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Safety design requirements for safety systems and components of JSFR

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Contents

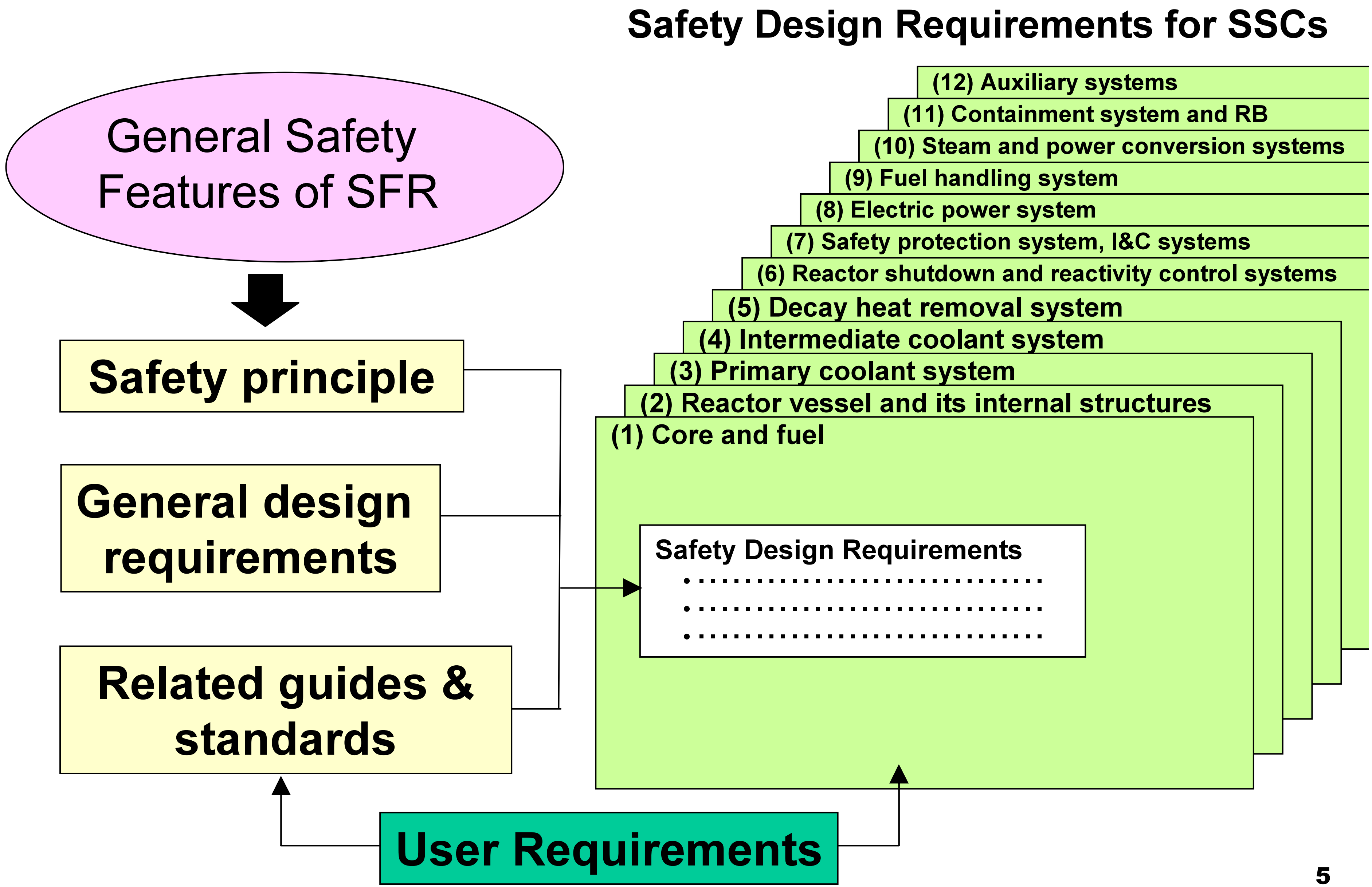
Introduction

- Conceptual design study of JSFR has been conducted in FaCT project since 2006.
- Target of demo plant initial start up is around 2025.
- Safety design requirements were provided for the design study and should be accomplished for preparing future licensing application.
- The safety design requirements should be a global standard.

General Features of Safety Design Requirements

- Structure of the Safety Design Requirements
- Elements of the Safety Design Requirements
- General Features of the contents

General Features of Safety Design Requirements (1/5)



General Features of Safety Design Requirements (2/5)

Safety principle

- ALARA, Defence in depth
- Consideration of BDBEs
- Reactor shutdown, Cooling, Containment
- Specific treatment for sodium chemical characteristics
- Probabilistic safety assessment

Reference

- Development targets of FaCT project
- Goals of GIF
- IAEA principle etc

General design requirements

- General requirements for overall NPP
- General requirements for each SCCs

Reference

- Practices of Monju, LWRs
- Domestic discussions for SFRs
- Foreign practices of CRBRP, PRISM, SPX etc
- IAEA standards

General Features of Safety Design Requirements (3/5)

General Safety Features of SFR

- ***Neutronics***
  - Negative reactivity feed back eases any power transients of DBEs with the help of doppler effect.
  - Not in the most critical configuration. Hypothetical core voiding or fuel compaction might lead to positive reactivity insertion (common feature on fast reactor).

- ***Coolant***
  - High thermal conductivity and high boiling temperature of sodium allow to realize low pressure heat transport system without coolant boiling.
  - Chemical reaction with air or water may cause damage on the safety functions.

General Features of Safety Design Requirements (4/5)

Lessons from the experience

- ***CDA: Core Disruptive Accident***
  - CDA was a crucial safety issue in licensing procedure of CRBRP, SNR-300, Monju and SPX.
  - It is important to show that severe mechanical energy release would not occur even under hypothetical severe plant conditions.

- ***Sodium leak***
  - Although many sodium leaks and sodium-water reactions happened, consequences of most cases were small enough. This fact demonstrates that safety design against sodium leak is correct in the past and present SFRs.
  - It is important to enhance the reliability of sodium related components so that the possibility of sodium leak can be reduced.

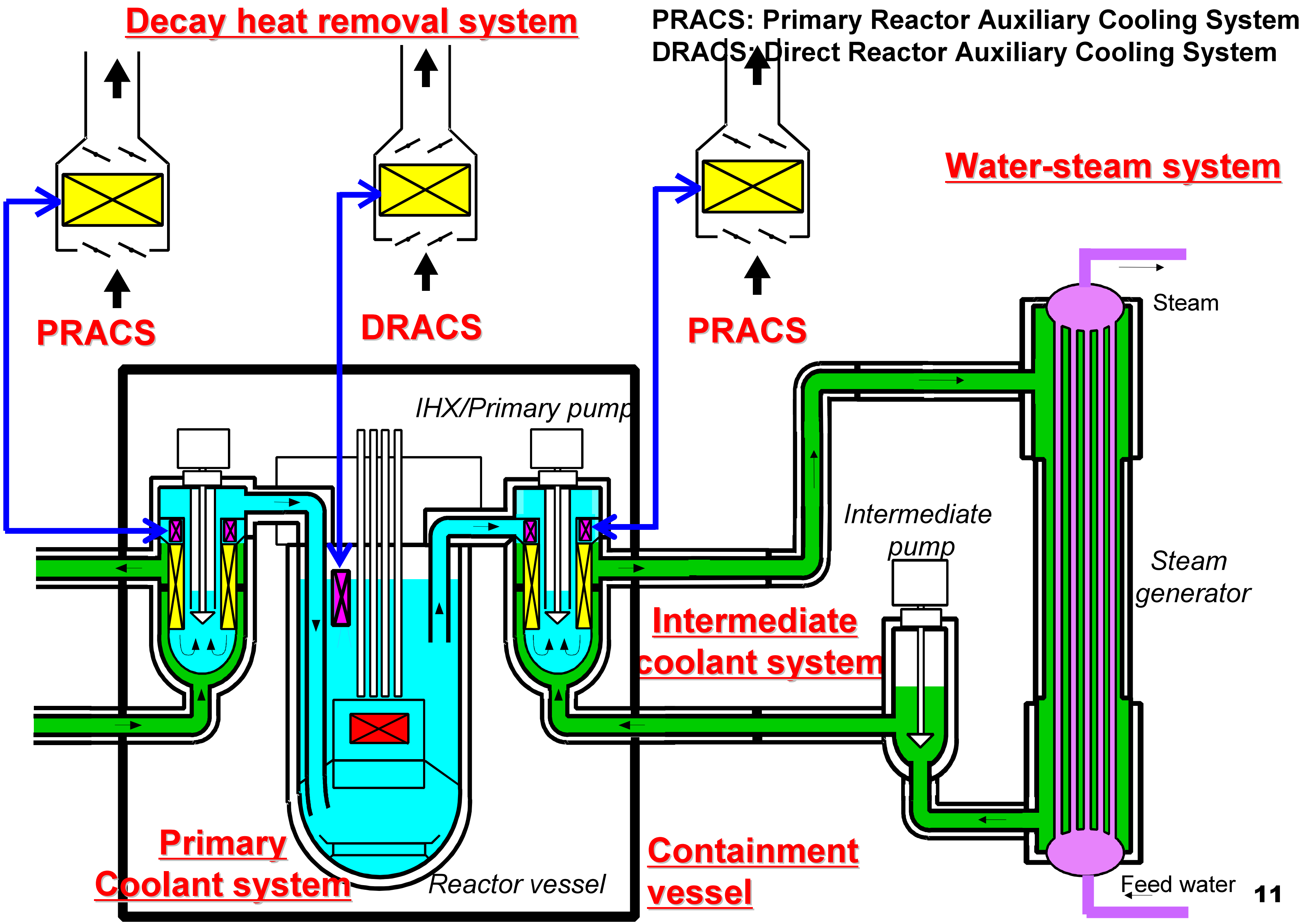
General Features of Safety Design Requirements (5/5)

General Features of Contents

- Achievement of higher reliability
- Achievement of higher inspectability and maintainability
- Introduction of passive safety features
- Reduction of operator action needs
- Design consideration against BDBEs
- In Vessel Retention (IVR) of degraded core materials
- Prevention and mitigation against sodium chemical reactions
- Design against external events

Basic Design Concept of JSFR

Basic Design Concept of JSFR

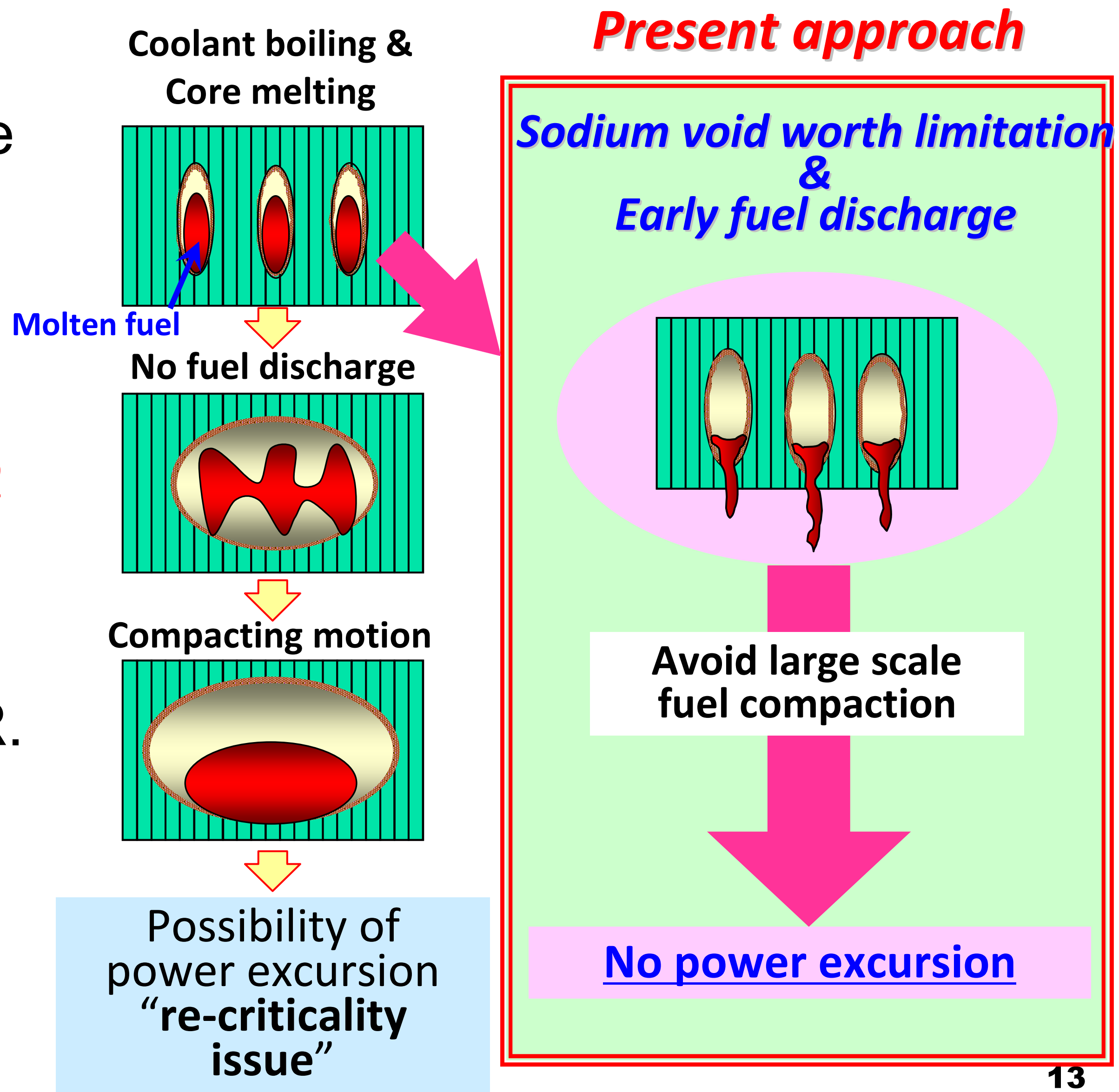


Main features of specific safety design requirements for JSFR

- Reactor core and fuel
- Reactor shutdown system
- Primary and Intermediate coolant system
- Decay heat removal system
- Containment system

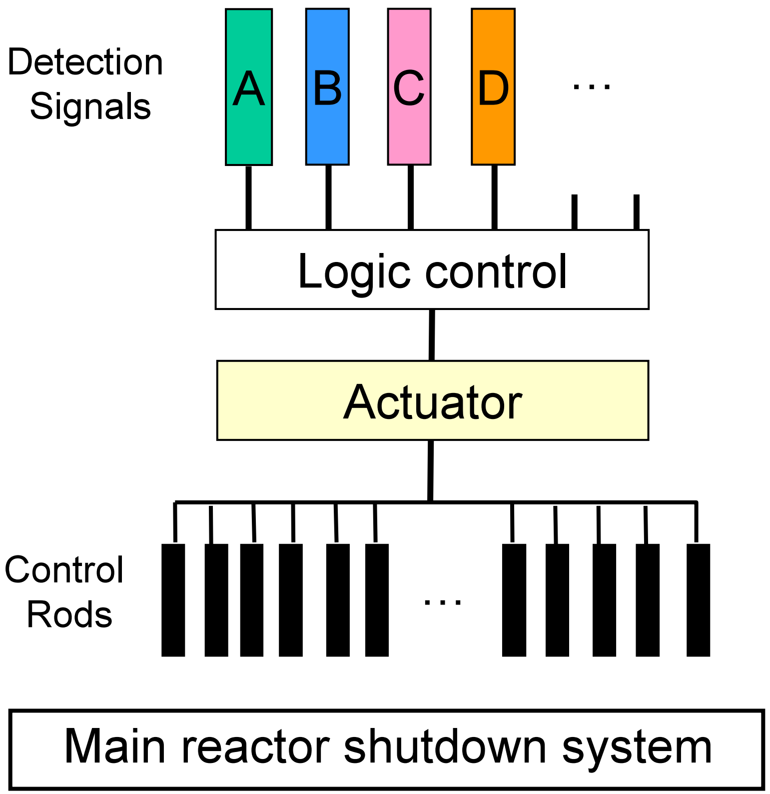
Reactor core and fuel

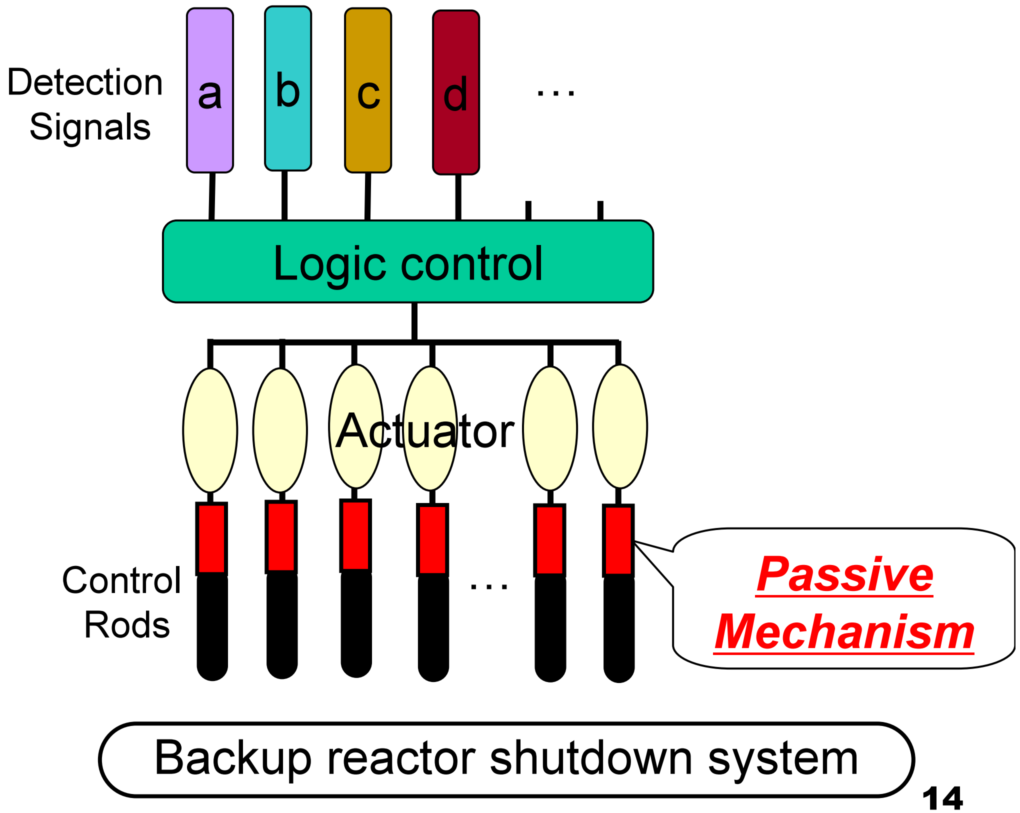
- The core shall be designed to have the negative power reactivity coefficient.
- ***<u>Prevention of severe mechanical energy release due to CDAs</u>*** shall be considered in the core and fuel design so as to achieve IVR. [BDBE]



Reactor shutdown system (RSS)

- ***Two independent active reactor shutdown systems*** shall be installed.
- ***Passive reactor shutdown capability*** shall be provided as a countermeasure against ATWS. [BDBE]





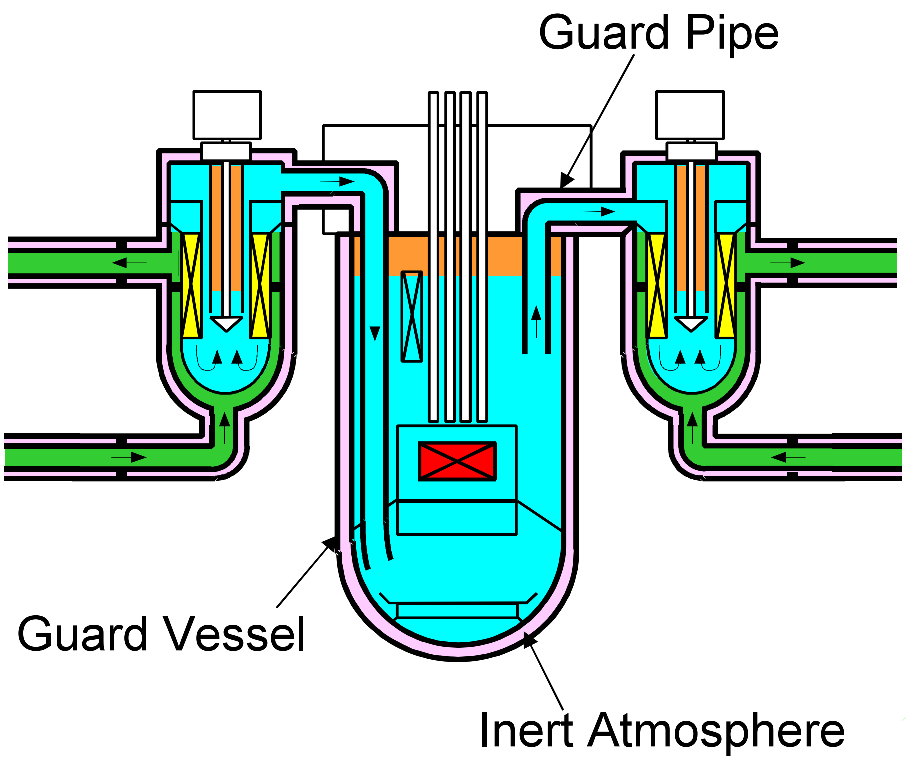
Primary and Intermediate coolant system (1/3)

- ***The double wall concept*** shall be applied as prevention and mitigation against sodium leak for all sodium contained boundaries of the primary coolant system and the intermediate coolant system.

- The design basis leak shall be defined based on an evaluation of ***leak-before-break*** assessment.

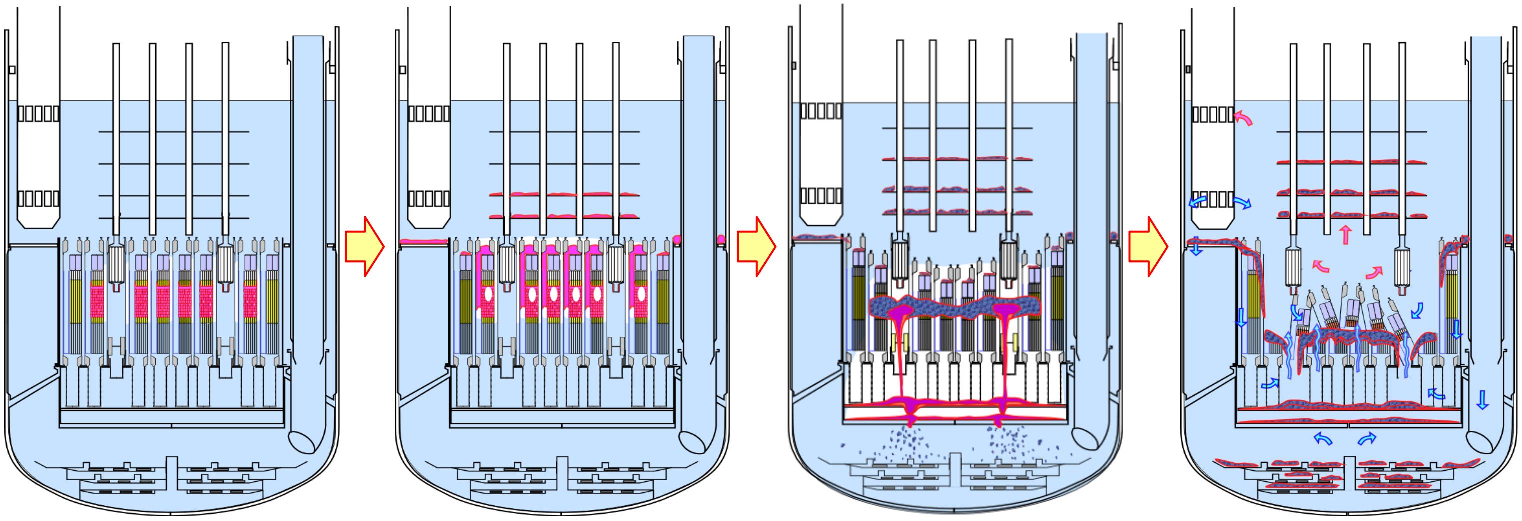
- ***The continuous leak monitoring*** shall be applied as a major inspection method for all the sodium contained boundary.

- The reactor vessel, its internal structures, the primary coolant system shall be designed to provide ***access routes for remote inspection***.



Primary and Intermediate coolant system (2/3)

- ***Mitigation of consequences due to CDAs*** shall be considered in the design of reactor vessel and its internal structures so as to achieve ***IVR***. [BDBE]

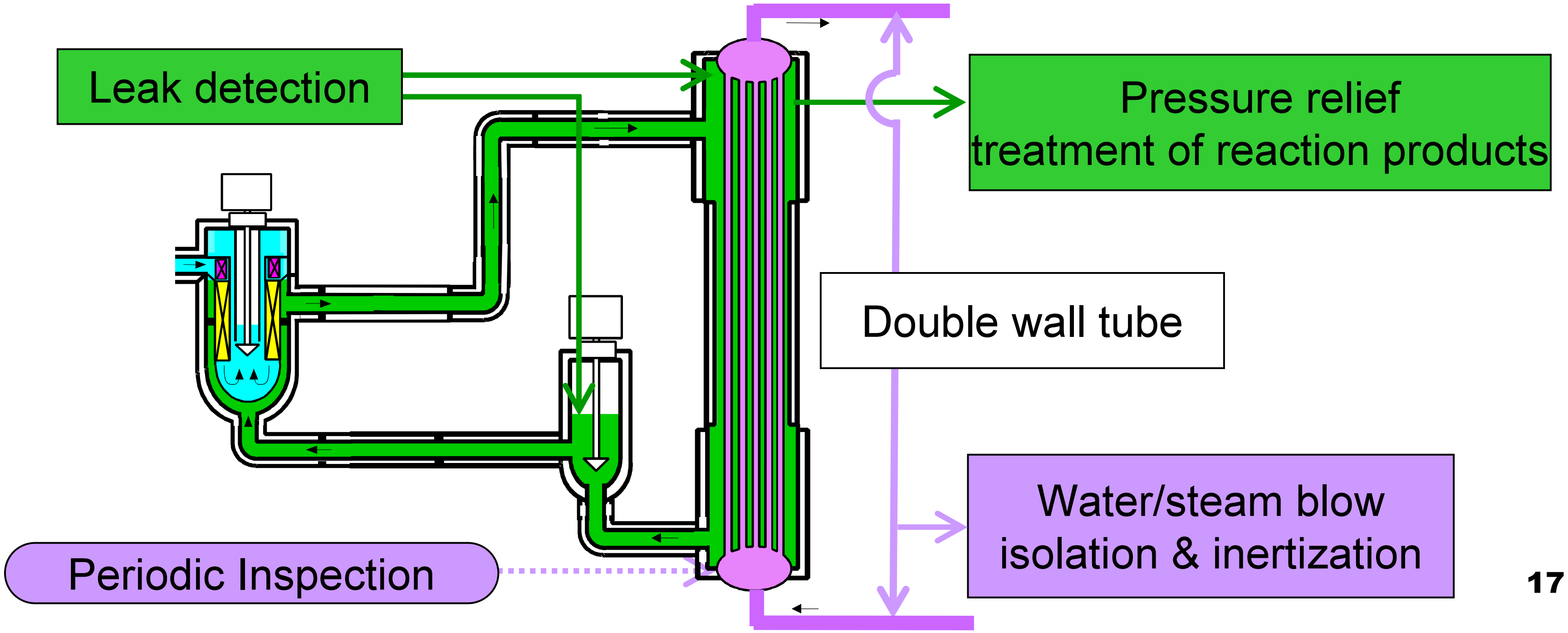


(1) Initiating phase *(2) Early fuel-discharge phase* *(3) Material-relocation phase* *(4) In-vessel cooling phase*

- *Expected progression of ULOF*

Primary and Intermediate coolant system (3/3)

- The ***double wall tube*** should be adopted to SGs in order to reduce the leak rate to be postulated as design basis as well as the leak possibility itself.
- A ***periodic inspection*** shall be applied for the sodium-water boundary.
- A ***leak detection*** system shall be installed.
- A set of protection system for ***pressure relief, treatment of reaction products, water/steam blow, isolation and inertization*** of water-steam side shall be provided.



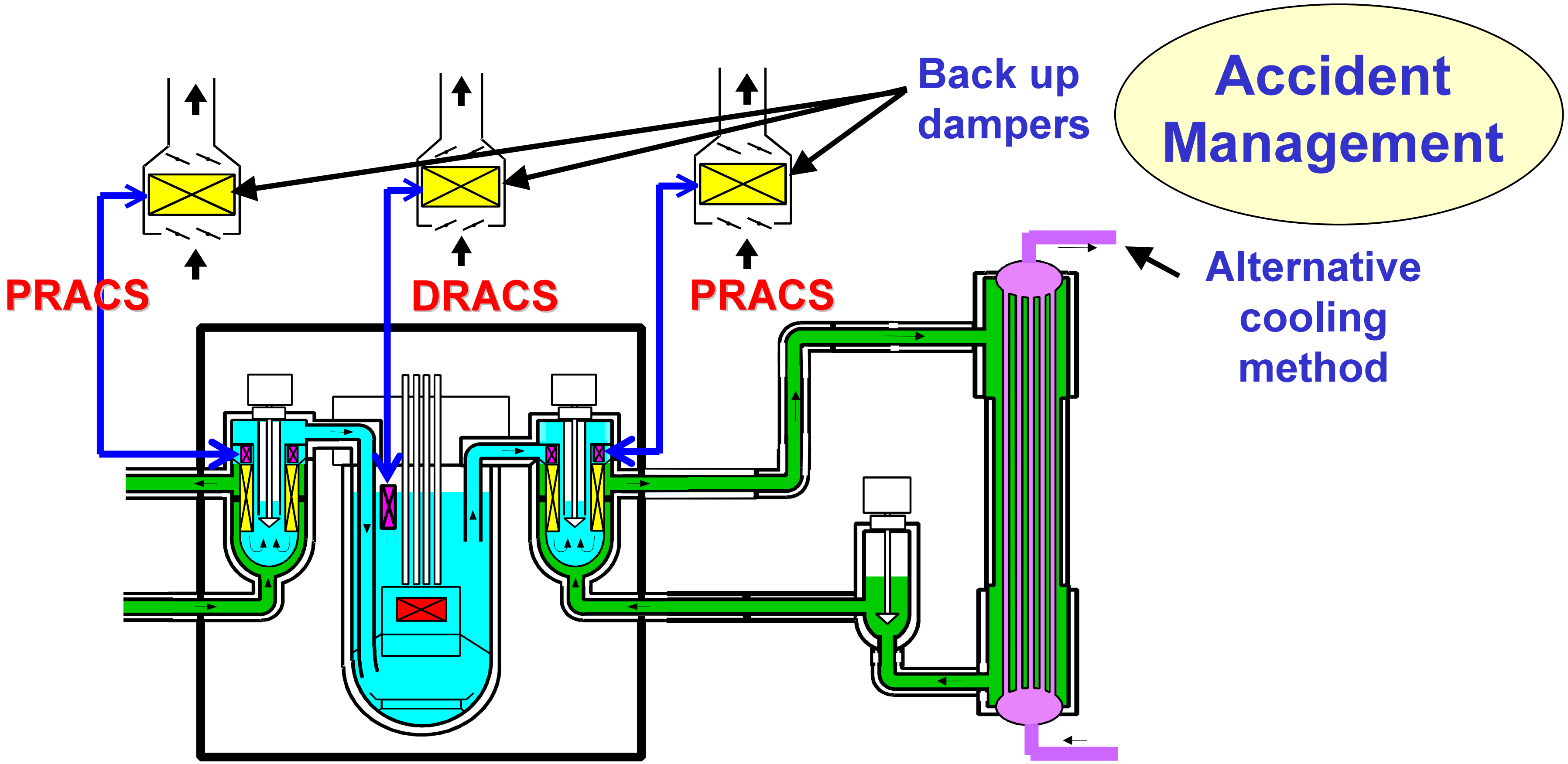
Decay heat removal system (1/2)

- DHRS shall be designed as ***passive operating system*** in order to achieve both system simplification and higher reliability.
- DHRS shall have independent subsystems so as to have ***sufficient redundancy***.
- The each subsystem shall have ***diversity*** in the component design and the configuration, i.e., DRACS or PRACS.
- Back up dampers shall be installed for each air cooler in addition to the redundant dampers as a ***measure for accident management***. [BDBE]
- ***Alternative cooling method*** by means of water-steam system should be provided. [BDBE]

Decay heat removal system (2/2)

Decay heat removal system

- **Passive operating function**
- **Sufficient redundancy & diversity**

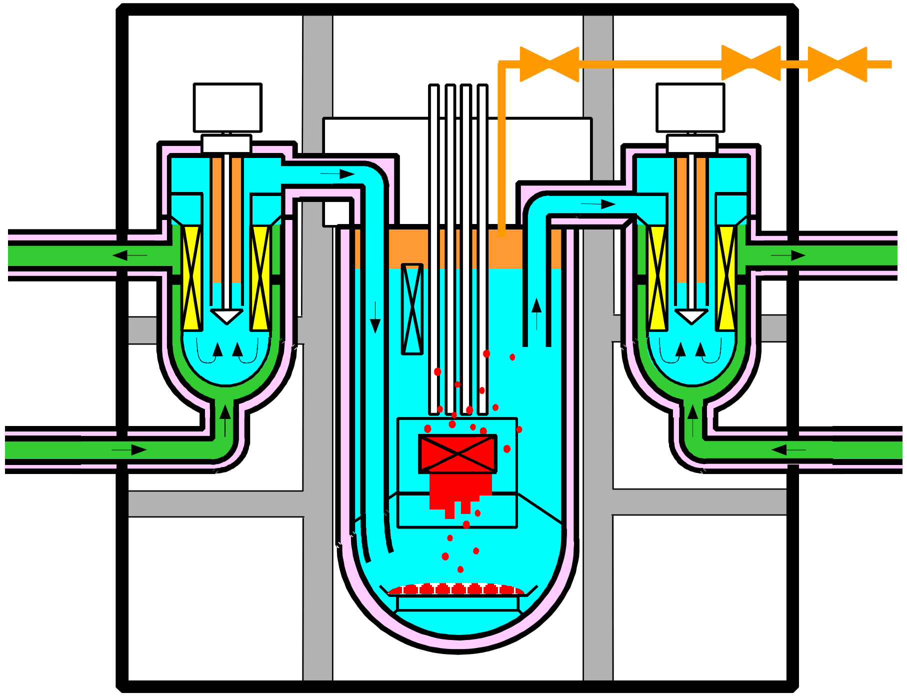


PRACS: Primary Reactor Auxiliary Cooling System
DRACS: Direct Reactor Auxiliary Cooling System

Containment system

- The reactor containment shall be designed to withstand the load caused by ***heat generation of gaseous fission products inside the containment and heat radiation from the sodium-contained components and piping***.

- ***External events*** such as air craft crash and internal missile will be considered according to the practice of LWRs.



Concluding Remarks

- Safety design requirements for JSFR were summarized.
  - General requirements
  - Specific requirements for each SSCs

- The essential part of the requirements will be commonly applicable for sodium cooled fast reactors.

Comparison of the Development Targets, Goals and Basic Principle

FaCT Project

SR-1 Equal level of safety
SR-2 Equal level of reliability

Generation-IV

SR-1 Operational safety & reliability
SR-2 Core damage frequency
SR-3 Offsite emergency response

IAEA/INPRO

BP1 Defence in depth

BP2 Appropriate, increased emphasis on inherently safe

BP3 Risk from radiation exposures characteristics and passive safety

BP4 development of analytical methods

Development Targets for FaCT Project

Safety and Reliability

SR-1	Ensuring safety equal to future LWR and related fuel cycle facilities
SR-2	Ensuring reliability equal to future LWR and related fuel cycle facilities

Sustainability

Environment Protection

EP-1	Radioactive influence through normal operation no more than future LWR cycle
EP-2	Emission control of environment transfer substances which can restrict in safety limits

Waste Management

WM-1	Reduction of an amount of radioactive waste compared with future LWR cycle
WM-2	Improvement of waste manageability equal to or more than future LWR cycle
WM-3	Reduction of radio-toxicity compared with future LWR cycle

Efficient Utilization of Nuclear Fuel Resources

UR-1	Breeding performance to enable transition to fast reactor, and its flexibility

Economic Competitiveness

EC-1	Electric generation cost which can compete with other power plants
EC-2	Investment risks no more than future LWR cycle
EC-3	External costs no more than future LWR cycle

Nuclear Non-Proliferation

NP-1	Adoption of institutional measures and application of technical features which can enhance non-proliferation
NP-2	System design of physical protection and its development to prevent theft of nuclear materials and sabotage

The development targets related safety and reliability in FaCT

- (1)To ensure a comparable safety level to that of next-generation LWRs

  [Design requirements]

  - Defence in Depth
  - Eliminate the activation of offsite emergency response
  - Risk level: Core Damage Frequency 10^{-6}/reactor-year, Containment Failure Frequency 10^{-7}/reactor-year

- (2)To ensure a comparable reliability level to that of next-generation LWRs

  [Design requirements]

  - Enhance operational safety to reduce unexpected outage and human errors
  - Reduce worker's routine exposure
  - Provisions of Inspection and repair technologies

Approach of JSFR design study

- Design targets, Safety and reliability, Sustainability, Economic competitiveness and Nuclear non-proliferation, are set.
- Defense-in-depth is basic principle of the safety design.
- Design extension conditions are taken account into the design at the beginning of the conceptual design.
- The design works are in deterministic way. Probabilistic approach is used as supplemental way, for instance for selection among design options.
- In order to ensure the reliability, components with advanced design should be proved its reliability by experimental data and/or simulation. Development of inspection and repair technologies and design consideration for easy maintenance are also important.
- Concerning human-machine interface, the state-of-the-earth technology of LWRs can be used.

The design approach (1/4)

- The deterministic approach
  - Selection of design basic events based on an engineering judgment
  - Set design criteria for fuel, coolant boundary etc
  - Single failure criteria
  - Consideration of uncertainties
  - Reactor shutdown system: two different signals of the reactor protection system for the anticipated transient (AT), one signal for the accident
  - Decay heat removal system: consideration of heat removal capacity under severest design basis events, for instance failure of one sub-system + single failure.
  - Redundant design for excluding common mode failure of the safety function

The design approach (2/4)

- Design extension conditions
  - Multiple failure of the safety function under AT
  - Hypothetical failure beyond DBE
  - Best-estimate base evaluation
  - Non-safety grade system can be applied as accident managements

- Application of PSA
  - Preliminary PSA will be conducted to check perspective for meeting the probabilistic target, i.e., 10-5/site-year of core damage frequency.
  - But it should not too much rely on it because there is limitation on the data base of component reliability.
  - It is used as reference for comparison of design options, for instance arrangement of cooling systems, heat capacity, number of sub-systems.

The design approach (3/4)

- Research and Development
  - Reactor shutdown system : function test by mock up, transient and material tests for Self Actuated Shutdown System (SASS), Irradiation test at JOYO for SASS
  - Decay heat removal system : simulation tests (1/10 full system water test, 1/5 partial system sodium test), development of evaluation tools, demonstration by MONJU
  - Recriticality-free concept : demonstration of molten fuel discharge by in-pile tests (IGR), development of evaluation tools

The design approach (4/4)

- For ensuring component reliability
  - Understanding basic function and related phenomena such as thermal hydraulics mechanical loads by scale model tests, development of design tools, design by analysis, ensuring sufficient margin against failure, demonstration by large-scale sodium test
    - Compact reactor vessel
    - Pump integrated intermediate heat exchanger
    - Double-walled straight tube steam generator
    - Advanced fuel handling system
  - Ensuring maintenability : design consideration, development of inspection and repair technologies