Advanced Nuclear Energy Systems: Heat Transfer Issues and Trends

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ENERGY SUSTAINABILITY

Conditions Needed for Energy Sustainability:

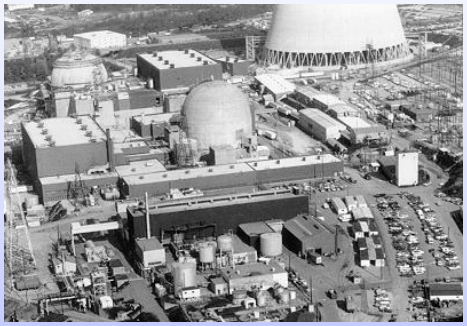
- **Economically feasible technology**
- **Minimal by-product streams**
- **Acceptable land usage**
- **"Unlimited" supply of energy resource**
- **Neither the power source nor the technology to exploit it can be controlled by a few nations/regions**

Nuclear energy systems meet these conditions and can be part of the solution for future energy growth (Electricity growth estimates range 1 - 4.5%/yr)

Evolution of Nuclear Power Systems

Generation I

Early Prototype Reactors



- Shippingport
- Dresden,Fermi-I
- Magnox

Generation II

Commercial Power Reactors

- LWR: PWR/BWR
- CANDU
- VVER/RBMK

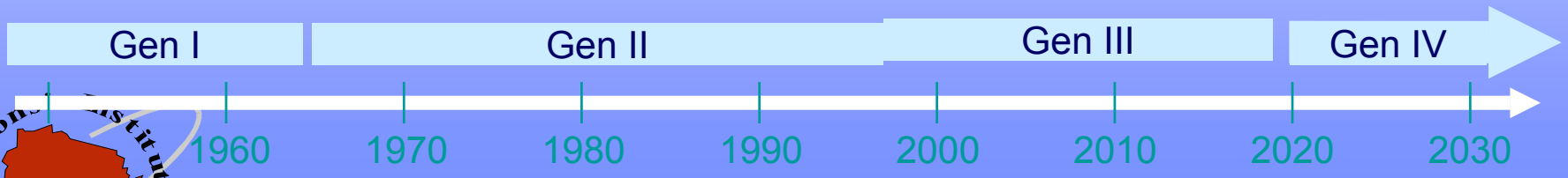
Generation III

Advanced LWRs

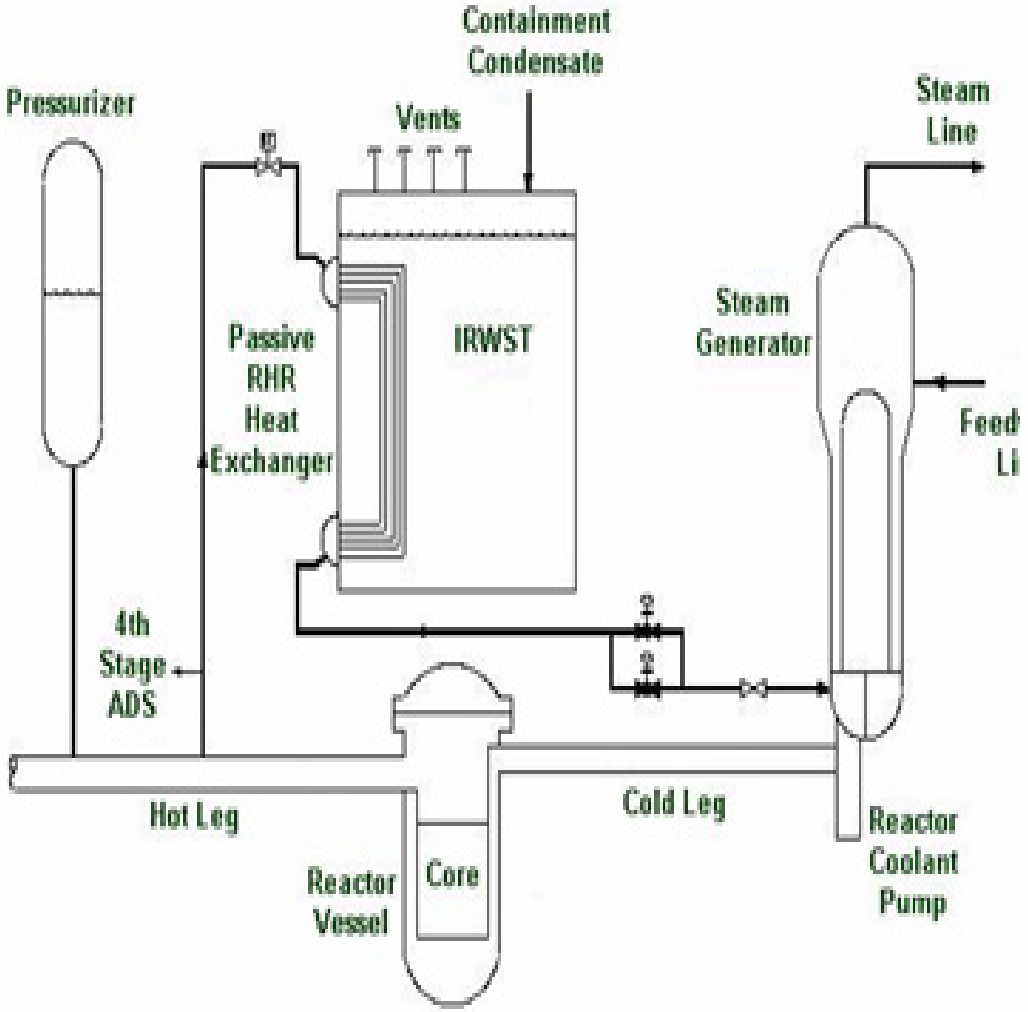
- System 80+
- ABWR
- AP1000
- ESBWR

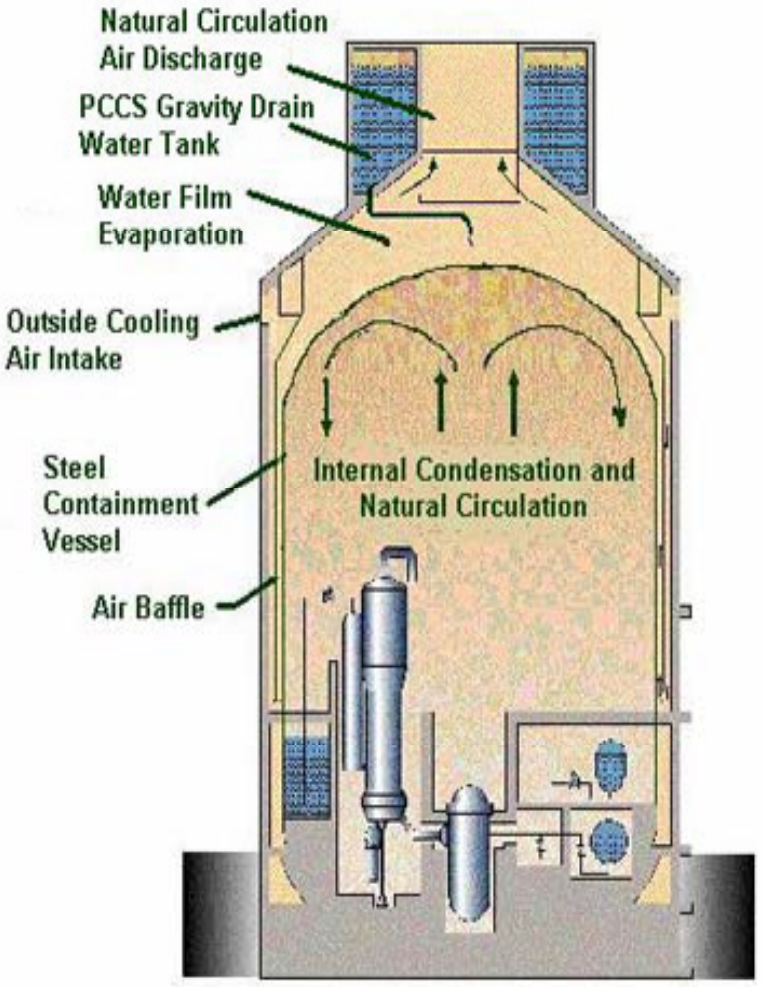
Generation IV

- Enhanced Safety
- More economical
- Minimized Wastes
- Proliferation Resistance

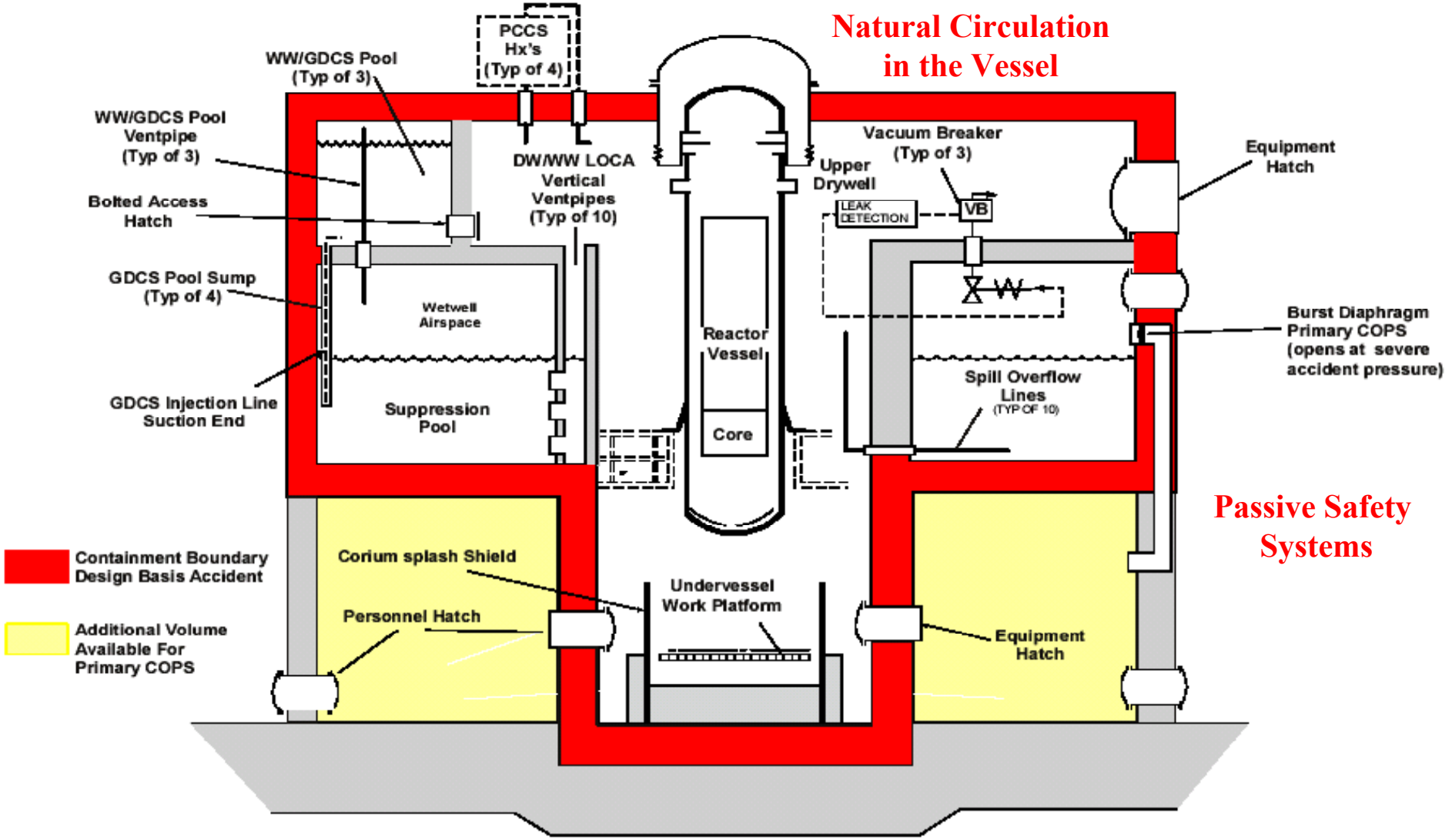


Advanced Light Water Reactors: AP1000-Enhanced Passive Safety





Advanced Light Water Reactors: ESBWR-Simplified Operation & Safety

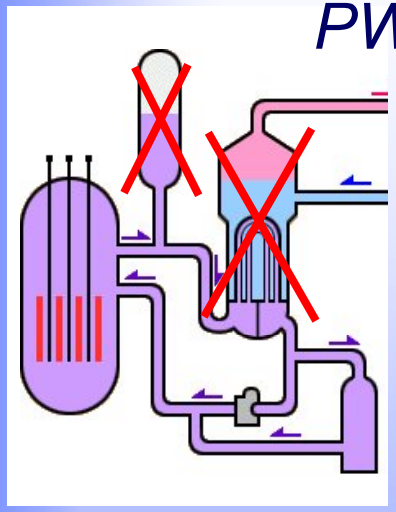


Advanced Light Water Reactors: Multiphase Heat Transfer Issues

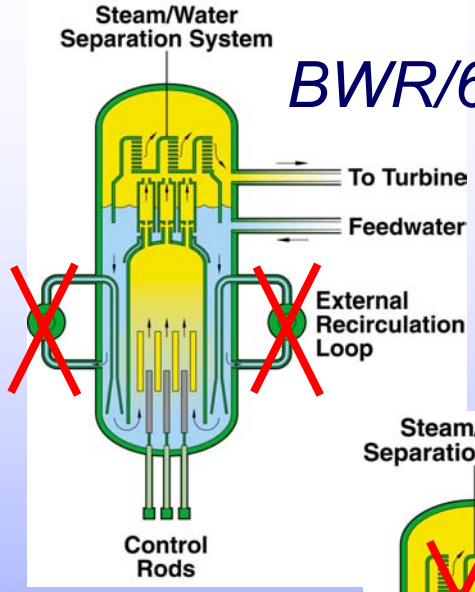
- Passive systems can simplify construction and operation but may complicate engr. analyses
- Natural-circulation multiphase flow in complex geometries (plant geom. dependent)
- Condensation heat transfer with non-condensible gases in reactor containment
- Multiphase/multicomponent heat transfer in safety analyses beyond the ALWR design base
  - In-vessel lower head cooling & Ex-vessel debris coolability
  - Multiphase/multicomponent direct-contact heat-exchange

A More Advanced LWR

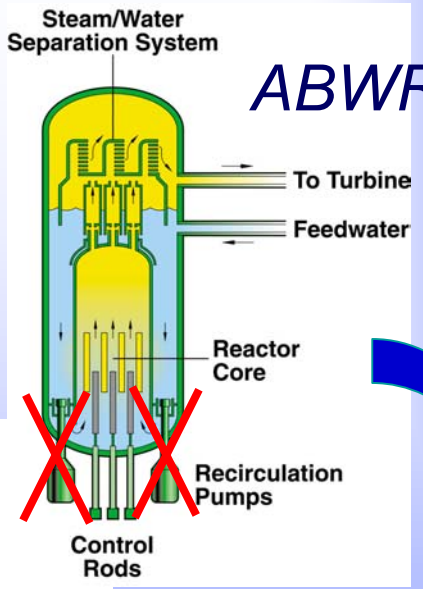
The next logical step in path toward simplification ?



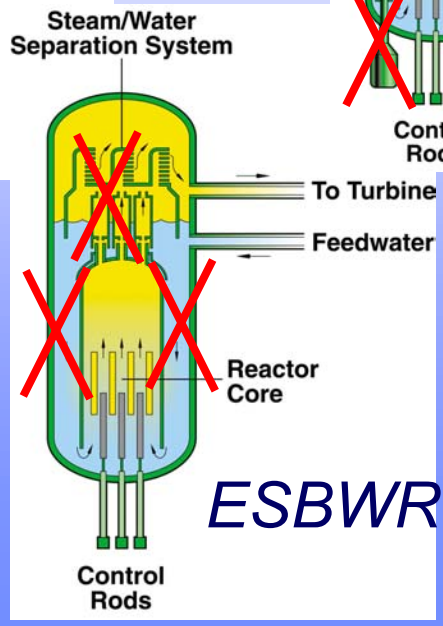
PWR



BWR/6



ABWR

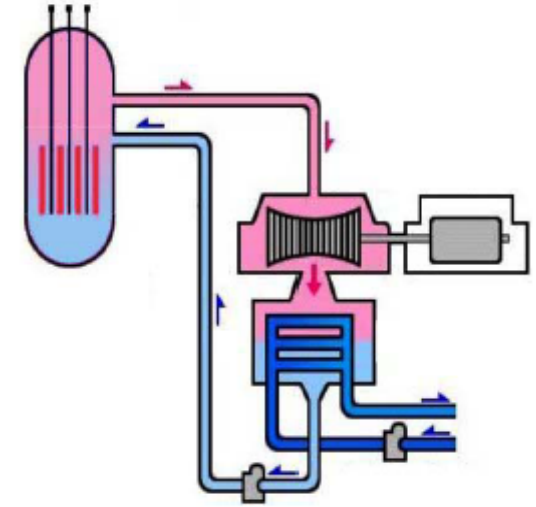


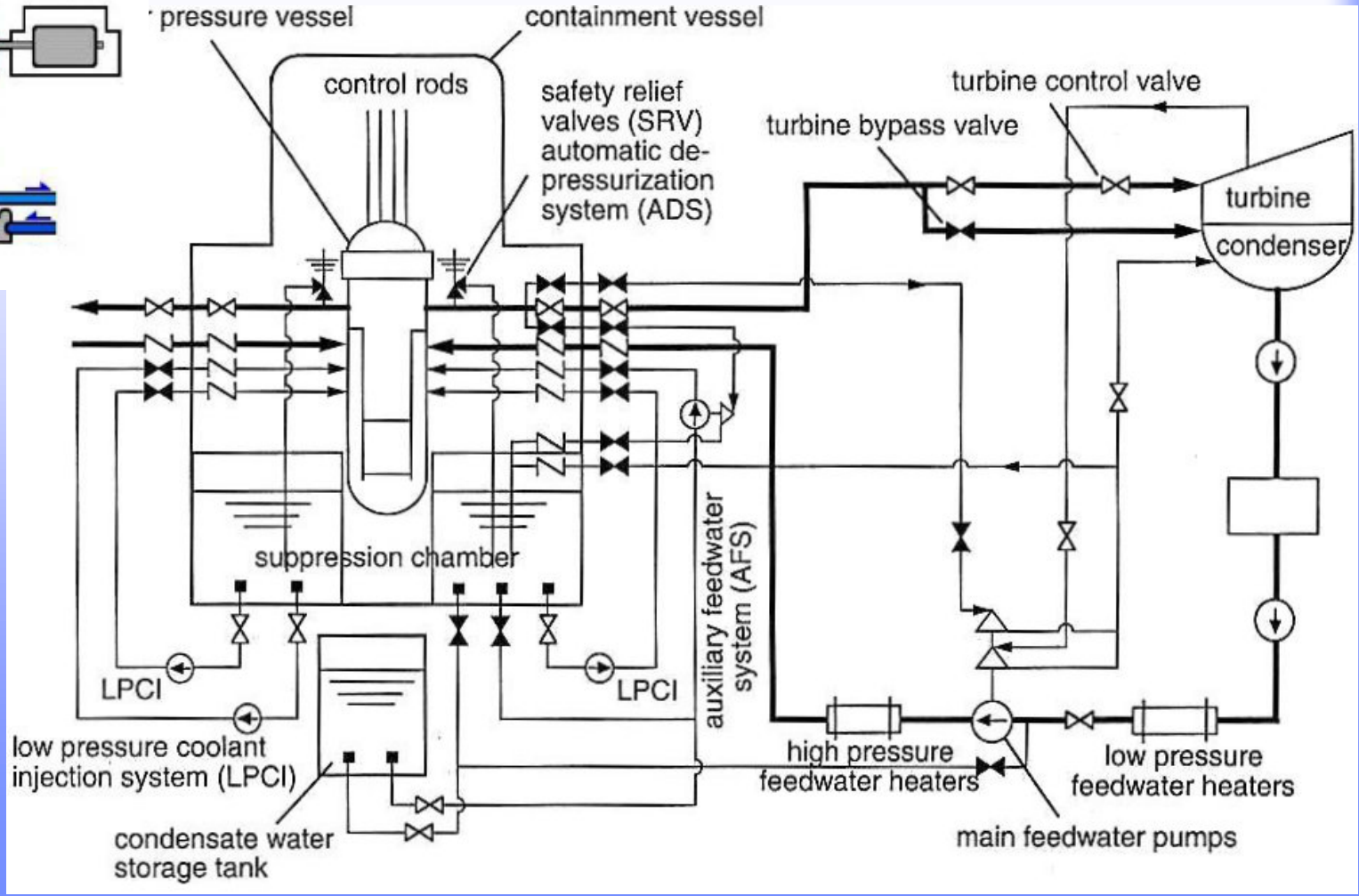
ESBWR

SCWR

A boiling water reactor
…without the boiling.

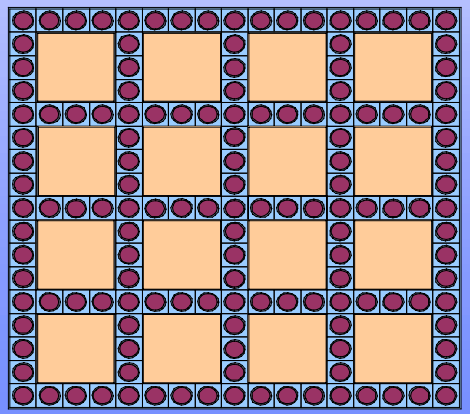
SUPERCRITICAL WATER REACTOR

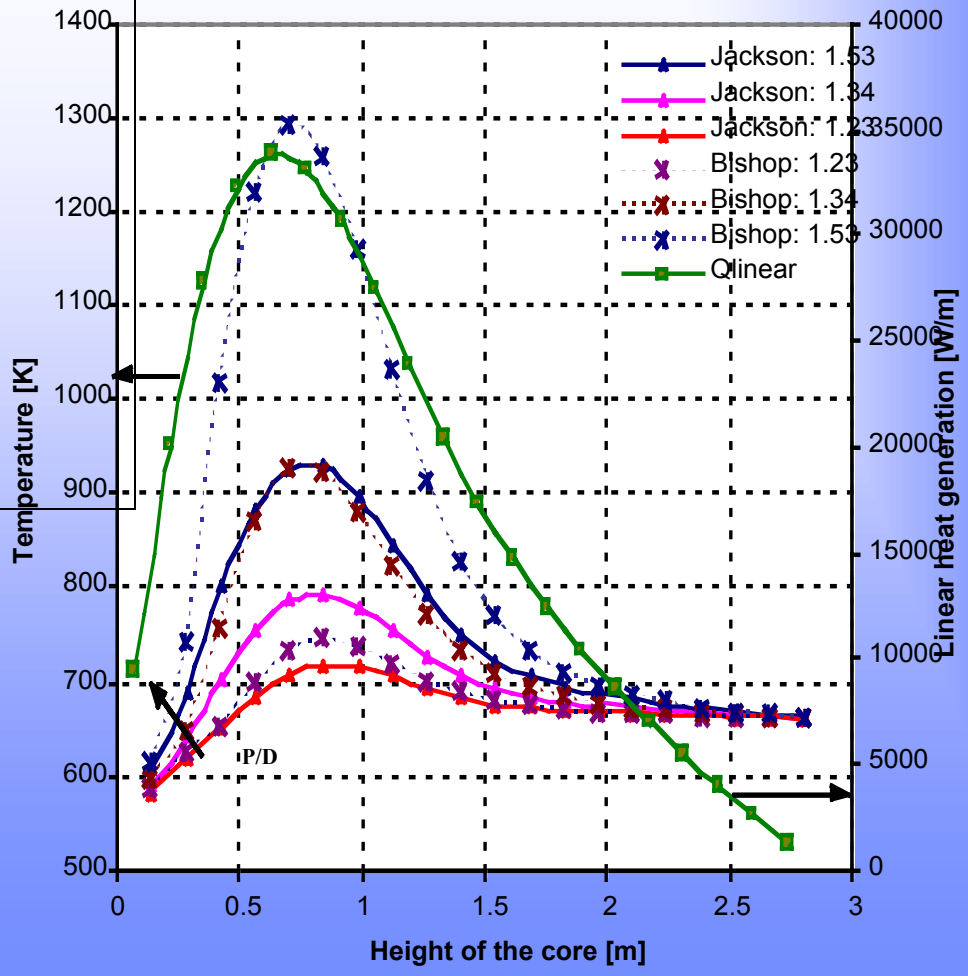




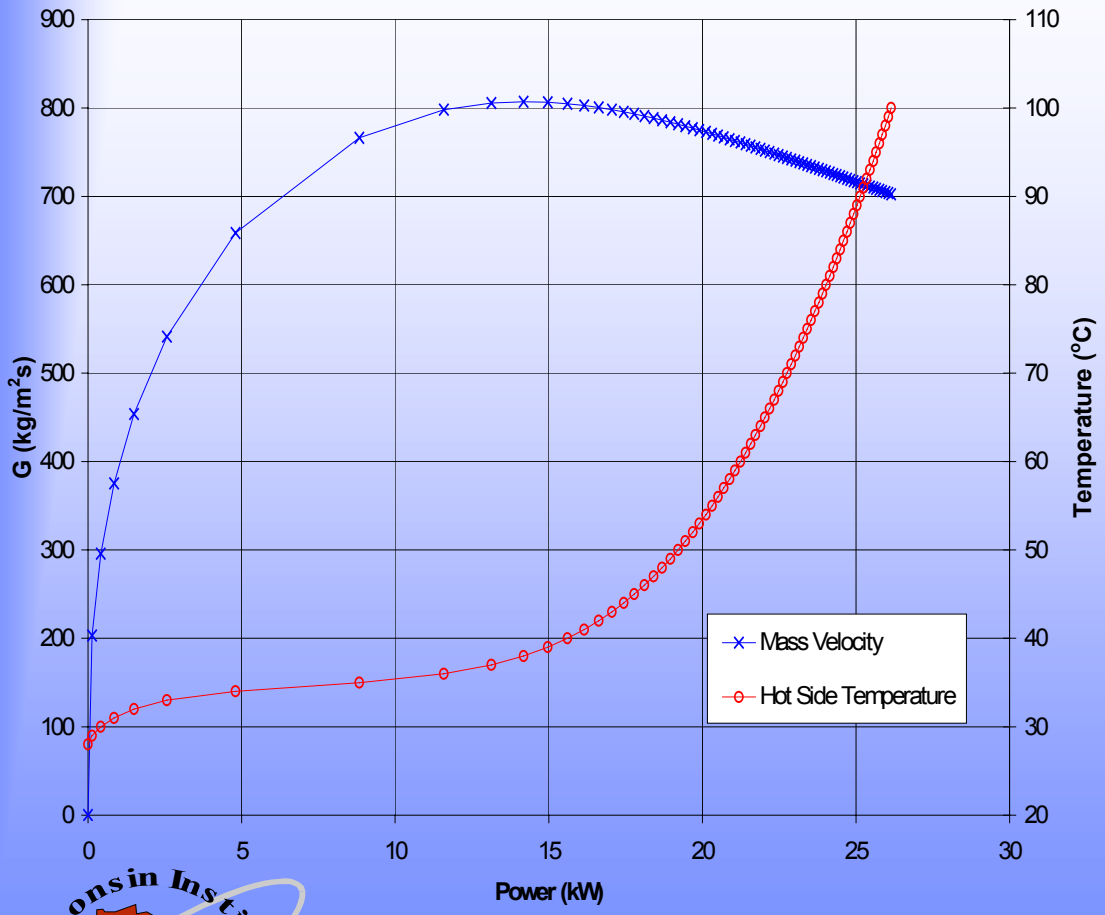
Heat Transfer in SCW Reactor:

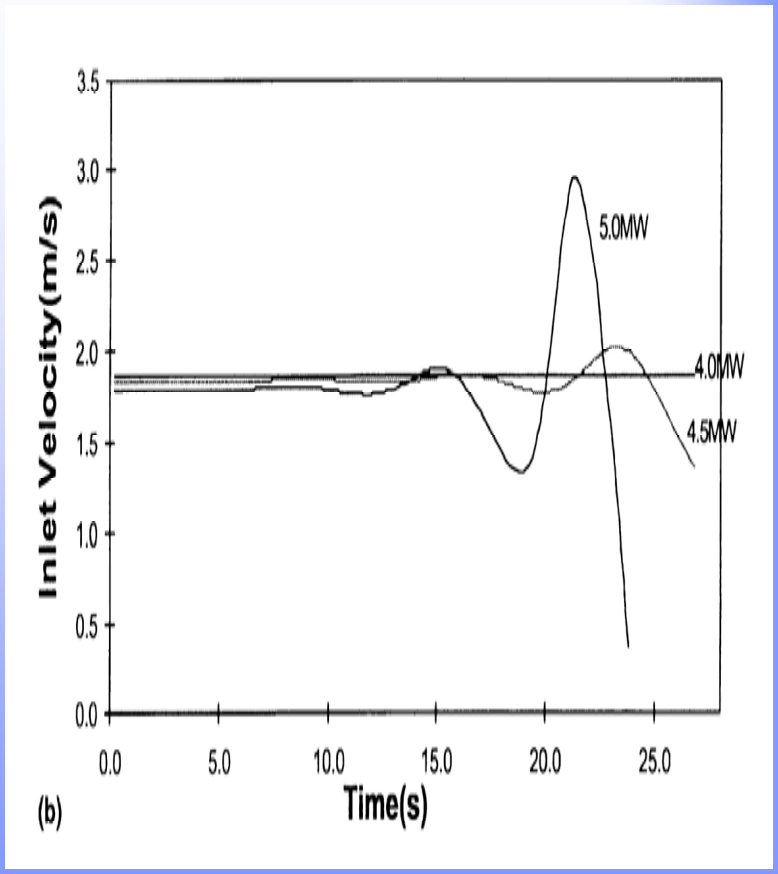
Absence of boiling crisis (CHF), but with heat transfer degradation



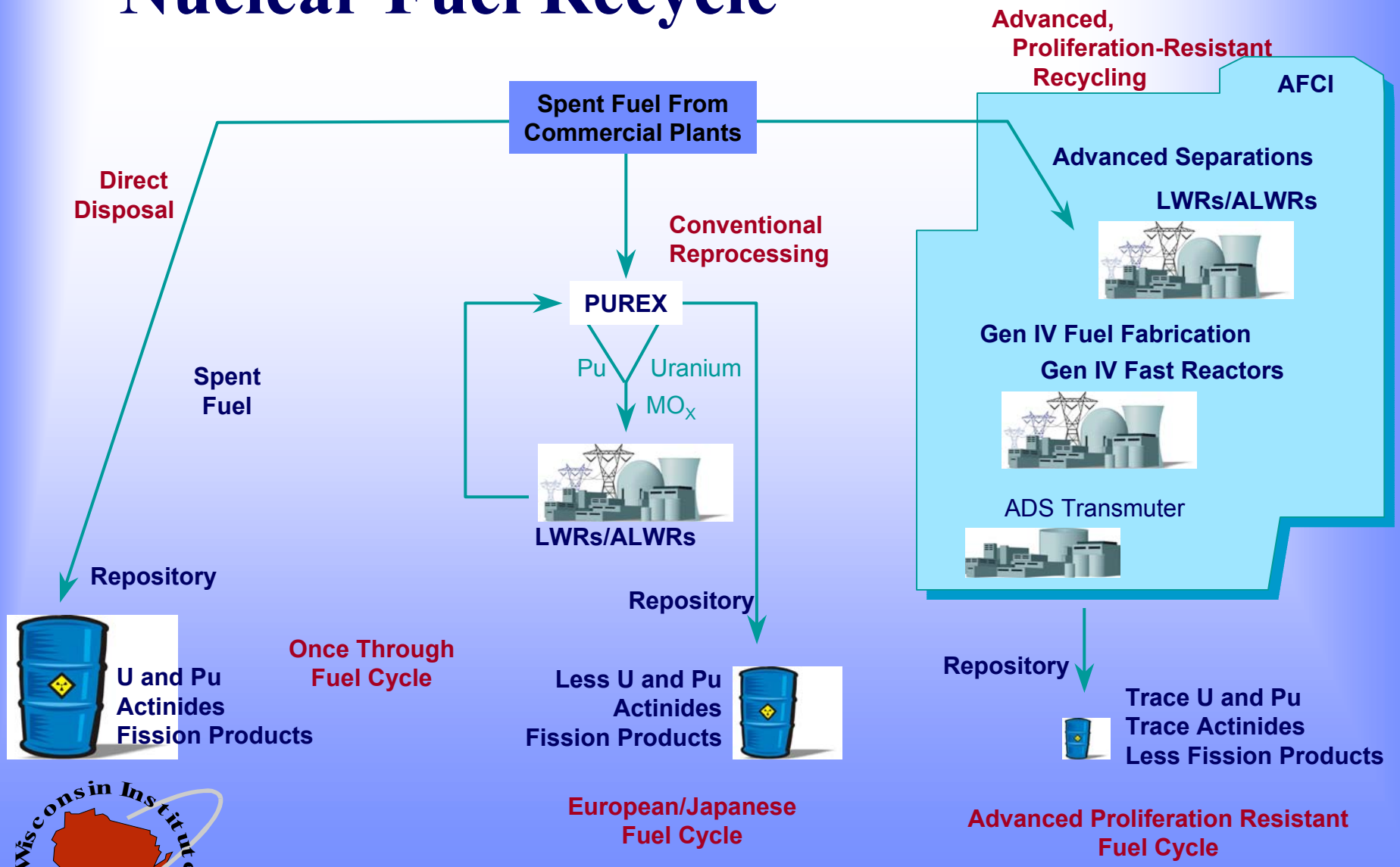


SCW Flow Control and Instabilities





Nuclear Fuel Recycle



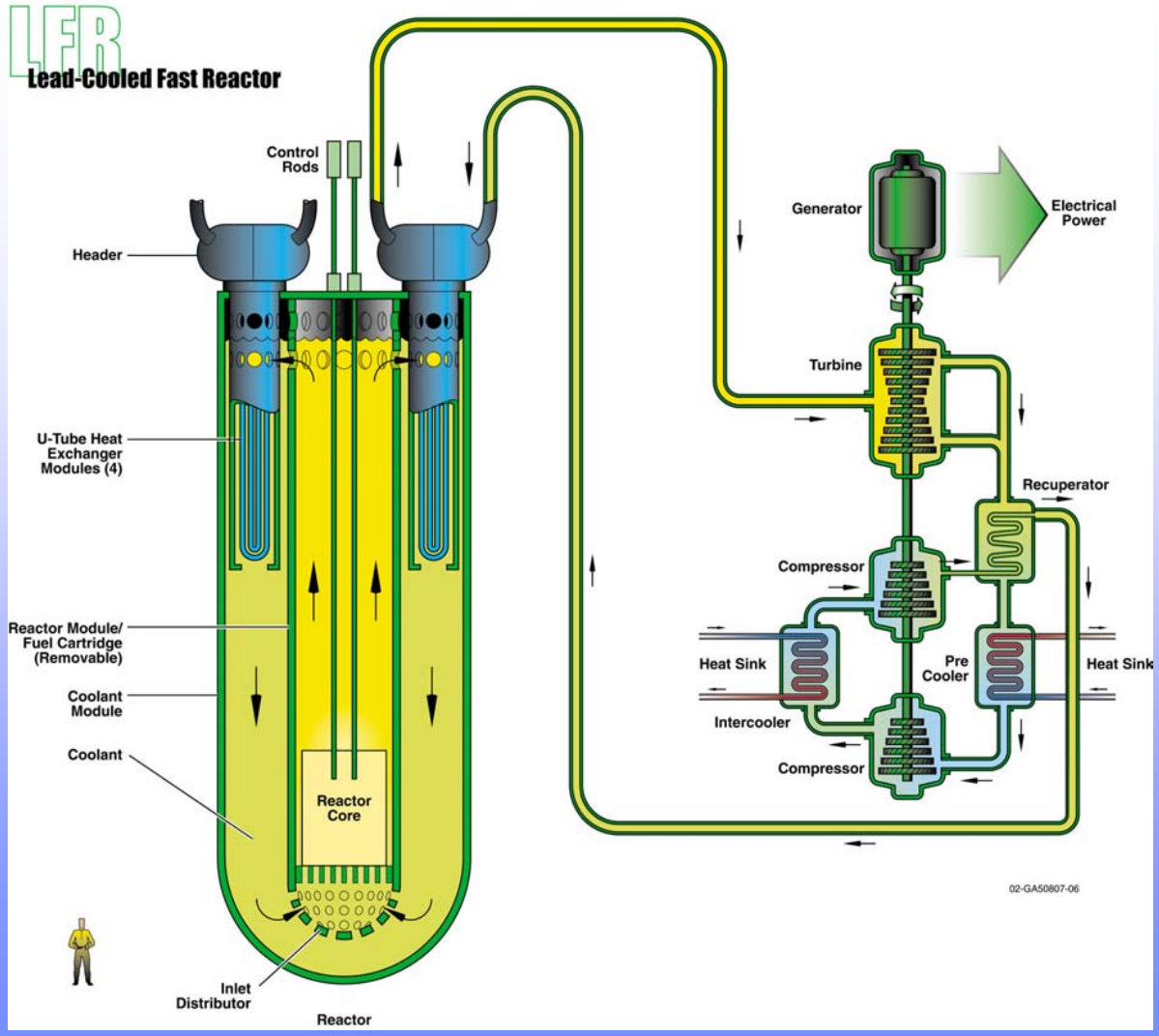
Liquid-Metal-Cooled Fast Reactor (e.g. LFR)

Characteristics

- ***Pb or Pb/Bi coolant***
- ***550°C to 800°C outlet temperature***
- ***120–400 MWe***

Key Benefit

- ***Waste minimization and efficient use of uranium resources***



Liquid Metal-Water Direct Contact HX

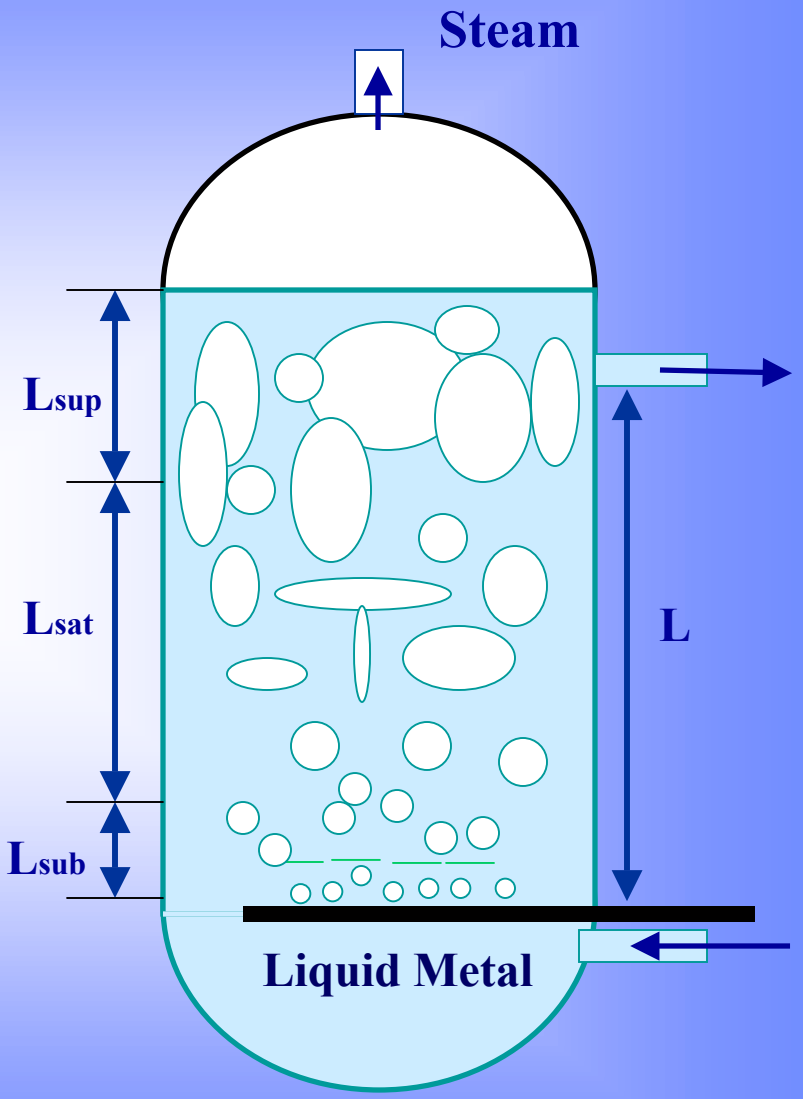
Advantages:

- Vigorous interaction between the liquid metal and the water

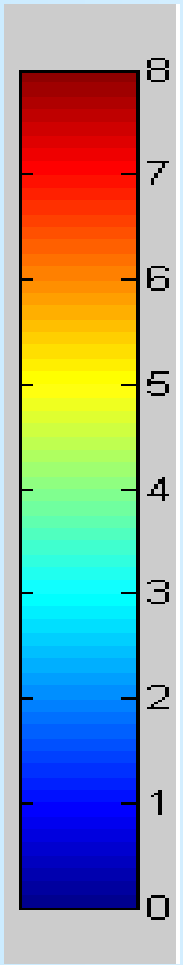
- Excellent contact so smaller volume is required to transfer the same amount of energy.

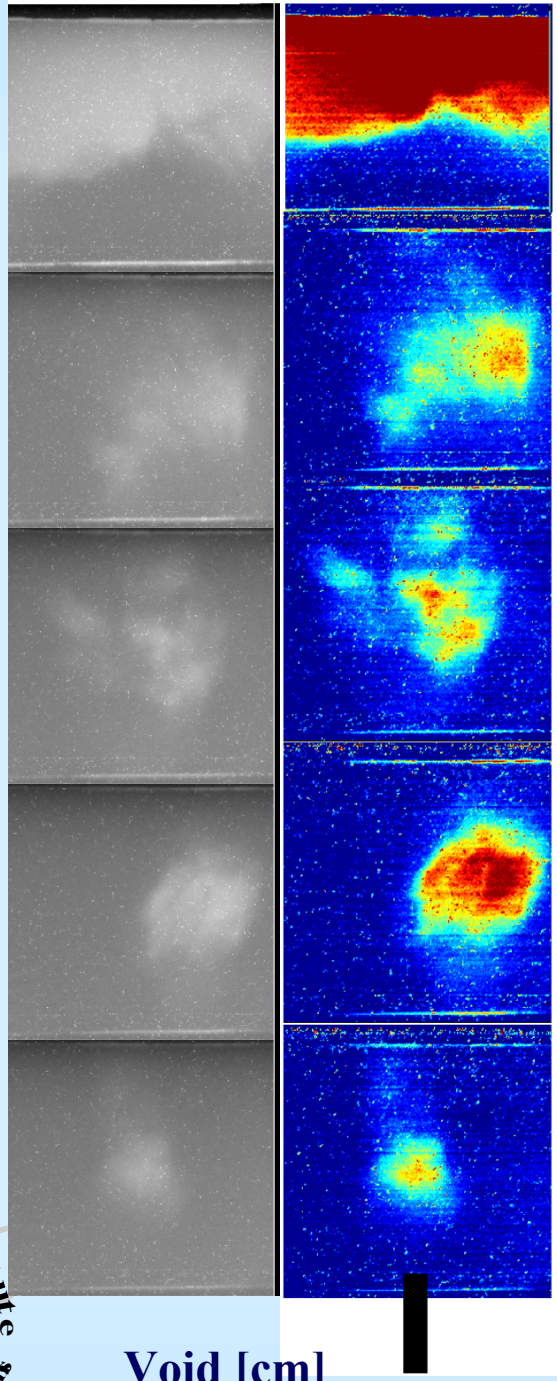
- Potential replacement of IHX loop.

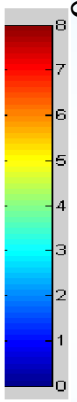
=> Need to determine the local heat transfer coefficient and flow stability for a range of flow rates and regimes.



DCHT via Xray Imaging







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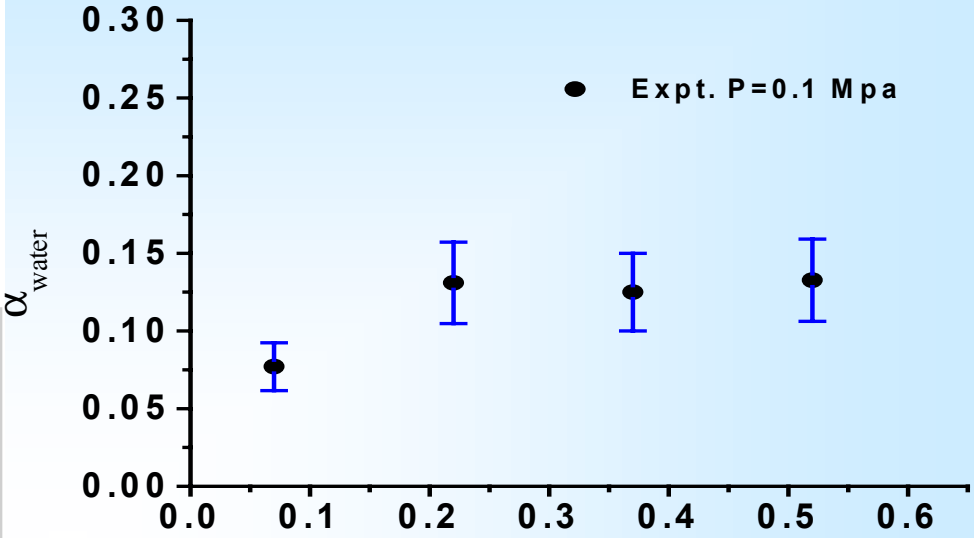
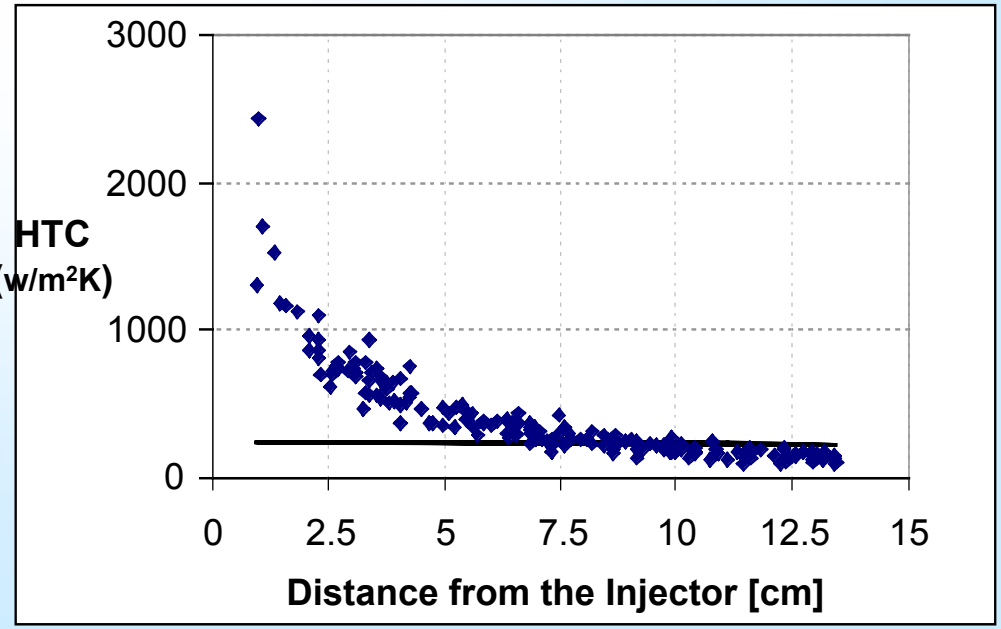




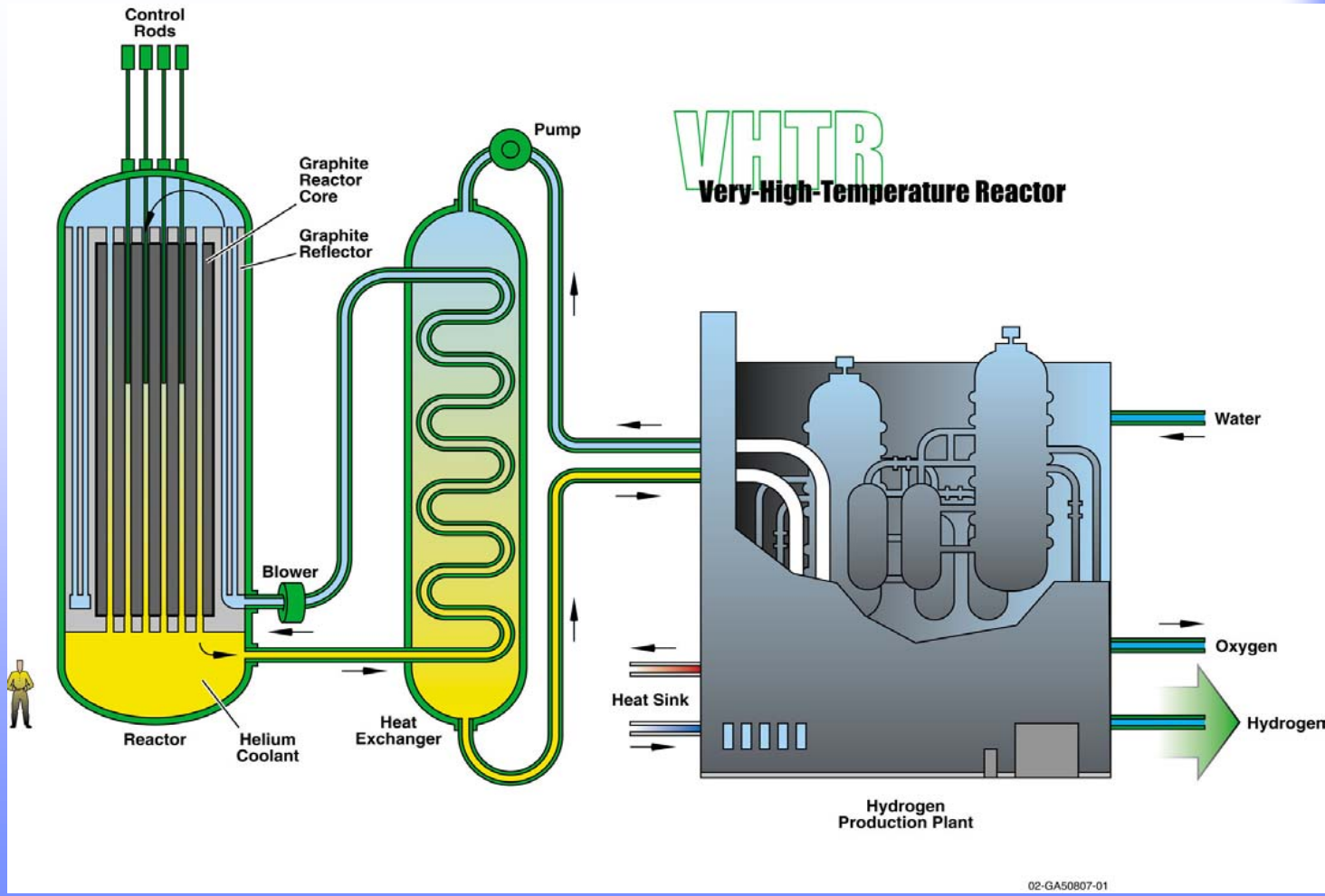
Very-High-Temperature Reactor (VHTR)

Characteristics

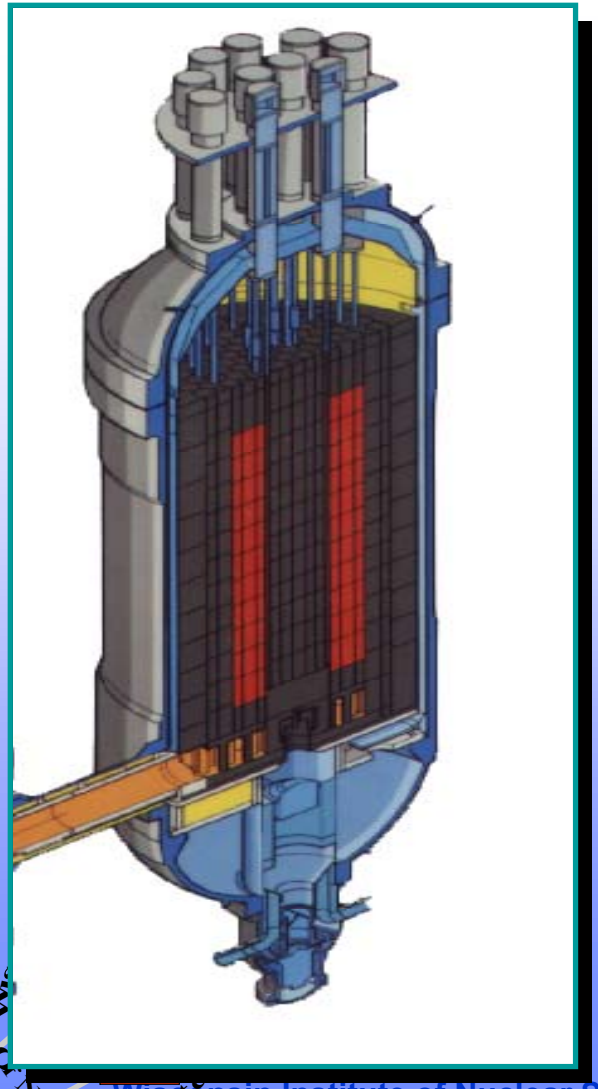
- Helium coolant
- 1000°C outlet temp.
- 600 MWth
- Water-cracking cycle

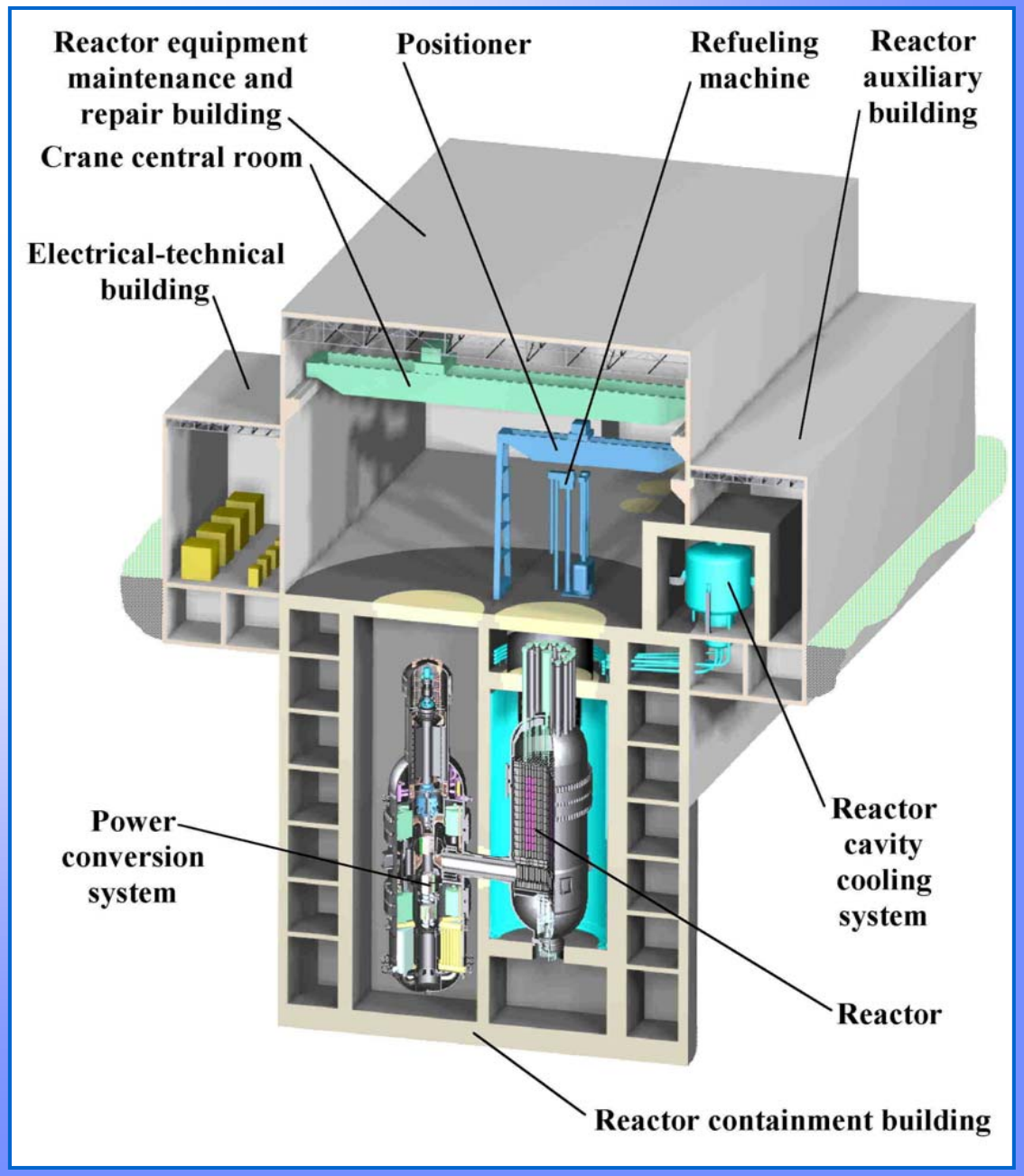
Key Benefit

- Hydrogen production by water-cracking



GAS-COOLED REACTOR



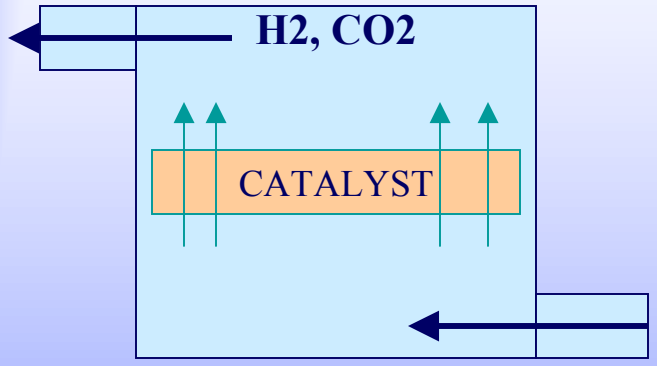


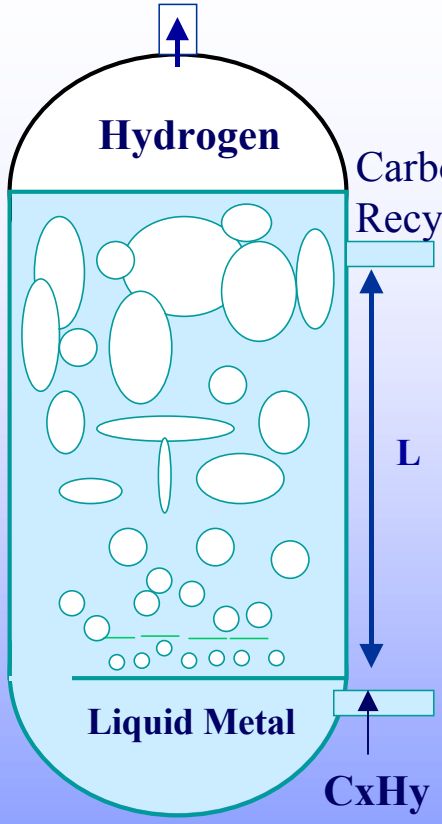
Process Heat for Hydrogen Production

200 C

1000 C

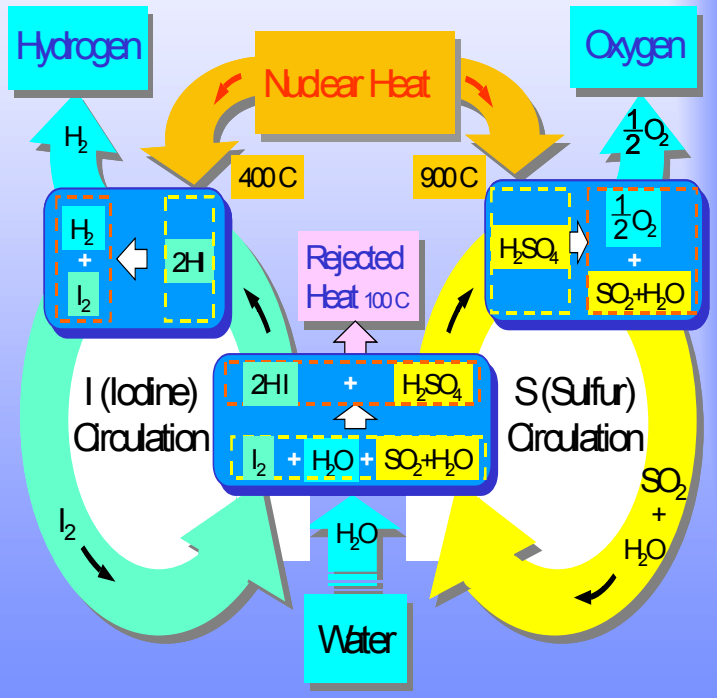
Aqueous-phase Carbohydrate Reforming (ACR)





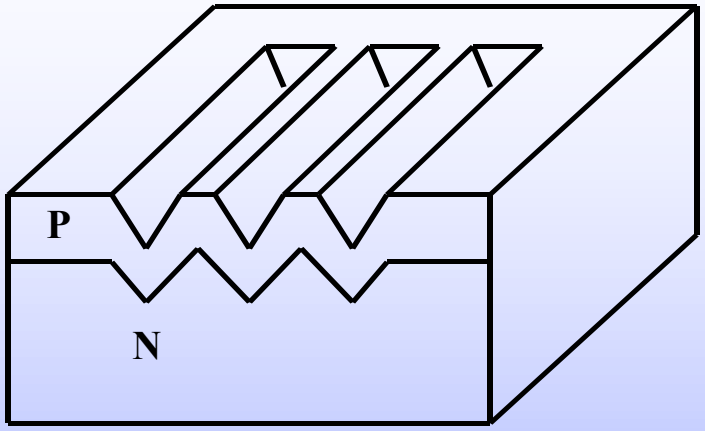
LM Condensed Phase Reforming (pyrolysis)

Iodine/Sulfuric-Acid Thermochemical Process

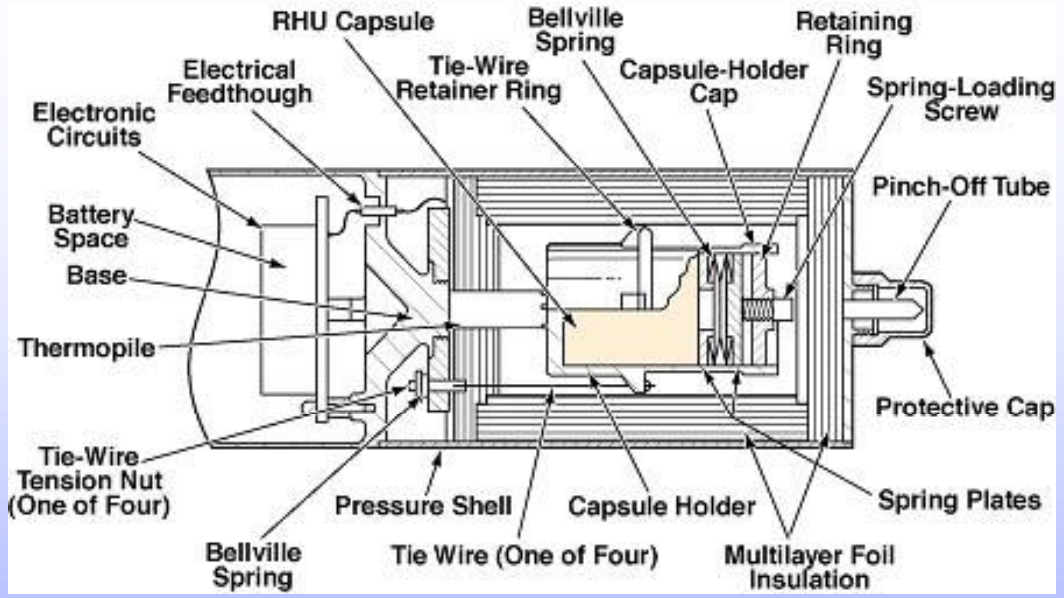


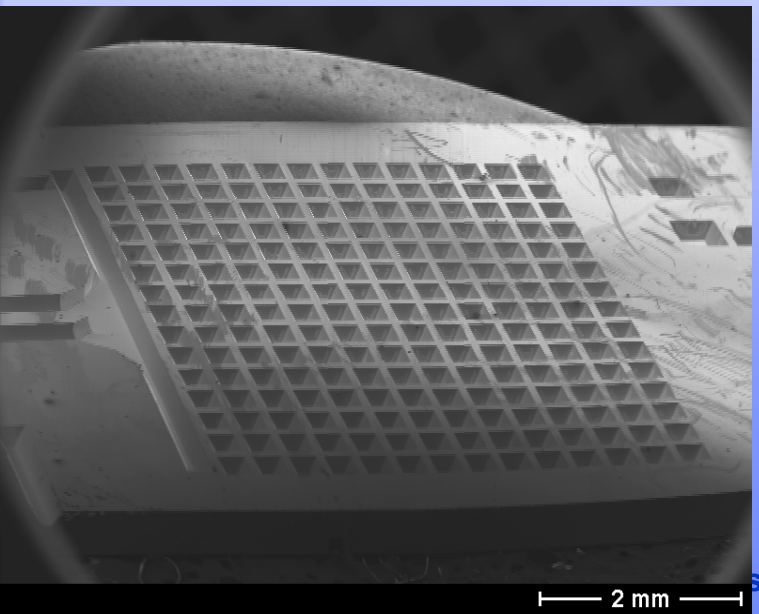
Micro-Nuclear Power Applications (NAE-Blanchard)

Direct Conversion (Electricity from radiation used to create ion-hole pair in PN Jnc)



Micro Thermoelectric or Thermionic Generator





Self-Reciprocating Cantilever Wireless Transmitter