Safety design approach featuring Severe accident countermeasures for GEN-IV SFR

- JSFR Approach -

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Contents

Introduction

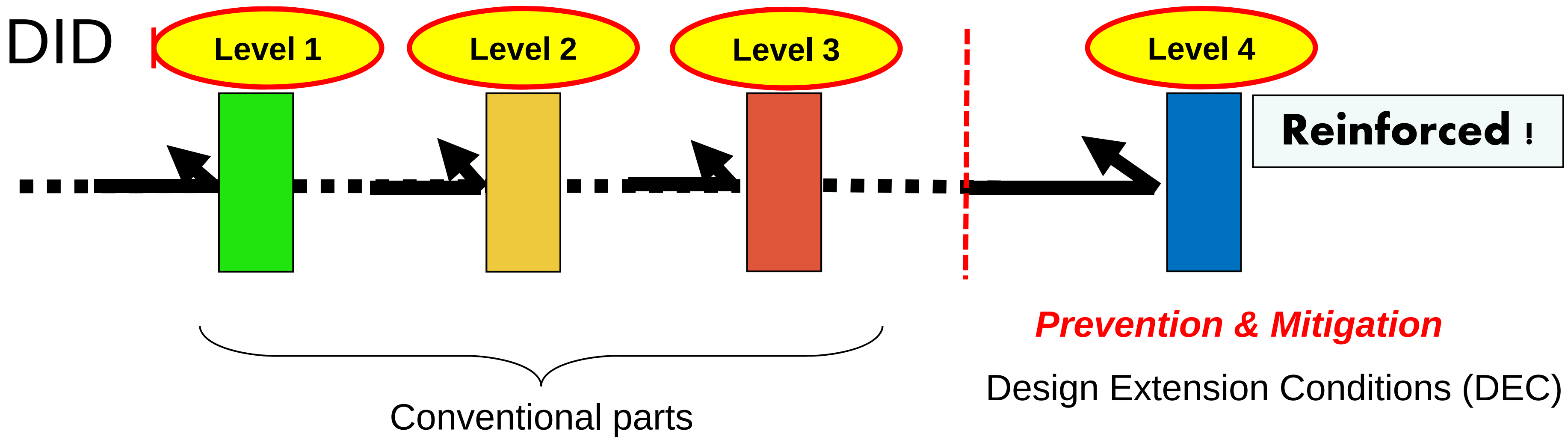
- **Design targets for Generation IV reactors; Excel in safety and reliability, sustainable and competitive energy generation, proliferation resistance and physical protection**
- **In order to achieve cost competitiveness as base load energy source, commercial SFRs shall cover large output power at least equivalent to current LWRs.**
- **For the last decades SFRs have been designed, constructed and operated worldwide to obtain important experiences related to reliable operation and responses to accident conditions in the involved countries. Safety research and development works have been done in the related field such as core fuel performance, molten fuel and radioactive materials behavior and sodium combustion, those include phenomenology of severe accident of SFR. Safety design of GEN-IV SFR can be established on these accumulated technical basis.**

Introduction

- In the design and evaluation of SFRs including Monju core disruptive accidents (CDAs), which are typical severe accidents of SFR, has already been addressed. And it is important to assure the measures against severe accidents reflecting the lesson learned from the TEPCO's Fukushima Dai-ichi NPS accident.
- It is crucial for development of GEN-IV SFR that Monju can show good performance as electric power generator and that effective severe accident management measures can be established for Monju.
- Based on these experiences and achievements, a practical safety design criteria (SDC) for GEN-IV SFR shall be established and shared among involved countries.

Basic idea for securing safety

- **Basic safety principle is Defence-in-depth (DID) which is same as LWRs. In addition to conventional three defence lines so-called "prevention of abnormal occurrence", "prevention of progression of abnormal conditions" and "control of accidents within design basis", "control of severe plant conditions" shall be required. GEN-IV SFR aims at "Elimination of the need for offsite emergency response" by enhancing prevention and mitigation of significant core damage in the severe plant conditions.**



Basic idea for securing safety

- In the TEPCO's Fukushima Dai-ichi NPS accident, as the result of entire loss of electric power supply caused by severe earthquake and tsunami, core cooling function could not be maintained and led to core melt.
- Design measures are required to prevent loss of important safety functions due to common cause failure. Diversification is the key point to cope with common cause failure. In addition to diversification of conventional active safety systems, introduction of passive functions is effective way.
- Measures against severe accidents shall be built-in rather added-on to enhance reliability and to ensure implementation by reducing operator actions. Reactor shutdown and core cooling capabilities based on natural behavior (passive or inherent features) shall be incorporated in the safety design.
- DID principle shall be also applied for safety design against sodium chemical reactions so that the consequences don't affect core safety.

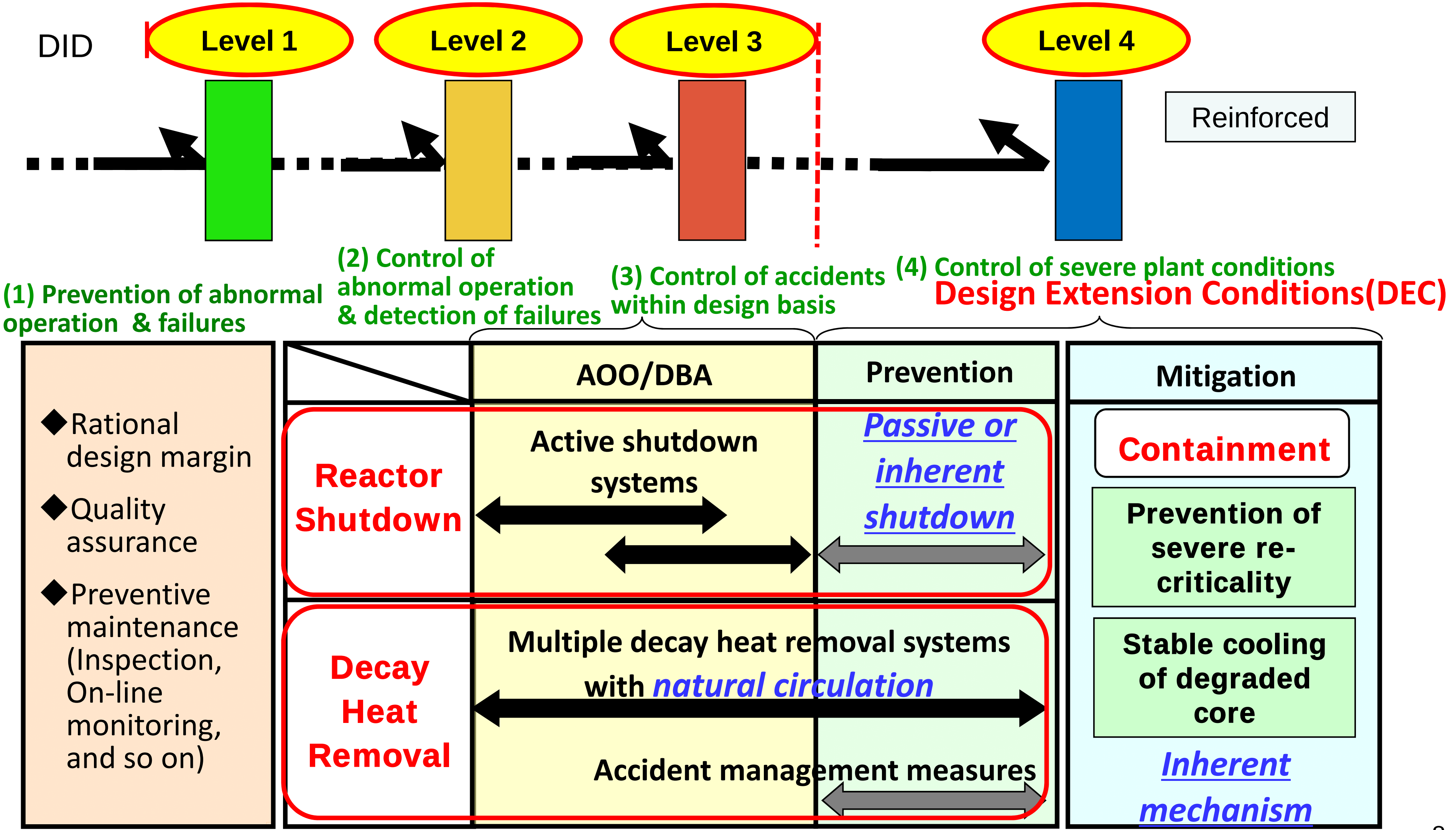
Safety design approach of JSFR

Comprehensive safety approach = Active engineered safety systems + Natural behavior (inherent or passive feature) to terminate SA + Accident Management

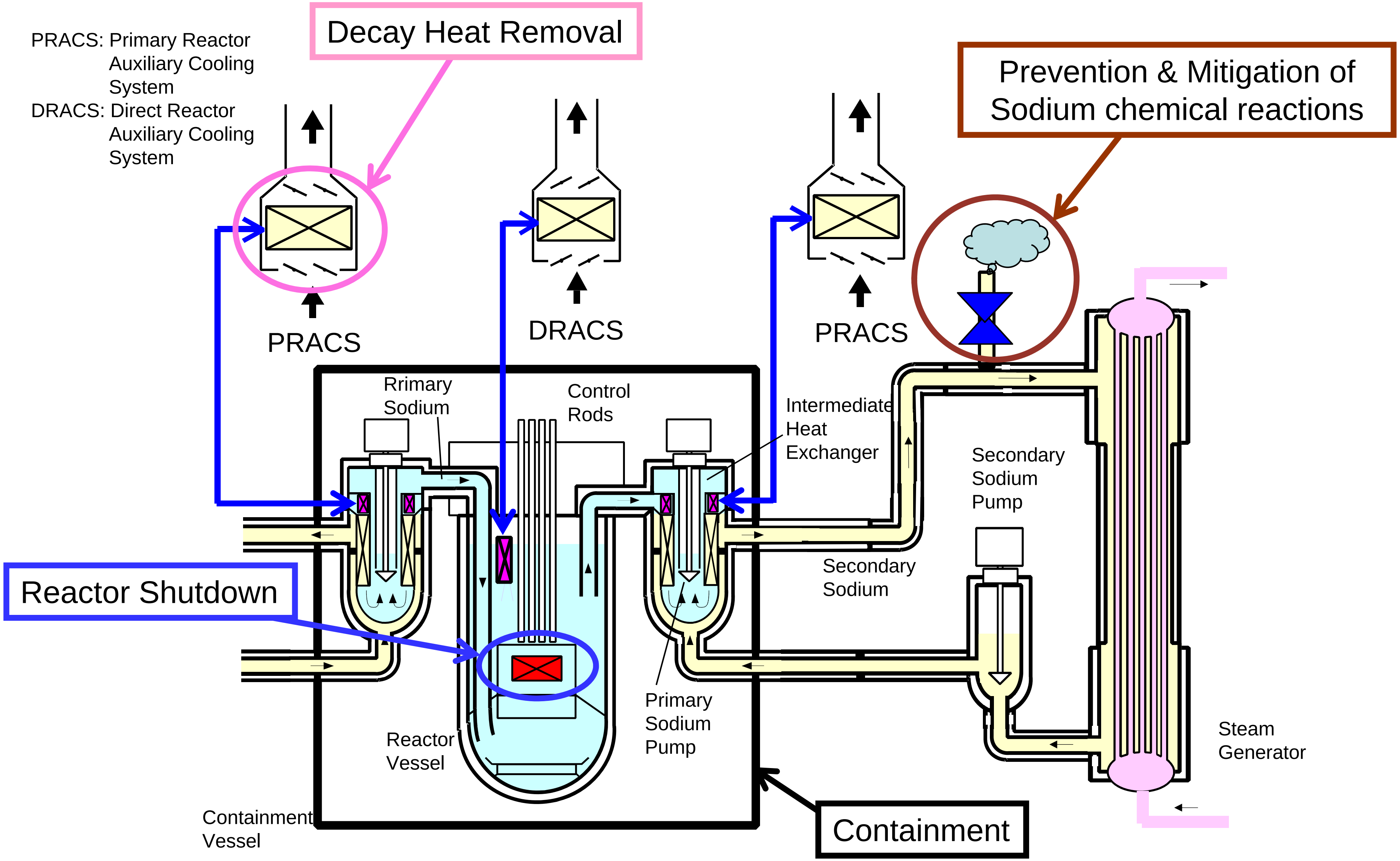
- **Proven technology based on the experiences of existing SFRs including Monju is fundamental.**
- **Passive or inherent reactor shutdown and core cooling capabilities are incorporated as built-in manner to prevent core damage in the severe plant conditions.**
- **Mitigation of core damage situations within containment is provided, which is based on inherent material relocation and cooling.**
- **Natural circulation cooling and containment of degraded core are based on the technologies already incorporated in Monju**
- **Accident management measures to be established for Monju will be adequately introduced.**

Safety design approach of JSFR

Comprehensive safety approach = Active engineered safety systems + Natural behavior (inherent or passive feature) to terminate SA + Accident Management



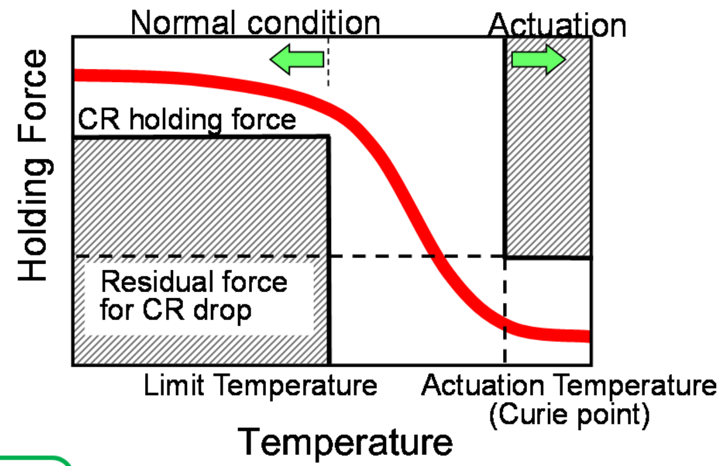
Safety design approach of JSFR

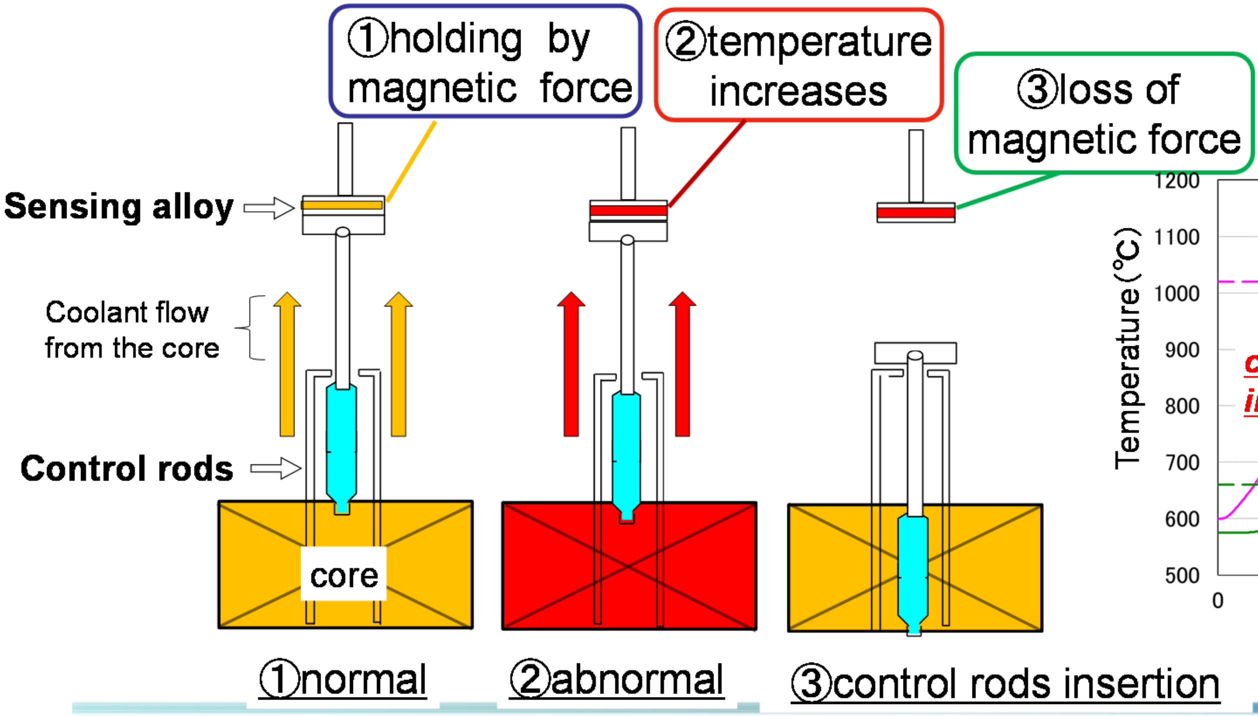


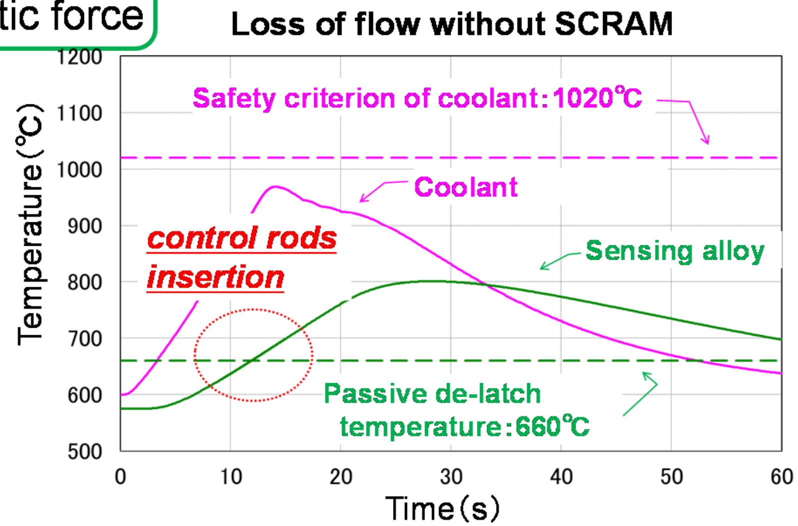
Reactor Shutdown System [RSS]

Two independent active RSSs [Primary & Backup]

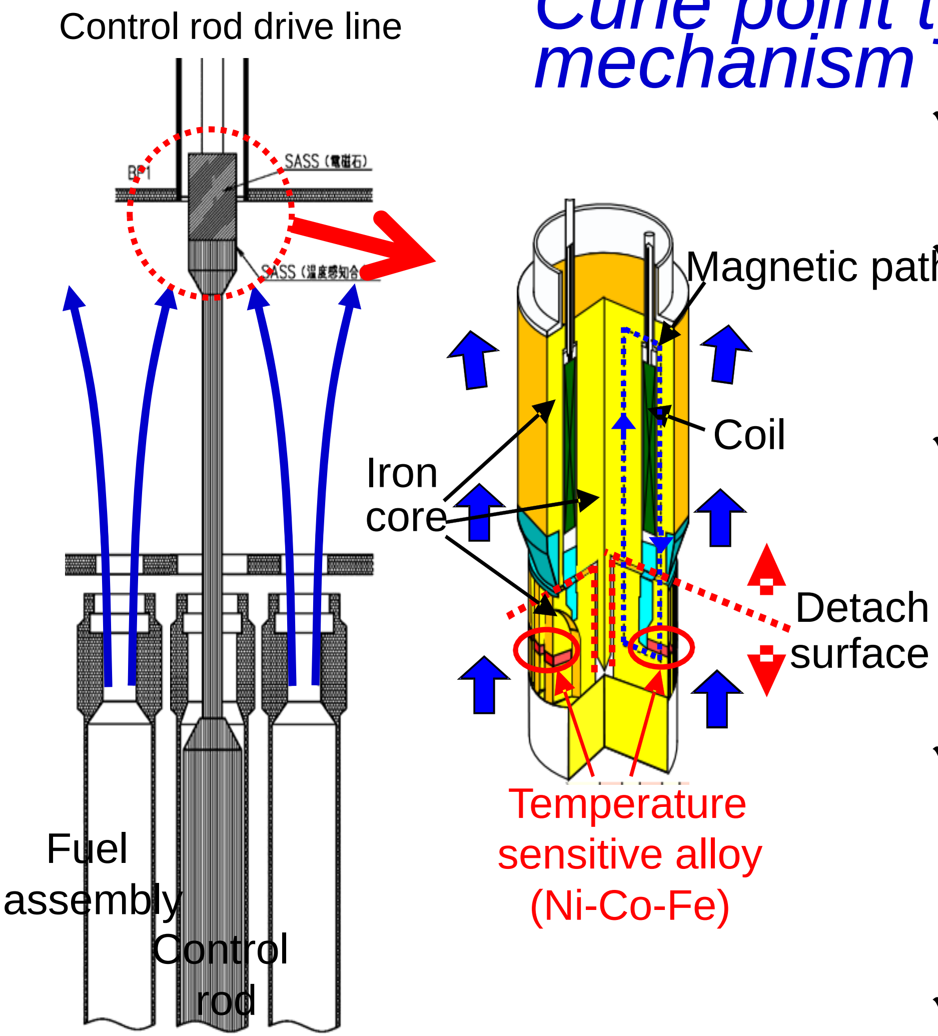
+ passive mechanism (Curie point type passive CR insertion mechanism)







Self Actuated Shutdown System (SASS)

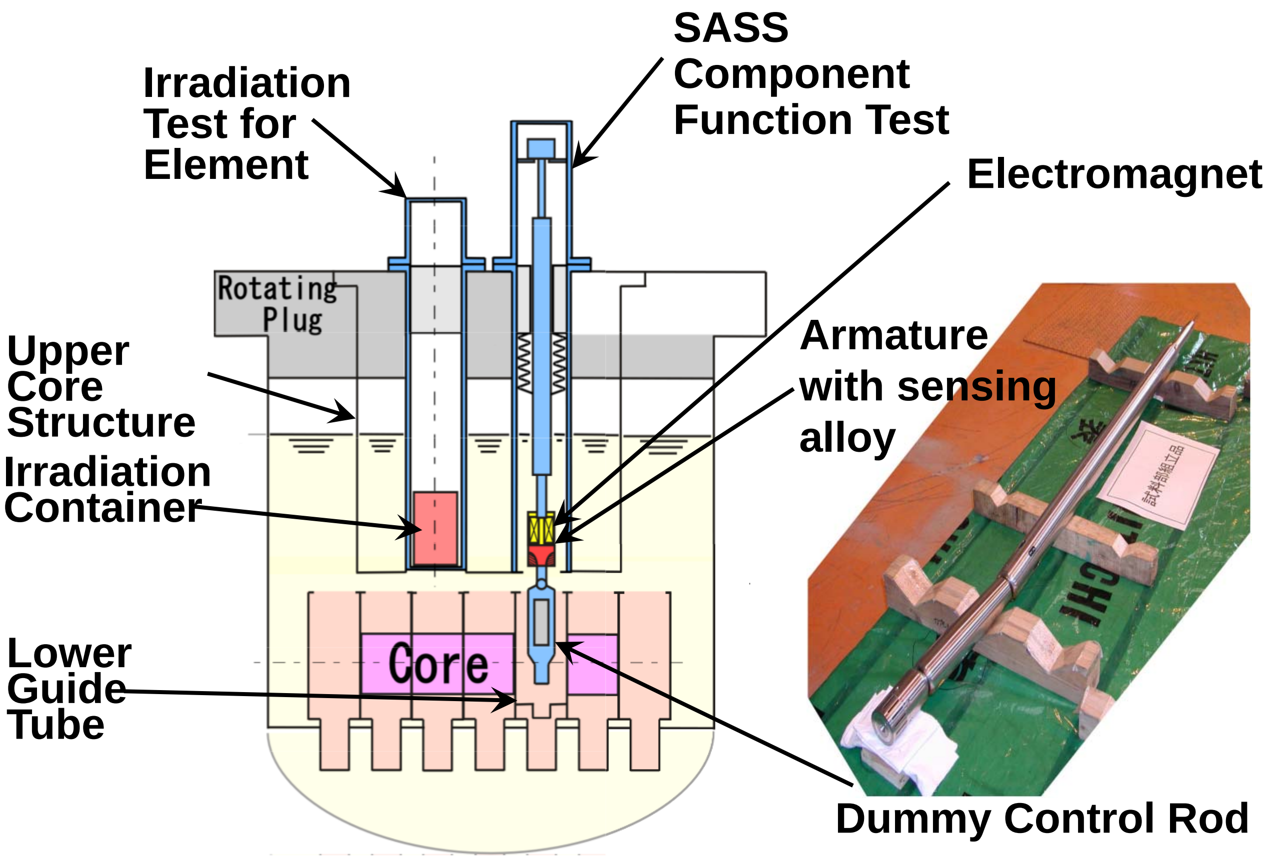


Curie point type passive CR insertion mechanism

- ✓ Effective for all types of ATWS, i.e., ULOF, UTOP and ULOHS
- ✓ One dimensional movement in a subassembly scale reduces the uncertainty for the behaviors during ATWS
- ✓ The de-touch mechanism is used both for active and passive operations and thus the safety function can be easily demonstrated and verified during the operation
- ✓ Robust core restraint structure ensures control rod insertion. (rod jamming can be eliminated from cause of reactor shutdown system's failure)
- ✓ The amount of the negative reactivity insertion is large enough to shut core down.

SASS Test in JOYO

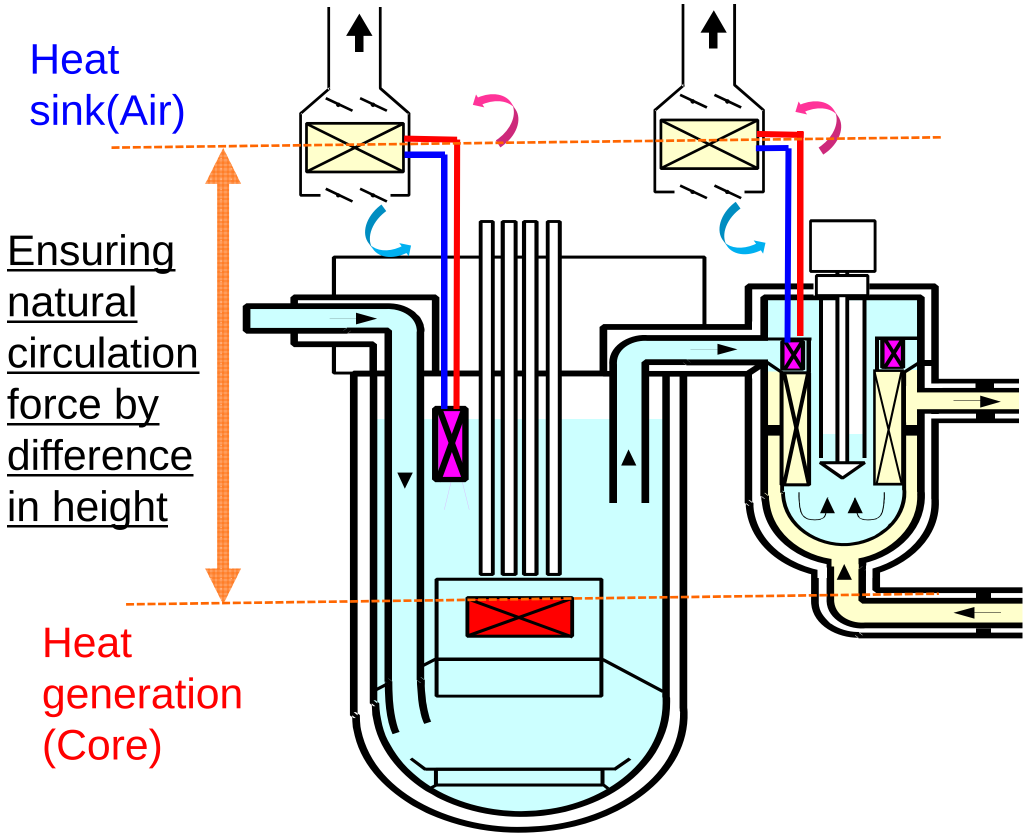
The component function test in JOYO demonstrated control rod holding stability by means of curie point electromagnet.

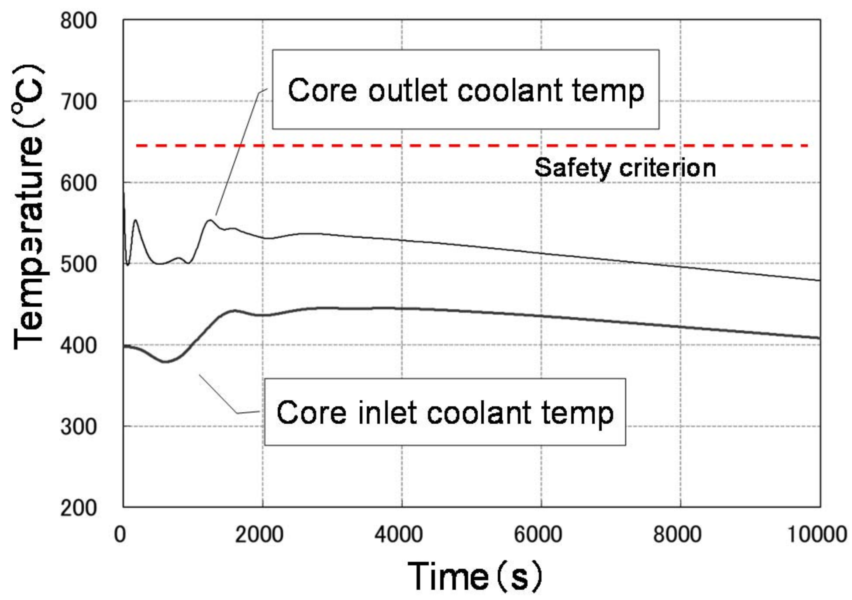


Installation of SASS

Decay Heat Removal

- As long as heat is generated from a reactor core, the heat can be removed by the **natural circulation** of coolant even under loss of electric power supply.
- Basic performance **of natural circulation** cooling has been demonstrated by JOYO etc.
- Confirmation of **natural circulation** by Monju is important step toward commercialization of SFR.

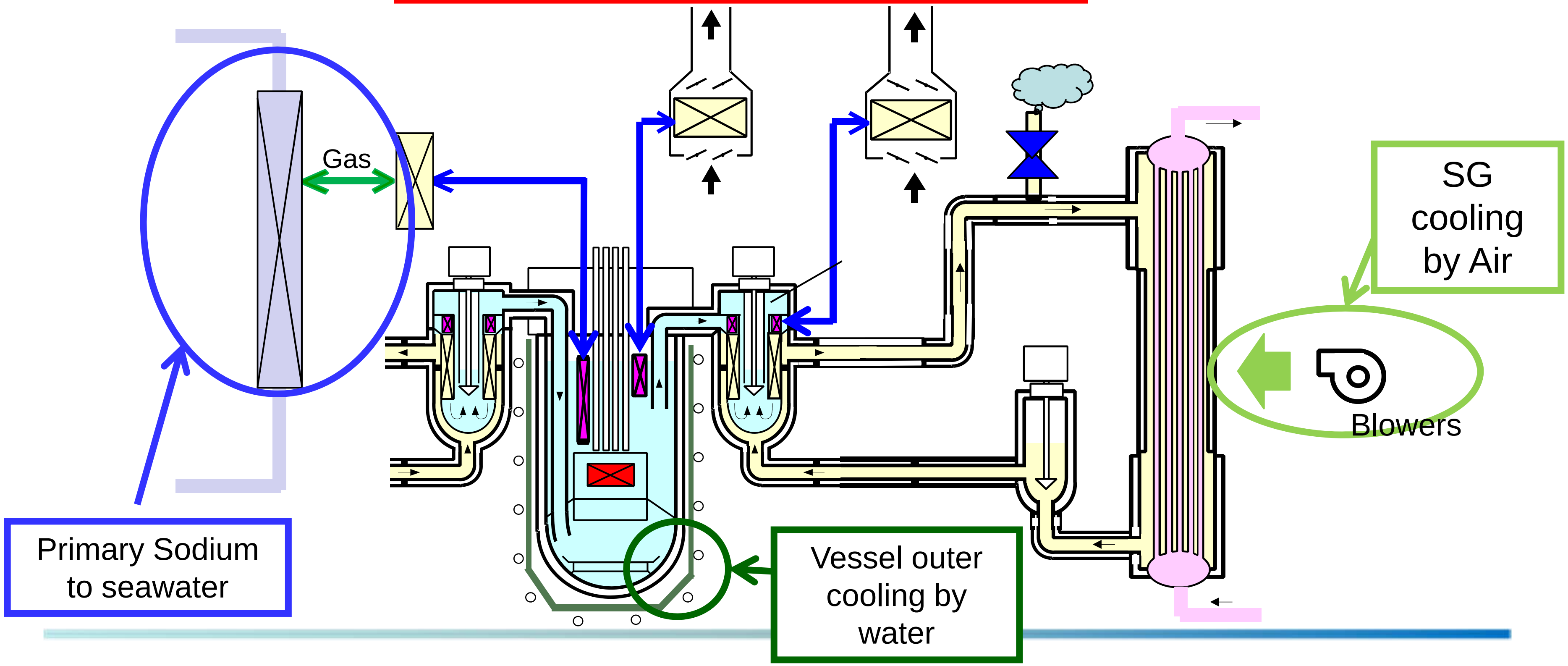




Decay Heat Removal

- For large scale SFR, enhancement of decay heat removal function is important, while heat capacity effect of structures is expected for small and medium scale SFRs.
- In order to diversify decay heat removal function, various alternative measures are available.
- These can be useful to suppress common cause failure.

Example of alternative cooling

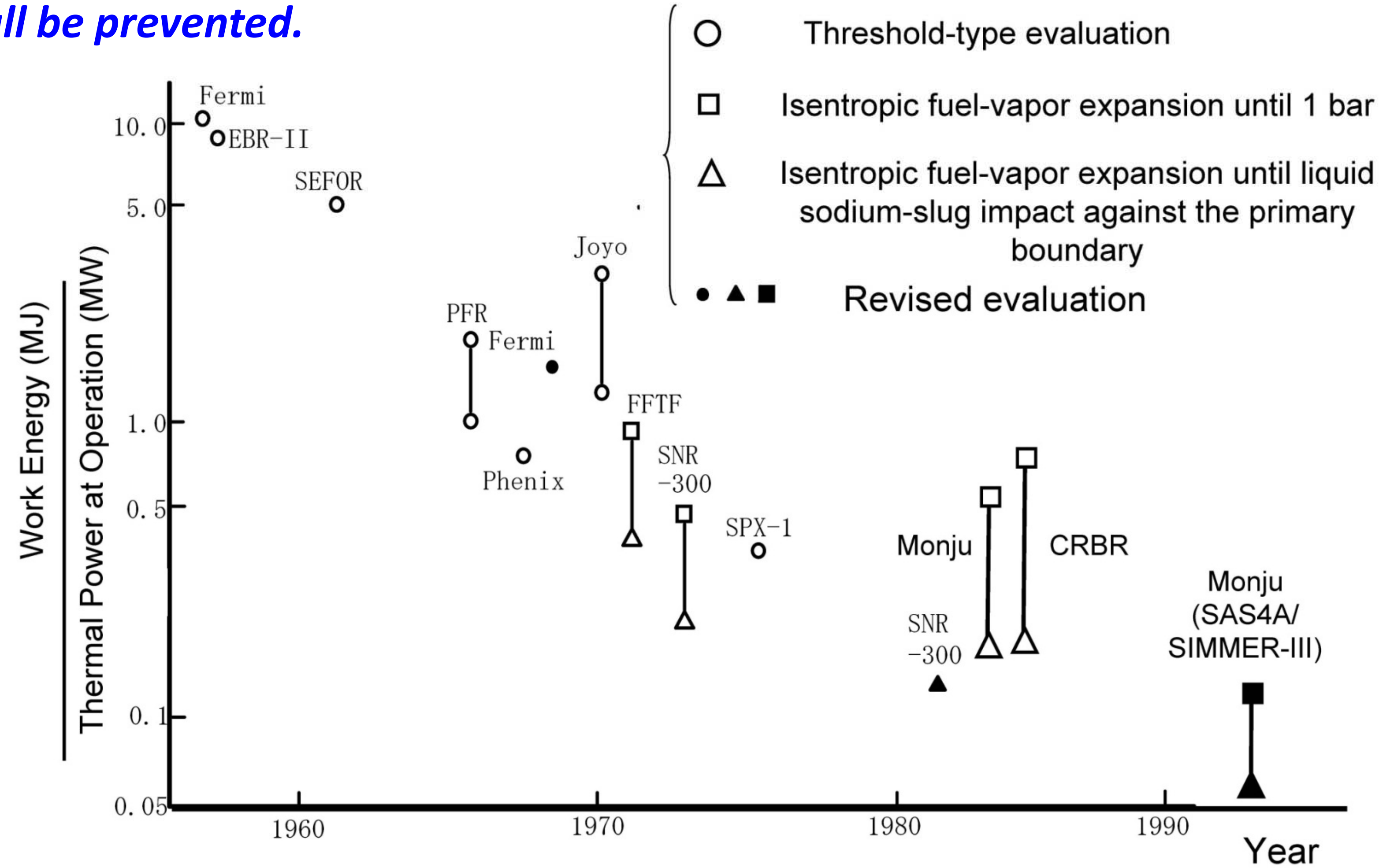


Containment

- Major challenging factor for containment is mechanical load from energetics accompanied by large sodium spray fire due to prompt criticality in Hypothetical Core Disruptive Accidents (HCDA or CDA).
- Avoiding energetics and retaining damaged core in the reactor vessel should be pursued. The former can be achieved by utilizing or enhancing **inherent dispersal nature of core materials** and by **limiting sodium void reactivity**.

History of CDA work energy evaluation

- ***Thanks to R&D outputs on phenomenology of core damage process, excess conservatism has been able to exclude.***
- ***Nevertheless, for large scale commercialized SFR, mechanical energy release shall be prevented.***

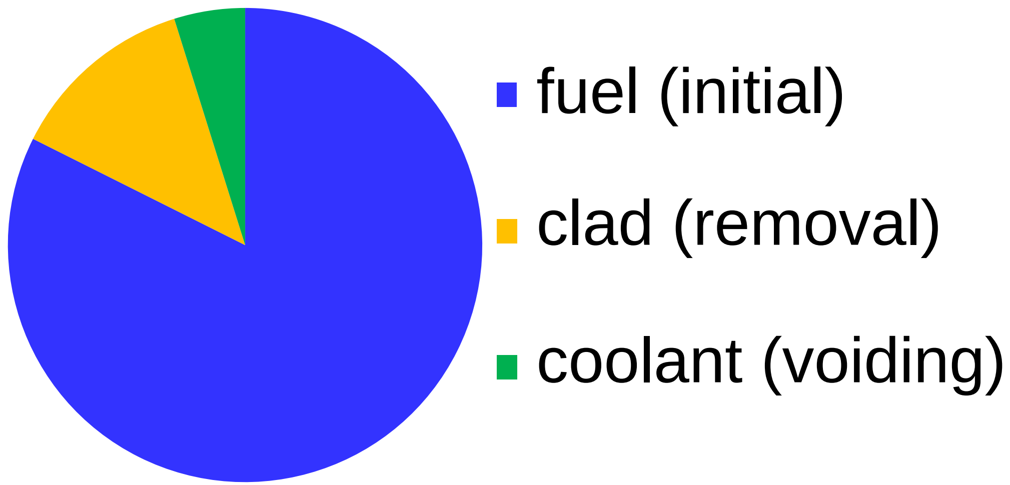


Reactivity worth

- The amount of reactivity worth is in the order of

  fuel > cladding > coolant

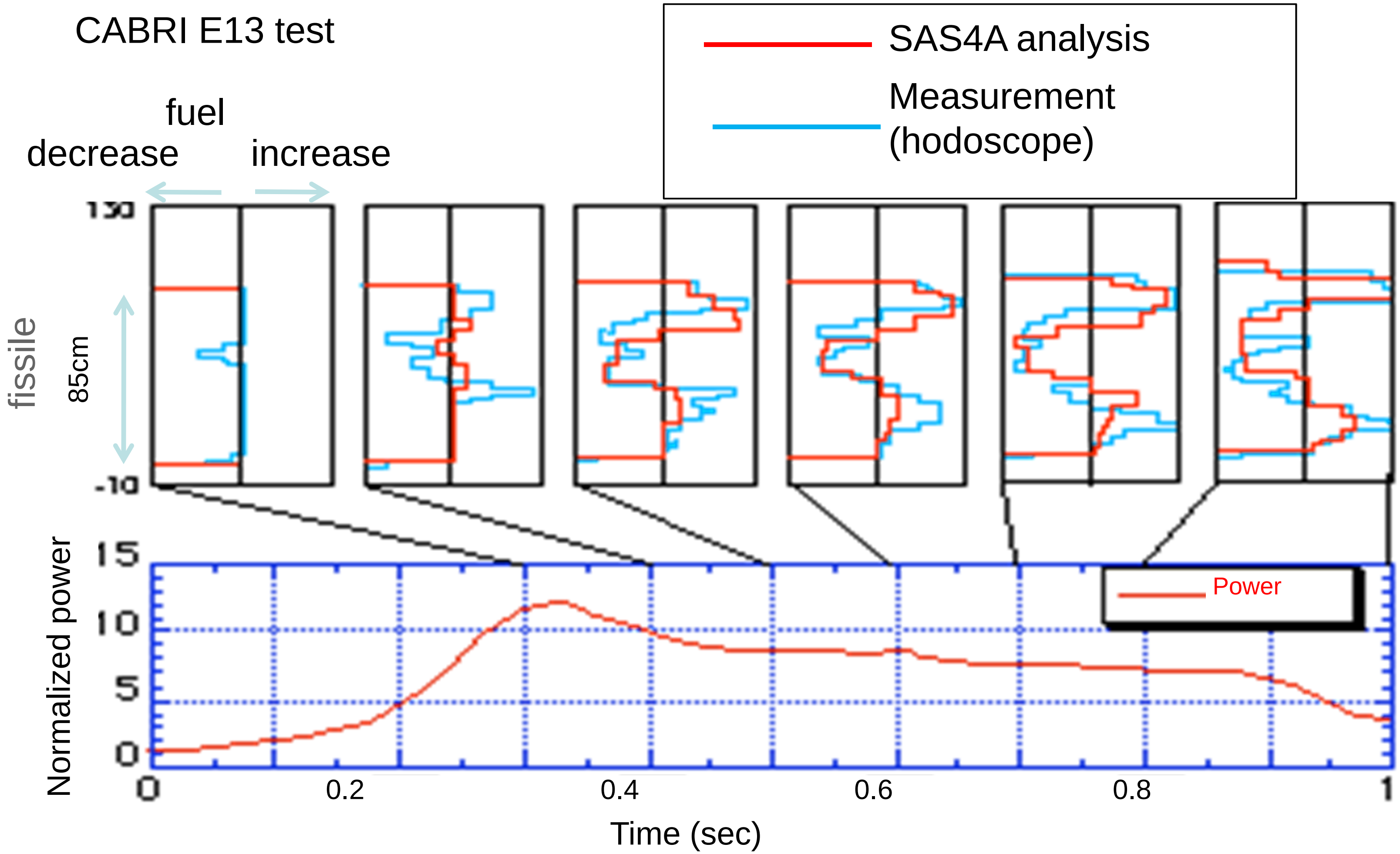
- In the course of coolant boiling, sodium void reactivity is dominant up to cladding and fuel melting.
- After that molten fuel and cladding motion is dominant.
- Strong negative feedback due to inherent molten fuel dispersion
- Positive sodium void reactivity can be defeated by negative fuel reactivity.



Comparison of fuel, steel and coolant void worths
(JSFR condition as an example)

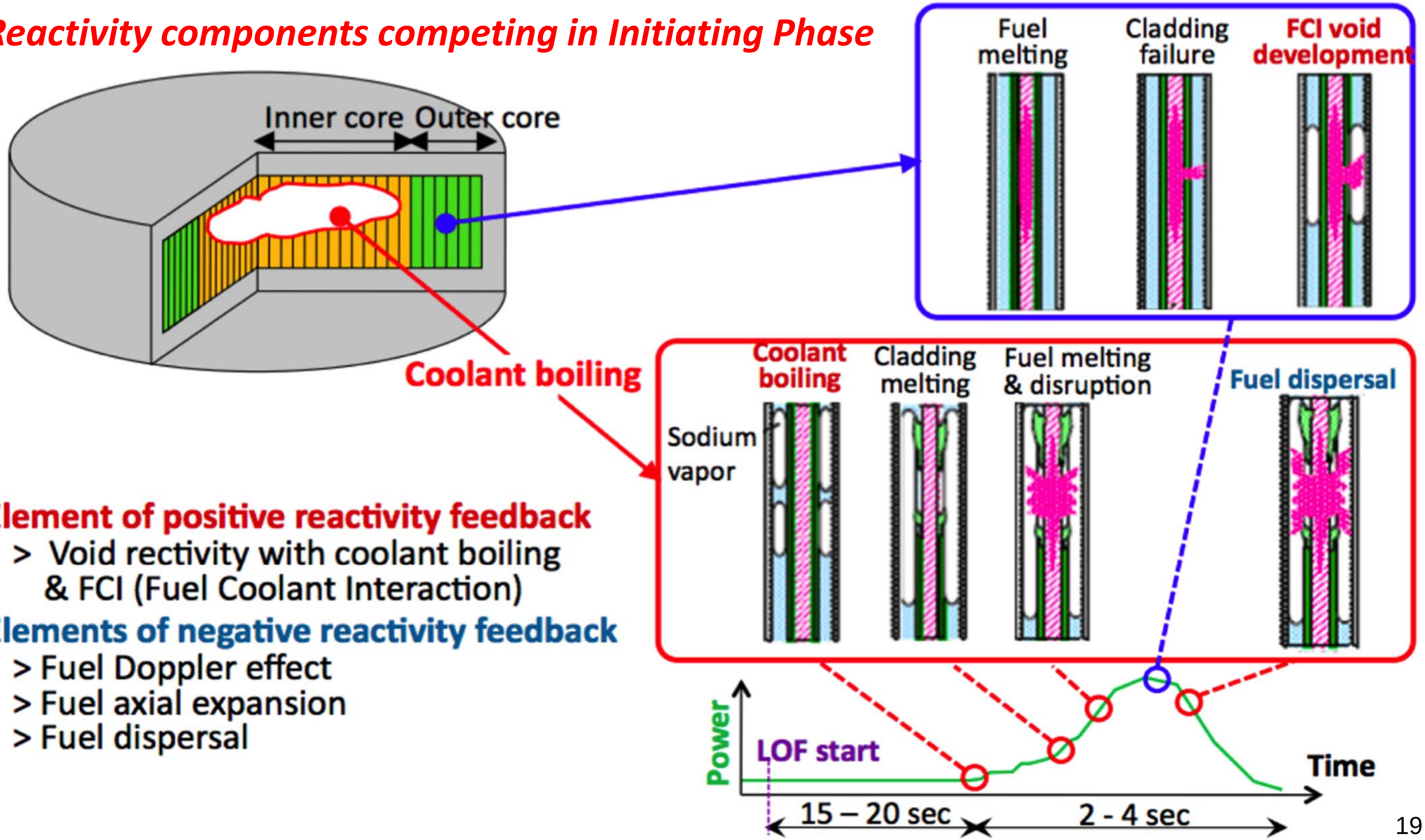
- Axial fuel dispersion with strong negative reactivity feedback is based on **natural behavior** appears in the course of fuel disruption.
- This fact has been observed in many fuel melt simulation experiments such as CABRI and TREAT.

An example of SAS4A validation focusing on fuel dispersal with CABRI test data



- Possibility of energetics is dependent on competition between positive/negative reactivity components.
- The energetics can be eliminated provided that appropriate design parameters are selected, e.g. **sodium void worth limitation**.

Reactivity components competing in Initiating Phase



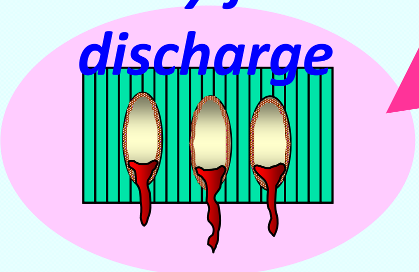
Element of positive reactivity feedback
> Void rectivity with coolant boiling & FCI (Fuel Coolant Interaction)

Elements of negative reactivity feedback
> Fuel Doppler effect
> Fuel axial expansion
> Fuel dispersal

- Potential cause of severe energetics is large scale molten fuel compaction after initial power transient. In order to avoid such situation **early fuel discharge** is required.
- Special fuel assembly called **FAIDUS** is installed for this purpose.

Present approach

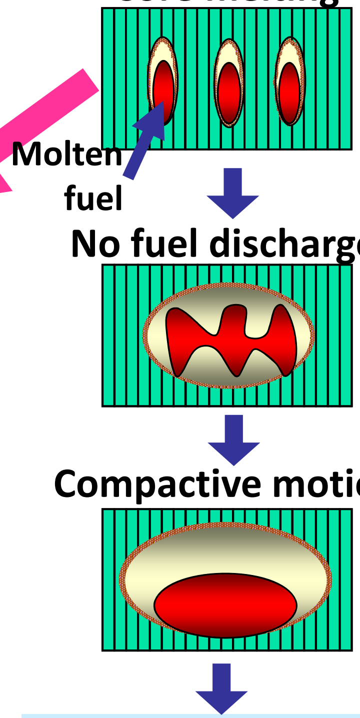
Early fuel discharge



Avoid large scale fuel compaction

No large power excursion

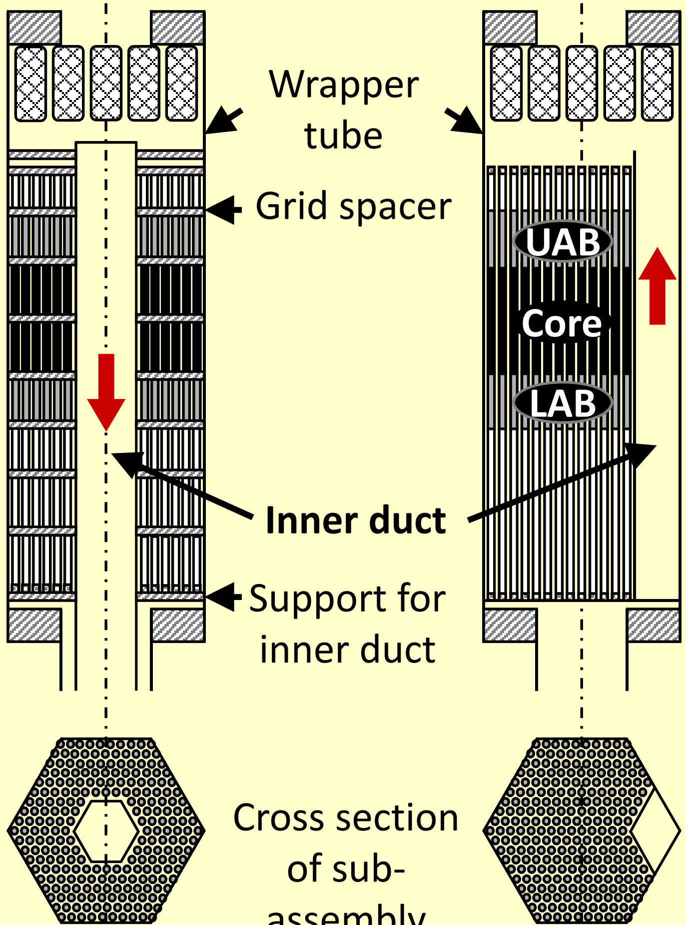
Core melting



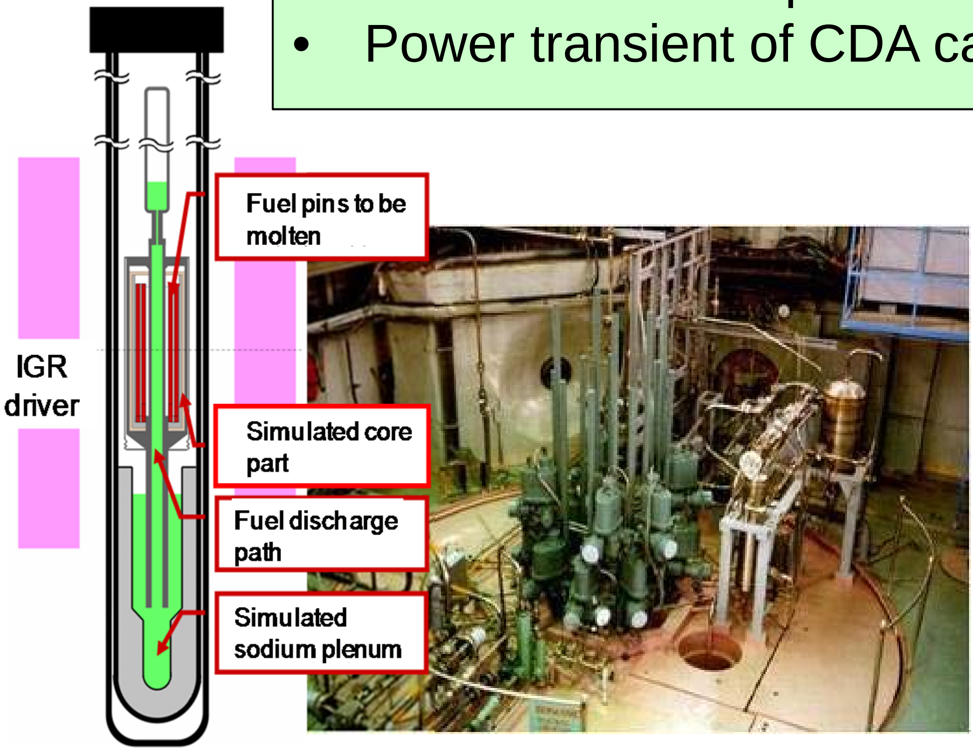
Possibility of large power excursion "**re-criticality issue**"

FAIDUS concept

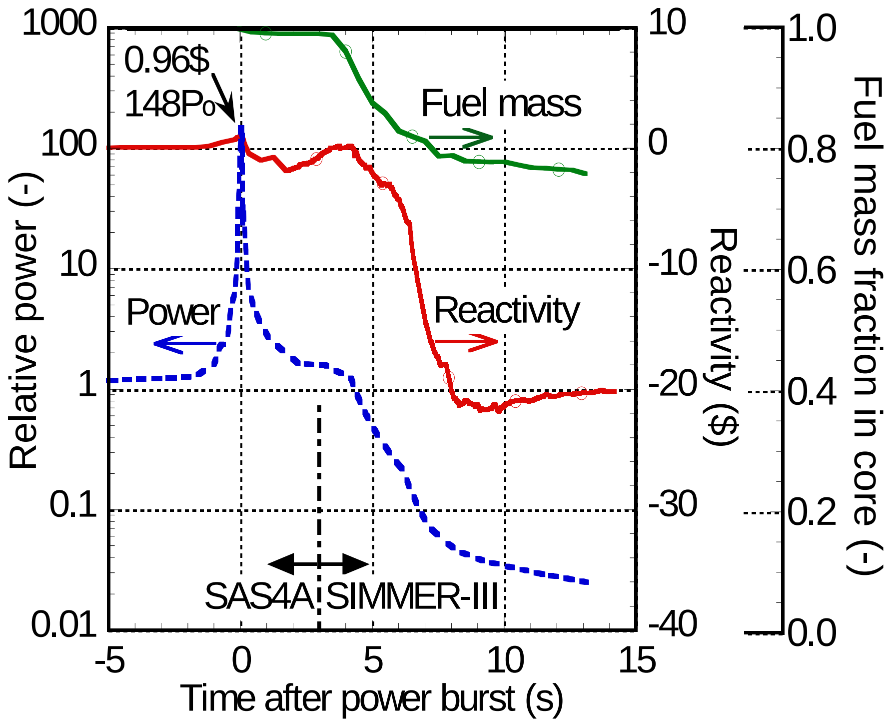
[Fuel Assembly with Inner Duct Structure]



- Molten fuel discharge mechanism of **FAIDUS** has been observed in an experimental simulation using IGR.
- Power transient of CDA can terminate in shutdown state.



IGR of NNC/Kazakhstan



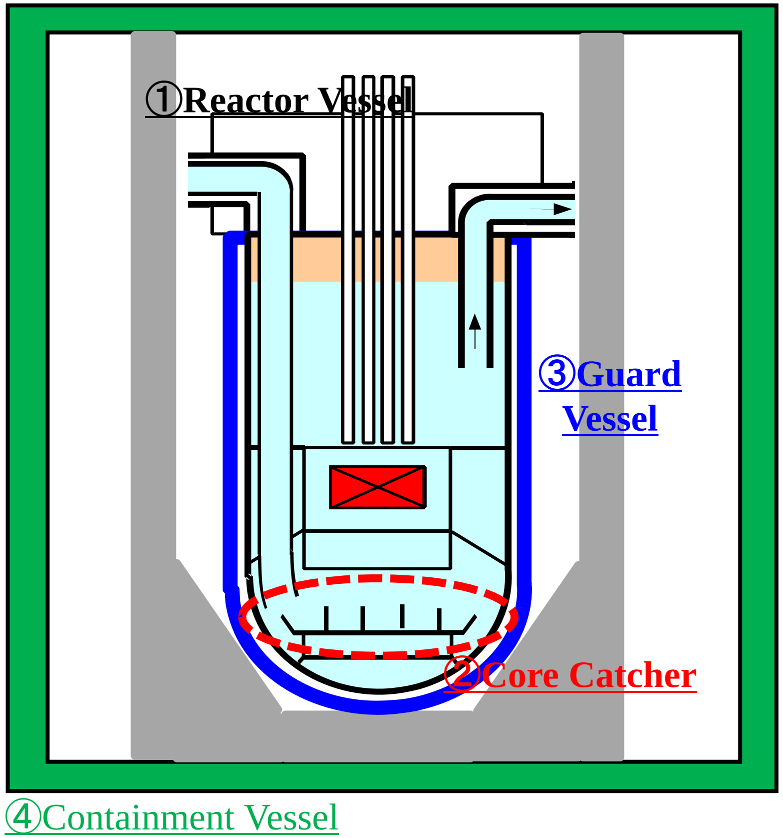
EAGLE Project :

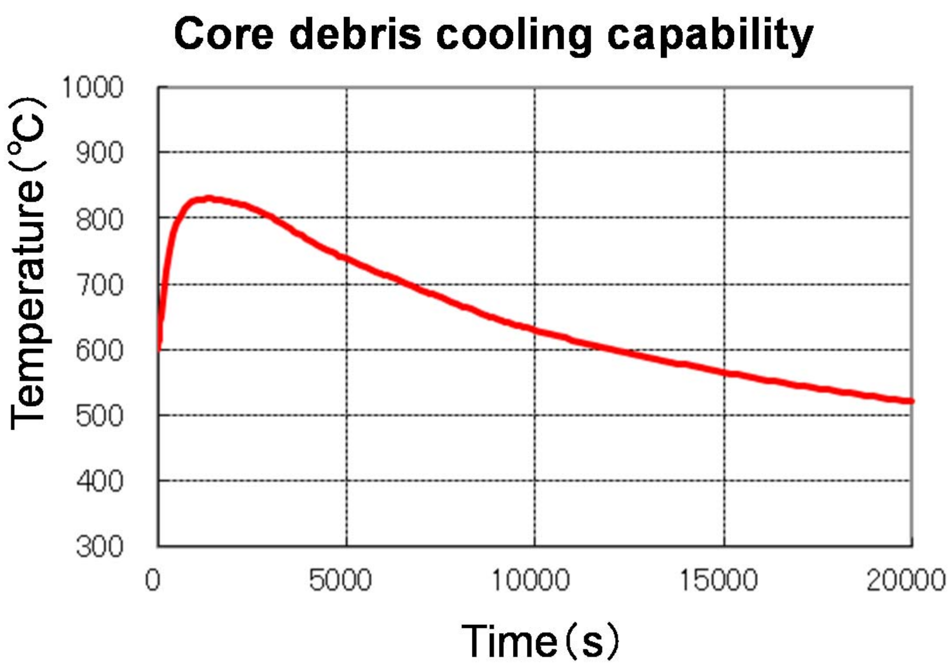
Experimental study on SA designs enhancing fuel discharge

ULOF Analysis for JSFR

Cooling of degraded core

- Retention and cooling of core debris by in-vessel core catcher
- The core debris cooling is achieved by **natural circulation** of Na.





Concluding Remarks

- **In order to realize the safety as GEN-IV SFR, comprehensive approach shall be taken, which is based on the technology matured through worldwide experiences of SFRs and incorporates natural behavior to terminate severe accidents within the containment in the terms of prevention and mitigation.**
- **Taking the lesson learned from TEPCO's Fukushima Dai-ichi NPS accident and feature of SFR into account, reactor shutdown, core cooling and containment based on natural behavior under severe plant conditions are important as well as accident management measures.**
- **International effort to find resolution to severe accident issue of SFR is important.**
- **Monju will provide valuable basis for Generation IV SFRs by the safety design featuring severe accidents, establishment of severe accident management measures and operational experience.**