IAEA Technical Meeting on the Benefits and Challenges of Fast Reactors of the SMR Type
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FEASIBILITY STUDY OF SMALL SODIUM COOLED FAST EACTORS

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Previous Studies

Introduction

JAEA has studied about small sodium cooled reactors in the Feasibility Study.

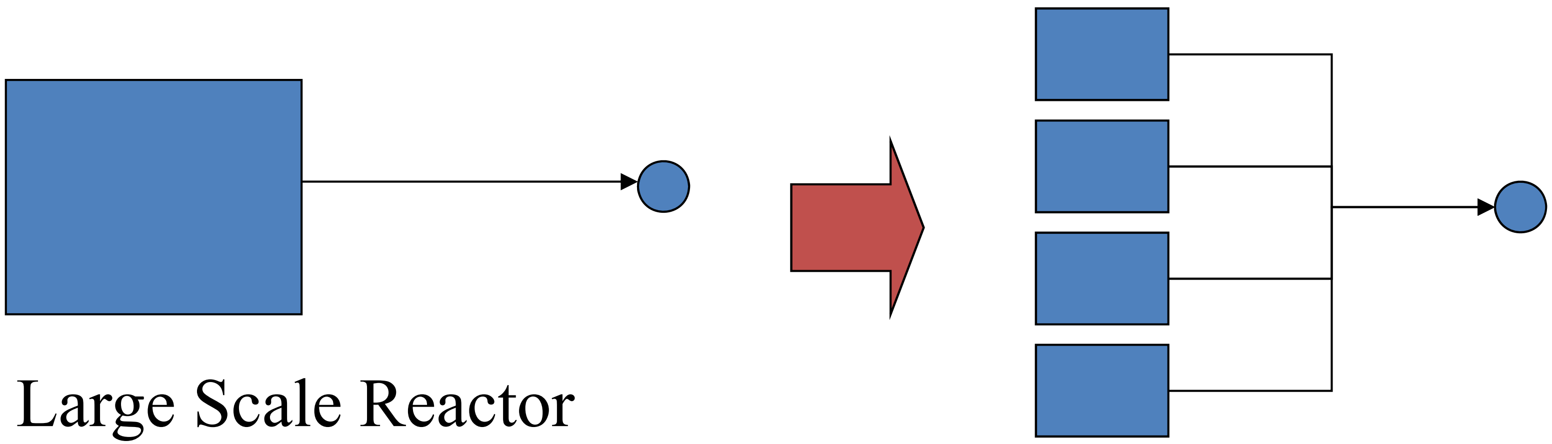
-Modular Reactor for base load power source

Today's Topic

-Remote Place Power Source (<50MWe)

-Multi-purpose Reactor (Hydrogen Production)

Modular Reactors



Large Scale Reactor
-High economic performance with scale effect
-High R&D risk

Modular Reactor
-High economic performance with standardization & Common use between units
-Low R&D risk

-IRIS, IMR, small BWR

M.D. Carelli, et al., ICAPP'05, No. 5059, Seoul, Korea, May, (2005).
T. Kanagawa, et al., ICAPP'05, No. 5204, Seoul, Korea, May, (2005).
H. Heki, et al., ICAPP'05, No. 5174, Seoul, Korea, May, (2005).

-IFR

Y.I. Chang, "The Integrated Fast Reactor", Nucl. Tech., Vol. 88, (1989).

Purpose

Energy Resource Sustainability,
Low Environmental Burden with
MA transmutation

Proposal of a commercialize **fast reactor** with low R&D risk
(major requirement)
-Economical competitiveness with large scale reactors
-Demonstration of reactor technologies
-Demonstration of **economical performance** including a whole fuel cycle system

Important for Commercialization

-Further cost reduction of modular fast reactor
-Evaluation of construction cost of a first kind of plant (FOAK) (demonstration plant) considering a whole fuel cycle system

Major Design Conditions

-Electric Output: 300MW-electric

-Fuel Type: U-TRU-Zr

> Low construction cost in the small fuel cycle facility

> MA transmutation

-Reactor Type: Loop Type

> Potential of Cost Reduction

-Spent Fuel Storage: In-vessel Storage (IVS)

> Simple ex-vessel fuel handling system

-Main Cooling System: One-Loop Main Cooling System

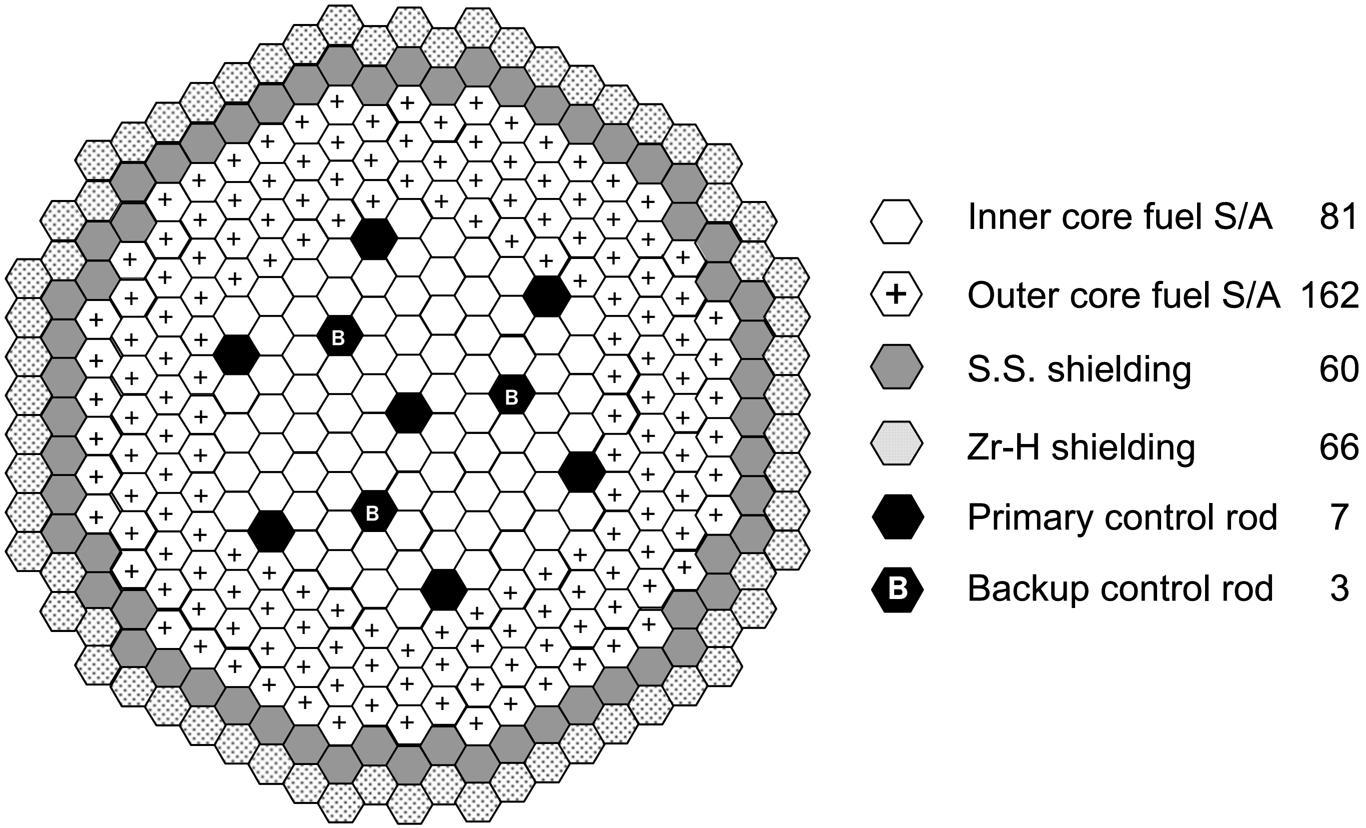
> Cost Reduction

-Main Pump: Electro Magnetic Pump (EMP)

> Technology for one-loop main cooling system

Core Design

Single Pu enrichment plural Zr content Regions Core



-Output: 714MW (300MW-electric)

-Operation Cycle: 2years (4batches)

-Burnup: 80GWd/t

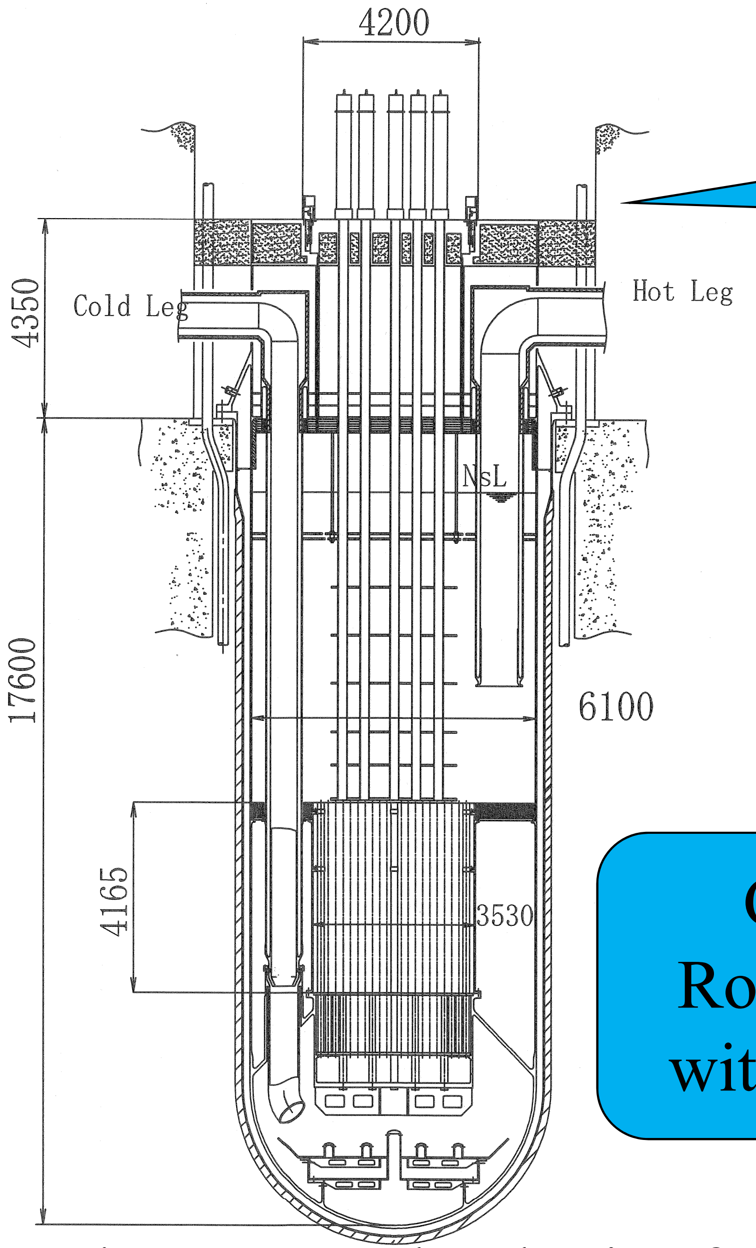
-Outlet Temp.: 550deg-C

Core Diameter:2.63m
Core Height:1m

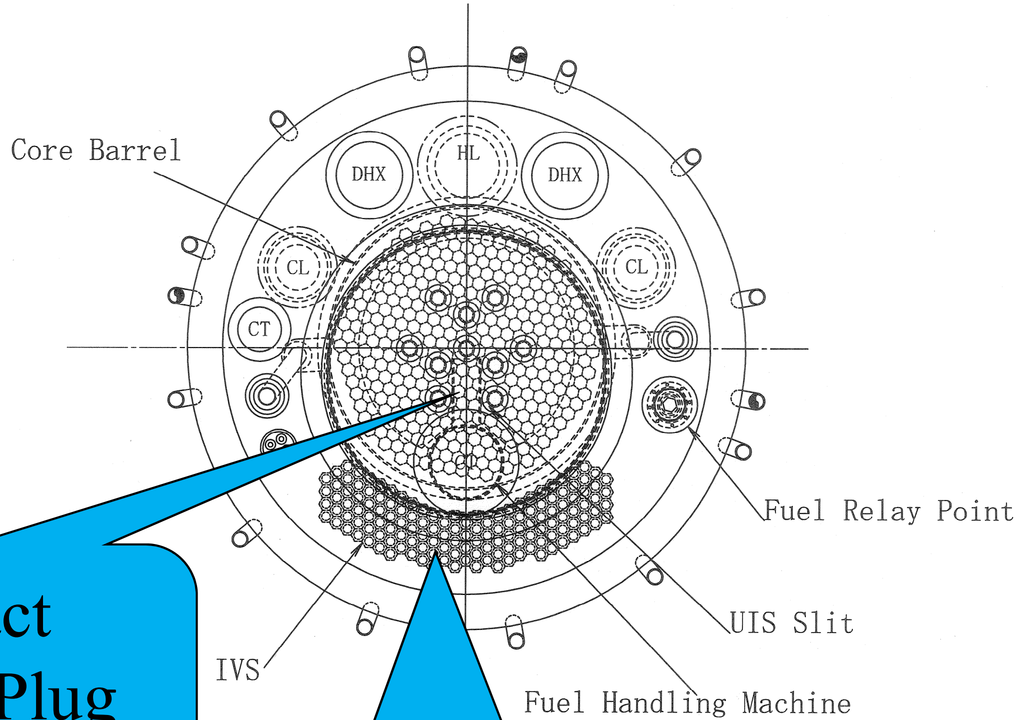
Pin Diameter:8.5mm
S/A pitch:157.2mm

S. Sugino, T. Ogawa, Y. Okano and T. Mizuno, GLOBAL 2005, No. 399, Oct., (2005).
T. Mizuno, T. Ogawa, K. Sugino and M. Naganuma, ICAPP'05, No.5195, Seoul, Korea, May, (2005).

Reactor Vessel



L shape piping with high chromium steel*



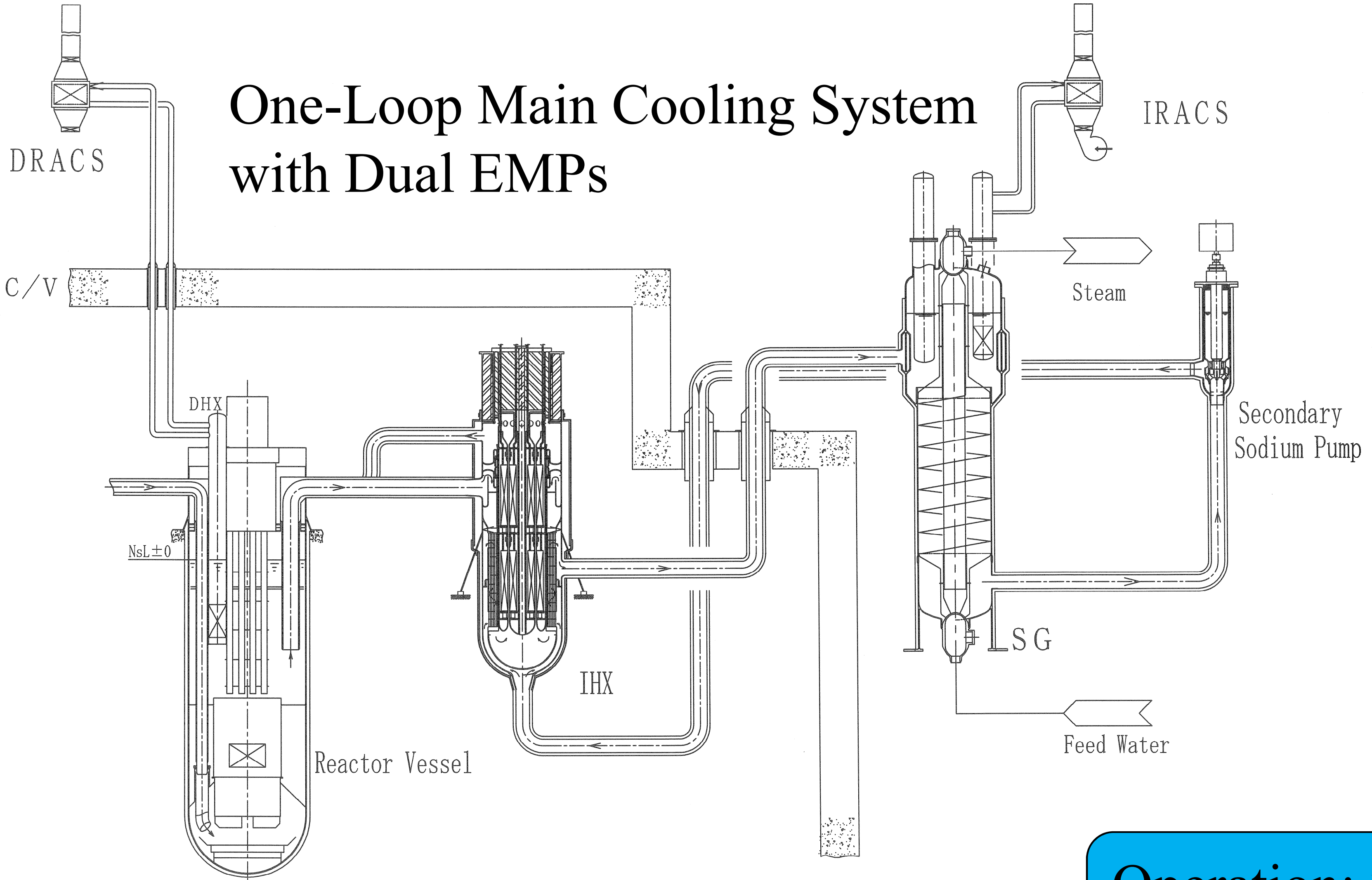
Compact Rotating Plug with Slit UIS*

IVS with capacity for 4 years storage

*: Same technologies from JSFR

Y. Shimakawa, et al. , Nucl. Tech., Vol.140, No. 1, (2002).

Reactor Cooling System



One-Loop Main Cooling System
with Dual EMPs

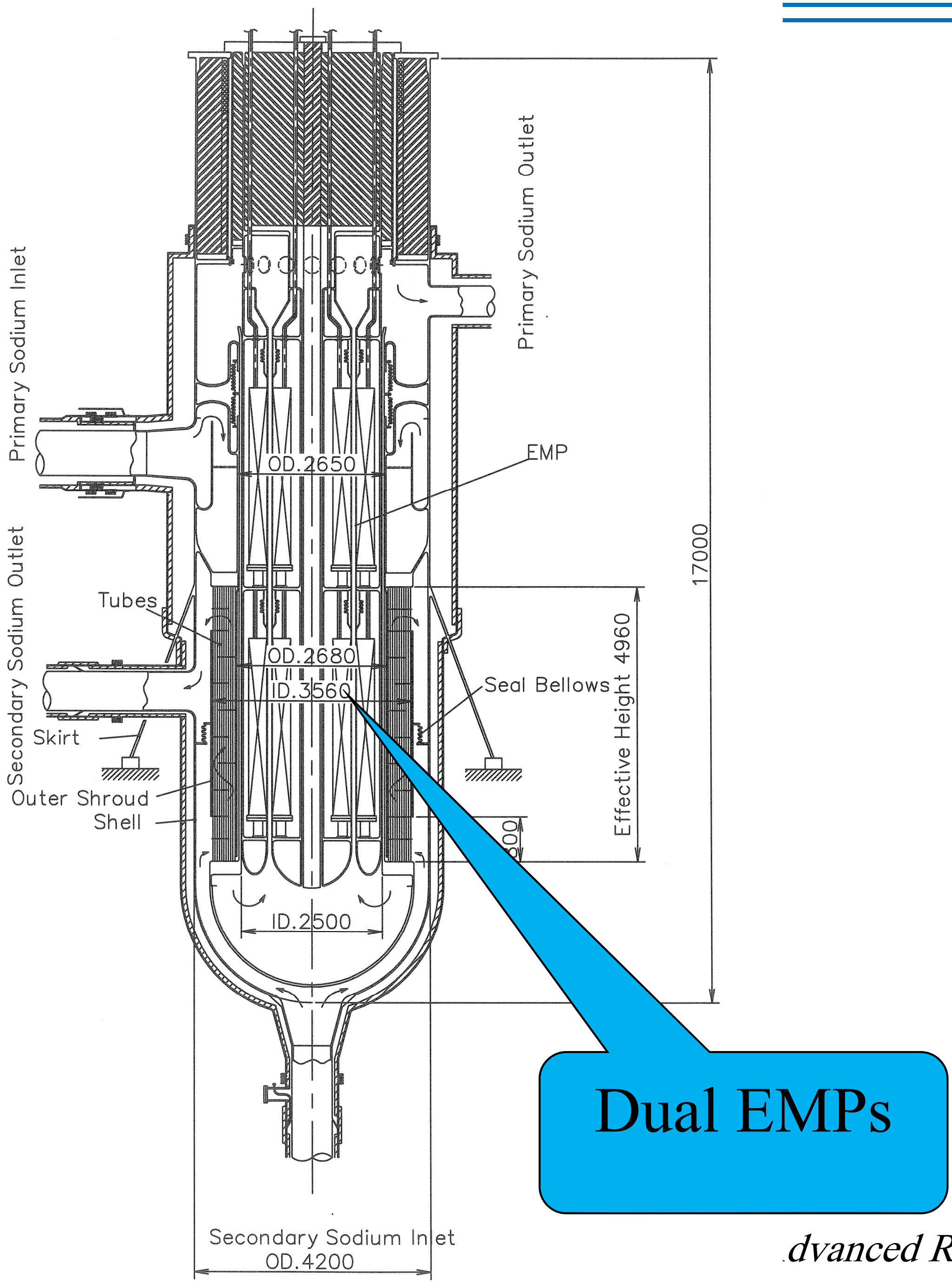
Annular Linear Induction Pump Experience

1m^3/min: A. Oto. et al, Nucl. Tech. Vol. 110, p159, (1995)
44m^3/min: W. Kwant et al., ICONE-5, No. 2553, (1997)
160m^3/min H. Ota, et al, J. of Nucl. Sci. and Tech., vol. 41, No. 4, p511-523, (2004)

Operation: 2550h
Efficiency: 40%

4RD

IHX with Internal EMP



Internal EMP

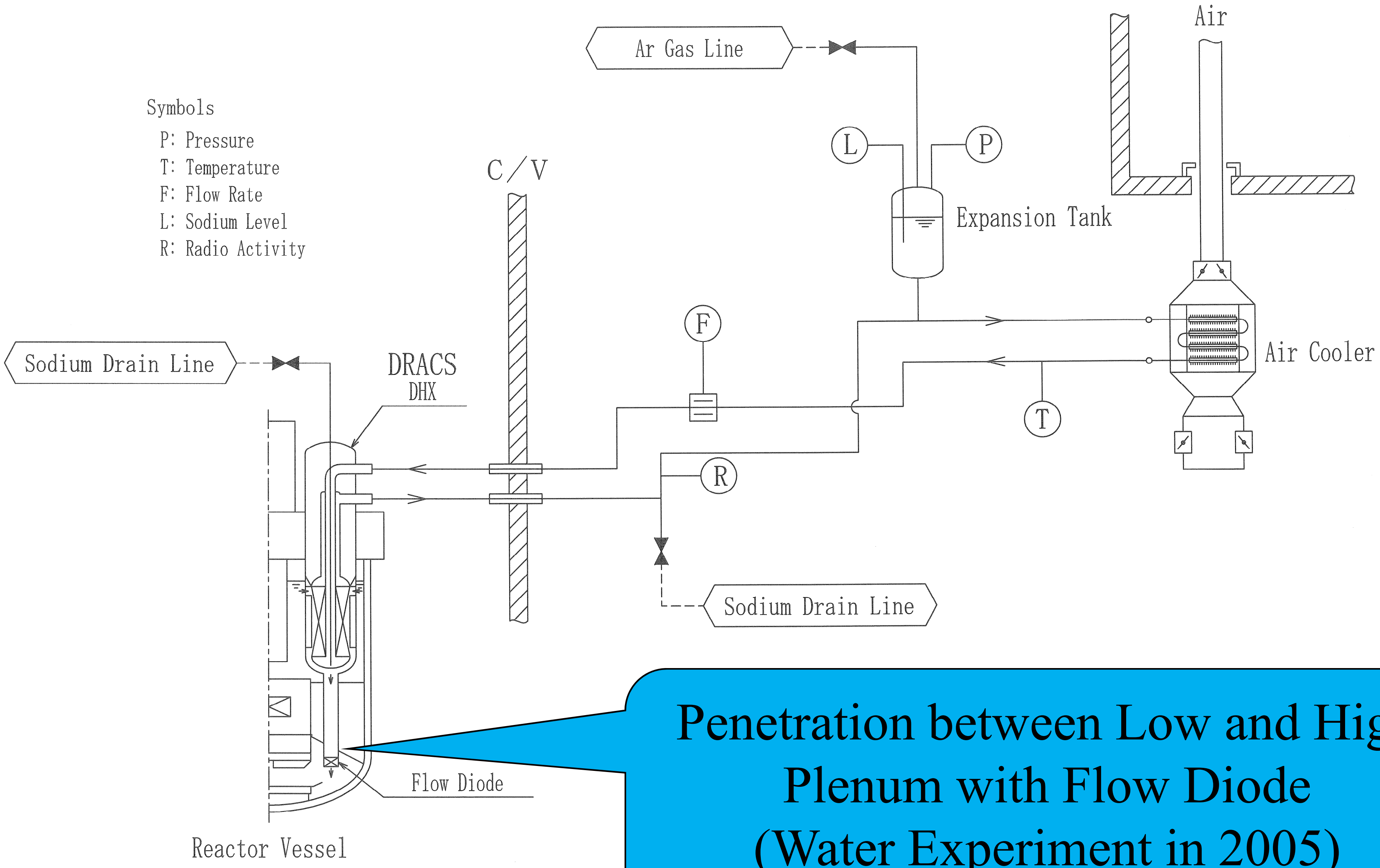
Items	Value
Temperature	395deg-C
Flow Rate	255m^3/min
Pump Head	0.4MPa

IHX

Items	Value
Capacity	714MW
Tube Outer Diameter	25.4mm
Tube Thickness	1.1mm
Tube Length	5m
Tube Quantity	4412
Tube Arrangement	Triangle
Tube Pitch	32mm
Heat Transfer Area	1700m^2
Material	12Cr

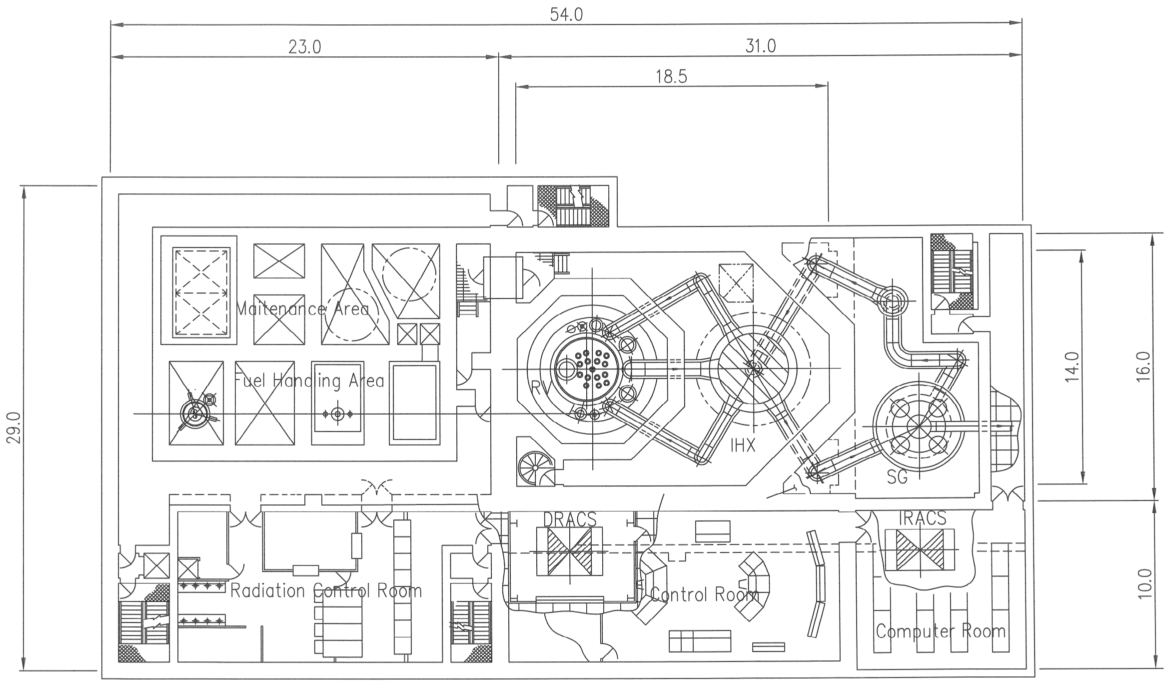
Decay Heat Removal System

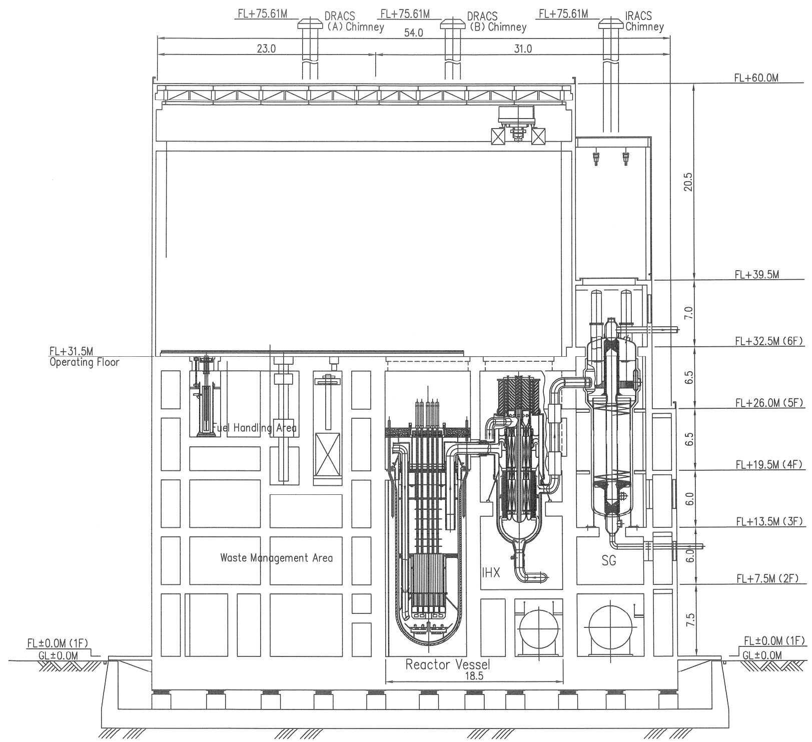
Two DRACS and one IRACS with Natural Convection



Penetration between Low and High Plenum with Flow Diode
(Water Experiment in 2005)

Layout





Total Volume **65,100m^3** for 300MW-electric
(Reactor Building of MONJU **207,000m^3** for 280MW-electric)

Construction Cost Estimation

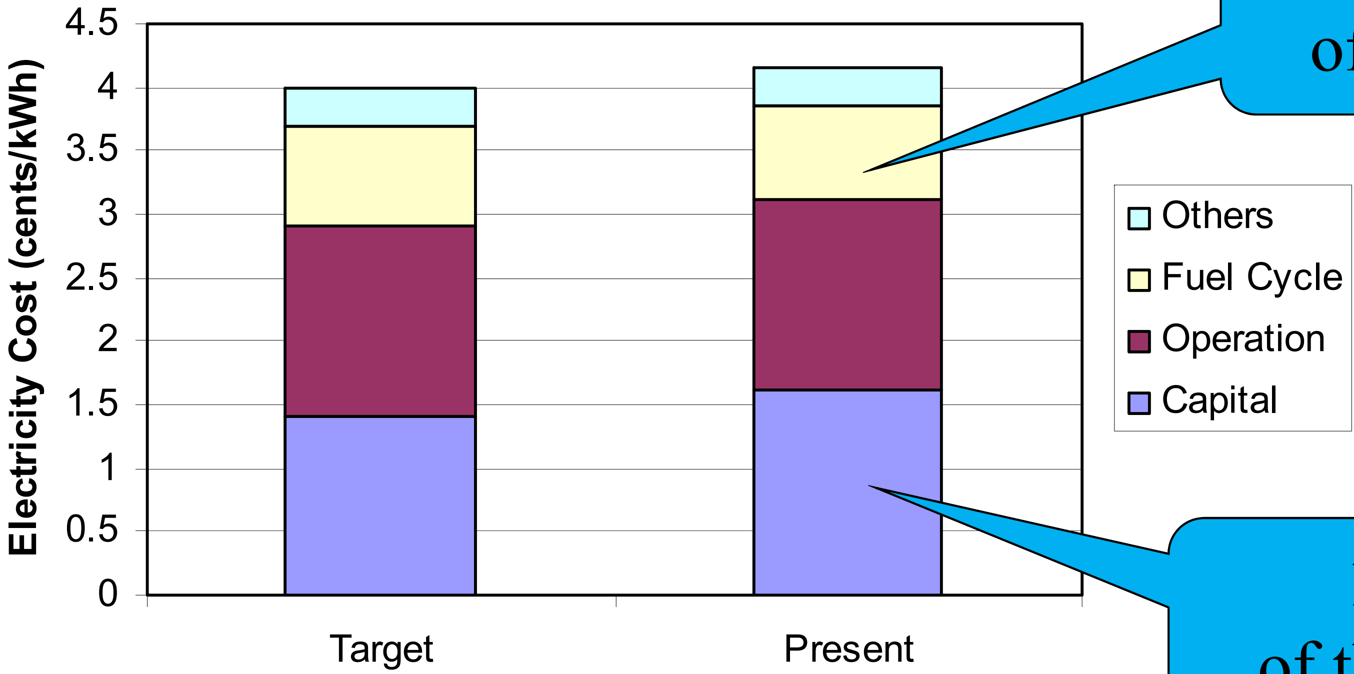
Item	Mass (ton)
Reactor Structure	107
IHX	125
Primary Circuit Pump	122
Primary Circuit Piping	72
SG	276
Secondary Circuit Pump	330
Total	1037

*Except EMP stator 154tonne

FOAK → 190% of Target (2,000$/kW, 1USD=100JPY)

NOAK → 115%

Economic Competitiveness



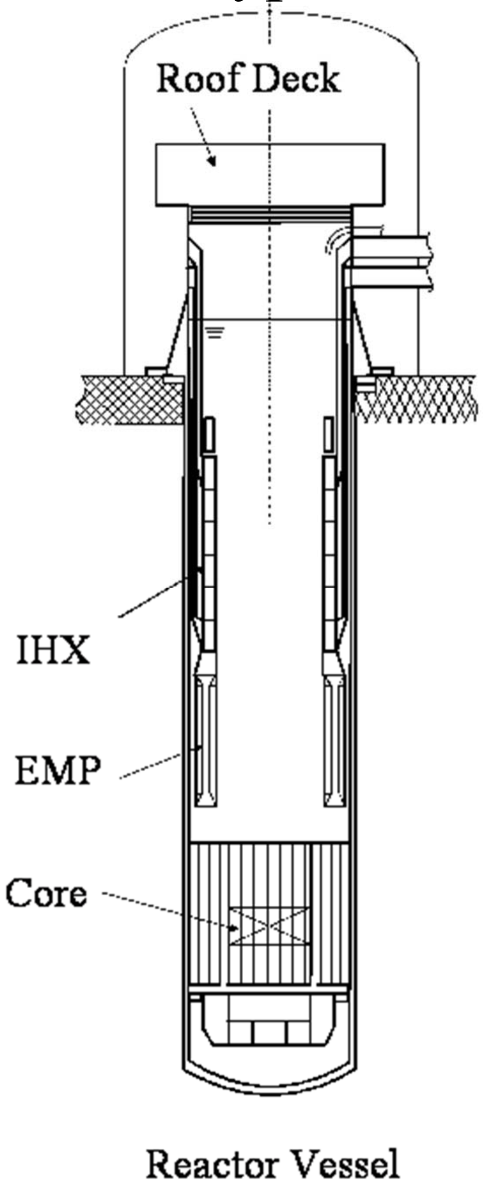
94%
of the target

115%
of the target

Target for Large Scale Reactor in Future Japan 4cents/kWh

300MWe SFR-SMR has a potential for economic competitiveness versus large scale plant.

JNC Tank Type SMFR



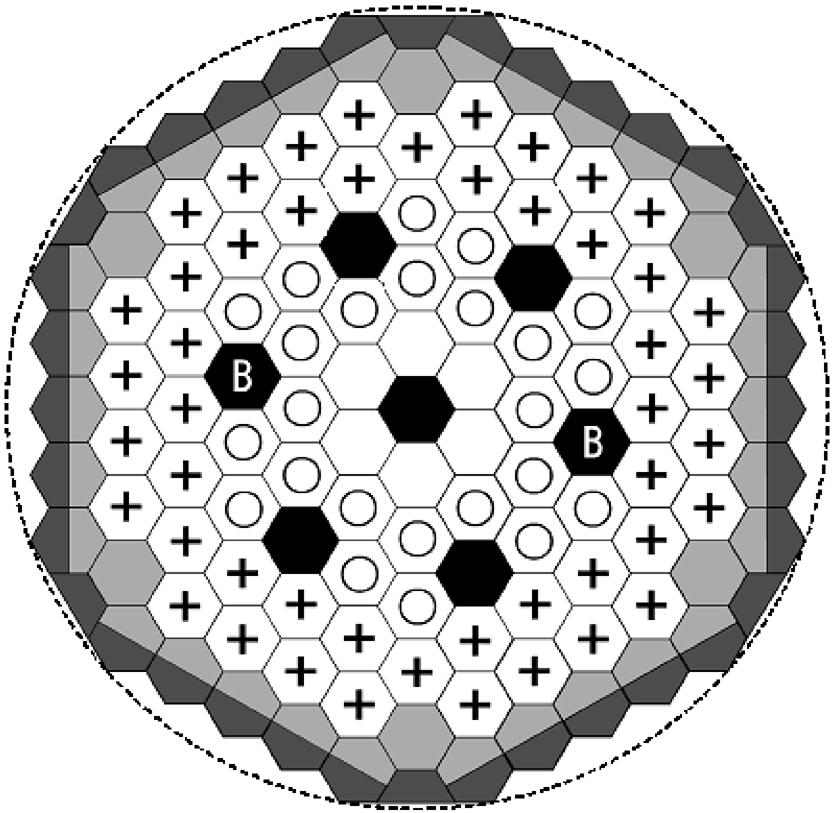
-JNC has studied about small sodium cooled Reactors since FY2001.

Design Condition in the present study

-Electric power 50MW
-Core life time 30y
-Without Refueling

Simple Compact Reactor Vessel

Core design



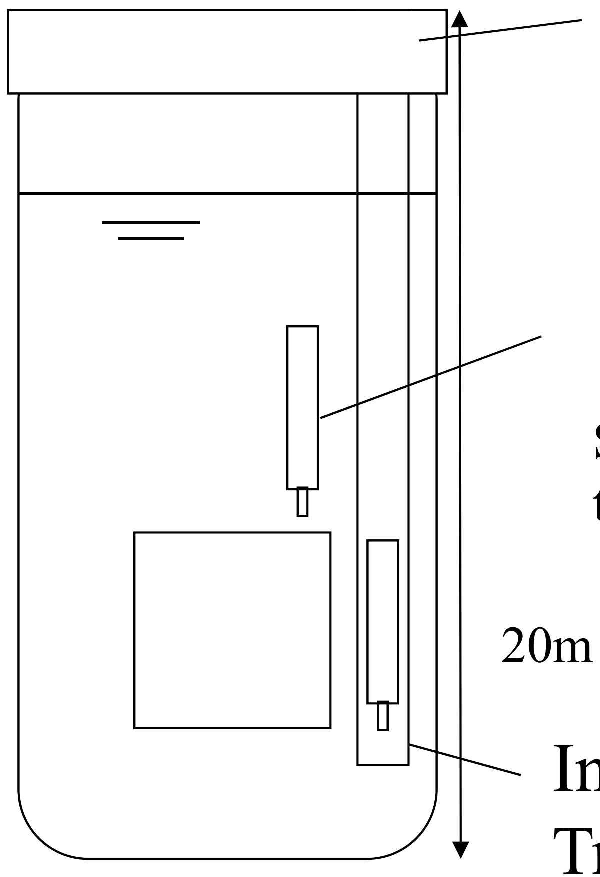
- Thermal output: 120MWt
- Electric output: 50MWe
- Fuel type : U-Pu-Zr ternary metal
- **Outlet temperature : 550°C**
- **Core life time : 30年**
- **Burnup reactivity : 1.2%Δk/kk'**
- Core height : 1.18m
- Core equivalent diameter : 1.82m
- Average discharge burnup : 74GW/dt

	Inner	Middle	Outer
Zr content	10%	10%	6%
Smear density	70%	79%	85%

Simplified Compact Reactor Vessel

Ordinary Loop Type

Rotaiting Plug

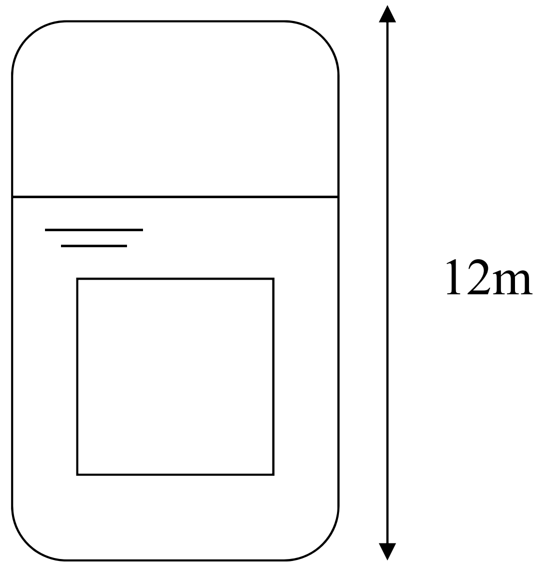


Subassembly in fuel handling

Sodium level is given by the requirement in fuel handling

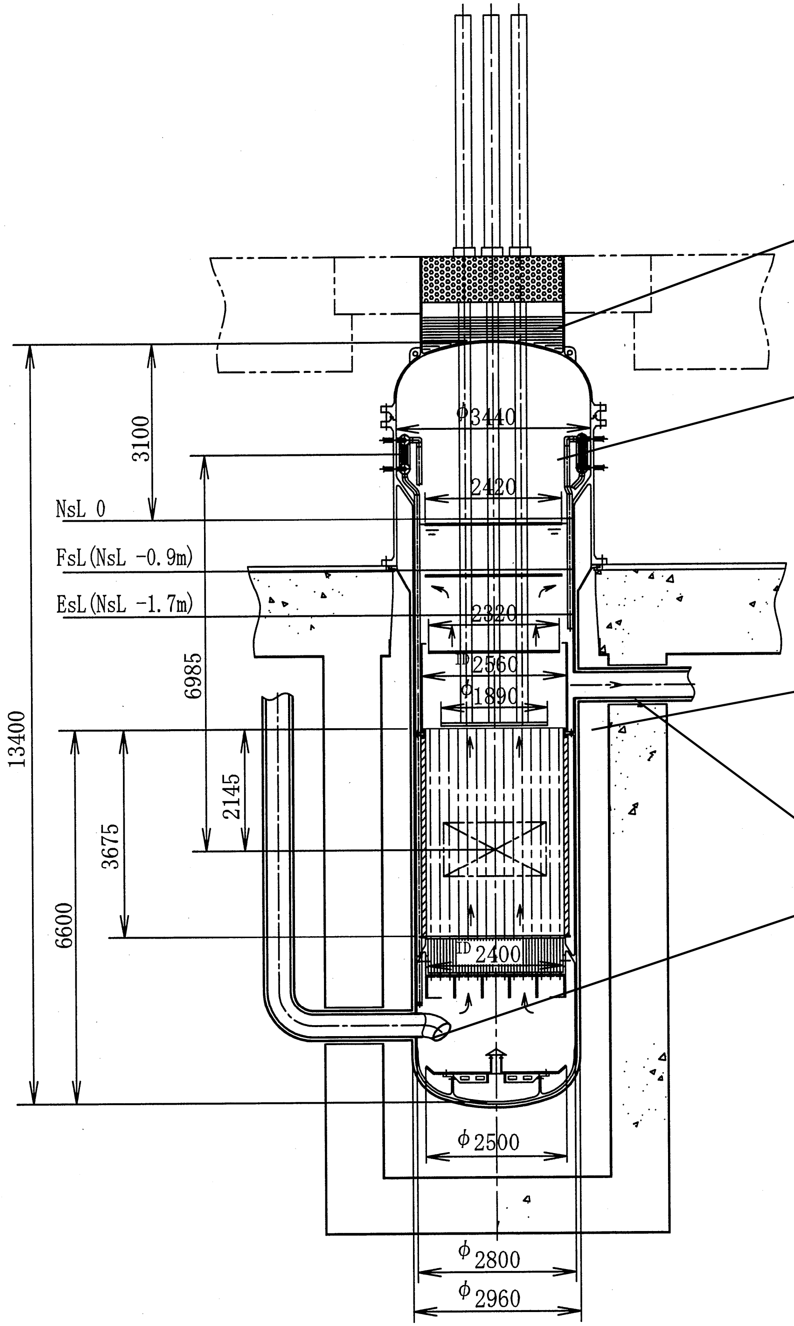
In-vessel Fuel Transfer Machine

Loop Type Without Refueling



- -Sodium level is restricted only in operating condition
- -Rotating plug and in-vessel Fuel Transfer Machine can be removed

Reactor Vessel



Simplified upper structure without rotating plug

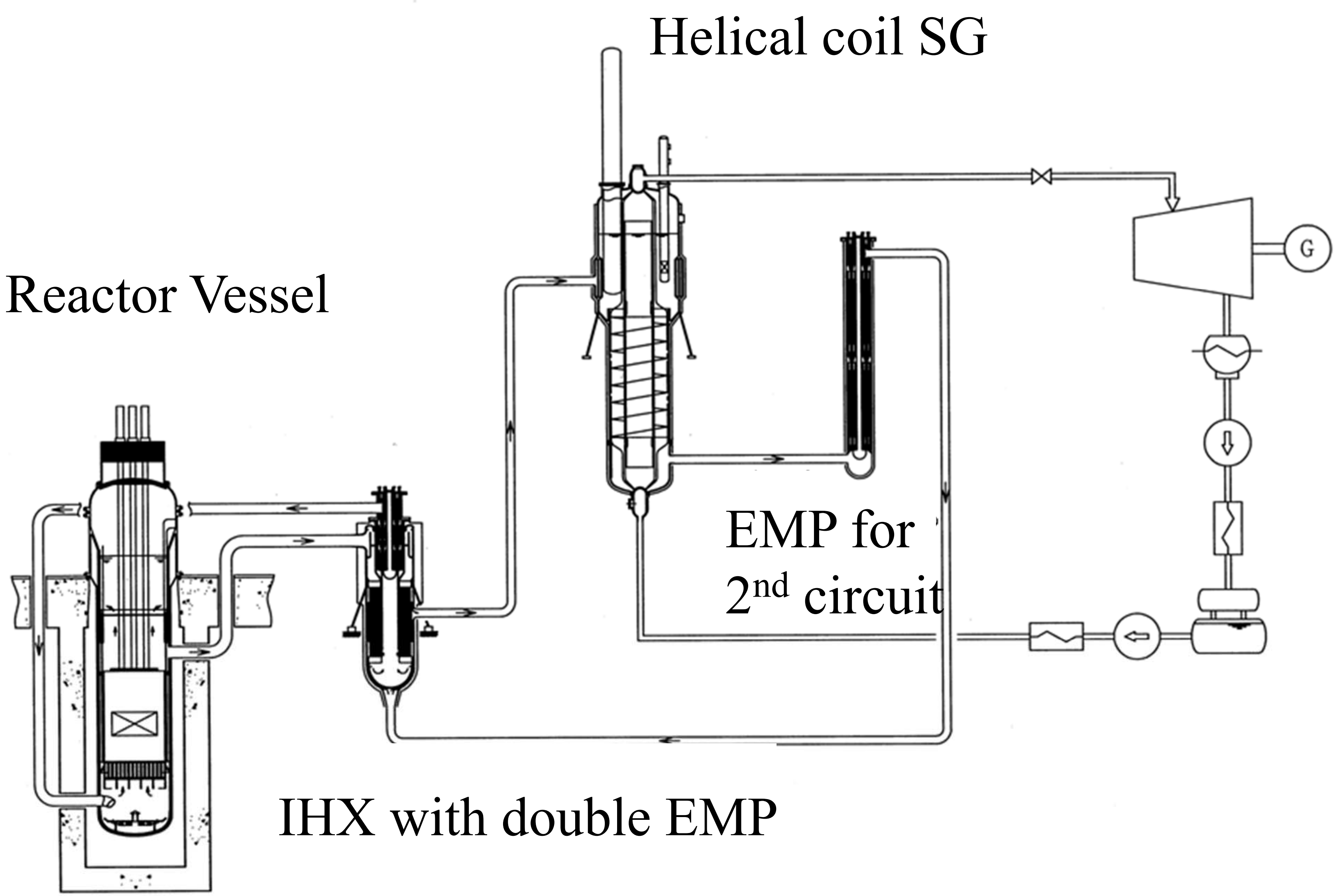
DHX at cover gas (reduction of RV height)

Direct subassembly support by RV (removing core barrel)

Piping with nozzles (reduction of RV diameter)

Diameter 2.8m
Height 13.4m

Total system (1 loop)



Mass Evaluation

Item	Previous Pool type design	Loop design
RV	70	38.5
In-vessel Structures	65	28
Roof Deck	40	18
GV	40	20.5
IHX	90	41.5
Primary Circuit Pump	40	13
Primary Circuit Piping	0	10
SG	90	97
Secondary Circuit Pump	35	35
Secondary Circuit Pump	7	7.1
Total	477	308.6

(ton)

Simplified Loop type design has a advantage in construction cost.

Present Study in JAEA

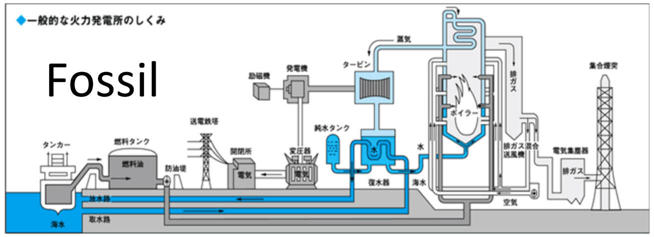
Innovative Energy System around 2050 and beyond

Innovation objectives:

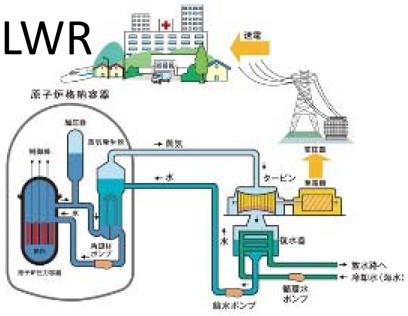
- Co-existence with renewable energy
- 80% CO_2 reduction in 2050

Current

https://www.fepc.or.jp/index.html



LWR



RE

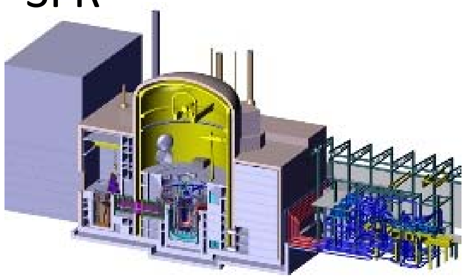
https://www.enecho.meti.go.jp/

Innovative energy system

HTGR

- ✓ No fossil fuel use
- ✓ LWR→SFR/HTGR
- ✓ Load following to VRE

SFR



RE

JAEA`s Nuclear Innovation Goals

- Set vision goals
- Evaluate R&D needs
- Implement R&D activities

1) **Significant cost reduction**
   - ✓ Reduce manufacturing cost
   - ✓ Raise fuel performance w/ extended burnup
   - ✓ Raising thermal efficiency to 50-60%
   - ✓ Standardization and non-nuclearization

2) **Fuel cycle synergy**
   - ✓ SFR＋HTGR closed fuel cycle - reduce or eliminate U use
   - ✓ Supply sufficient Pu required for zero emission grid
   - ✓ MA burning, etc.

3) **Zero emission grid**
   - ✓ Capability to follow variable renewables while operating reactor at baseload
   - ✓ Capability to produce hydrogen and heat at low demand/price of electricity
   - ✓ Smart grid system integrating requirements of environment, market, safety, maintenance, grid resilience, regulation, etc.

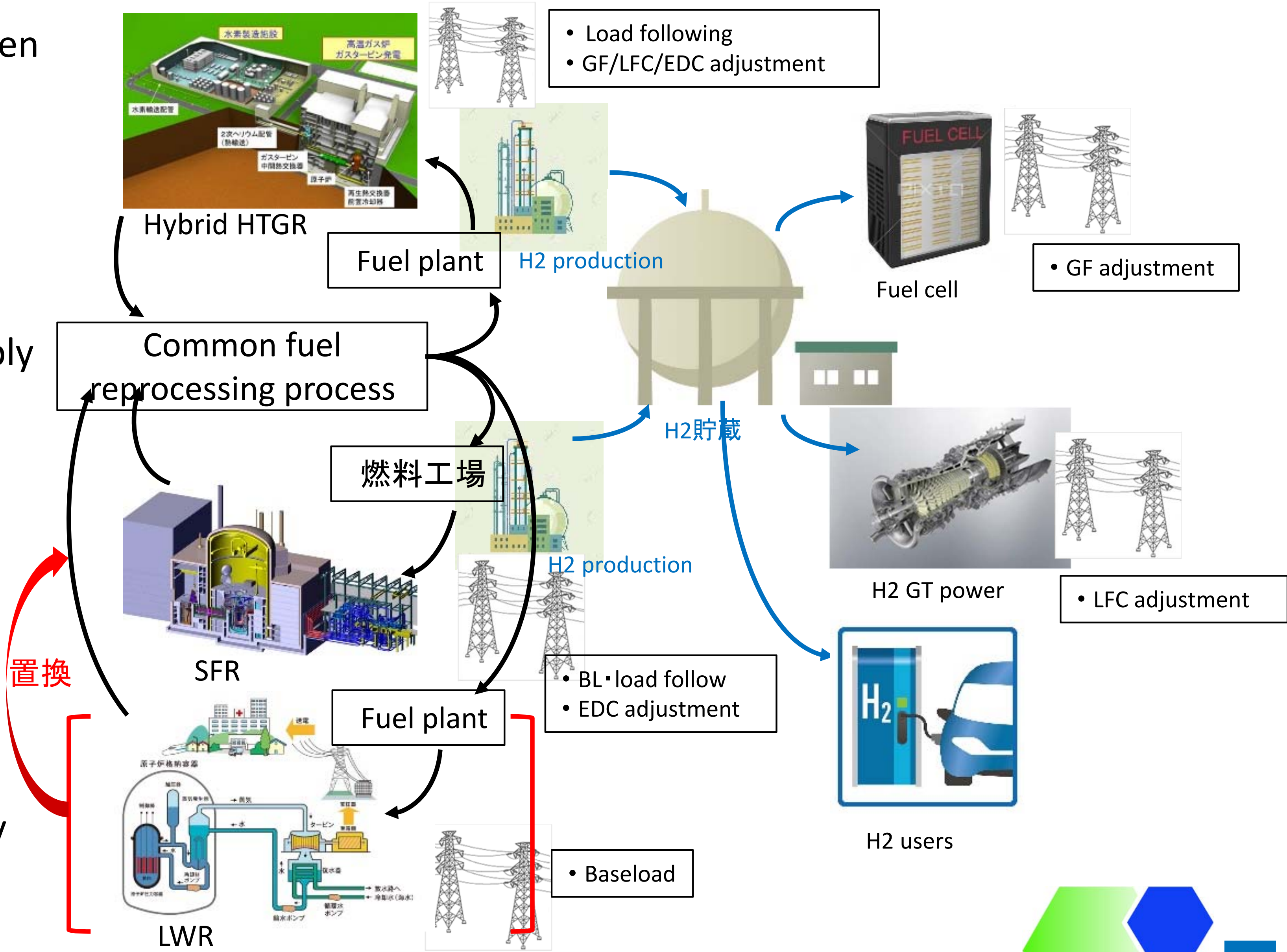
4) **Significant nuclear safety improvement**
   - ✓ Order of magnitude reduction or elimination of risk of core melt, radioactive material release, combustion chemicals

Innovative Nuclear System for Grid

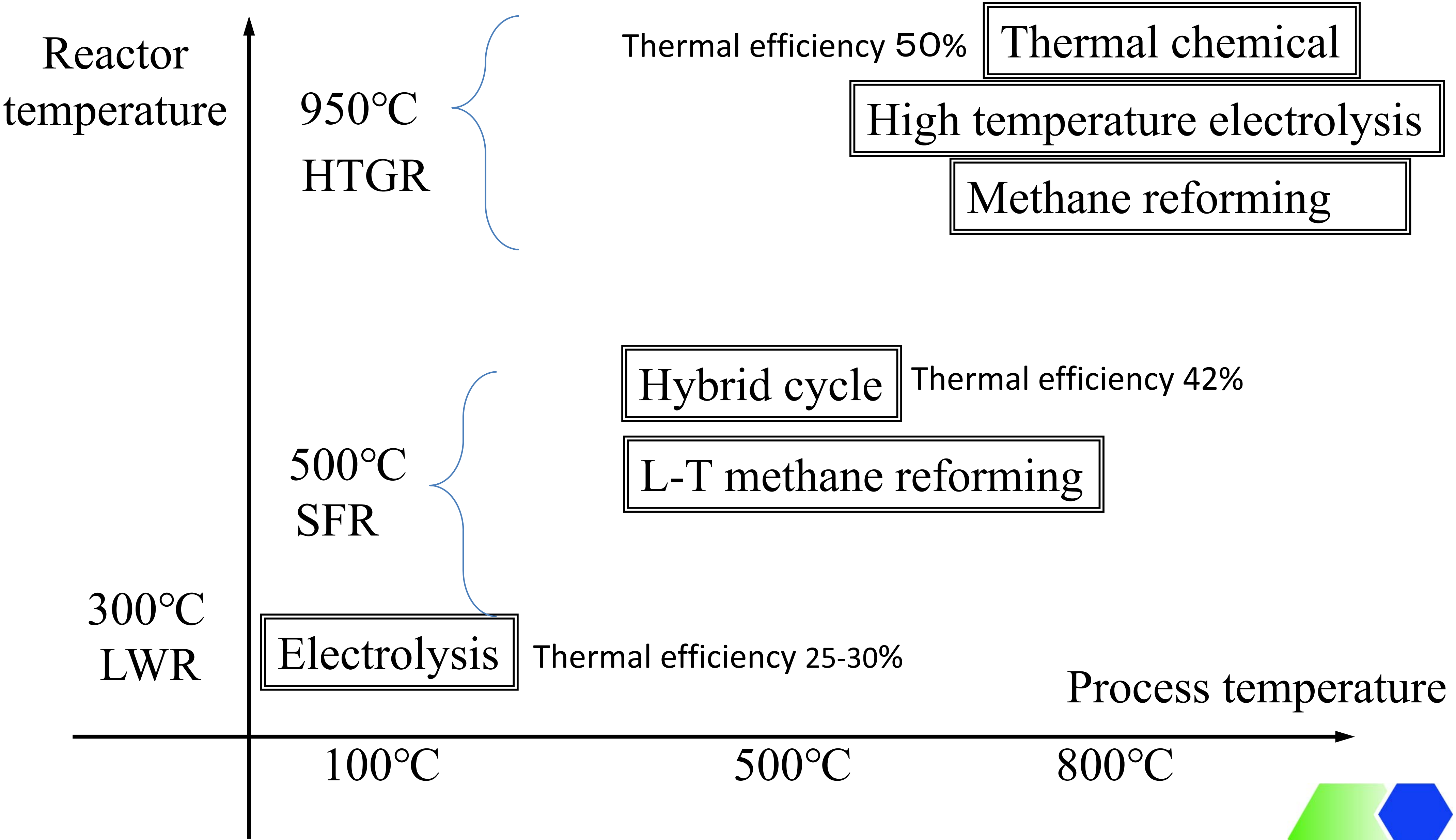
HTGR roles :
- Process heat and hydrogen supply
- Load following
- GF/LFC/EDC power adjustment

SFR roles :
- Pu burning and fuel supply
- Pu cleanup
- MA burning
- Hydrogen production for electricity storage
- BL and load follow
- EDC power adjustment

LWR role :
- Baseload (BL) electricity

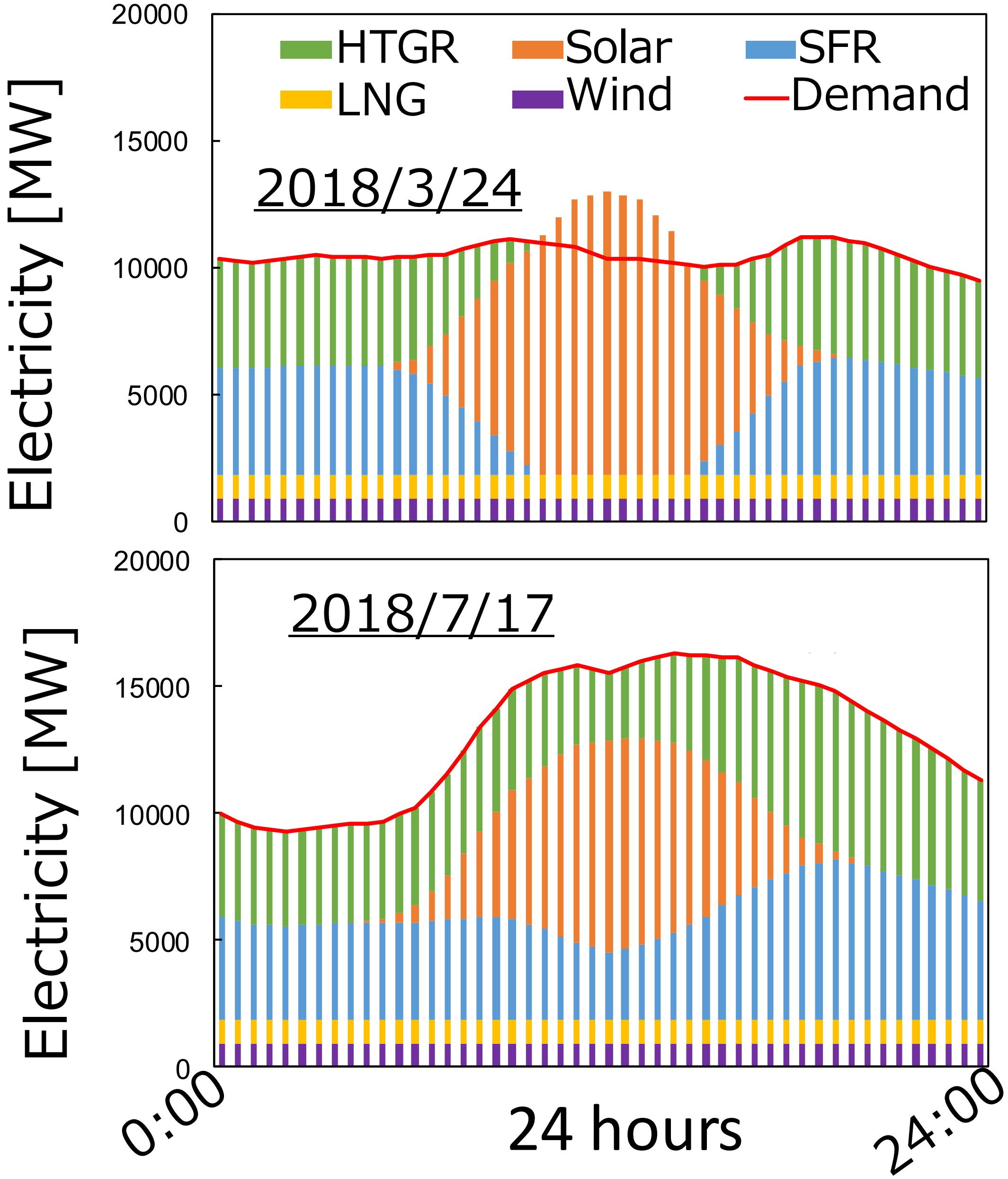


Nuclear production of hydrogen processes



Zero-emission energy by RE+NU

Japan 9 regional utilities' average in 2018



Sector

会, 2019年6月.
ー水素の経済性とCO2排出量 Vol.2, 平成30年2月.

SeFARD

Why SMR?

- Flexible introduction
  - SFR: Pu management flexibility (Pu burning/breeding, and Pu cleanup from LWRs)
  - HTGR: Flexibility of co-existence with renewable energy
  - SMR: Lower investment cost and lower R&D risks
- Safety enhancement
  - SFR: Lower void coefficient for Pu management core
  - HTGR: High passive safety ability with large heat capacity of the core
- Requirement from the society
  - Hydrogen energy…etc.