Safety design approach for JSFR toward the realization of GEN IV SFR

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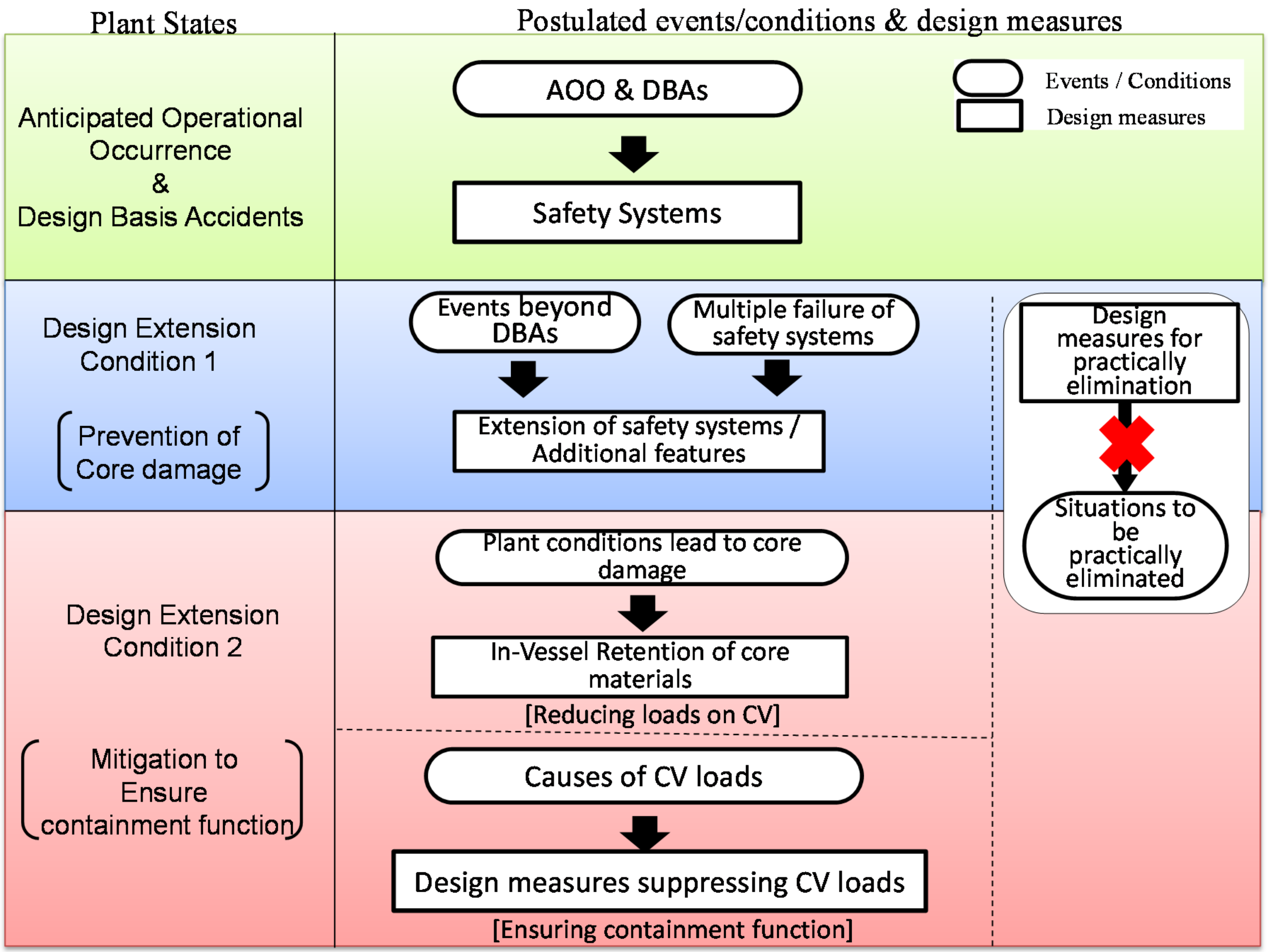
Contents

Safety design approach for JSFR

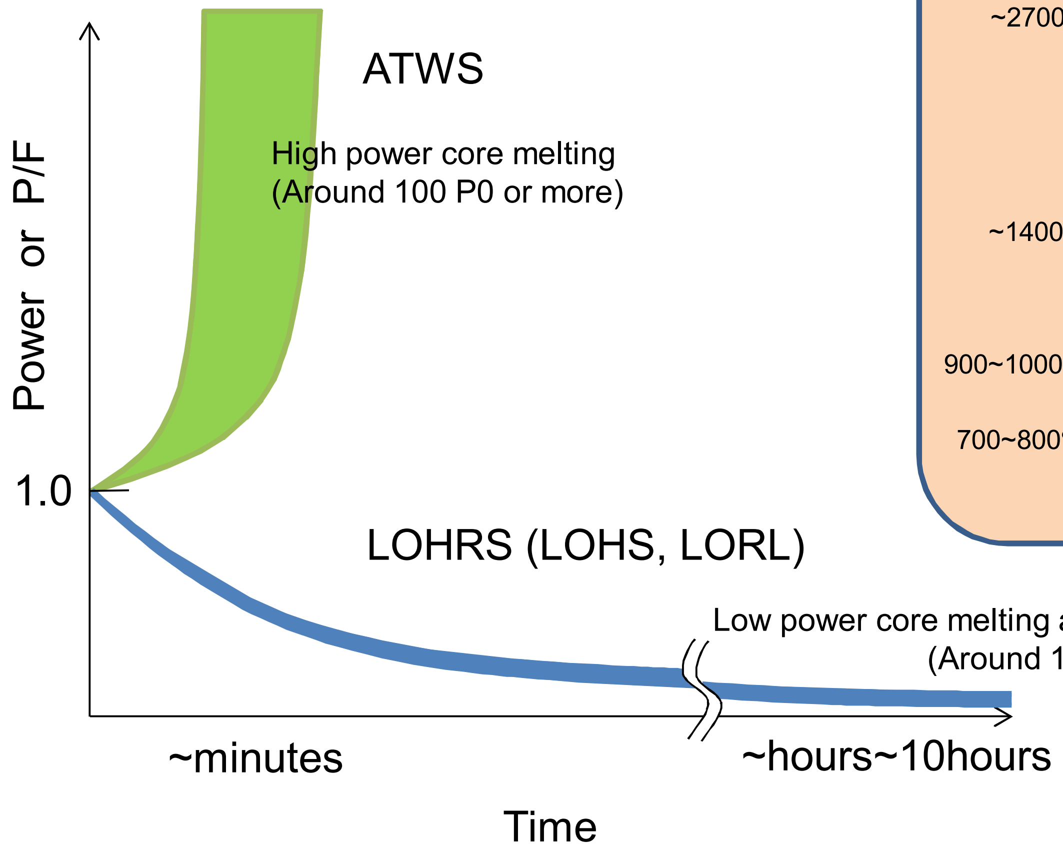
- Basis : The safety design criteria for Generation-IV SFR [GIF-SFR-SDC] developed in the framework of the Generation-IV International Forum
  - ✓ Enhancement of design measures against design extension conditions including those for external events considering the lessons learned from the TEPCO's Fukushima Dai-ichi nuclear power plants accident
  - ✓ Practical Elimination of accident situations , not reasonably manageable by design improvement, that could lead to a significant and sudden radioactive release due to a possible cliff edge effect

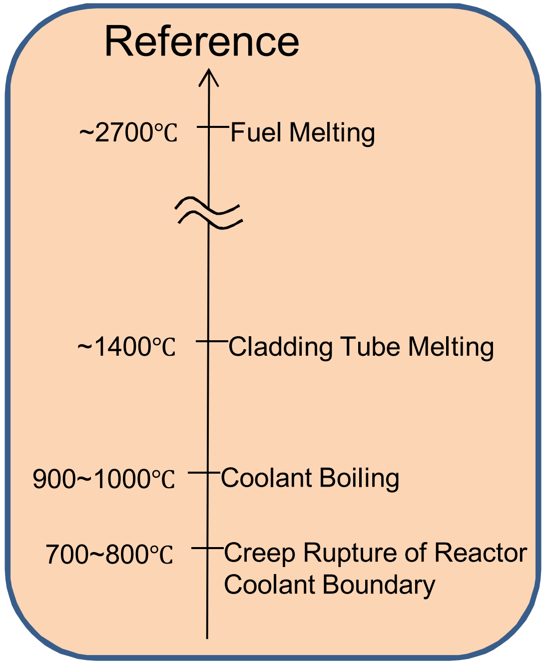
Safety Design Approach for JSFR



Difference between ATWS and LOHRS

- Since the event progressions of ATWS and LOHRS are very different, design measures shall be determined according to their characteristics.

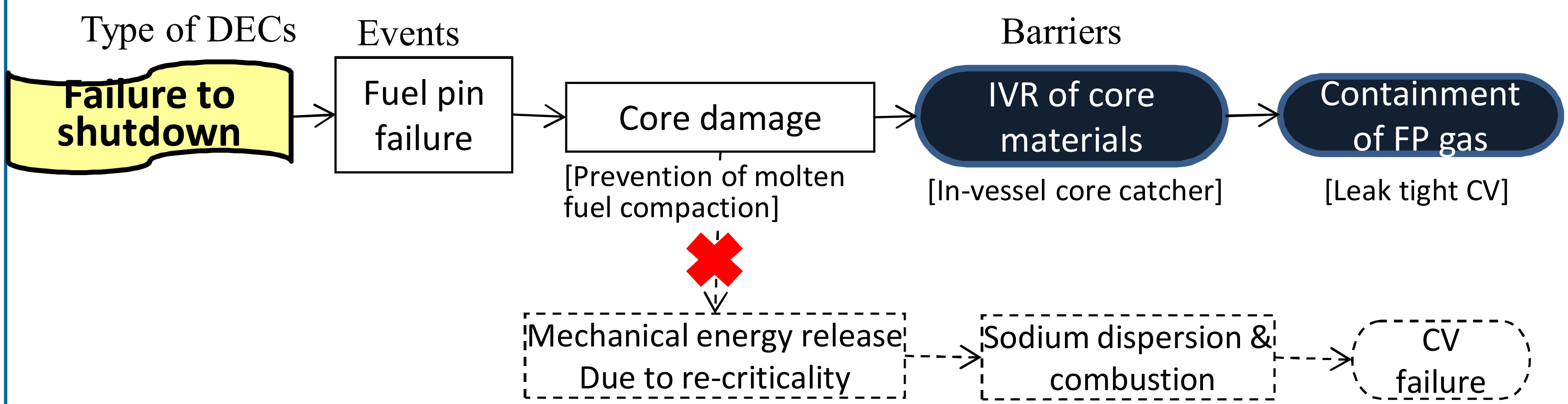




ATWS: Anticipated Transient Without Scram, LOHRS: Loss Off Heat Removal System

Measures for ATWS

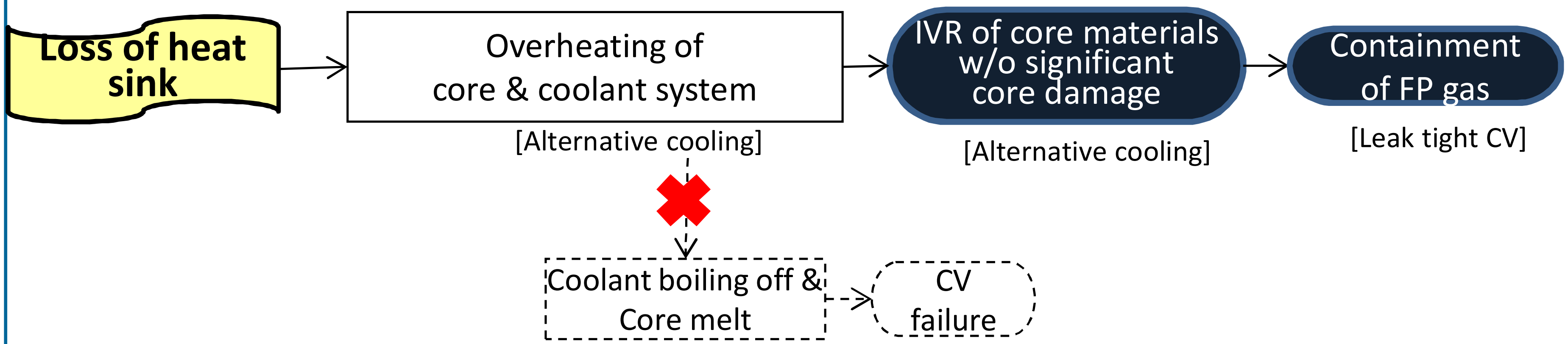
- In-balance of power and cooling might causes core damage within a shorter time period.
- Severe mechanical energy release might appear in the core damage situations.
- Prevention: Passive shutdown mechanism
- Mitigation: Prevention of severe mechanical energy release and In-Vessel Retention [IVR]



[ ]; Design measures, IVR; In-Vessel Retention, CV; Containment Vessel, FP; Fission Product, SCCV; Steel plate reinforced concrete CV

Measures for LOHRS

- Sufficient time margin to make recovery action for failed DHRSs and/or implementation of back up cooling measures.
- Core melt situations might cause significant thermal loads not to cope with on the containment. Such situations shall be practically eliminated by design measures for enhancing core cooling capability.
- Essential requirements regardless of the core condition, intact or degraded, are to fill the core with sodium and to circulate coolant to the heat sink.



[ ]; Design measures, IVR; In-Vessel Retention, CV; Containment Vessel, FP; Fission Product, SCCV; Steel plate reinforced concrete CV

Candidates of Situations Practically Eliminated

Specific situations which can be threat to the containment and for which the containment failure is hard to be prevented shall be practically eliminated by design measures.

- **Abnormal reactivity insertion lead to prompt criticality (Large bubble ingress into the core, core configuration change due to beyond design basis earthquake, core displacement due to significant failure of the core support structure)**
- **Severe mechanical energy release due to coherent sodium boiling or molten fuel compaction, failure of decay heat removal from degraded core in ATWS type events**
- **Significant core damage in LOHRS type events**
- **Large scale sodium spray combustion inside the containment**
- **Hydrogen accumulation and deflagration/detonation due to sodium-concrete reaction inside the containment**
- **Containment bypass due to large scale rupture of SG tubes**
- **Fuel melt in the fuel storage system**

□ Design Measures of JSFR

- Failure to shutdown (ATWS) and abnormal reactivity insertion
- Failure to remove heat from the core (LOHRS)
- Containment

Failure to shutdown and abnormal reactivity insertion

AOO & DBA

- **Inherent reactivity feedback characteristics with negative power coefficient.**
- **Operation temperature range: sufficiently below the coolant boiling temperature**
- **The safe reactor shutdown: 2 active reactor shutdown systems**

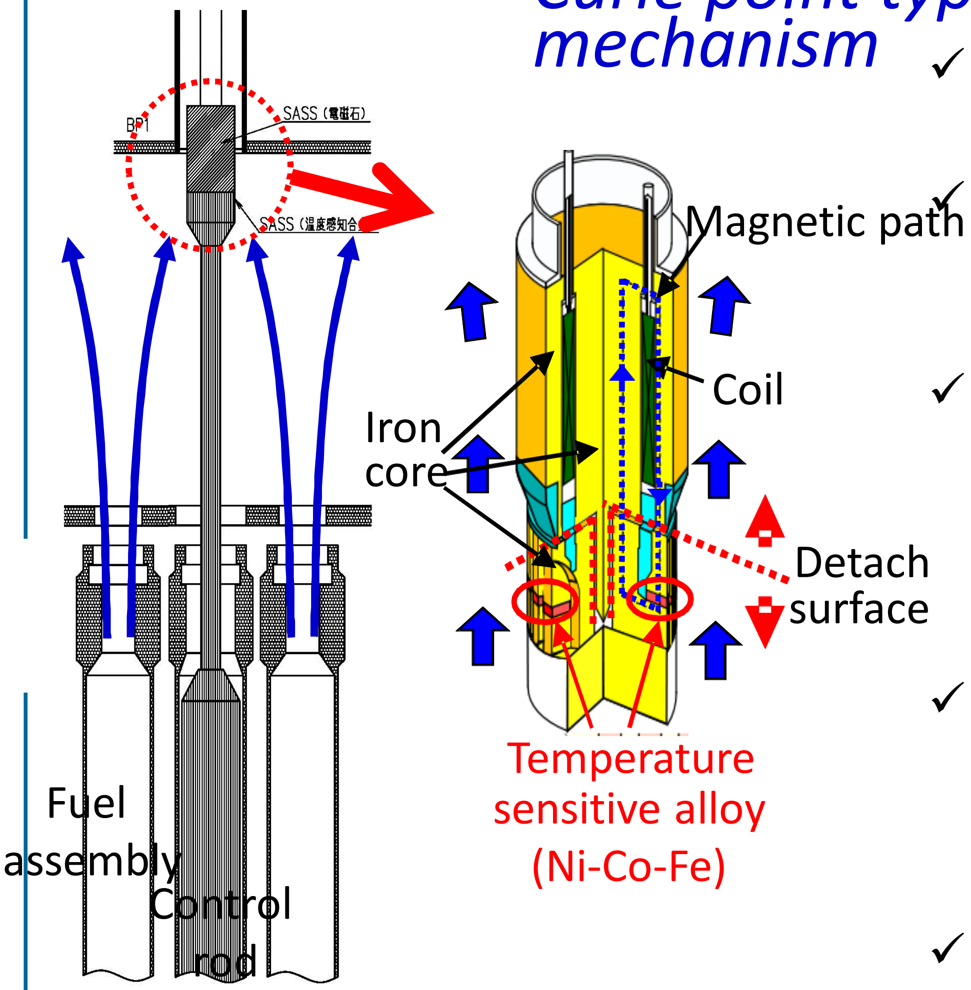
DEC

- **Passive shutdown capability : SASS (Self Actuated Shutdown System)**
- **Mitigation of core damage:**
  - **Prevention of severe mechanical energy release: limitation of core sodium void worth and molten fuel discharge capability by FAIDUS (Fuel Assembly with Inner Duct Structure)**
  - **In-Vessel Retention: in-vessel core catcher**

Practically eliminated

- **Causes of rapid positive reactivity insertion : e.g., significant core configuration changes are prevented by the stiff core restraint and support structures.**

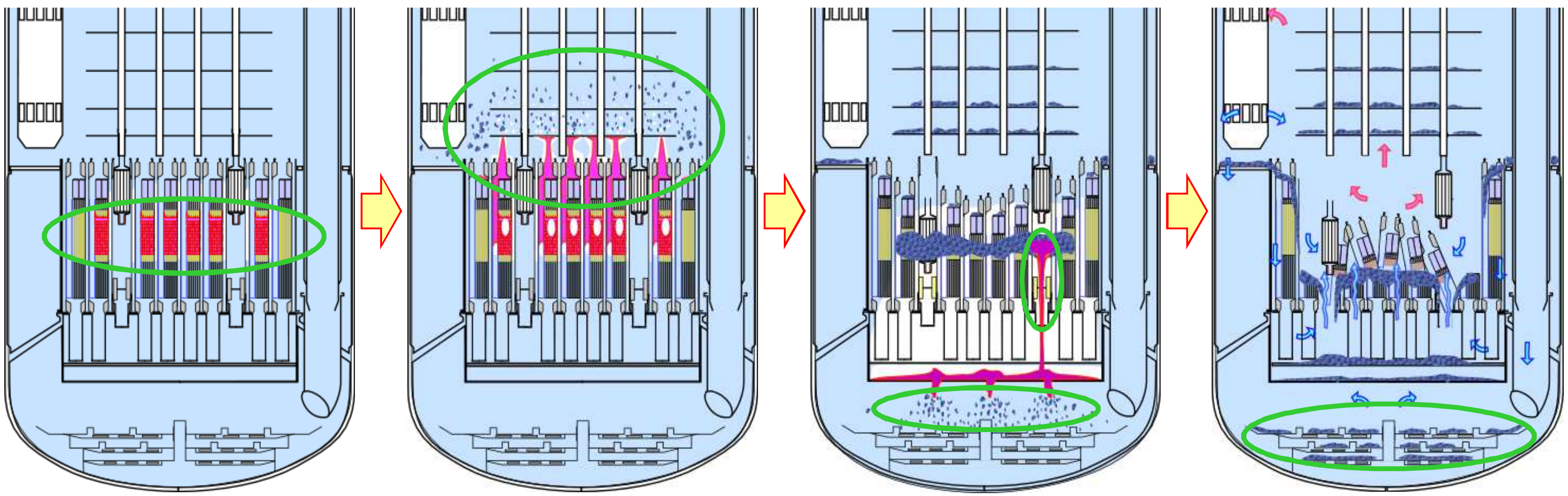
Self Actuated Shutdown System (SASS)



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.

Mitigation of core damage



Phases	*Initiating phase*	*Early-discharge phase*	*Material-relocation phase*	*Heat-removal phase*
Required Conditions	No severe energetics caused by coolant voiding	No severe energetics caused by large-scale fuel compaction in molten-core pool	No severe energetics caused by the motion of core-remaining materials, & no thermal failure of RV caused by the contact of discharged molten materials	No failure of stable cooling avoiding the excess of coolable-limitation thickness in debris bed
Design Measures	Suppression of maximum void worth less than 6 $	Installation of FAIDUS for the molten-fuel discharge before the formation of molten-core pool	Enhancement of fuel discharge through primary CRGT, & design optimization of inlet/lower plenums for quenching discharged molten materials	Installation of multi-layer debris tray to enhance the debris dispersion and to suppress the debris thickness below coolable limitation

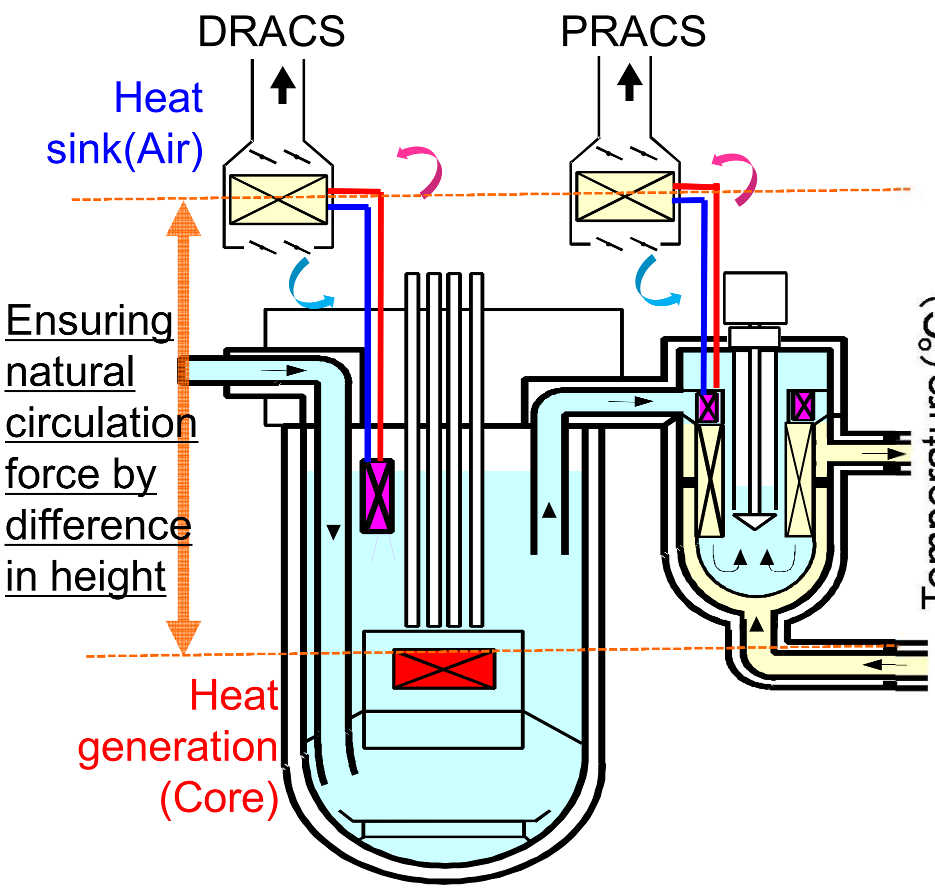
Failure to remove heat from the core

Since various measures can be used during the longer time period by the core melt, the design measures shall be such that significant core damage is practically eliminated.

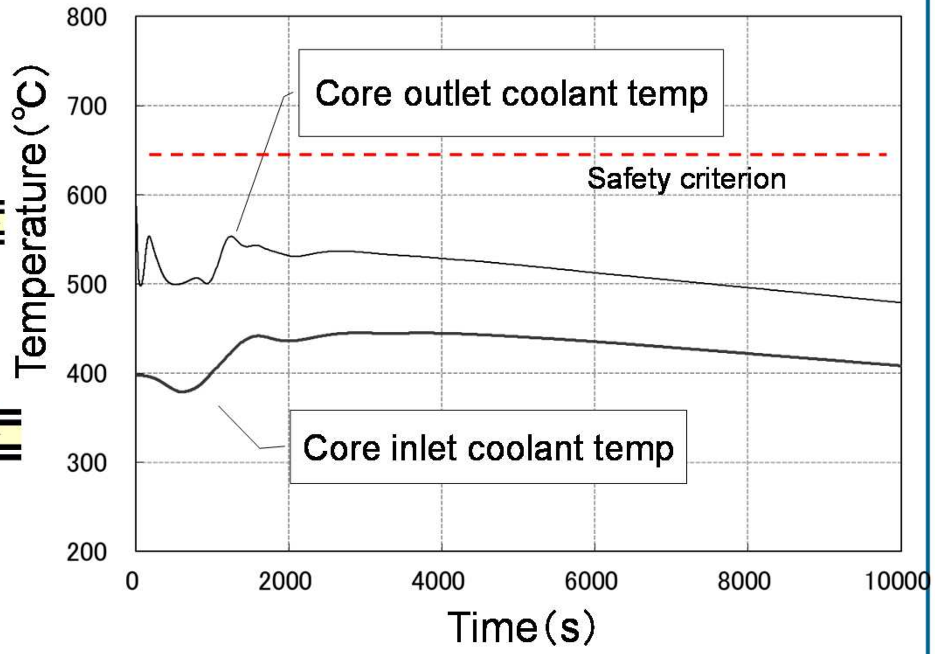
- Natural circulation DHR for the decay heat transport to the atmospheric air
  - Hardly affected by tsunami and flooding
  - Available in case of loss of AC power
  - Reinforcement of air stacks for strong wind, physical barriers and separation for external missiles
  - Accident management: manual adjusting the damper opening to maintain the cooling performance even under DC power depletion for instrumentation and control
- Alternative cooling measures: gas cooling of the water side of steam generators, additional cooling circuit to the sea water

Failure to remove heat from the core

- 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.
- Available in case of long-term loss of AC power, sever tsunami and flooding

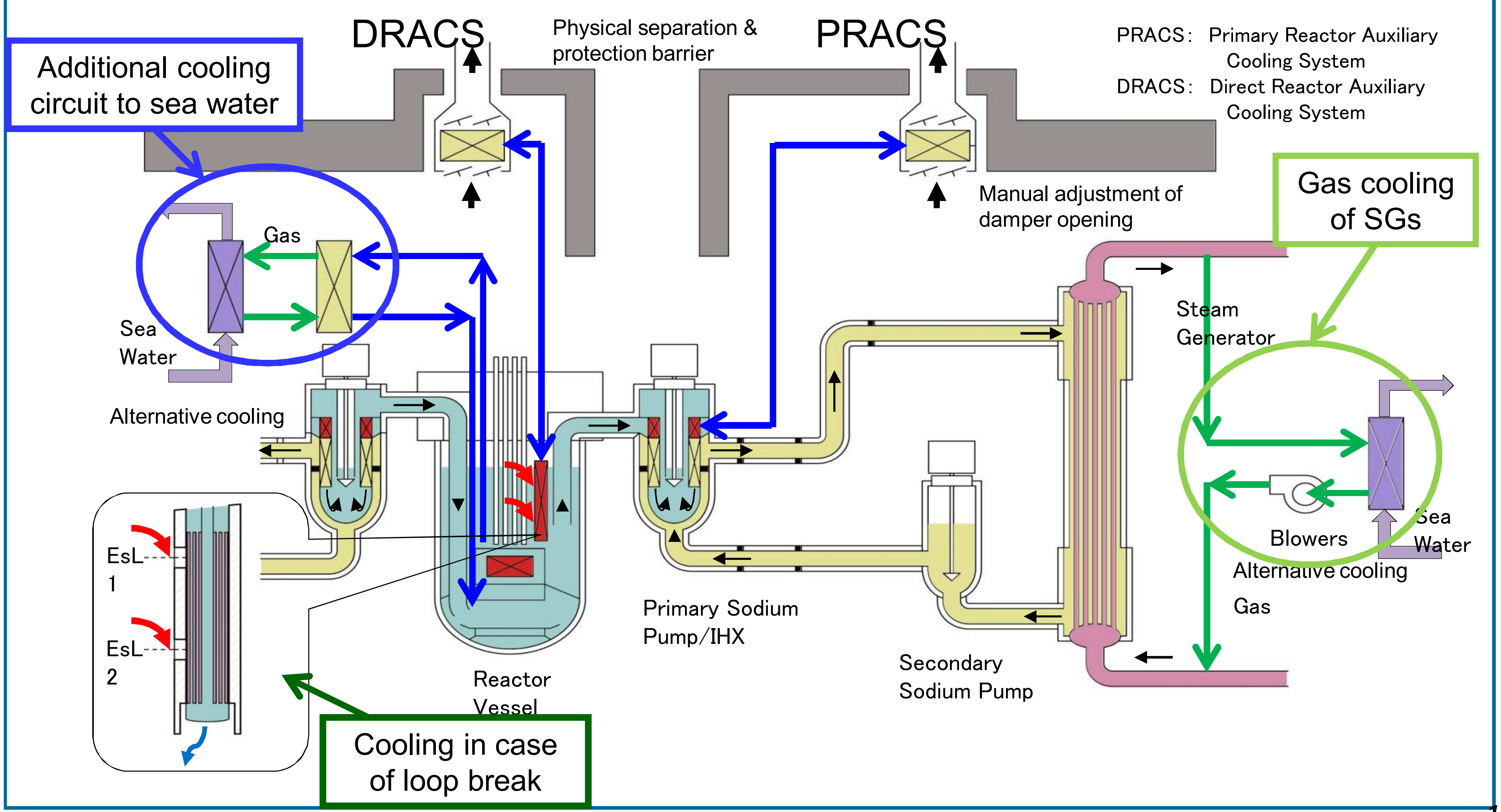


PRACS : Primary Reactor Auxiliary Cooling System
DRACS : Direct Reactor Auxiliary Cooling System



Failure to remove heat from the core

Example of alternative cooling

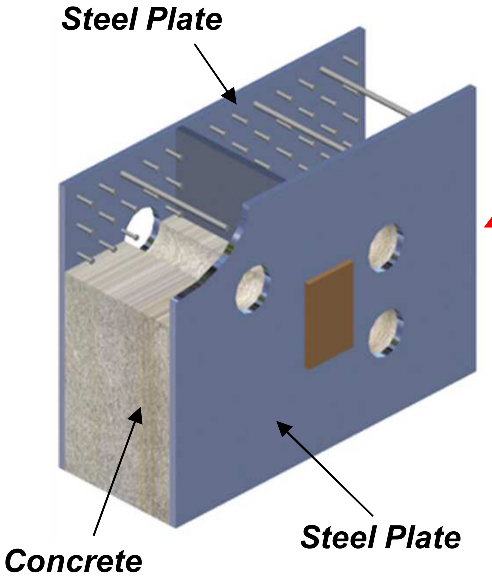


Containment

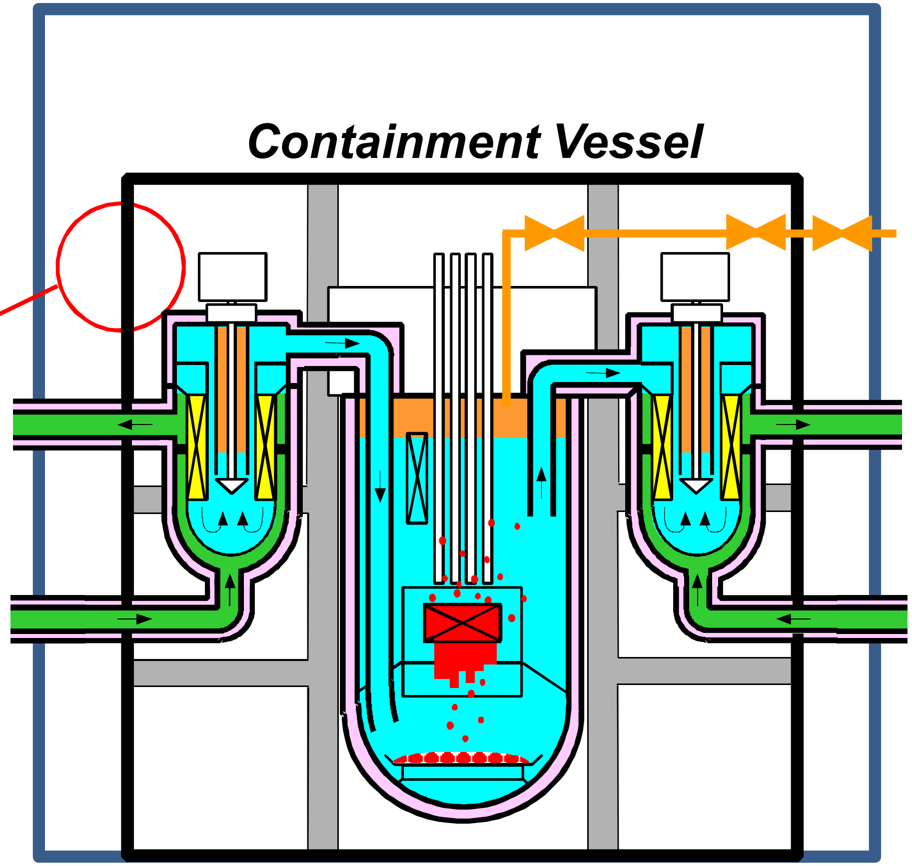
- Design measures to practically eliminate the following situations are considered.
  - mechanical energy release as a consequence of recriticality
  - deflagration/detonation of accumulated hydrogen induced by fuel debris-concrete interaction or sodium-concrete reaction
  - large-scale sodium leak and fire
- Prevention of mechanical energy release and fuel debris-concrete interaction : prevention of severe recriticality and IVR
- Prevent of large-scale sodium leak and fire, sodium-concrete reaction : double boundary concept, inertization
- Load condition: decay heat from the gaseous and volatile fission products dispersed in the containment vessel, and latent heat from leaked sodium.

Containment

- The JSFR reactor building is steel-plate reinforced concrete structure, and the section designated for primary coolant system is designed as containment vessel .



Steel-plate reinforced concrete structure



Conclusion

Safety Design Approach for JSFR

- Based on the safety design criteria for Generation-IV SFR
- DECs, Situations practically eliminated and related design measures are identified and selected with due consideration of the safety features of SFR and the lessons learned from the TEPCO's Fukushima Dai-ichi nuclear power plants accident

Safety Design Concept of JSFR

- For failure to shutdown: Passive shutdown capability, Mitigation of core damage (Prevention of severe mechanical energy release, In-Vessel Retention)
- For failure to remove heat: Prevention of significant core damage (Natural circulation DHR, Alternative cooling measures)
- Containment: Prevention of sever dynamic loads by design measures (IVR, double boundary concept, inertization)