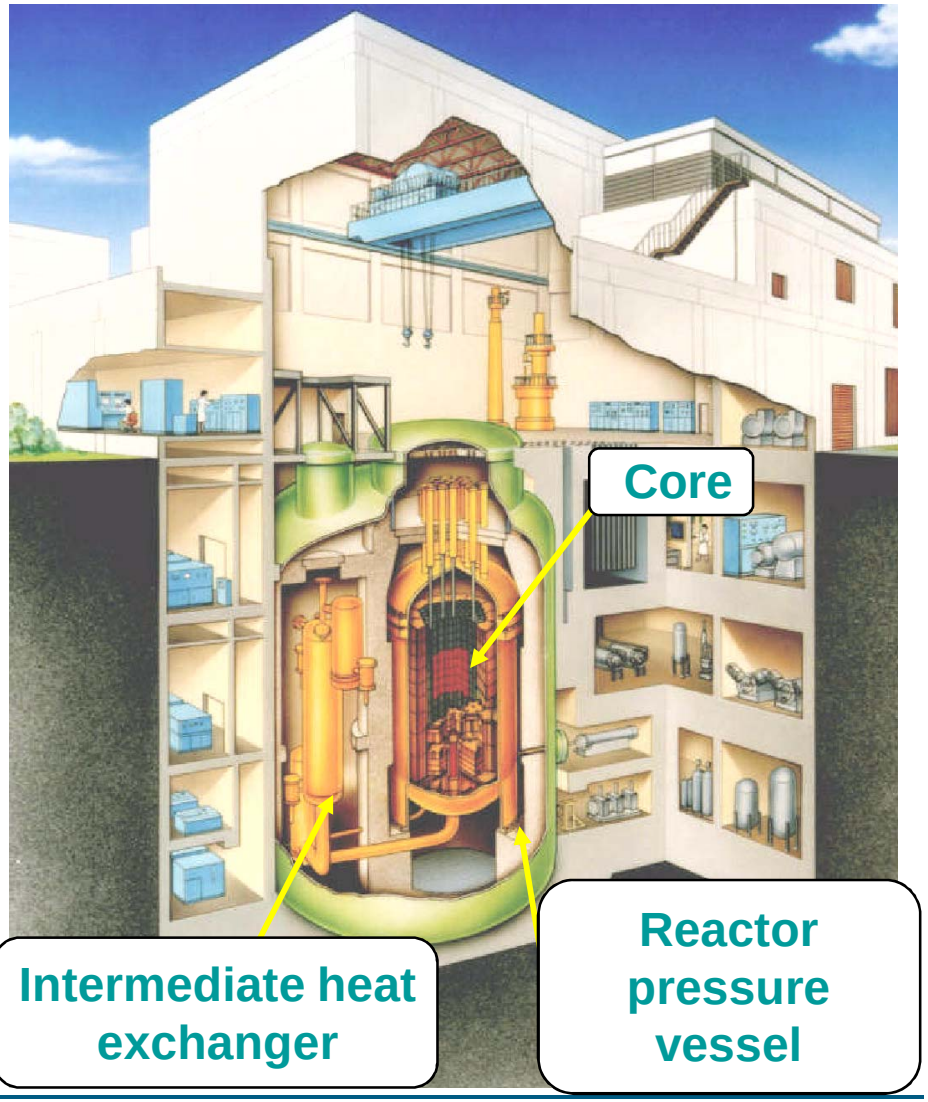
HTGR Fuel Element Designs



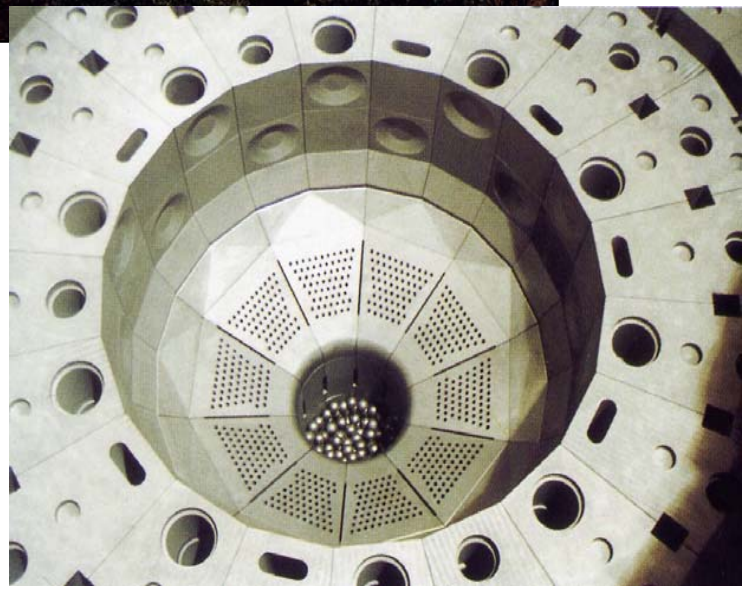
Reactors Operated with CP Fuel

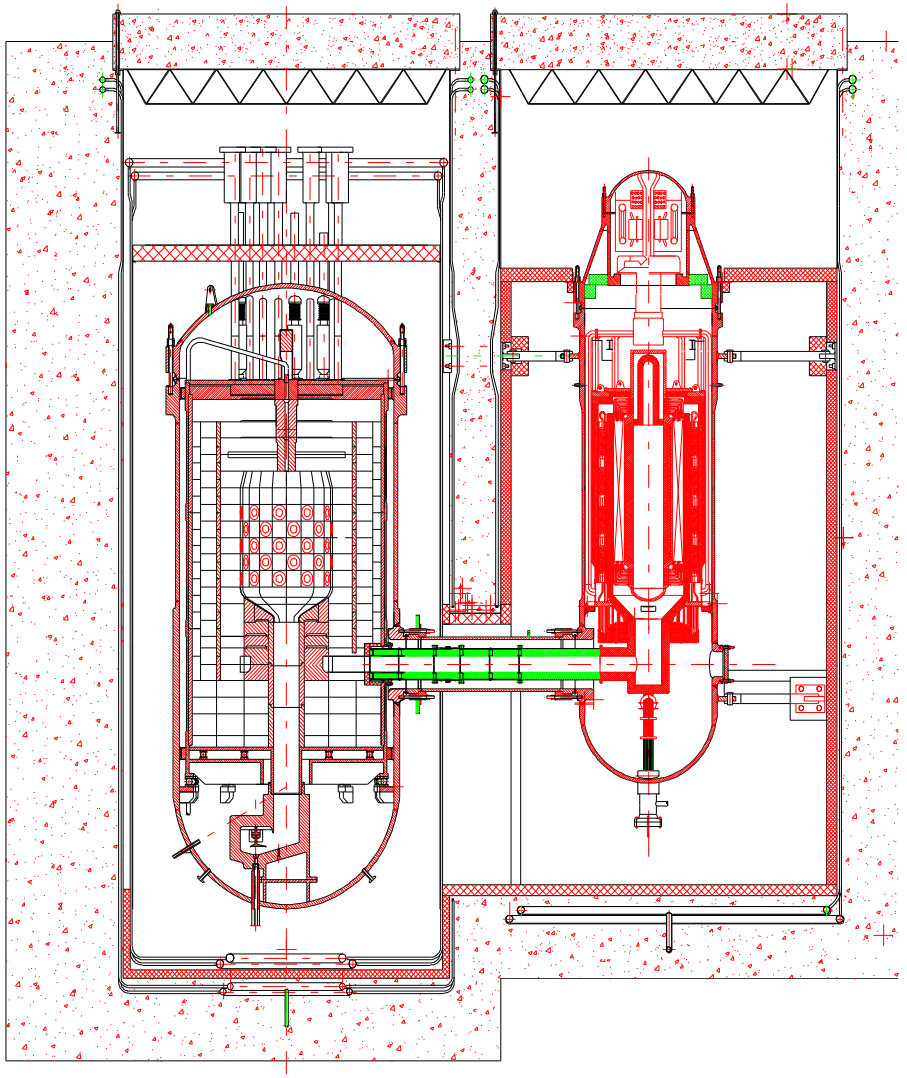
Reactor	Country	Year	Thermal Power (MW)
Dragon	Great Britain	1964-77	30
Peach Bottom	U.S.	1966-74	115
UHTREX	U.S.	1967-70	3
AVR	Germany	1966-89	46
Fort St. Vrain (FSV)	U.S.	1967-89	840
Thorium High Temperature Reactor (THTR)	Germany	1983-89	750
High Temperature Engineering Test Reactor (HTTR)	Japan	1998-	30
HTR-10	China	2002	10
... Coated particle fuel with >45,000 kg heavy metal produced for these reactors			

HTTR in Japan



HTR-10 in China





Requirements to a Process Heat HTGR System

- Guaranteed reliable supply of process heat;
- Flexible in operating conditions, i.e.,
  easily adjustable to the wide field of applications
  and customer‘s requirements;
- Small-size (modular-type) HTGR for economic process plant operation (170 – 250 MW_{th});
- Safety concept
  - Leak criteria between primary and secondary circuit
  - Thermodynamic interaction between nuclear and chemical facility
  - Explosion hazards
  - Licensing and emergency plans.

Objectives of PNP Project

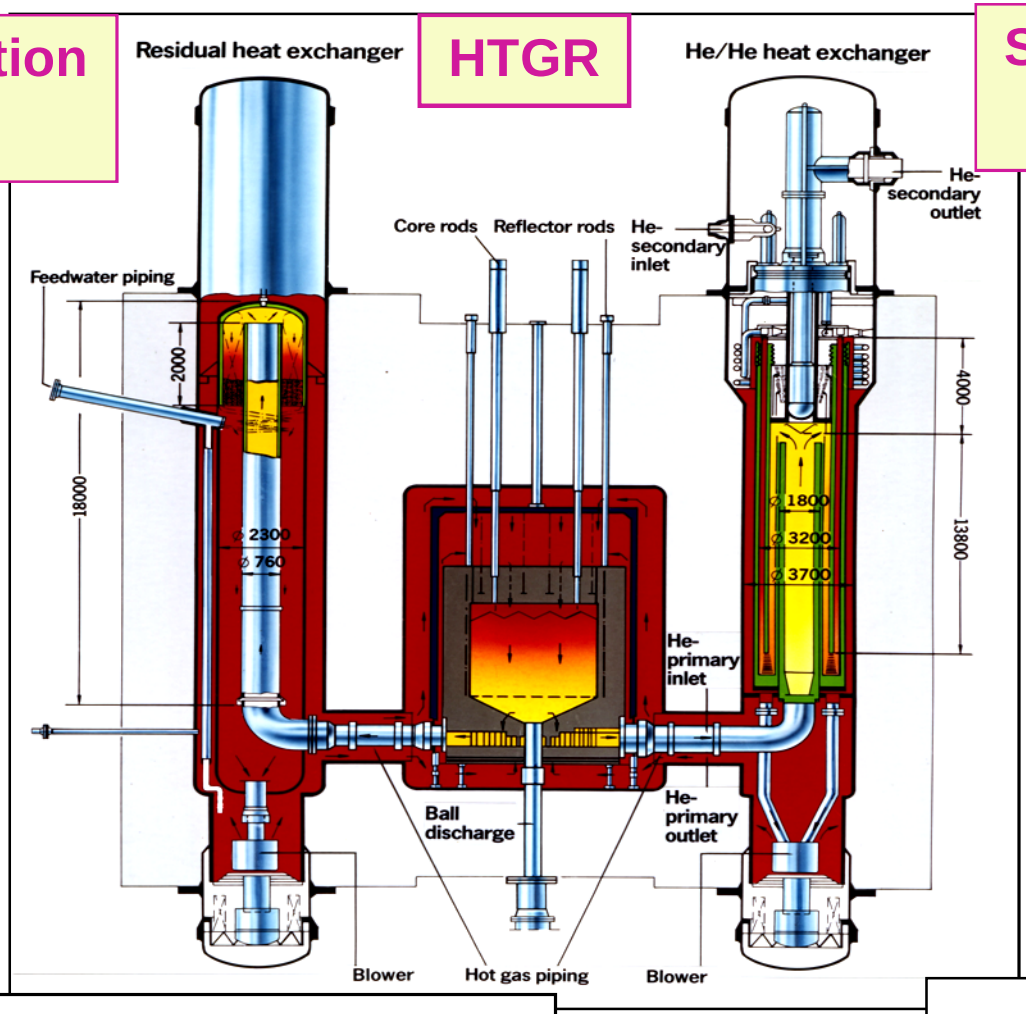
- Identify suitable coal gasification processes on lab scale
- Test selected processes on semi-technical scale
- Construct and operate pilot plants for selected processes
- Design large-scale nuclear plant for process heat prod.
- Construct and operate prototype nuclear coal gasification plant
- Construct and operate commercial nuclear coal gasification plant

Prototype Plant PNP-500

Hydro gasification of lignite

HTGR

Steam gasification of hard coal

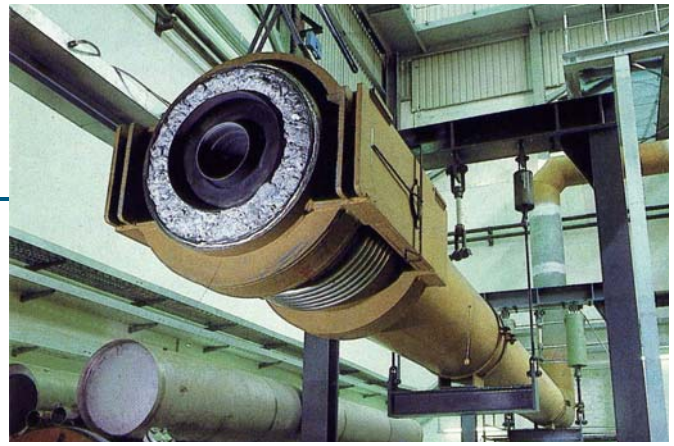


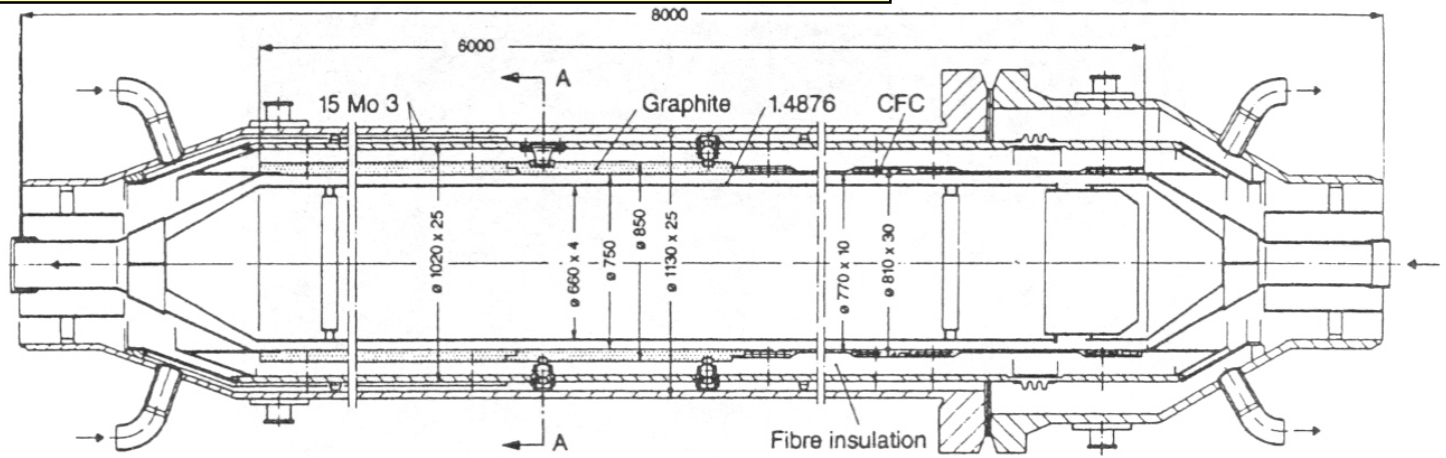
166 t/h coal
→ 26,500 m³ SNG + 18.4 t/h charcoal

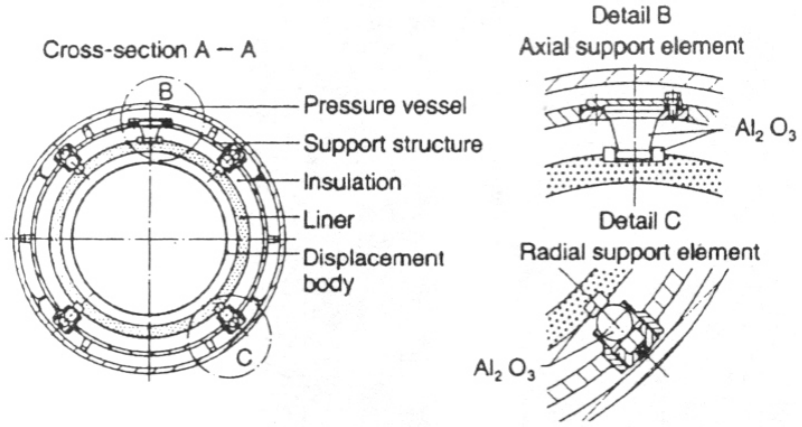
50 t/h coal
→ 41,000 m³ SNG

Hot Gas Duct

coaxial double-tube horizontal pressure vessel to provide connection between RPV and IHX and also between IHX and PHX



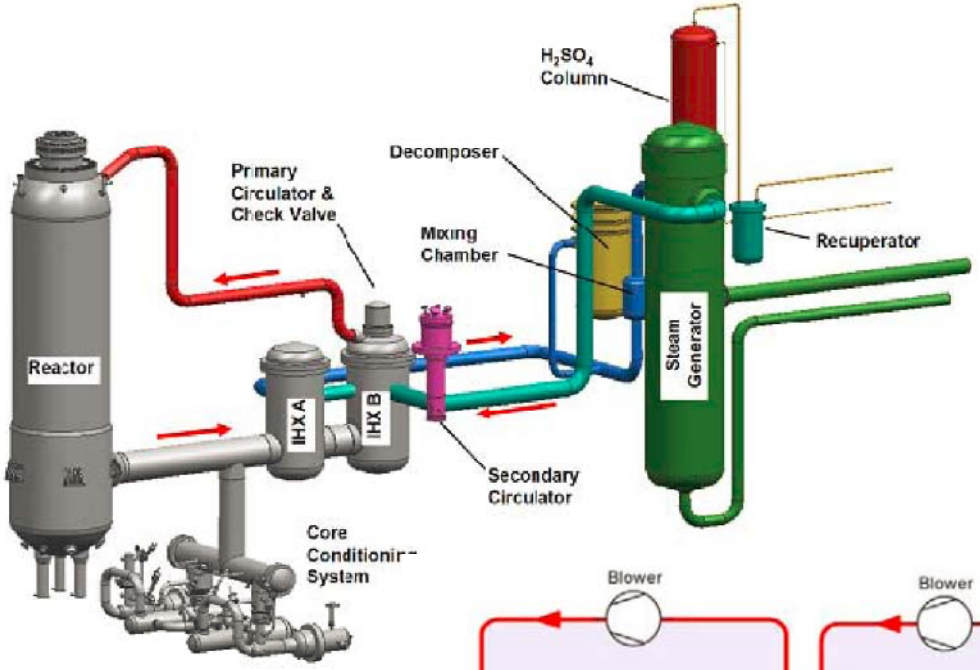


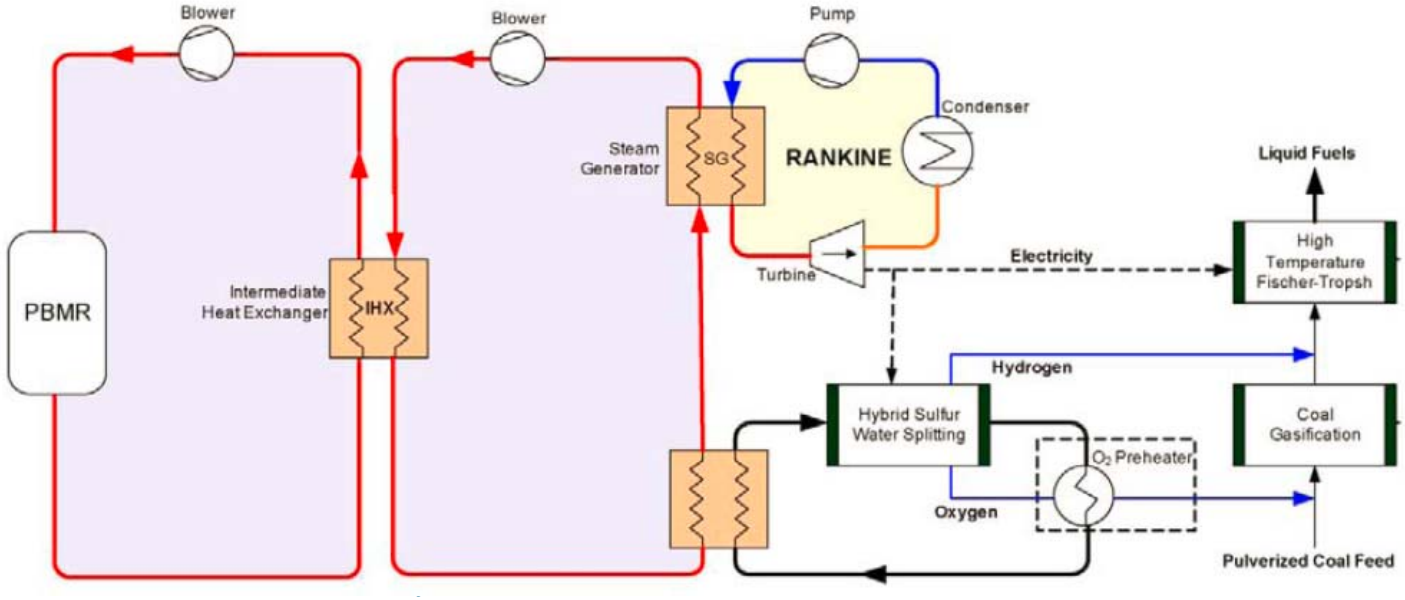


PNP hot gas duct designed for 950°C and 4-5 MPa with flow velocities of ~60 m/s

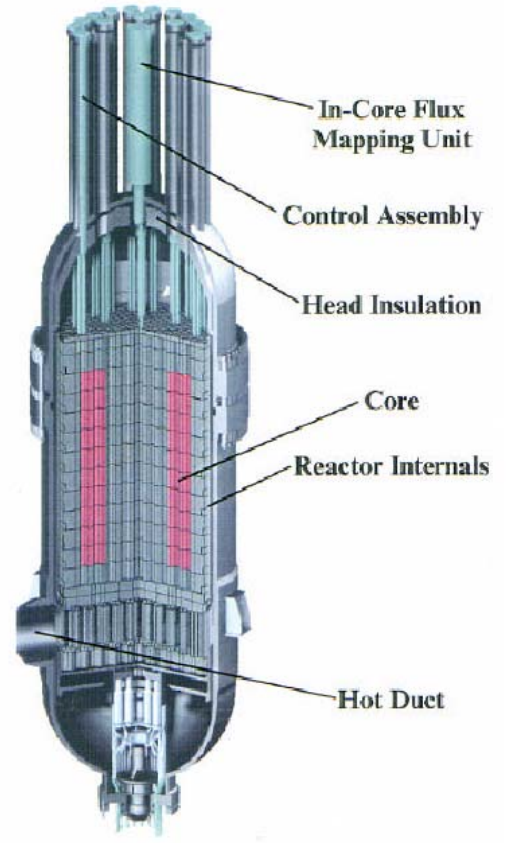
Inner insulation made of metallic foils or solid fibers, or carbon ceramics

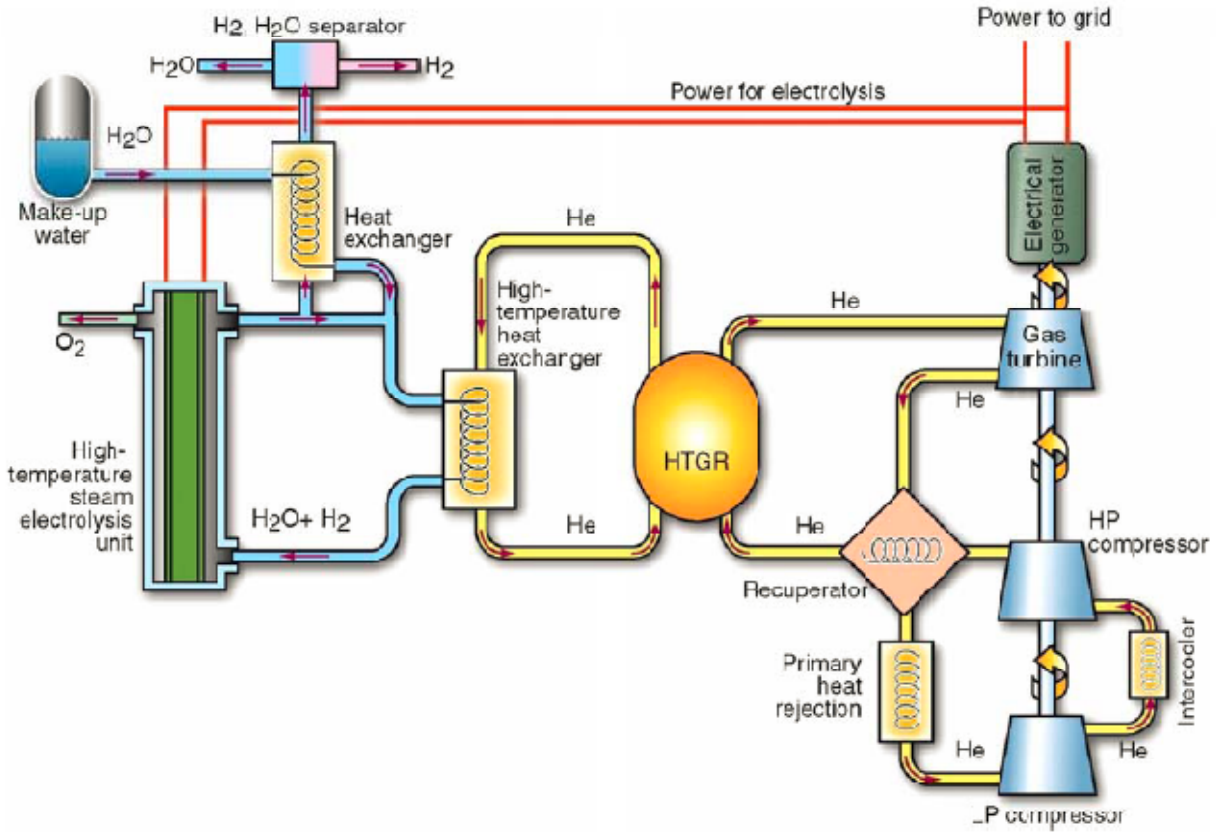
Project PBMR (South Africa)





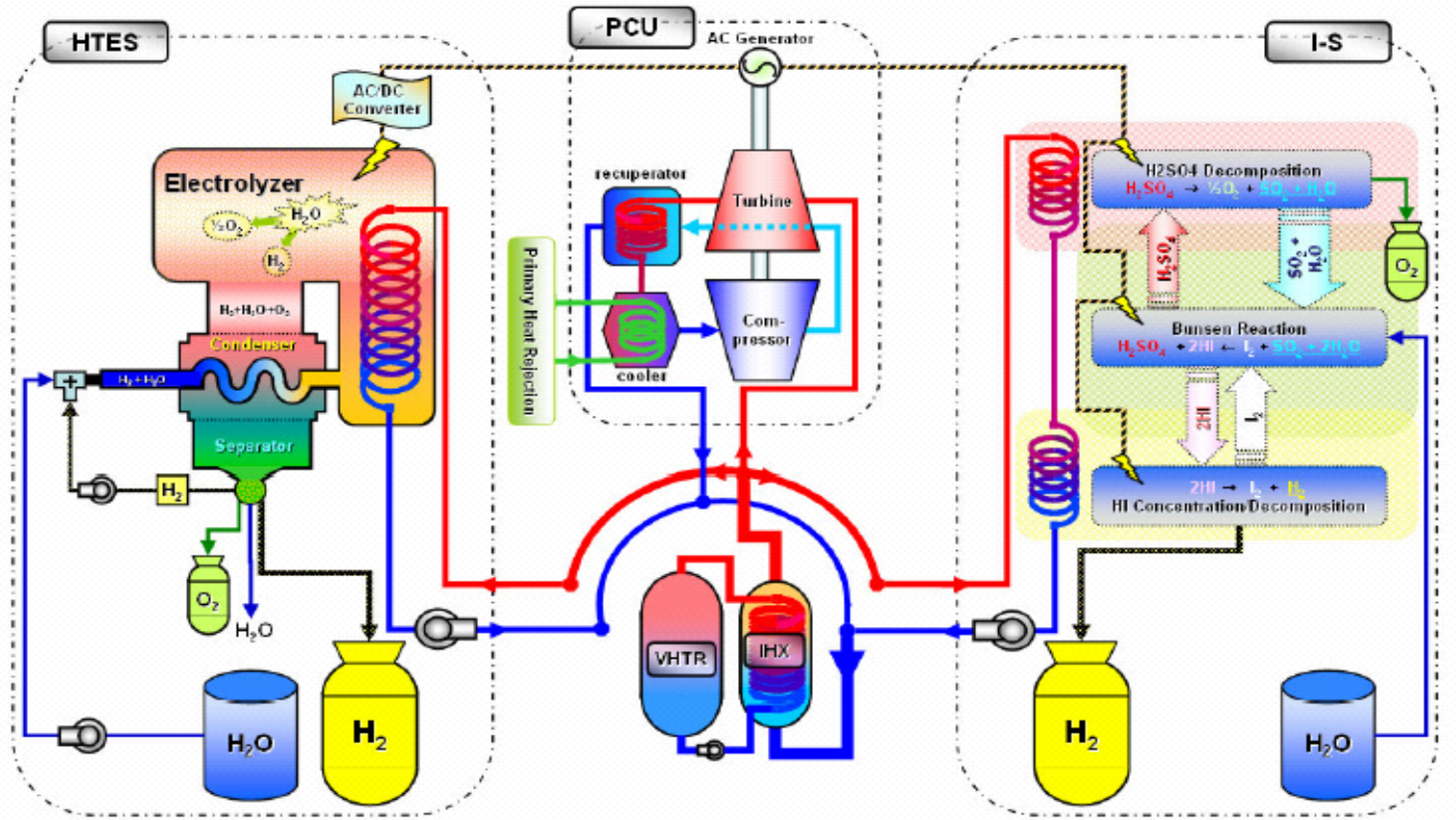
Block-Type HTGR (USA)





GT-MHR

Nuclear H_2 R&D Projects (Rep. of Korea)



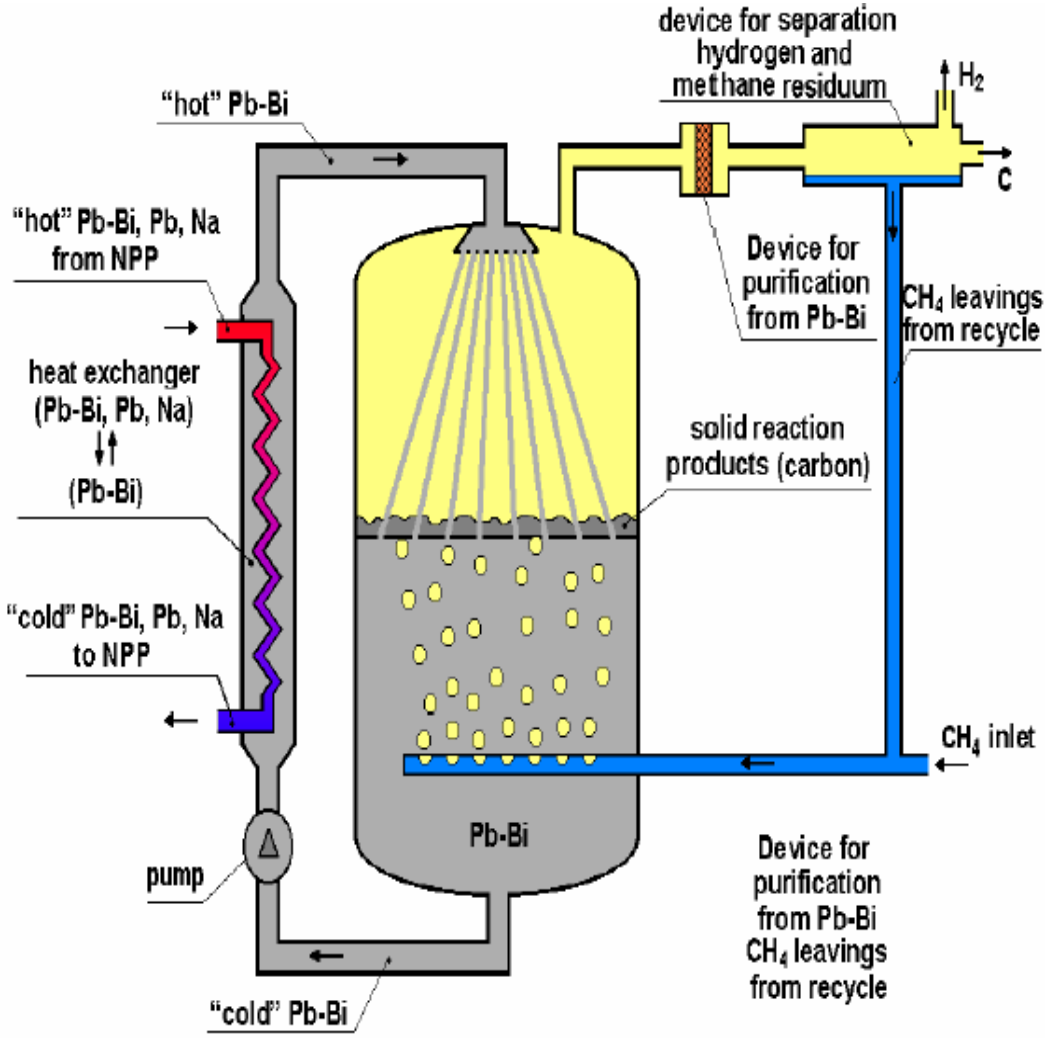
Nuclear Hydrogen Development and Demonstration (NHDD) project

Nuclear H_2 R&D Projects (Russia)

LMCFR for direct-contact methane decomposition

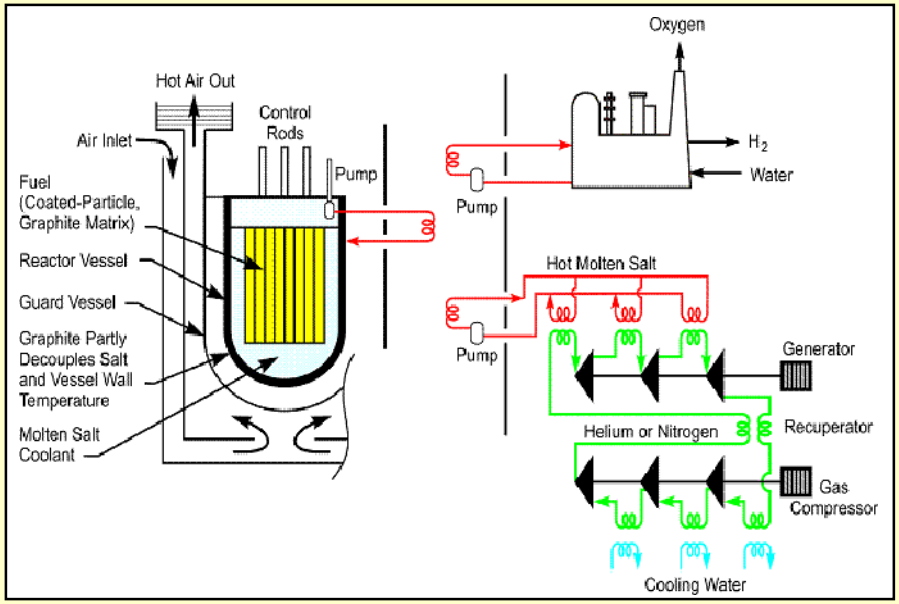
metal/metal IHX

secondary coolant lead-bismuth @ ~ 700°C



Nuclear H_2 R&D Projects (USA)

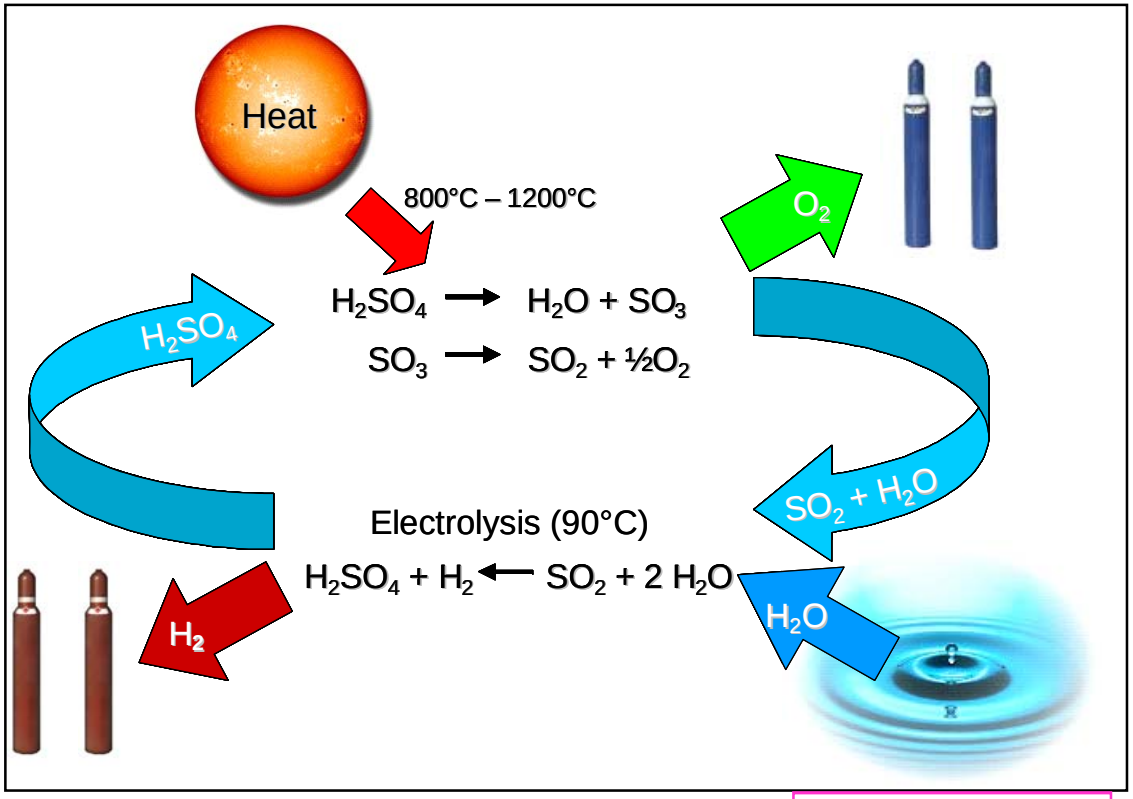
- **H2-MHR**
  based on 600 MW GT-MHR, H_2 production by HTE,
- **STAR-H2** (Secure Transportable Autonomous Reactor Hydrogen)
  400 MW heavy liquid metal cooled fast reactor, sec. coolant „FLiBe“ to produce, apart from H_2, electricity and potable water
- **AHTR** (Advanced High Temperature Reactor)
  - up to 4000 MWt
  - coolant is liquid fluoride salt @ 700-1000°C
  - H_2 via S-I at lower temp. using membrane techn.



EU-FP6: HYTHEC Project 2004-2007

Sulfur-Iodine (S-I) cycle to be coupled to nuclear heat source

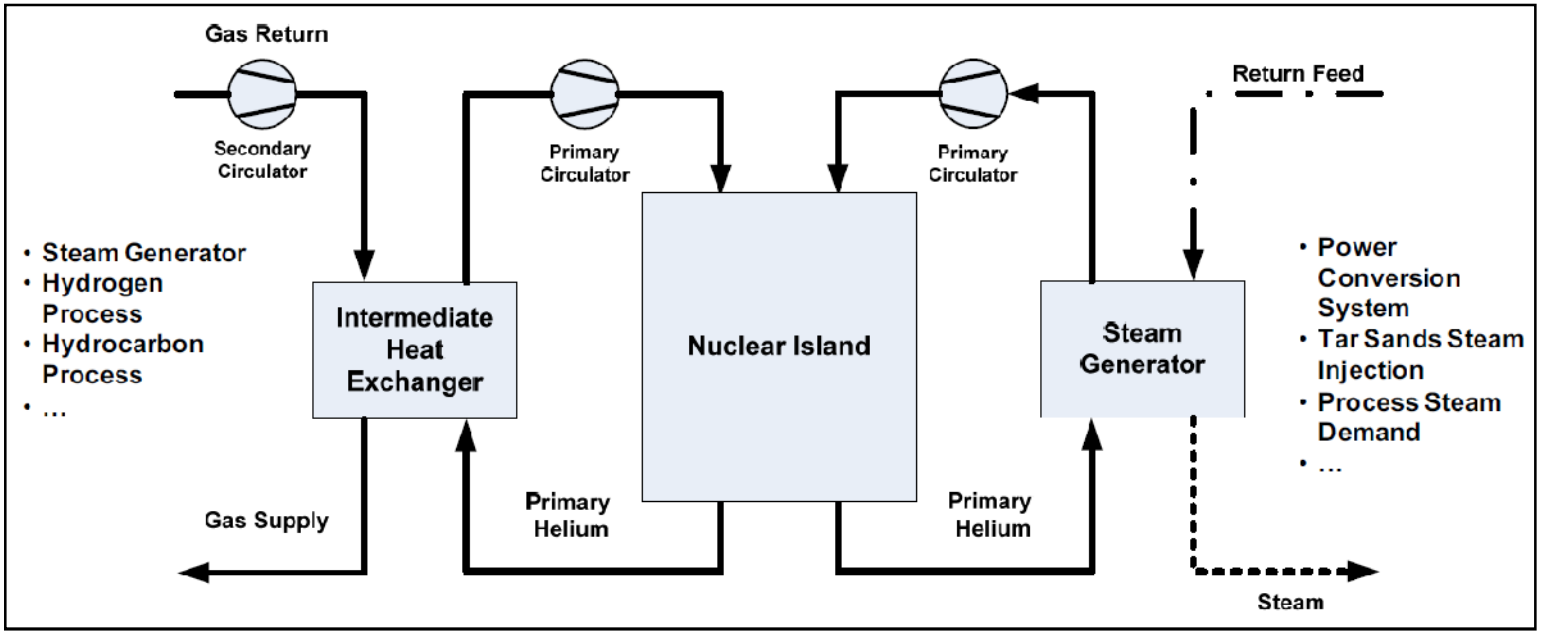
Hybrid Sulfur (HyS) cycle to be coupled to solar heat source



Le Duigou 2007

Succeeded by HycycleS

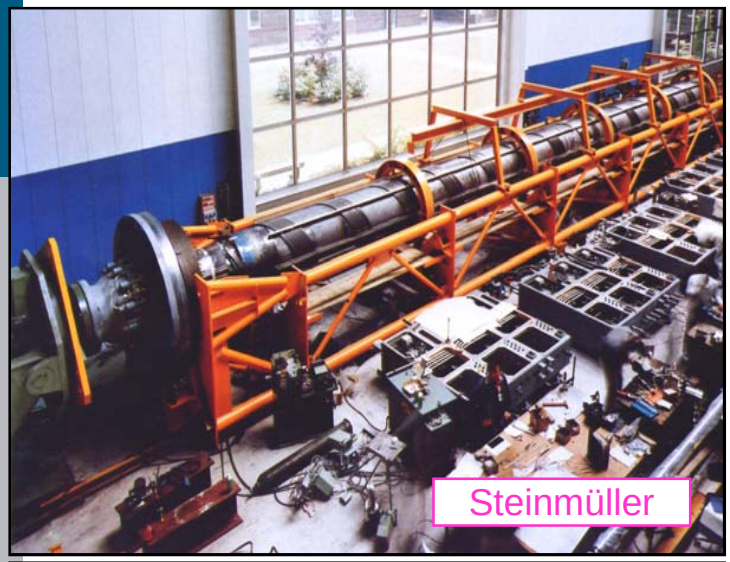
Generic Reference Configuration

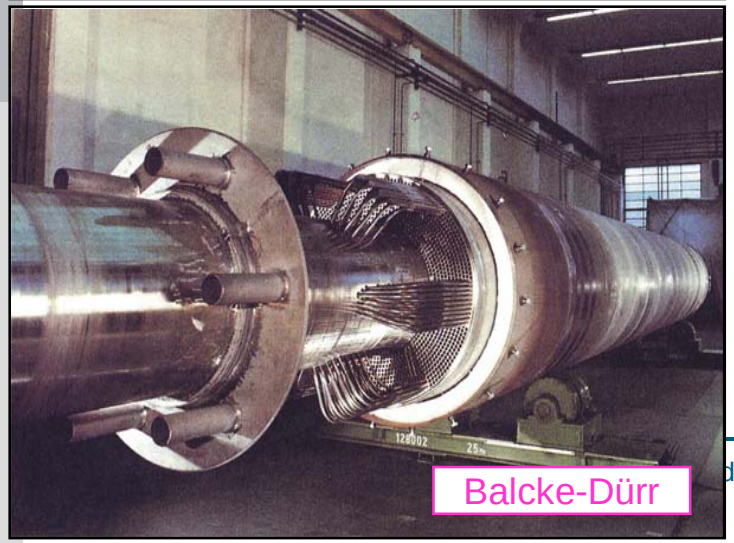


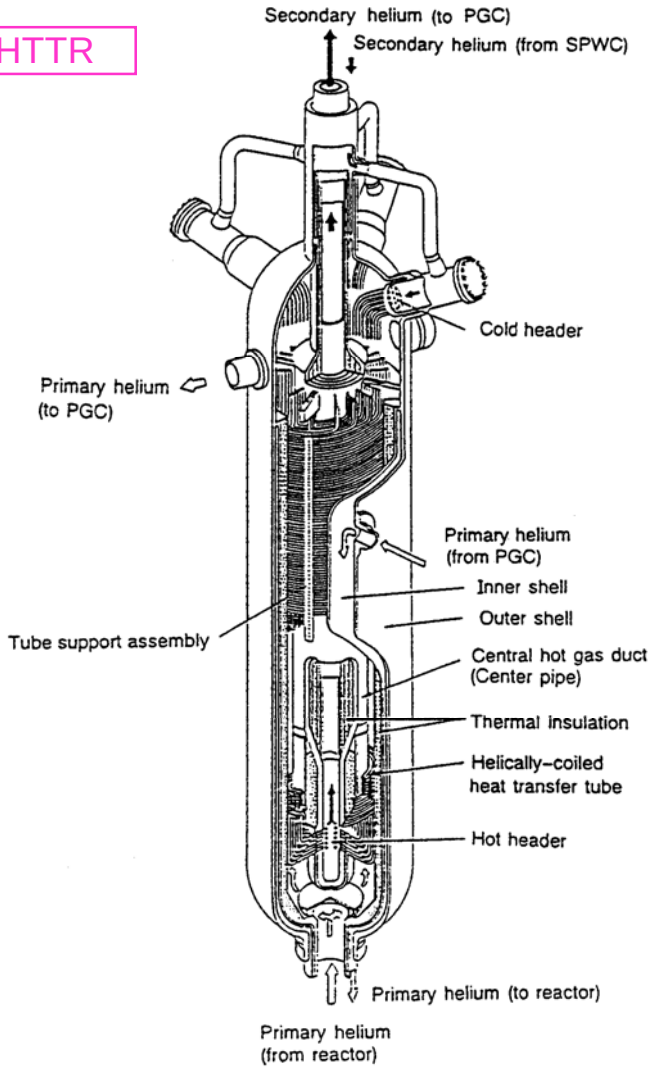
System with HTGR includes use of an IHX (Intermediate Heat Exchanger)

- no primary helium in process plant
- no process gases in reactor building
- conventional design of process plant components
- repair works under non-nuclear conditions

Intermediate Heat Exchanger

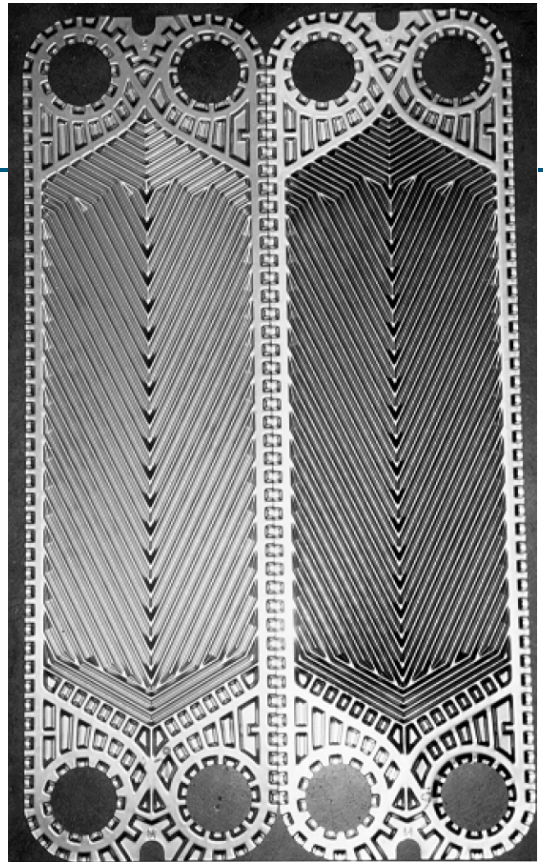


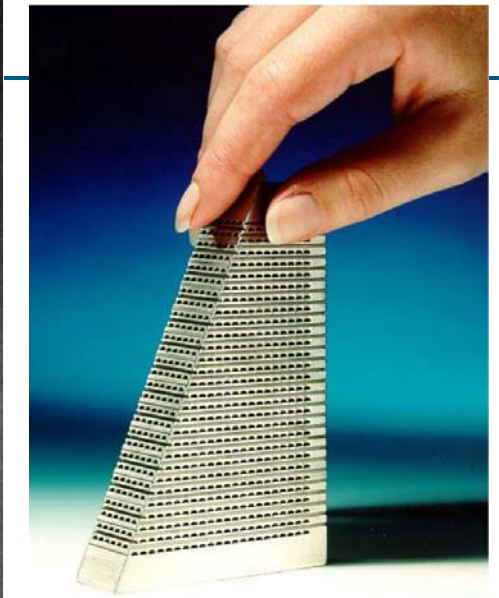




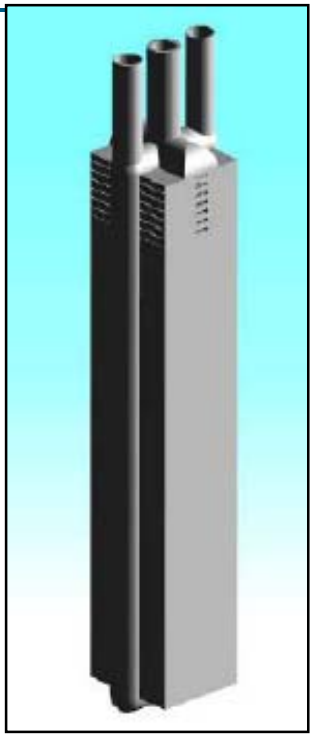
IHX

Plate HX





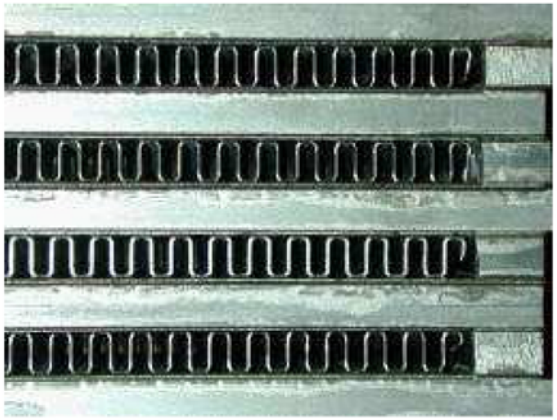
Printed Circuit HX

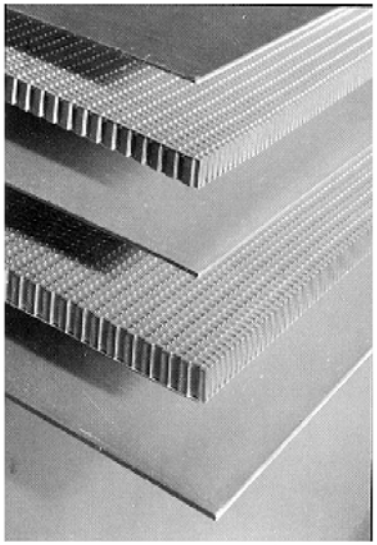


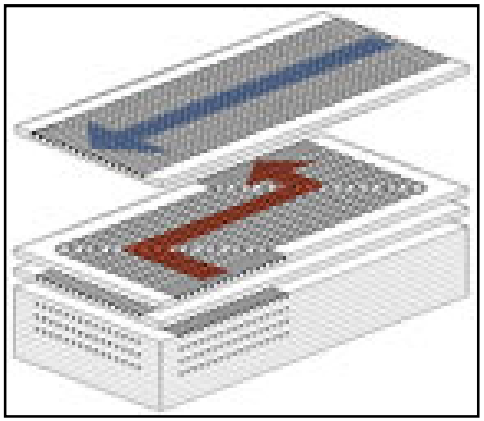
Heatric

Tochon 2008

Plate fin HX





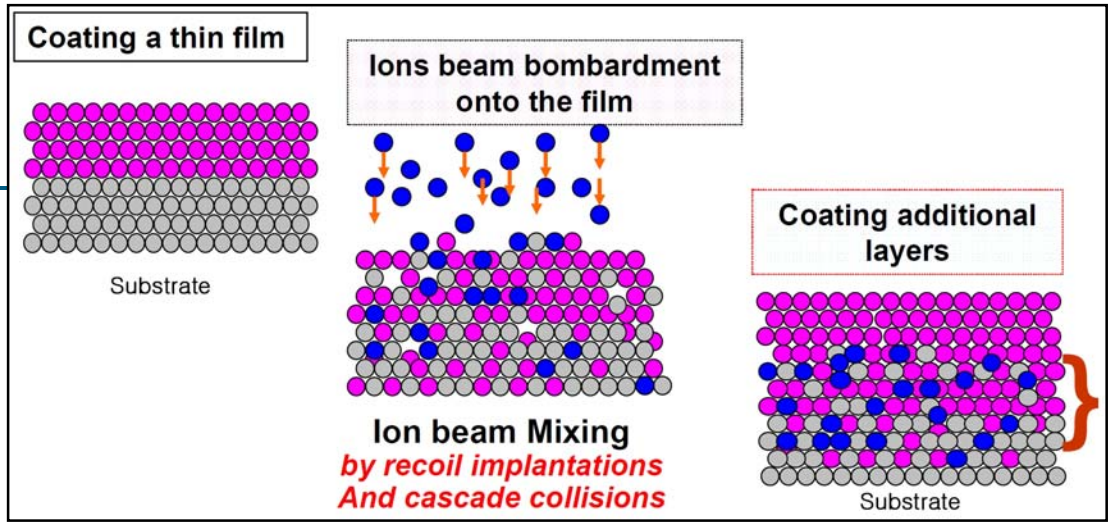


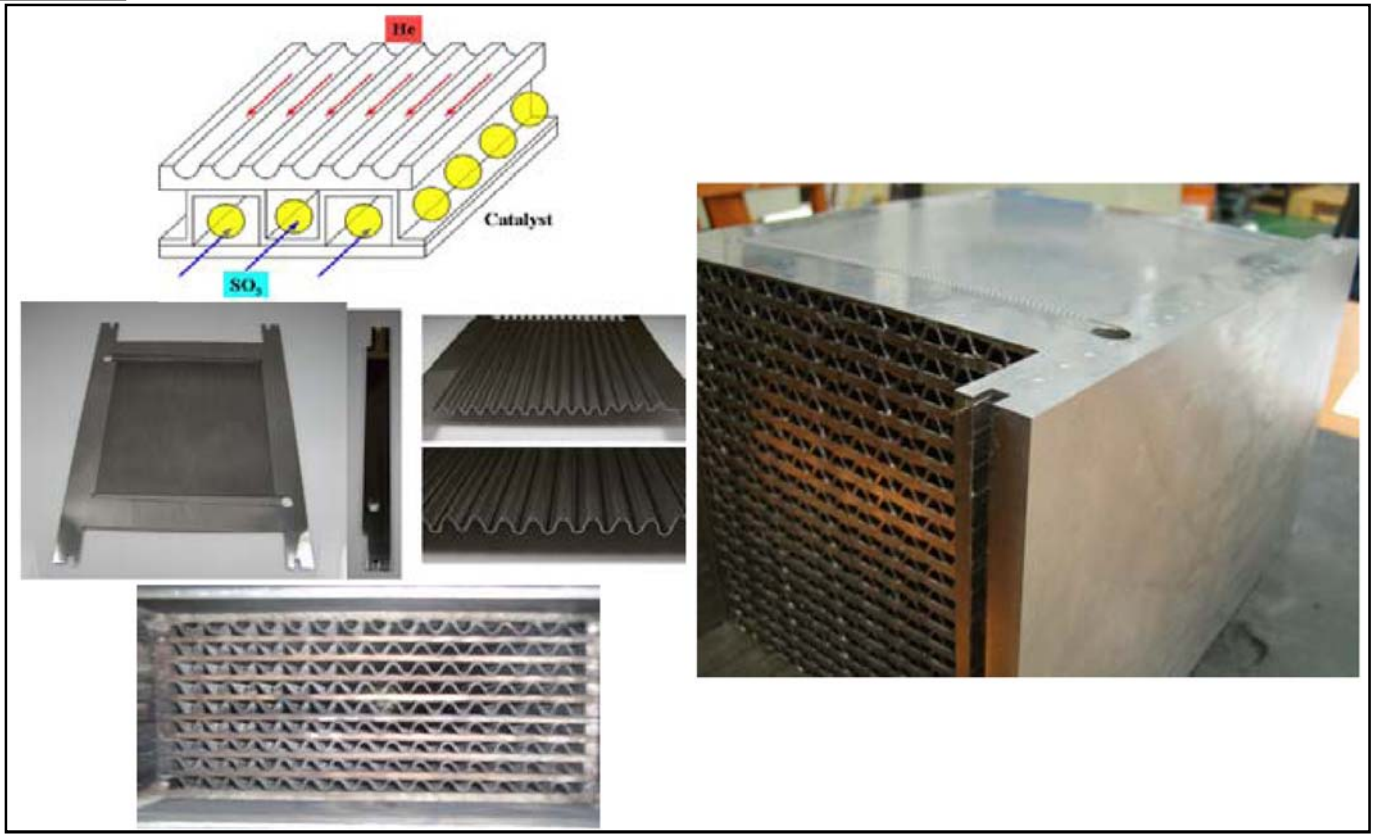
Korea PHX

10 kW PHX being tested

primary side: nitrogen of up to 1000°C at 6 MPa

secondary side: SO_3 of 950°C at 1 MPa





LeeWJ 2009

Thank You
for Your Attention

Power sources in Jülich

nuclear (AVR) & solar

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