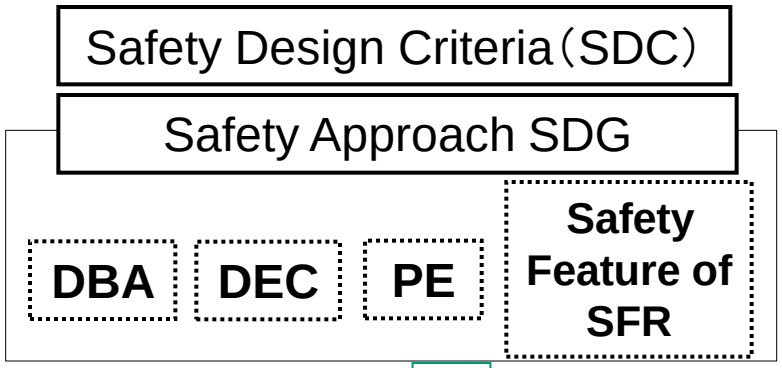
Status of SDG development for Structures, Systems and Components (SDG for SSCs)

S. KUBO

GIF SDC Tack Force Member

Application policy for SDG for each system (1/2)



IAEA Safety Design Guideline for LWR（NS-G(*2)）

Refer the structure, terminology, definition, etc.

Further Specification of criteria

SDG for each system (*1)

■NS-G-1.12（2005）:
Design of the Reactor Core for NPP

■NS-G-1.9（2004）:
Design of the Reactor Coolant System and Associated Systems in NPP

■NS-G-1.10（2004）:
Design of Reactor Containment Systems for NPP

☐ Reactor Core

☐ Reactor Coolant System

☐ Reactor Containment System

（*1）Level of technical detail : Equivalent to IAEA NS-G series.

（*2）IAEA guidelines are based on NS-R-1, and do not include “DEC” measures

***DBA: Design Basis Accident, DEC: Design Extension Condition, PE: Practically Eliminated**

Application policy for SDG for each system (2/2)

SDC	Relevant statement in NS-G	Approach for categorization	Category	Example
Criterion ○○	A*	Statements in NS-G can be applied to SDG for each system without modification	A	・Single failure criterion ・Separation of safety systems
Criterion ○○	A	Statements can be applied to SDG for each system with modification for SFR	B	・Decay heat removal function ・Containment function
Criterion ○○	N/A*	No relevant statements in NS-G can be found, the point of SDC should be added.	C	・Na reaction ・Measures for Gen-IV SFR (DEC, PE)

* A: Available, N/A: Not available

⇒Comprehensive incorporation of the criteria in SDC and NS-G to SDG for each system

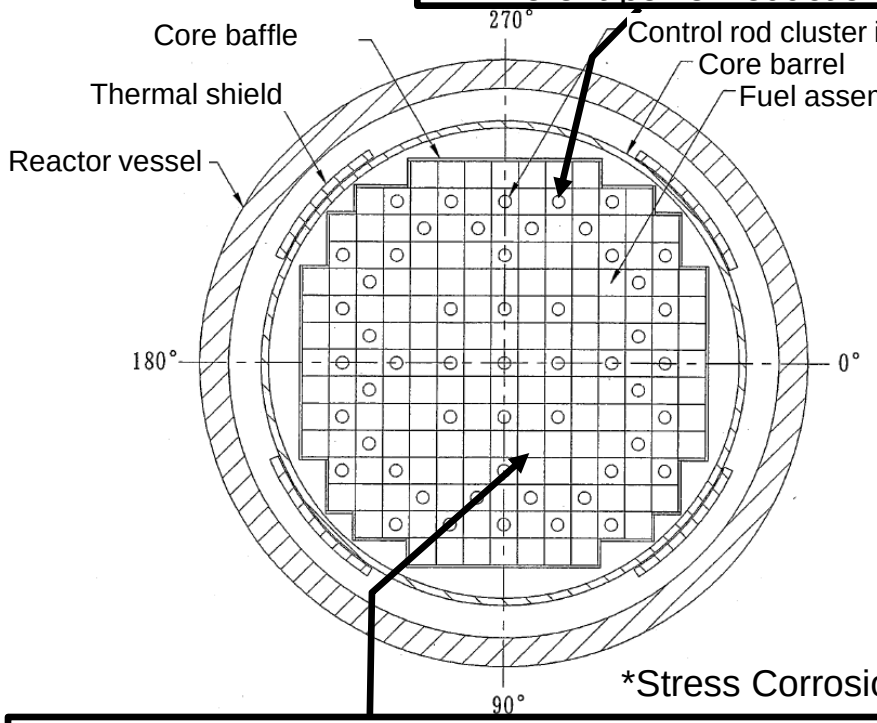
Identification of discussion points for Gen-IV SFR

- Since IAEA NS-G series for LWRs will be used as a basis, discussion points (modification, addition and deletion) of the SDG will be clear by comparing safety features of Gen-IV SFR and LWRs.
- Gen-IV SFR design features to be considered for core, cooling and containment systems are identified in comparison with LWR (PWR) as shown in the following slides.

Discussion points for Gen-IV SFR (Reactor core (1/2))

PWR core structure

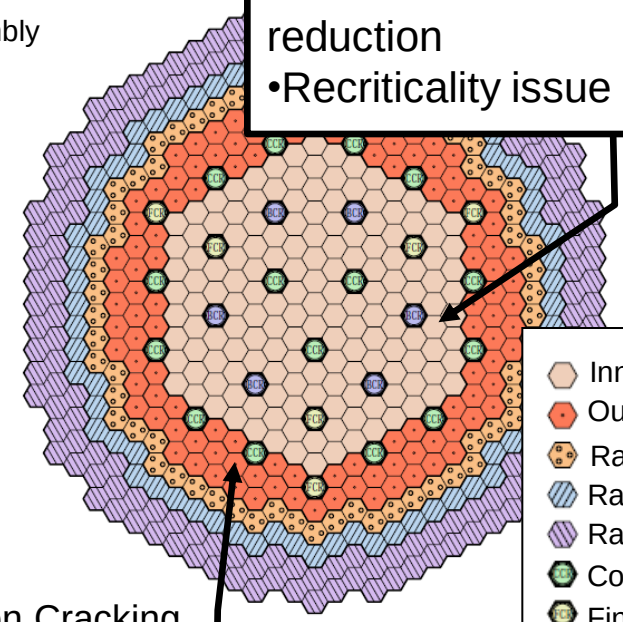
Reactivity control
- One active reactor shutdown
- Boron concentration
- Inherent power reduction



Coolant
- Water chemistry control (SCC* prevention)
- Hydrogen generation due to Zr-water reaction

SFR core structure

Reactivity control
- Two active reactor shutdown systems
- Passive shutdown / Inherent power reduction
- Recriticality issue in core damage



Inner core fuel assembly
Outer core fuel assembly
Radial blanket
Radial shield
Radial shield
Course control rod
Fine control rod
Backup control rod

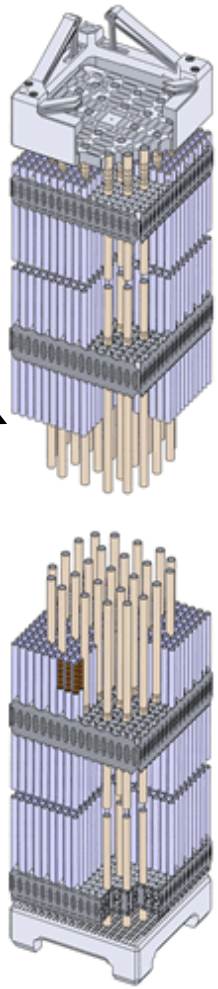
Coolant
- Na radioactivity

*Stress Corrosion Cracking

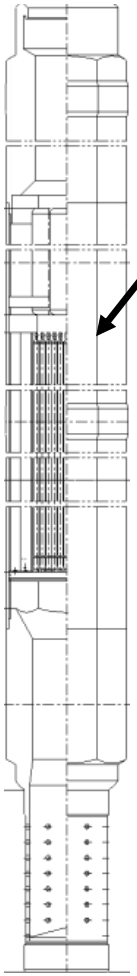
Discussion points for Gen-IV SFR (Reactor core (2/2))

PWR fuel assembly structure

Fuel
- Relatively low temperature and dose environment
- Utilize thermal neutron, low power density



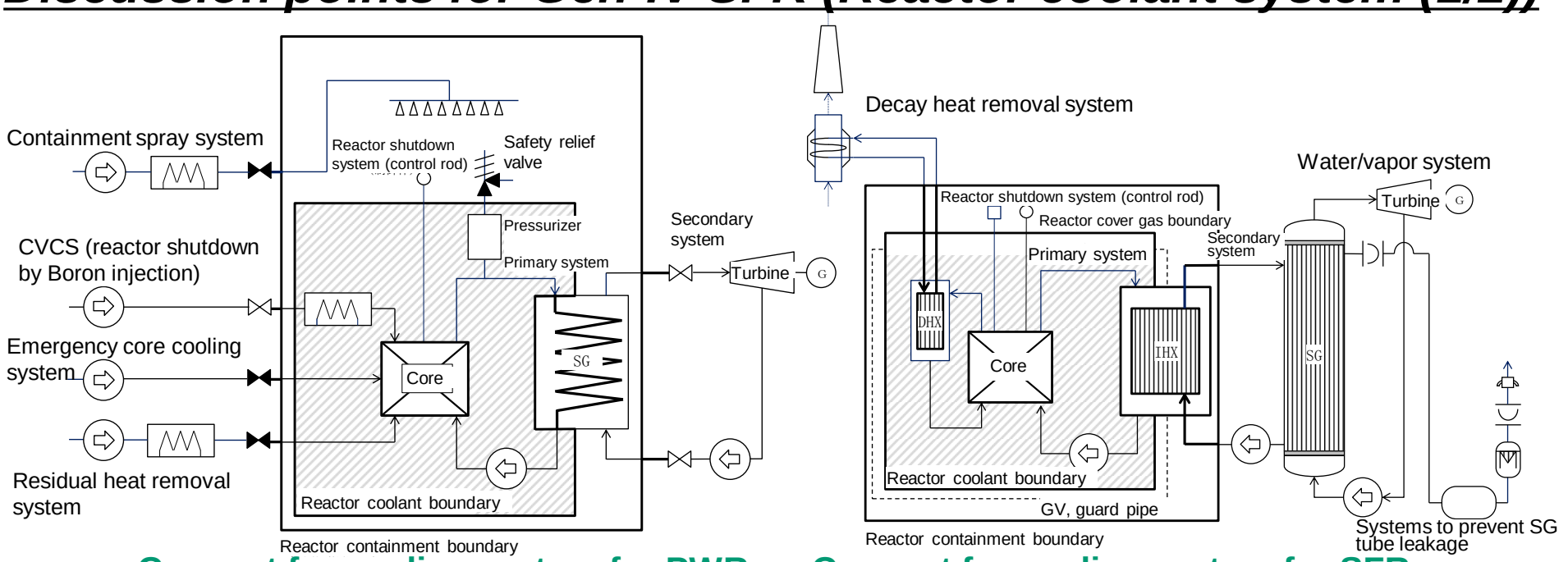
SFR fuel assembly structure



Fuel (Oxide)
- High temperature, high inner pressure, high dose environment
- Utilize fast neutron, high power density
- Tight fuel pin bundle

Core and associated structure
- Fuel handling (Prevention of misloading)
- Failure detection/monitoring

Discussion points for Gen-IV SFR (Reactor coolant system (1/2))



Concept for cooling system for PWR

Concept for cooling system for SFR

	PWR	SFR
Coolant	Water (Chemically stable, transparent, low boiling point)	Na (Chemically active, opaque, activation, high boiling point)
Intermediate loop	Not used	Used (Not to affect to the core in case of Na-water reaction)
Barrier against FP	Reactor coolant boundary	Reactor coolant boundary and reactor cover gas boundary
Decay heat removal	Released to sea water from residual heat removal system through auxiliary cooling system	Released to ambient air through independent Na loop
Coolant leakage	Water injection by emergency core cooling system	Coolant can be maintained by static components, e.g. guard vessels

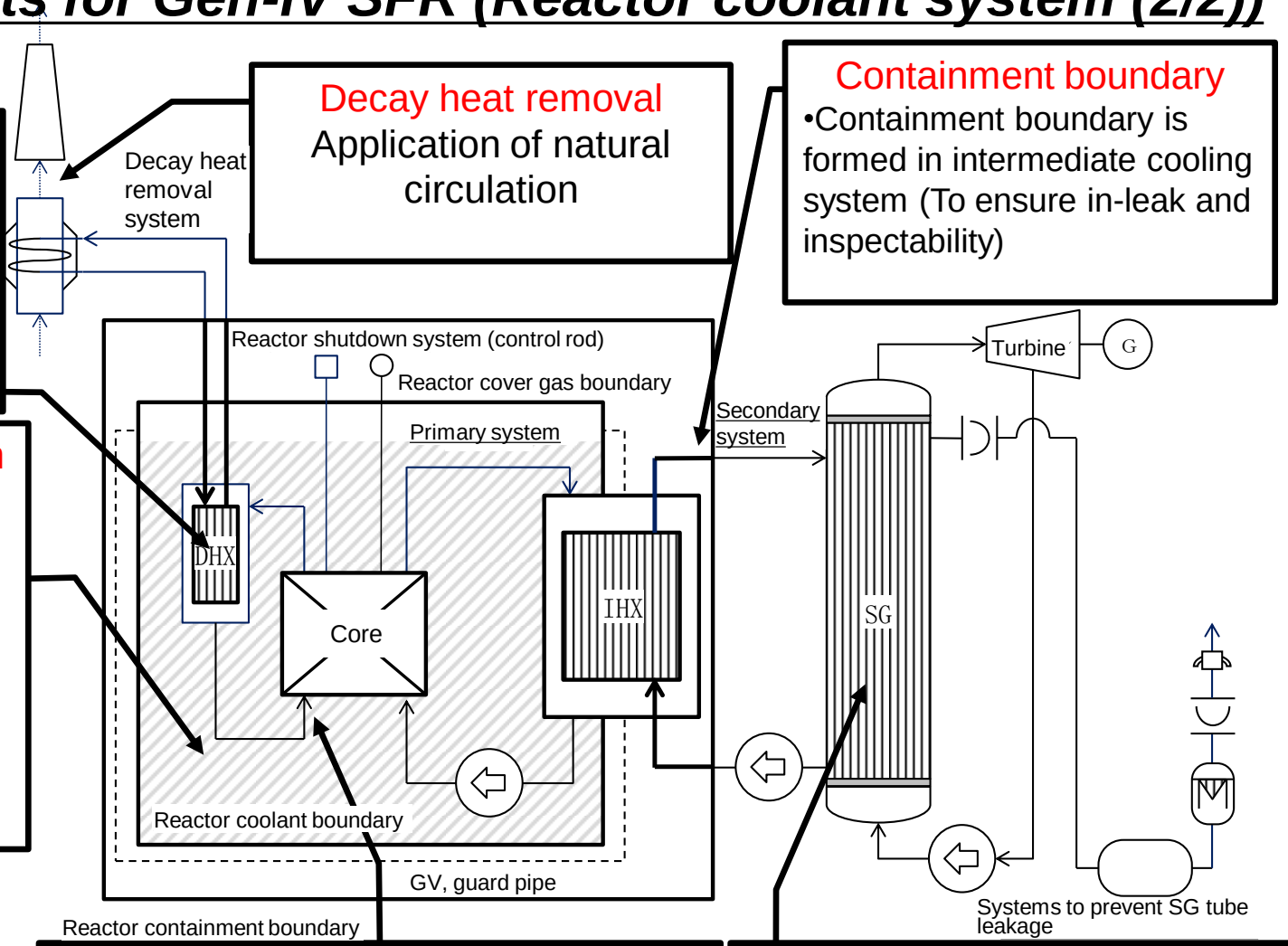
Discussion points for Gen-IV SFR (Reactor coolant system (2/2))

Operational condition
High temperature, low pressure (Stress due to thermal expansion, creep, temperature change)

Decay heat removal
Application of natural circulation

Containment boundary
•Containment boundary is formed in intermediate cooling system (To ensure in-leak and inspectability)

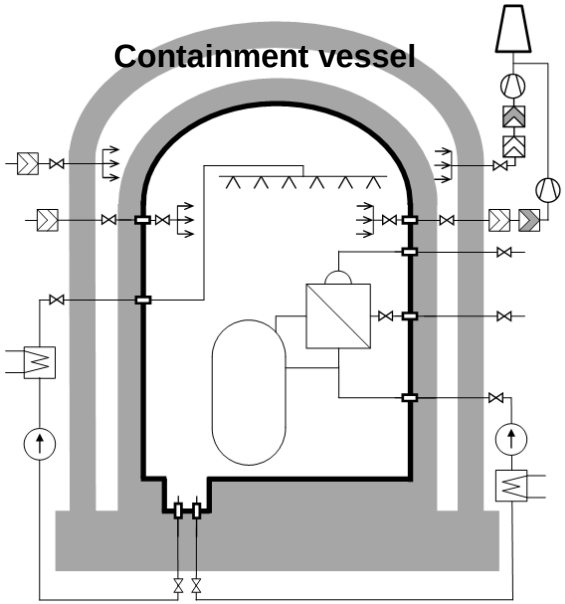
Primary coolant system
•Cover gas boundary
•Coolant level maintenance under normal operation
•Coolant level maintenance by GV (& guard pipes)



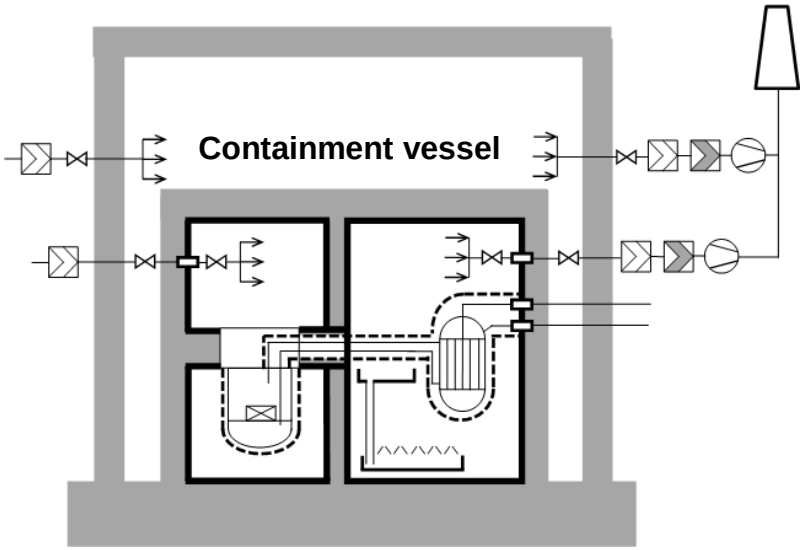
Coolant
•Characteristics of Na (High boiling point, risk of freezing, etc.)
•Na leakage prevention and detection

Chemical reaction
Na-water reaction countermeasure (Detection, blow, pressure release, reaction products treatment, etc.)

Discussion points for Gen-IV SFR (Containment system)



Concept for containment system for PWR



Concept for containment system for SFR

	PWR	SFR
Load factors	Pressure and temperature generated by energy from coolant which is released into the containment due to LOCA.	Na leakage and combustion are major load factors for containment (Mitigation of thermal effects is more important than pressure tightness.)
Counter-measures	・ Steel CV or PCCV with pressure tightness ・ Systems to reduce temperature and pressure such as containment spray system and residual heat removal system	・ Containment vessel (relatively lower P than LWR). ・ Facilities to prevent Na leakage (Guard pipes/vessel) ・ Facilities to prevent combustion (e.g. Inert gas cell) ・ Facilities to mitigate thermal loads (e.g. Catch-pan, heat insulator)

Table of contents for Reactor Coolant System (Tentative)(1/3)

1. INTRODUCTION
(1) Background
(2) Objective
(3) Scope
(4) Structure
2. EXTENT OF THE REACTOR COOLANT STSTEM
(1) Reactor coolant system
(2) Connected systems
(3) Associated systems
(4) Ultimate heat sink
3. GENERAL CONSIDERATIONS IN DESIGN
(1) Objectives of the design
(2) Safety systems
(3) Safety classification
(4) Design basis
(5) Postulated initiating events (internal events)
(6) Seismic considerations (external events)
(7) Reliability
(8) Selection of materials
(9) Prevention of boundary failure
(10) Measures against sodium leak and combustion
(11) Prevention of sodium freezing
(12) Piping design
(13) Layout considerations
(14) Interface considerations
(15) Consideration of containment function
(16) Considerations of isolation between systems
(17) Instrumentation and control system
(18) Calibration, testing, maintenance, repair, replacement, inspection, and monitoring of items important to safety.
(19) Considerations for multi-unit nuclear power plants

Table of contents for Reactor Coolant System (Tentative)(2/3)

4. SPECIFIC CONSIDERATIONS IN DESIGN
   4.1 Primary coolant system
      (1) System functions
      (2) Integrity of reactor coolant boundary and reactor cover gas boundary
      (3) Ensuring reactor coolant level
      (4) Measures against coolant leak
      (5) Application of natural circulation to remove decay heat
      (6) Protection against radiation exposure
      (7) Purification of coolant
      (8) Component design of primary coolant system
         a. General
         b. Reactor vessel
         c. Reactor vessel internals
         d. Pump
         e. Intermediate heat exchanger
         f. Guard vessel

4.2 Secondary coolant system
   (1) System functions
   (2) Sodium-water reaction considerations
   (3) Containment considerations
   (4) Decay heat removal considerations
   (5) Cleanup and purification for the secondary coolant
   (6) Consideration of component design of secondary coolant system

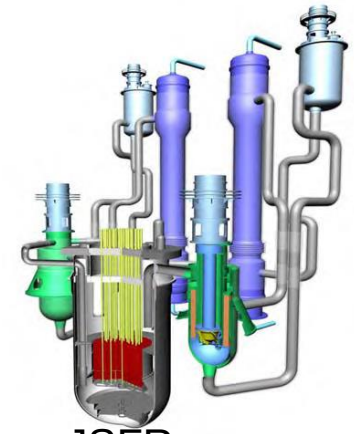
Table of contents for Reactor Coolant System (Tentative)(3/3)

- **4.3 Decay heat removal system**
  - **(1) System functions**
  - **(2) Containment considerations**
  - **(3) System separation considerations**
  - **(4) Reliability considerations**
  - **(5) Redundancy or diversity considerations**
  - **(6) Natural circulation considerations**
  - **(7) Postulated initiating events**
  - **(8) Monitoring considerations**
  - **(9) Accident management considerations**
  - **(10) Load condition considerations**
  - **(11) Functional test considerations**
  - **(12) Component design considerations**
- 4.4 Steam and feed water system
  - (1) System function
  - (2) Breakage prevention considerations
  - **(3) Steam generator tube rupture considerations**

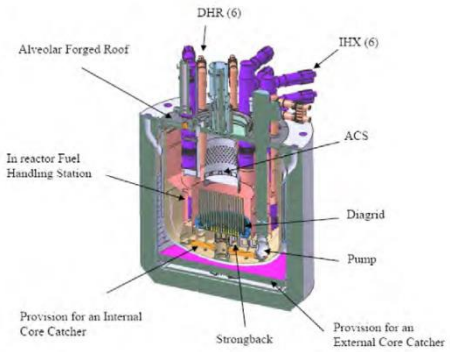
- **4.5 Other energy conversion system**
  - **(1) Fundamental function and consideration on accidents**
- 4.5 Heat transfer to ultimate heat sink
  - (1) System function
  - (2) Considerations for site and environment

SFR Design Options under GIF (1/2)

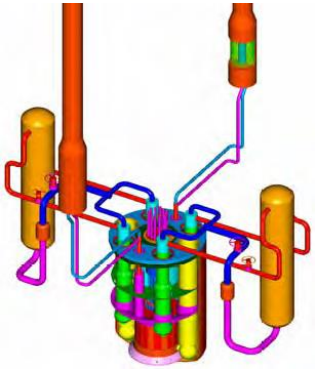
- ***A large size (600 to 1,500 MWe) loop-type reactor with mixed uranium-plutonium oxide fuel and potentially minor actinides, supported by a fuel cycle based upon advanced aqueous processing at a central location serving a number of reactors***
- ***An intermediate-to-large size (300 to 1,500 MWe) pool-type reactor with oxide or metal fuel***
- ***A small size (50 to 150 MWe) modular pool-type reactor with metal alloy fuel, supported by a fuel cycle based on pyrometallurgical processing in facilities integrated with the reactor***



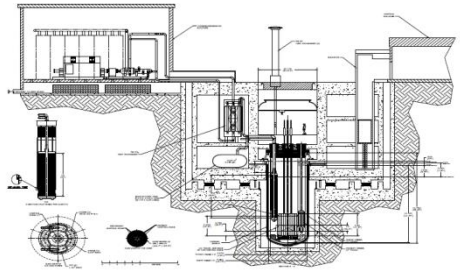
JSFR
[Large Loop]



ESFR
[Large Pool]



KALIMER
[Pool]



SMFR
[Small Modular]

SFR Design Options under GIF (2/2)

Core size	Fuel	Plant type	Reactivity control/ shutdown	Decay heat removal	Containment/ confinement
Small (50-150MWe) **Middle** (300-600MWe) **Large** (600-1500MWe)	**Oxide** **Metal** **Nitride**	**Pool-type** **Loop-type**	**Inherent feed back (Doppler, core expansion etc.)** **Passive mechanism (absorber insertion, gas expansion etc.)**	**DRACS** **PRACS** **IRACS** **RVACS** **SGACS** **….**	**Reactor Building** **Guard vessel + Upper dome** **….**

Concluding Remarks

- ***Key Structures, Systems and Components SDG***
  - ***Reactor Core***
  - ***Reactor Coolant System***
  - ***Reactor Containment System***
- ***IAEA NS-G series are used as reference***
- ***Discussion points are going to be identified based on the SFR characteristics.***
- ***Design specific issues such as small-large, oxide-metal, pool-loop) will be discussed.***

Thank you
for your attention !!