Core Group
Non-PWR/BWR Reactors

Lecture 1
22.033/22.33 – Nuclear Engineering Design Project
Sep. 12, 2011

Main Parameters to Consider

- Coolant
- Moderator
- Thermo. cycle
- T_{in} & T_{out}
- Neutron spectrum
- Materials
- Power density
- Special features
- Commercial readiness
- Safety (active/passive)
- Efficiency
- Fuel

Relative Scales for Parameters

Outlet Temperature

Low: <400°C

Low-temp process heat for H_2 & biofuels

Medium: 400-700°C

Higher temp. process heat for more flexibility

High: >700°C

Very high quality process heat, maximum flexibility

Power level

Low: 100-300MWe

Medium: 300-750MWe

High: >750MWe

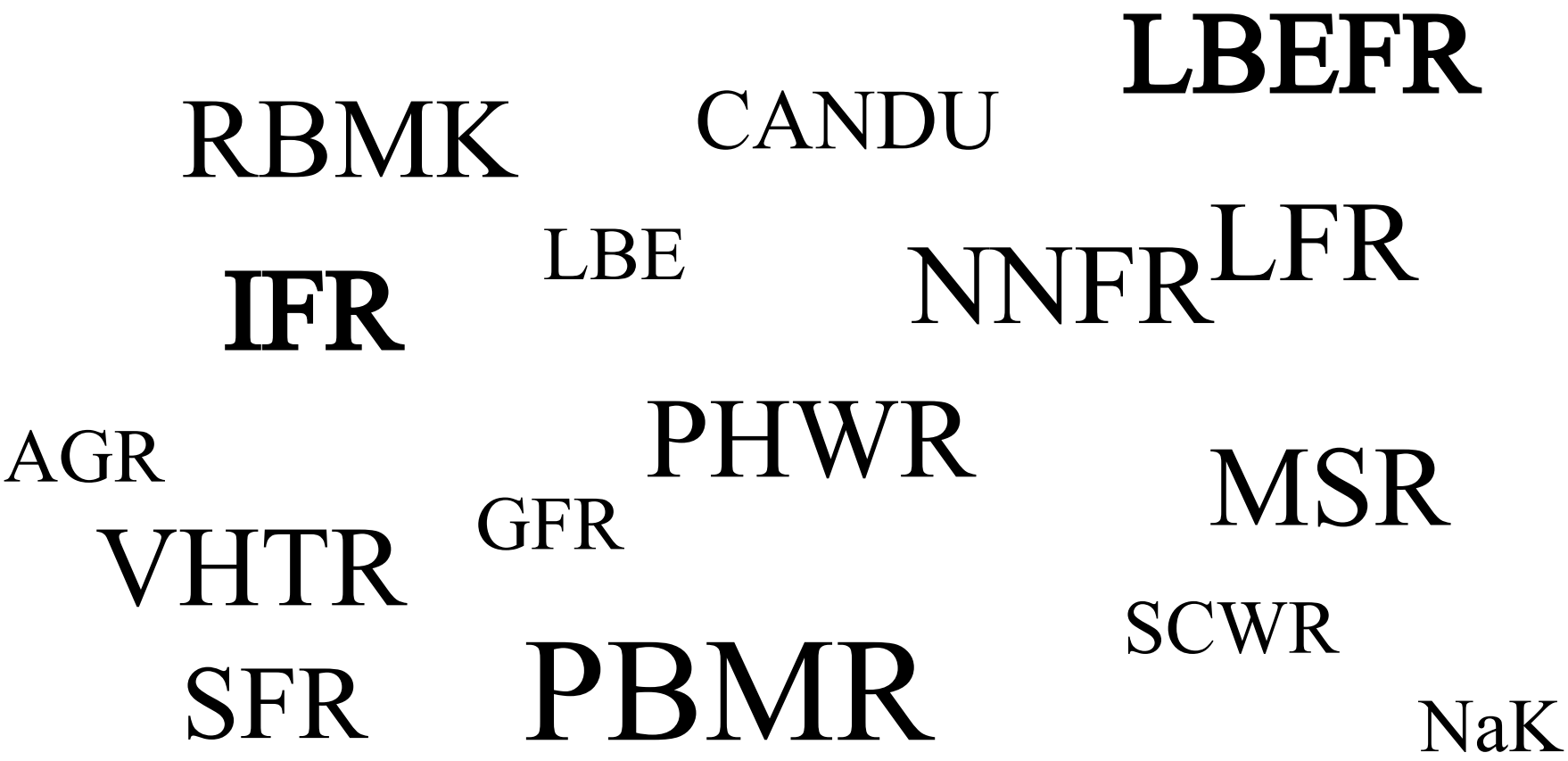
Feasibility

Low: Test reactors only

Medium: Few operated plants, some designs

High: Operating plants, mature designs

Acronyms!


LBEFR
RBMK
CANDU
LBE
LFR
NNFR
IFR
PHWR
AGR
MSR
GFR
VHTR
SCWR
PBMR
SFR
NaK

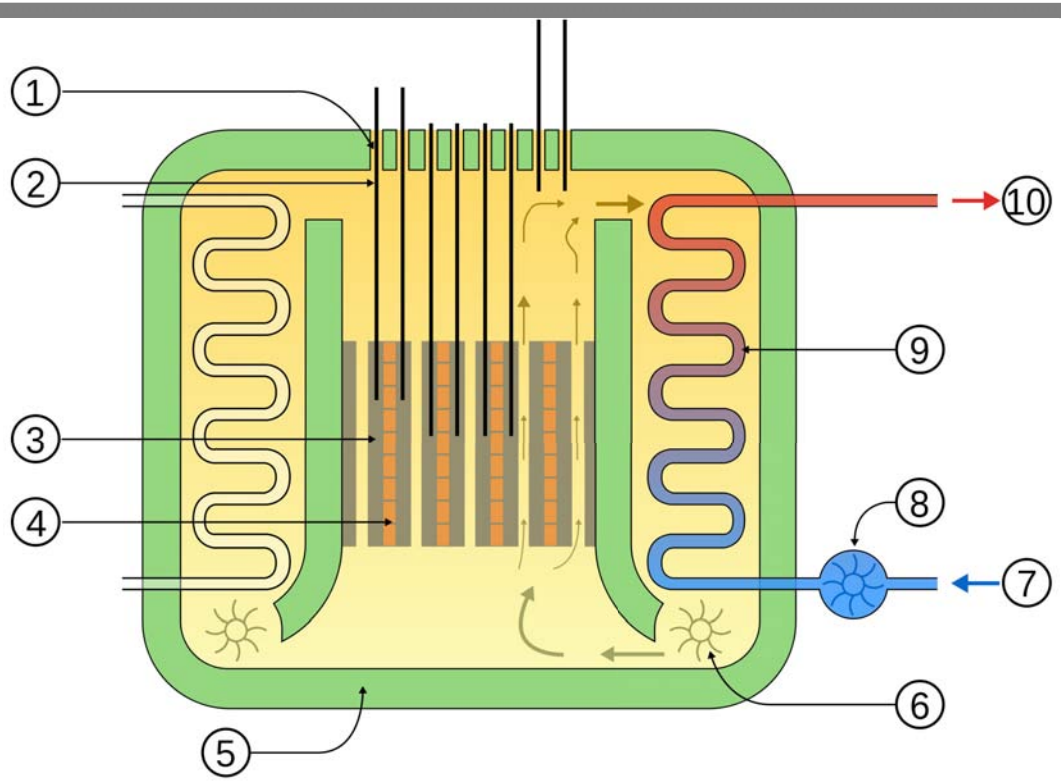
Gas Cooled Reactors

More acronyms:

-NU (natural uranium)

-(L,M,H)EU – (low, medium, high) enriched uranium

AGR (Advanced Gas-cooled Reactor)



- Coolant: CO_2
- T_{out}: Med-high
- Fuel: LEU
- Moderator: Graphite
- Power level: Med.
- Power density: Low (Why?)
- Feasibility: High

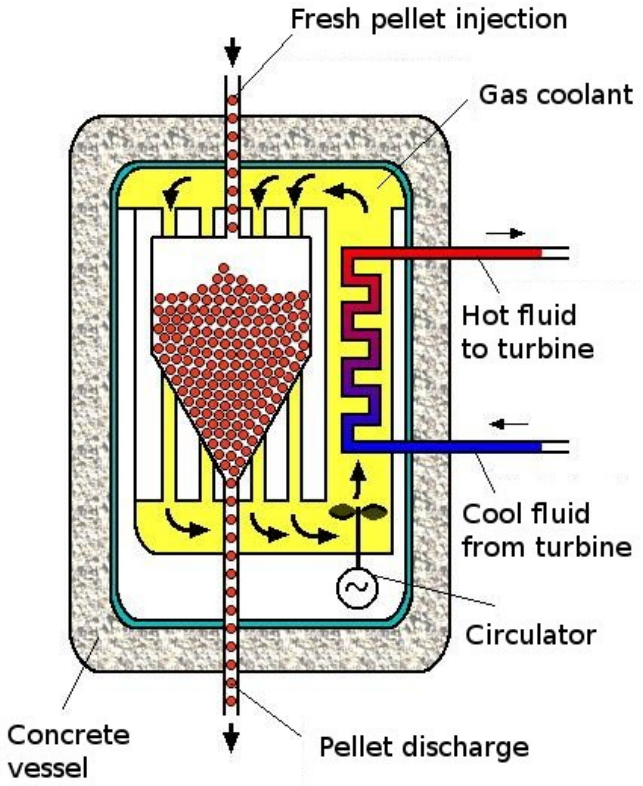
AGR
Special Features, Peculiarities

Courtesy of Sellafield Ltd. Used with permission.

Windscale Prototype AGR
Image source: http://www.sellafieldsites.com/

- Capable of on-load fueling (or part-load)
- Graphite moderator must be cooled due to oxidation in CO_2

PBMR (Pebble Bed Modular Reactor)



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Adapted from: Wikimedia Commons

Coolant: Helium

T_{out}: High

Fuel: LEU - MEU

Moderator: Graphite

Power level: Low – Med.

Power density: Low

Feasibility: Low – Med.

PBMR
Special Features, Peculiarities

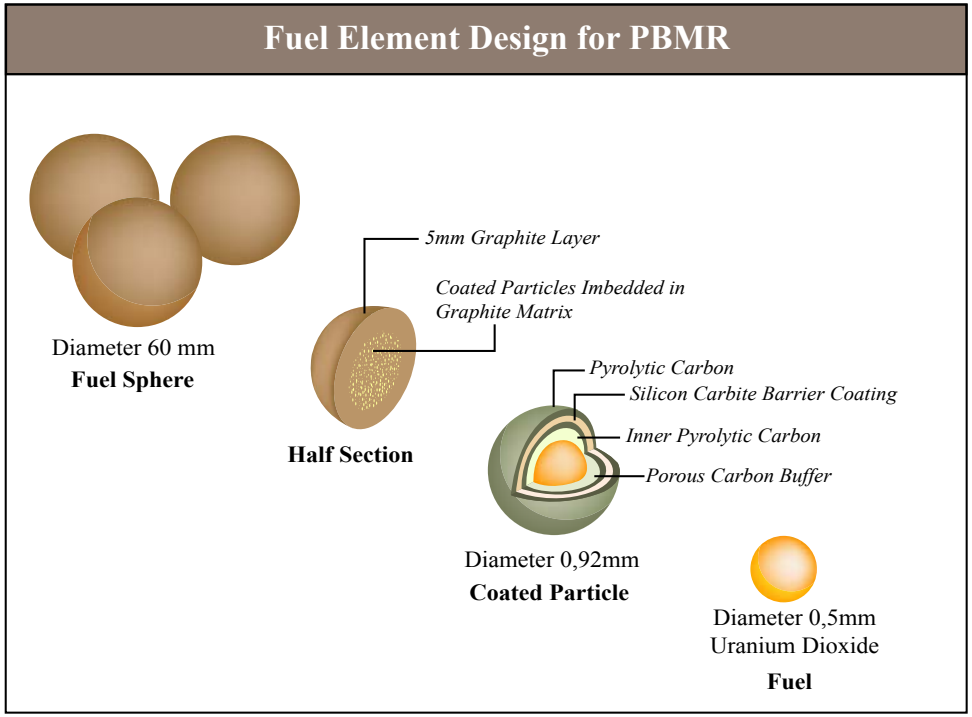
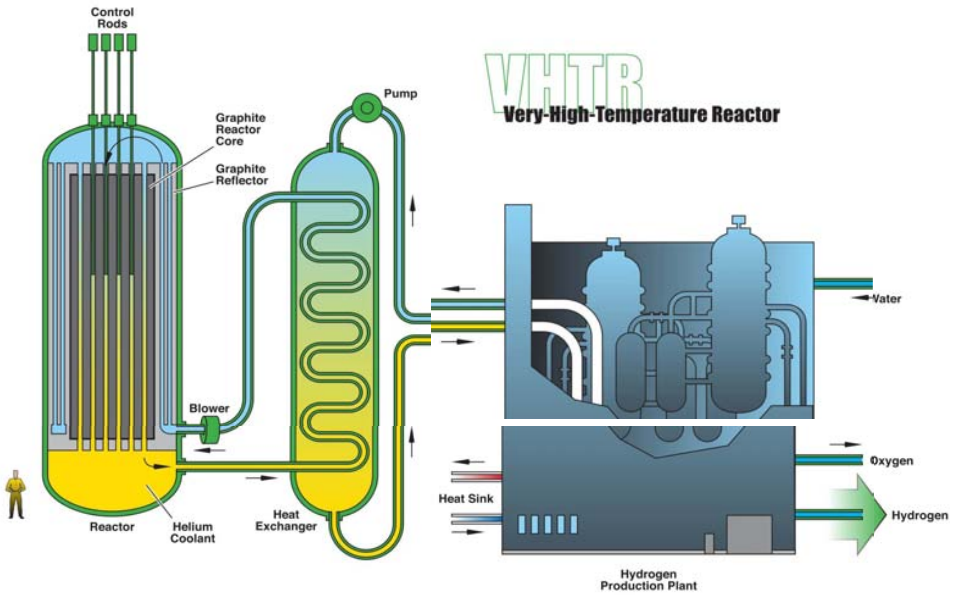


Image by MIT OpenCourseWare.

- Continuous fuel cycle
- Pebble fuel (not rods)
- Pebbles act as built-in disposal methods
- Very passive safety systems (nat. circ.)
- Unknowns: material concerns (fission products), stresses

VHTR
(Very High Temperature Reactor)



Courtesy of Idaho National Laboratory. Used with permission.

Coolant: Helium, molten salt

T_{out}: High (very!)

Fuel: LEU - MEU

Moderator: Graphite

Power level: Low

Power density: Low or high

Feasibility: Low – Med.

VHTR
Special Features, Peculiarities

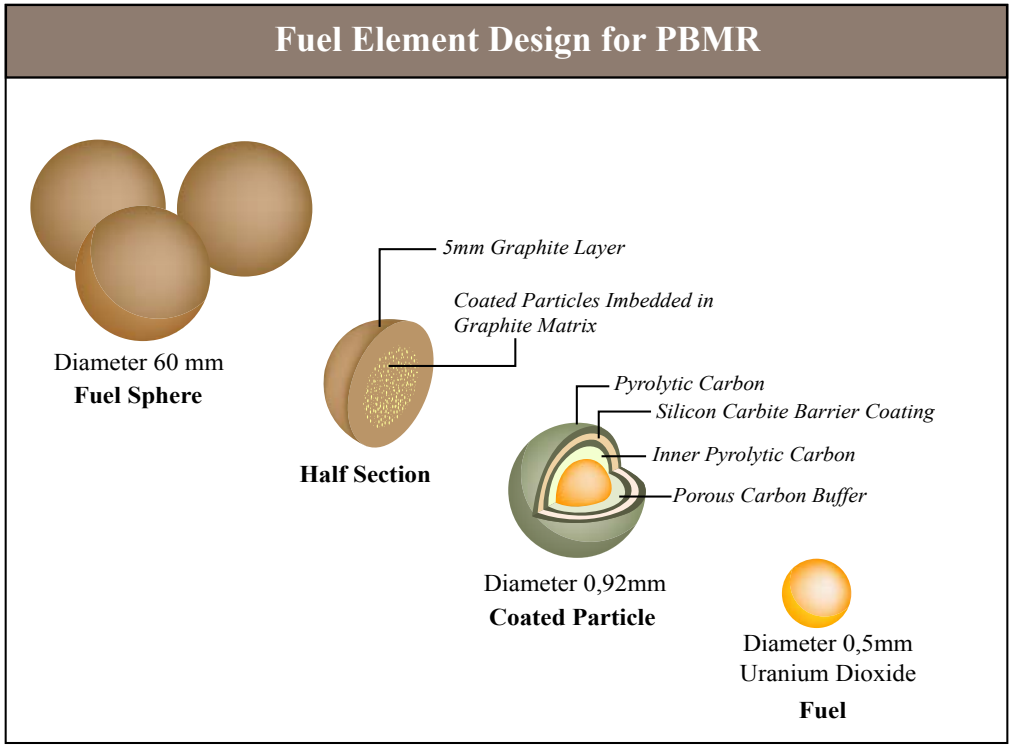


Image by MIT OpenCourseWare.

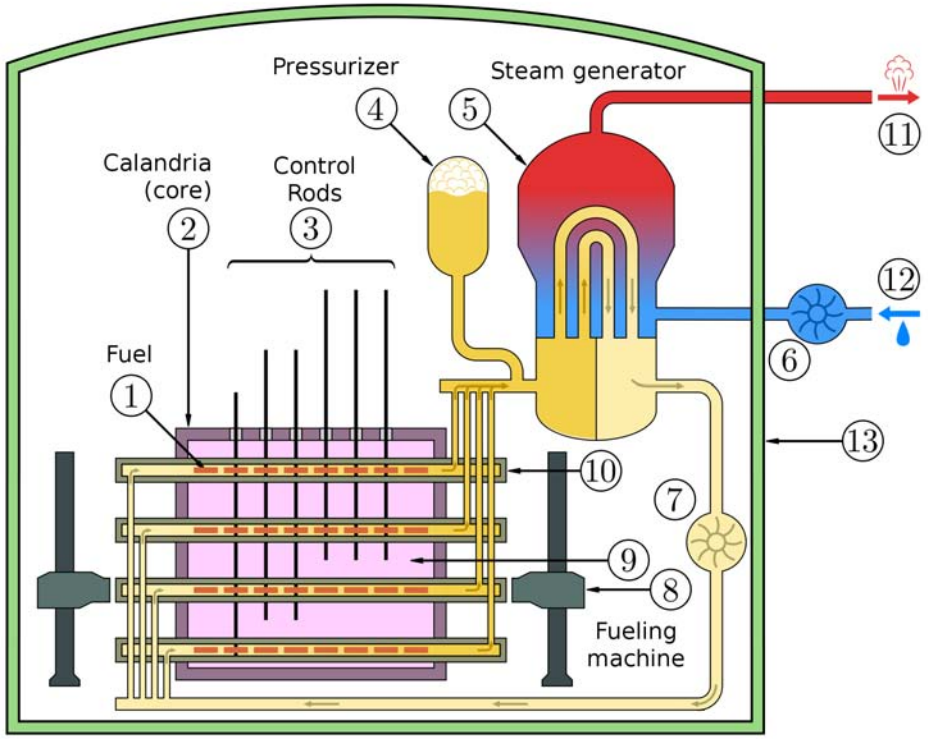
- High T_{out} opens up all doors to hydrogen
- Significant high-T materials concerns
- Molten salt variety can be more corrosive
- Single phase coolant
- TRISO particles, ups & downs

Water Cooled Reactors

More acronyms/symbols:

-D_2O – Deuterium oxide (heavy water)

CANDU – (CANada Deuterium-Uranium reactor)



Courtesy of Wikipedia User:Inductiveload. Used with permission.

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Coolant: D_2O

T_{out}: Low

Fuel: NU - LEU (Why?)

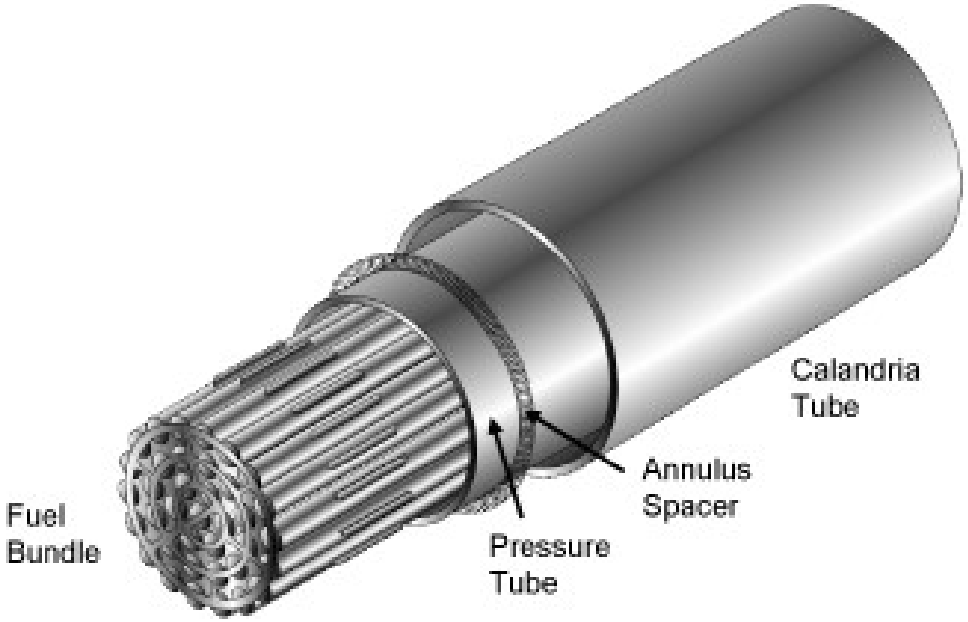
Moderator: D_2O

Power level: Med. - High

Power density: Med.

Feasibility: High

CANDU
Special Features, Peculiarities



CANDU fuel bundle. Image source: http://www.civil.uwaterloo.ca/watrisk/research.html

- Continuous fuel cycle
- Expensive moderator
  - ~25% of capital cost
- Moderator is unpressurized, thermally insulated

RBMK – Reaktor Bolshoy Moshchnosti Kanalniy

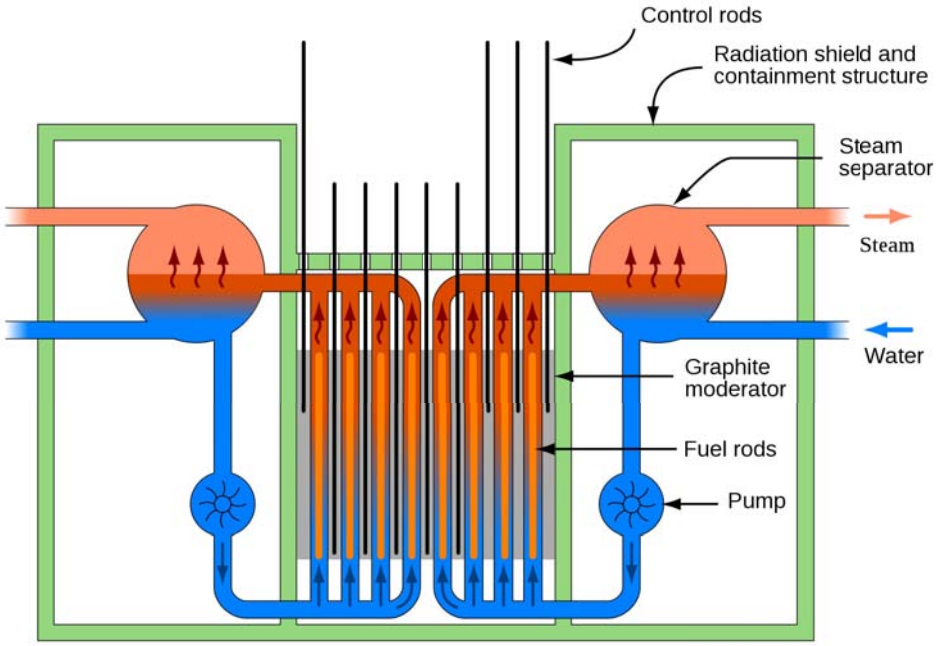


Image source: Wikimedia Commons

Coolant: H_2O

T_{out}: Low

Fuel: NU - LEU

Moderator: Graphite

Power level: High

Power density: Low

Feasibility: Med. (safety)

RBMK
Special Features, Peculiarities

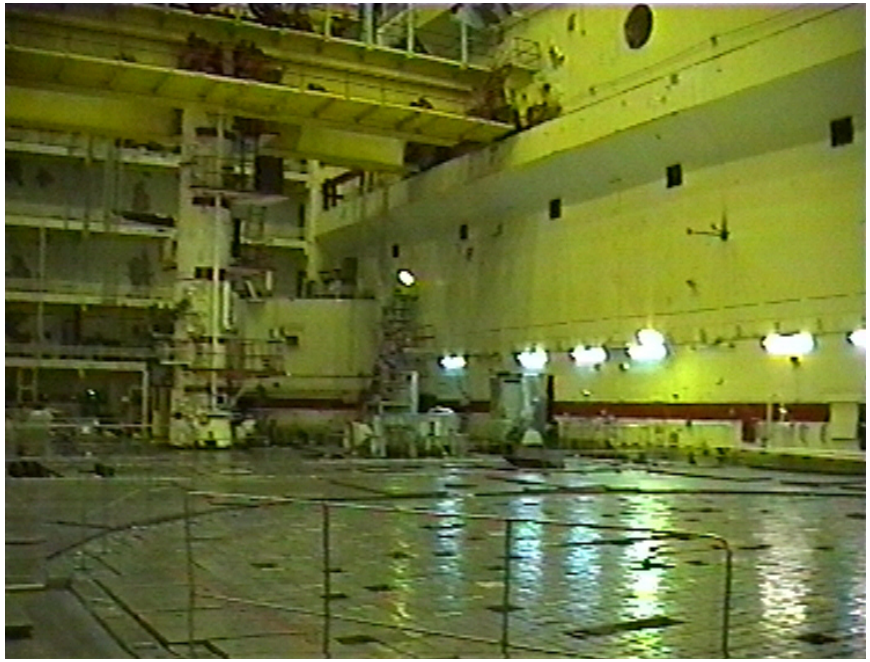


Photo courtesy of Wikipedia User:Cs szabo. License CC BY.

Online refueling possible

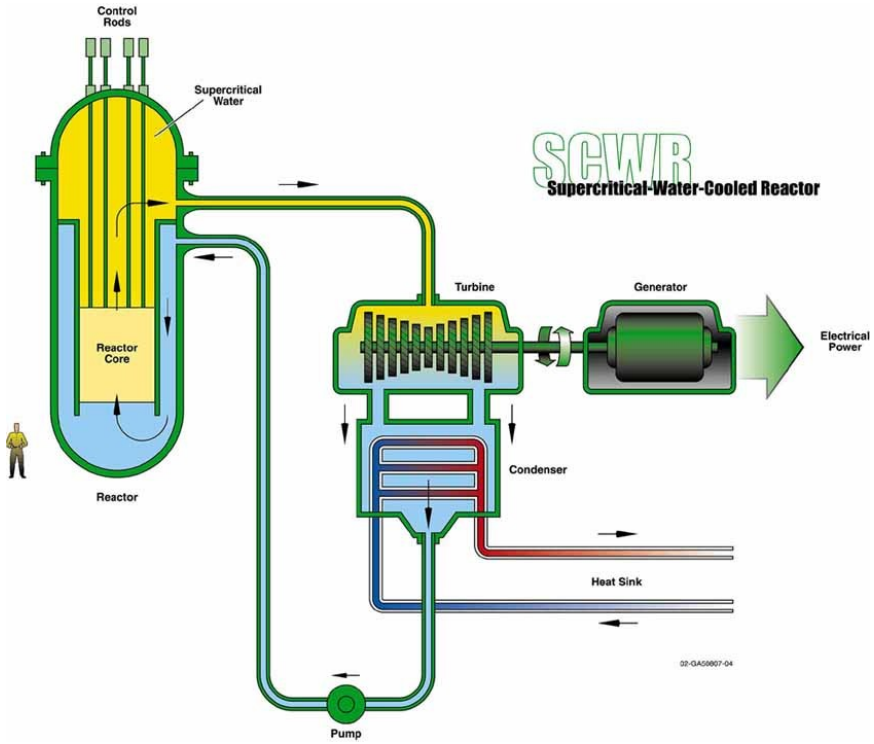
High positive void coefficient – Why?

Improvements in design

-No more graphite-tipped control rods

-More control rods

SCWR
Supercritial Water Reactor



Courtesy of Idaho National Laboratory. Used with permission.

Coolant: SC-H_2O

T_{out}: Med.

Fuel: NU - LEU

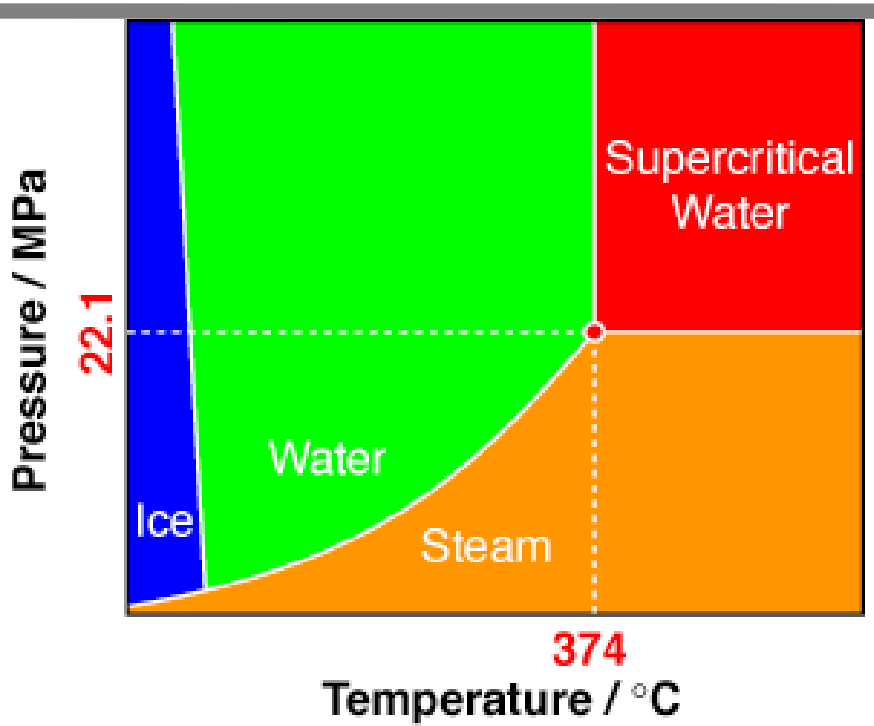
Moderator: SC-H_2O

Power level: High

Power density: High

Feasibility: Low (now)

SCWR
Special Features, Peculiarities



Phase diagram for water. Image source: http://geothermania.blogspot.com/2011/05/research-of-supercritical-water-may.html

- Very simple design
- Significant materials concerns
- Coolant/moderator voiding a non-issue
- High efficiency
- Start-up procedures (pre-heating) to bring coolant supercritial

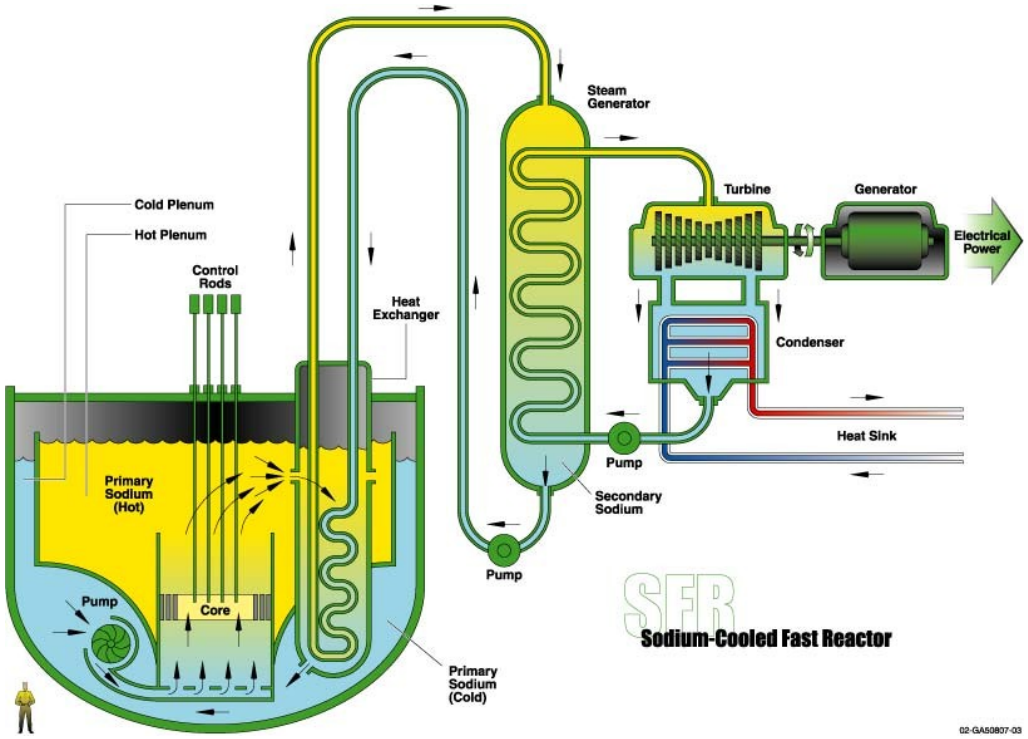
Liquid Metal Cooled Reactors

More acronyms/symbols:

-LBE – Lead-bismuth eutectic

-NaK – Sodium-potassium alloy

SFR (or NaK-FR)
Sodium Fast Reactor



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Coolant: Liquid sodium

T_{out}: Med.

Fuel: NEU - HEU

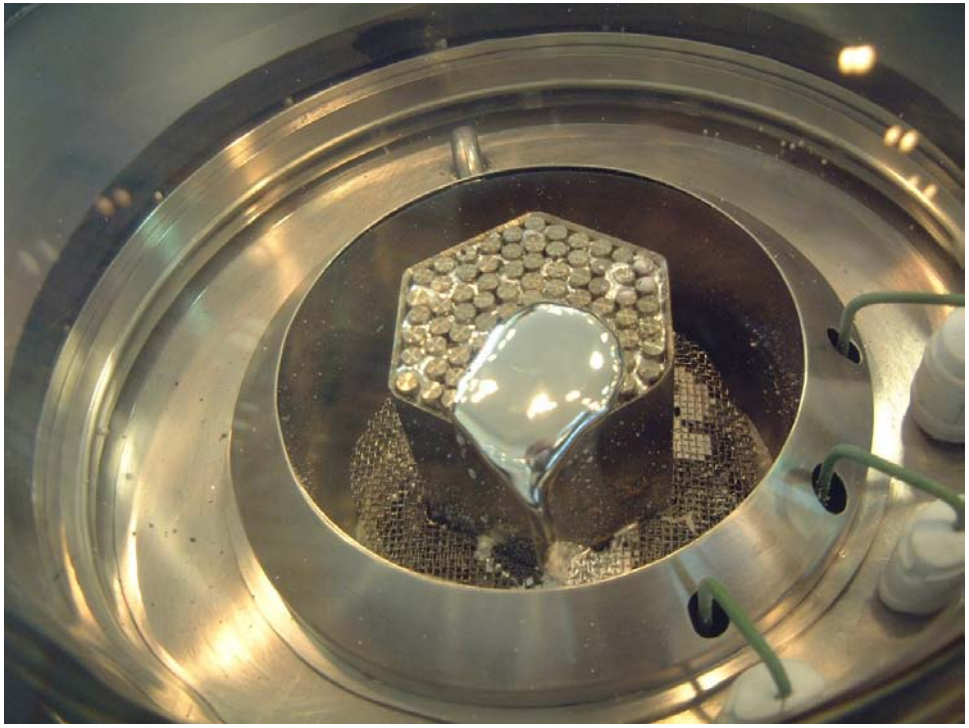
Moderator: None

Power levels: All

Power density: High

Feasibility: Low-Med. (now)

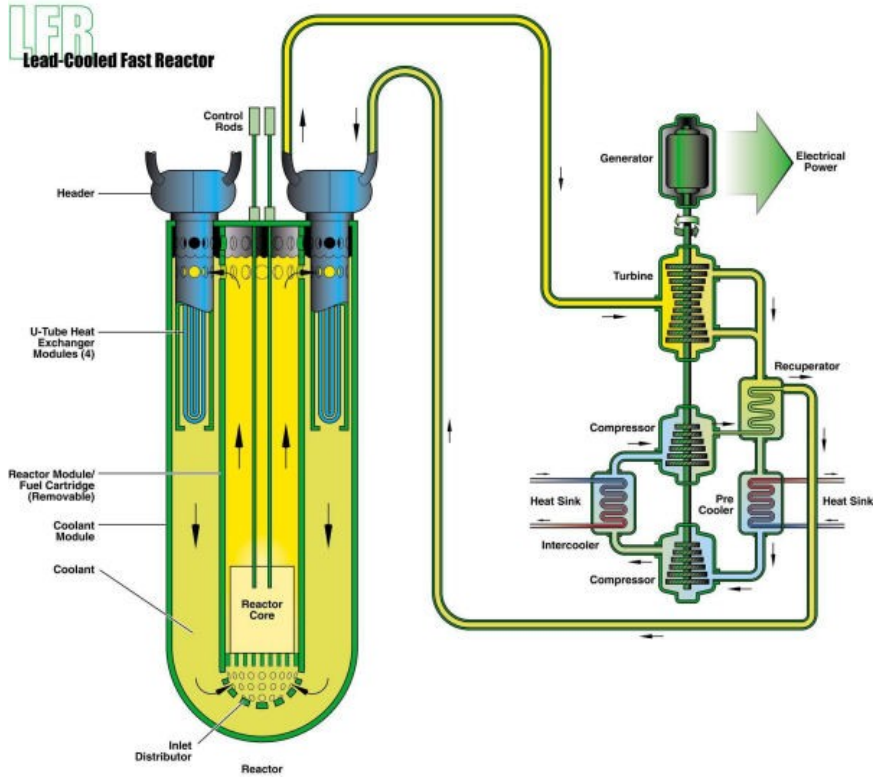
SFR
Special Features, Peculiarities



Molten sodium at MONJU, Japan. Image source: http://www.ecolo.org/photos/visite/monju_02/monju.sodium.hot.melted.jpg

- No pressurization
- Very high k, c_P
- High material compatibility
- High boiling margin
- Neutron activation – worker dose concerns
- $Na + H_2O$ = RUN AWAY

LFR (or LBEFR)
Lead Fast Reactor



Courtesy of Idaho National Laboratory. Used with permission.

Coolant: Lead (or LBE)

T_{out}: Med. (higher soon...)

Fuel: MEU

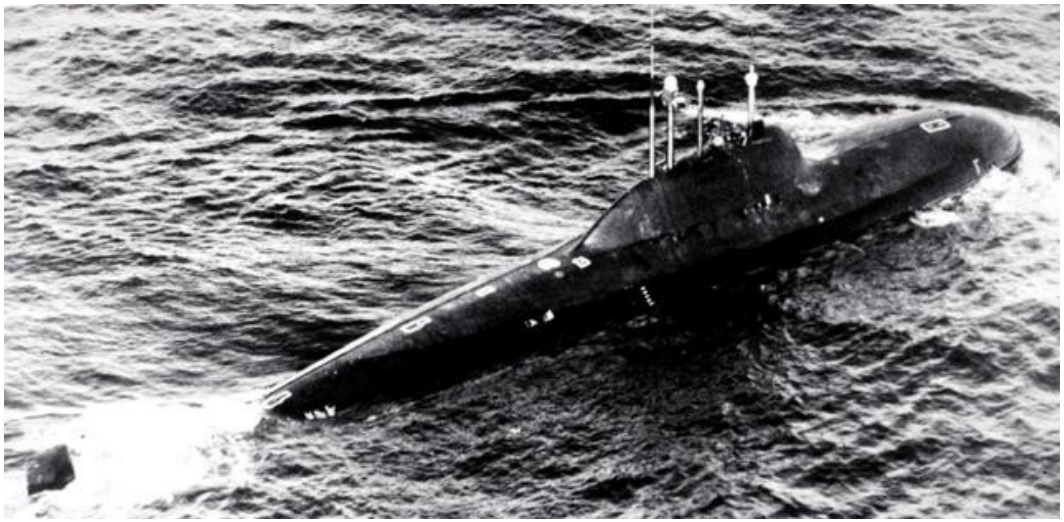
Moderator: None

Power levels: All

Power density: High

Feasibility: Low-Med. (now)

LFR
Special Features, Peculiarities



Alfa-class Russian submarine, using a LFR as its propulsion system. Image source: Wikimedia Commons
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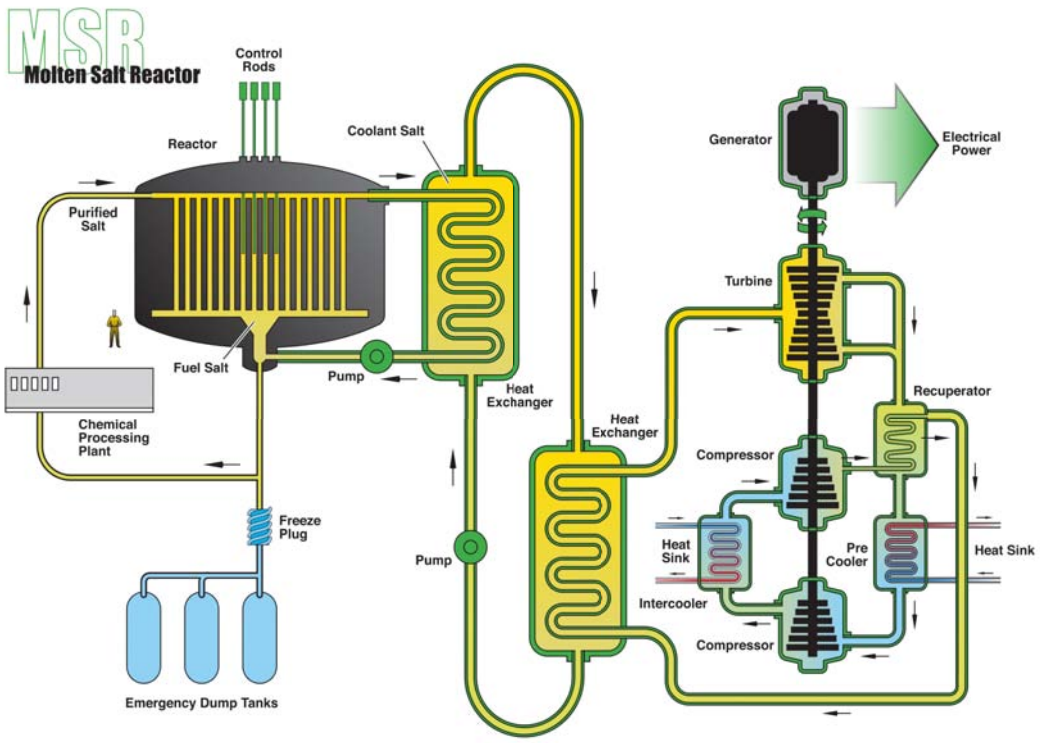
- High heat capacity
- Self-shielding
- Must melt coolant first
- Essentially no coolant voiding possible
- Polonium creation
- Material corrosion
- Coolant cost (LBE)

Molten Salt Cooled Reactors

More acronyms/symbols:

-FLiBe – Lithium & beryllium fluoride salts

MSR
Molten Salt Reactor



Courtesy of Idaho National Laboratory. Used with permission.

Coolant: FLiBe, UF_4

T_{out}: Med. - High

Fuel: MEU

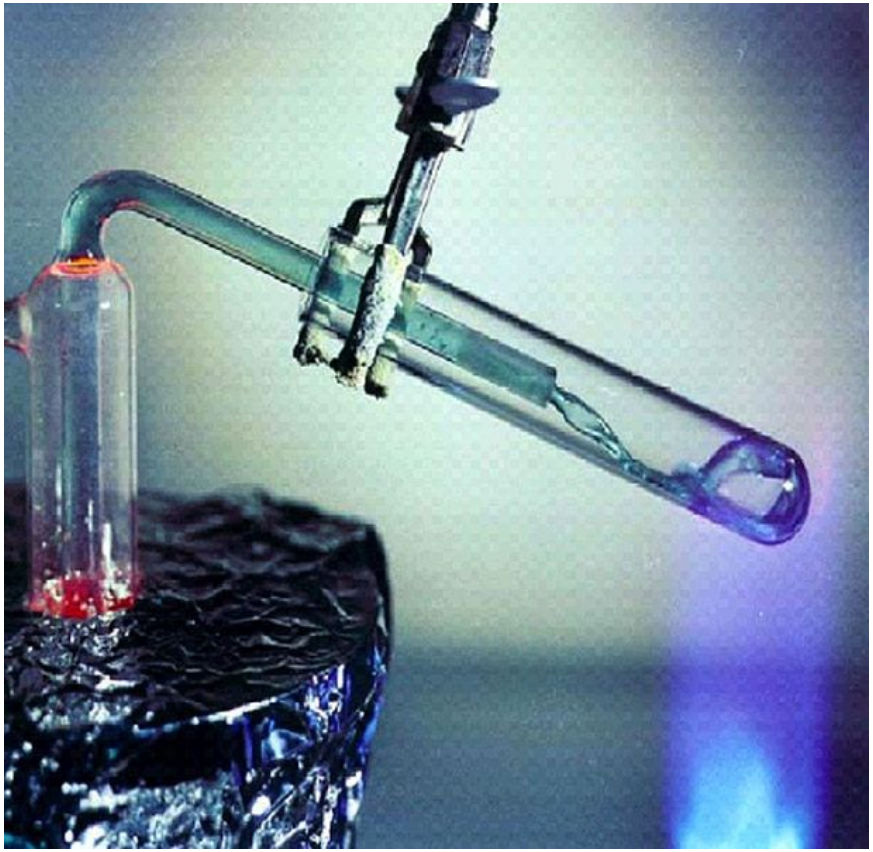
Moderator: Graphite

Power levels: All

Power density: High

Feasibility: Med. (now)

MSR
Special Features, Peculiarities



Molten FLiBe. Image source: Wikimedia Commons

- Unpressurized core
- ThF_4/UF_4 fluid can be both fuel & coolant
- Very negative temperature coeff.
- High neutron flux causes $Li \rightarrow {}^3H$, ${}^3H + F^- \rightarrow HF$ (hydrofluoric acid)
- On-site salt reprocessing

Core Group - Questions

Which coolant to use?

What outlet temperature?

How big of a reactor?

Primary / secondary / tertiary cycles?

Recuperator?

How much electricity vs. process heat?

Where in the cycle should process heat exit?

22.033 / 22.33 Nuclear Systems Design Project

Fall 2011