Safety design approach for JSFR featuring fuel material characteristics (Oxide and Metal Fuel)

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Introduction

Background

•Feasibility study on commercialized fast reactor cycle systems (F/S) : 1999-2005

•Selected concept for FaCT; JSFR (SFR with MOX fuel core) + advanced aqueous reprocessing and simplified-pellet fuel fabrication

•SFR with metal fuel core + metal electrolysis reprocessing and injection casting fuel fabrication was selected as the alternative.

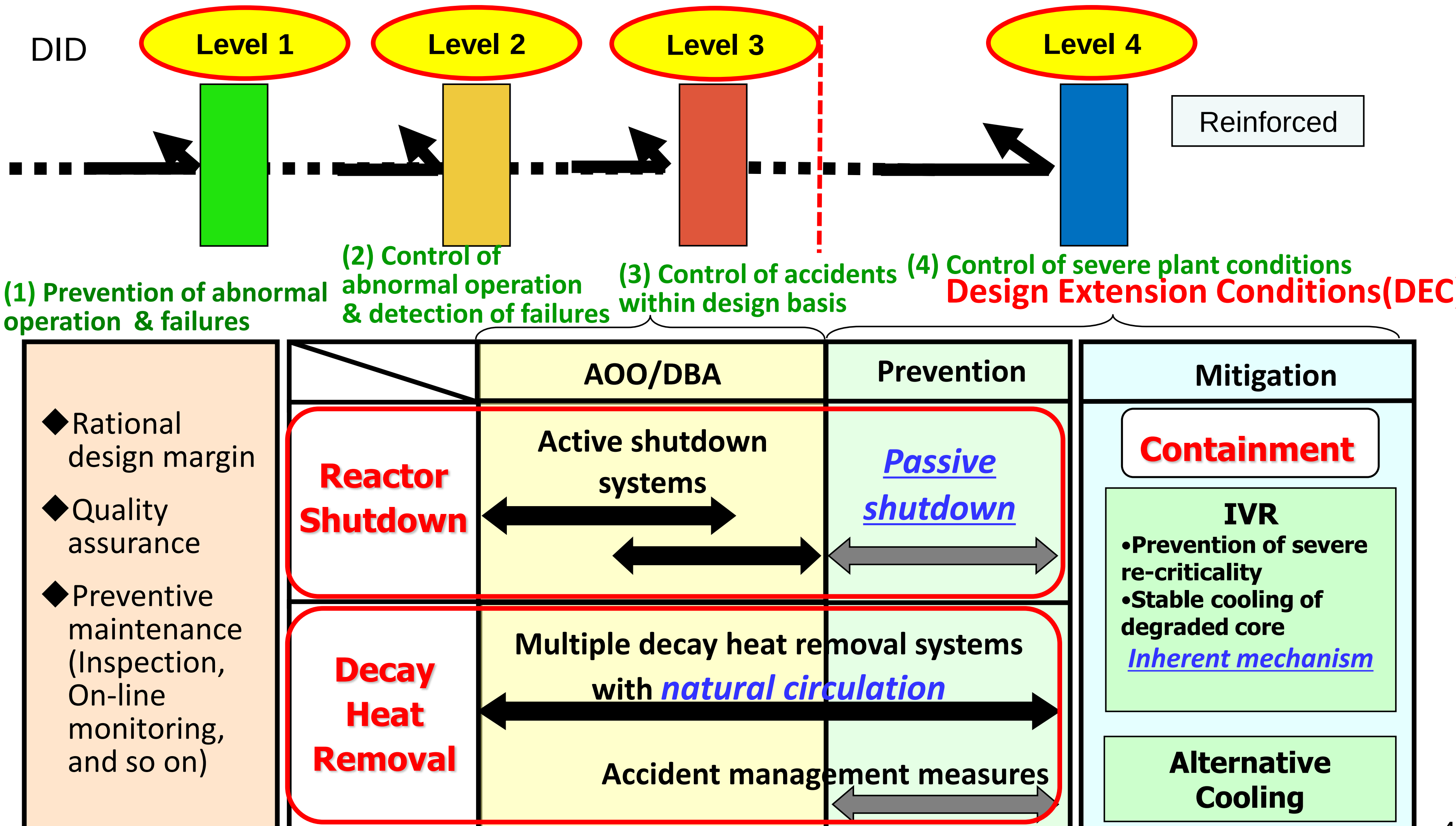
Focal point

•Safety design shall utilize the characteristics of materials such as oxide fuel and metal fuel.

•Feasibility of metal fuel for JSFR safety design approach is discussed in this presentation.

Safety design approach of JSFR

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



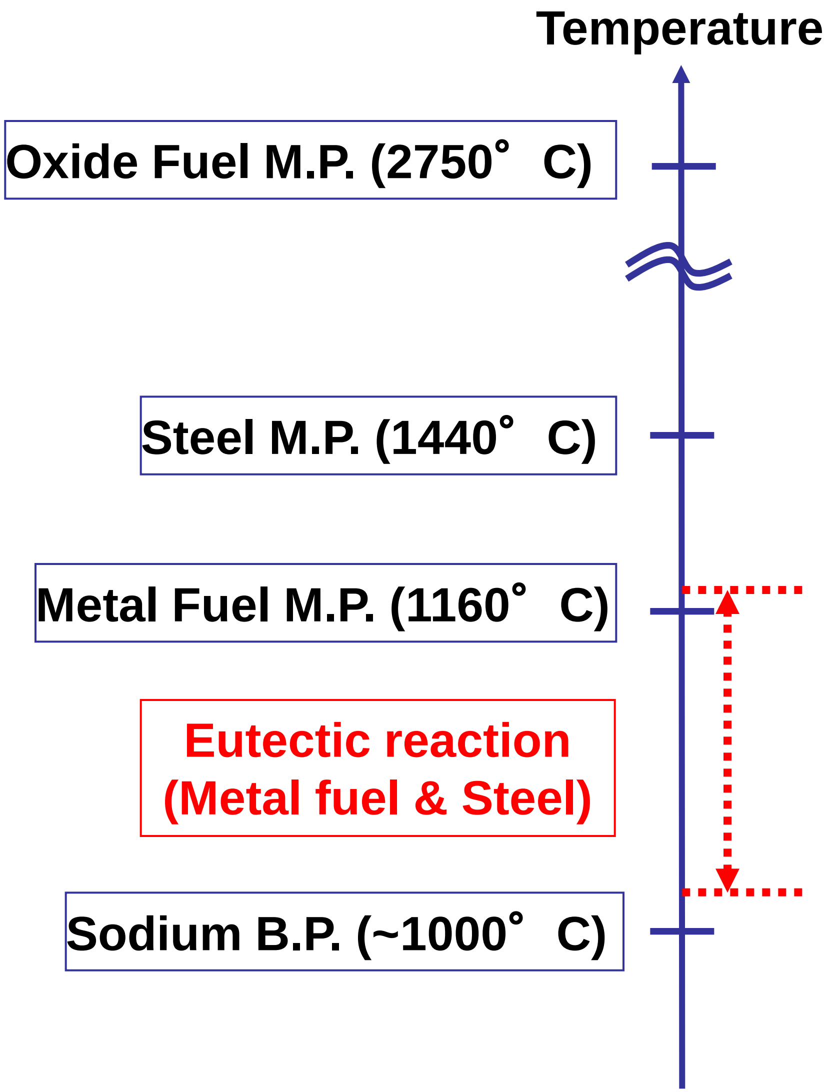
Safety aspects of metal fuel (1/2)

- Higher thermal conductivity
- Lower melting point
- Operated in lower temperature range
- Lower stored energy

		Oxide Fuel	Metal Fuel
Composition		UO_2-20% PuO_2	U-15% Pu-10% Zr
Density	g/cm^3	10.6	15.8
Thermal Conductivity	W/cm/° C	0.023	0.22
Specific Heat	J/g/° C	0.38	0.20
Thermal Expansion Coefficient	/° C	$1.2X10^{-5}$	$2.0X10^{-5}$
Melting Point	° C	2750	1160

Ref: J. Cahalan, R. Wigeland, G. Friedel, G. Kussmaul, J. Moreau, M. Perks, P. Royl, “Performance of metal and oxide fuels during accidents in a large liquid metal cooled reactor”, International Fast Reactor Safety Meeting, Snowbird, Utah, US, 1990

Safety aspects of metal fuel (2/2)



- Both of oxide fuel and metal fuel are operated far below the melting point.
- For metal fuel, fuel surface temperature is limited in order to prevent liquefaction at fuel-cladding tube interface.
- Eutectic reaction should be limited in the accidents.

Safety Design Measures

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**
  - ✓ **In-Vessel Retention: in-vessel core catcher**

Evaluation of AOO & DBA (1/3)

Design options for this study

	Large Oxide Core (compact type)	Medium Oxide Core (high conversion type)	Large Metal Core (compact type)
Plant parameters			
Power output	1500MWe / 3570MWt	750MWe / 1785MWt	1500MWe / 3750MWt
Primary coolant temperature	550° C / 395° C	550° C / 395° C	505° C / 350° C
DHRS	PRACS×2 + DRACS×1	PRACS×2 + DRACS×1	IRACS×2 + DRACS×1
Fuel pin conditions			
Fuel pin diameter	8.8mm	10.4mm	8.5mm
Fissile length	800mm	1000mm	900mm
Maximum linear power	420W/cm	420W/cm	470W/cm
Maximum cladding temperature	700° C	700° C	650° C
Maximum fuel temperature	~2200° C	~2200° C	930° C
Reactivity coefficients (at EOEC)			
Doppler coefficient	-4.7E-3 Tdk/dT	-5.3E-3 Tdk/dT	-4.1E-3 Tdk/dT
Coolant temperature coefficient	5.2E-6 ⊿k/kk'/° C	5.1E-6 ⊿ k/kk'/° C	10.5E-6 ⊿k/kk'/° C

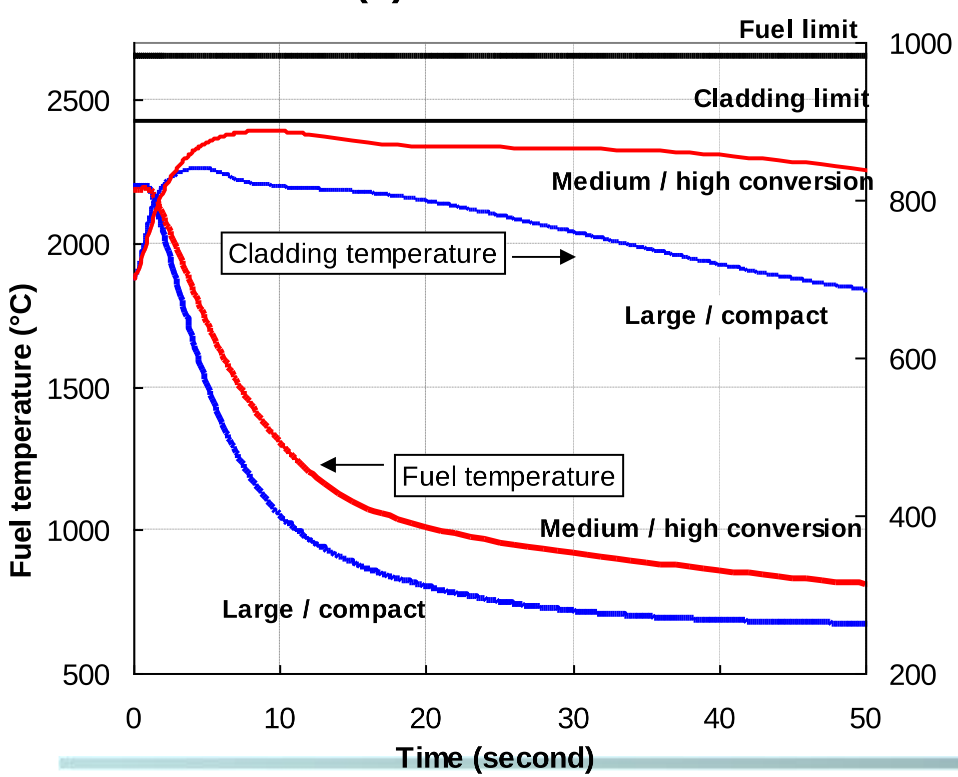
Evaluation of AOO & DBA (2/3)

Loss-of-flow type event； Primary pump stick

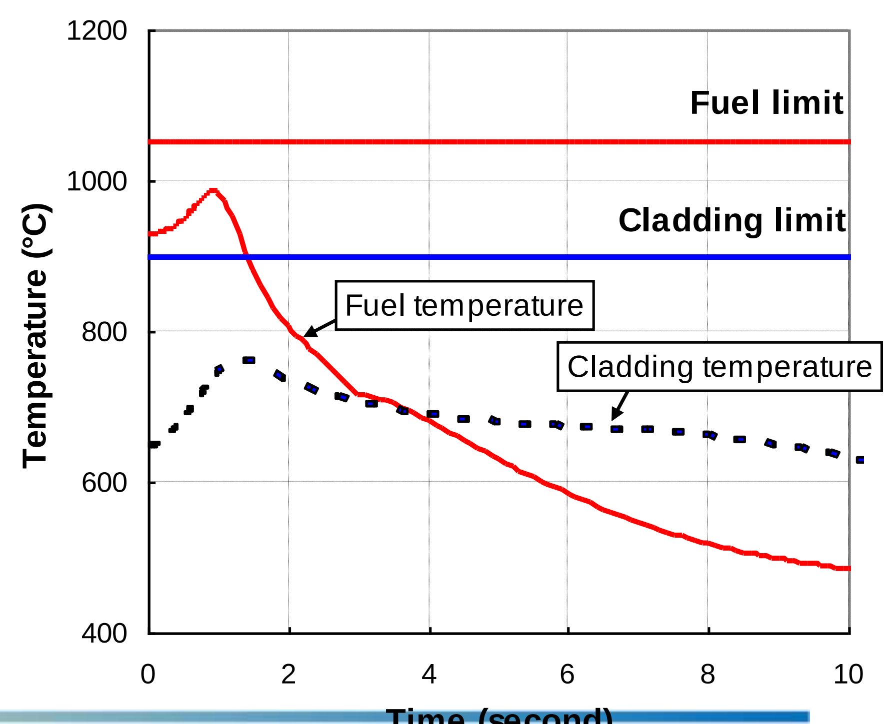
Conditions

- ◆Scram signal: low primary pump speed (80%)
- ◆Halving time of the primary flow rate : 5.5 seconds

(a) Oxide Core



(b) Metal Core

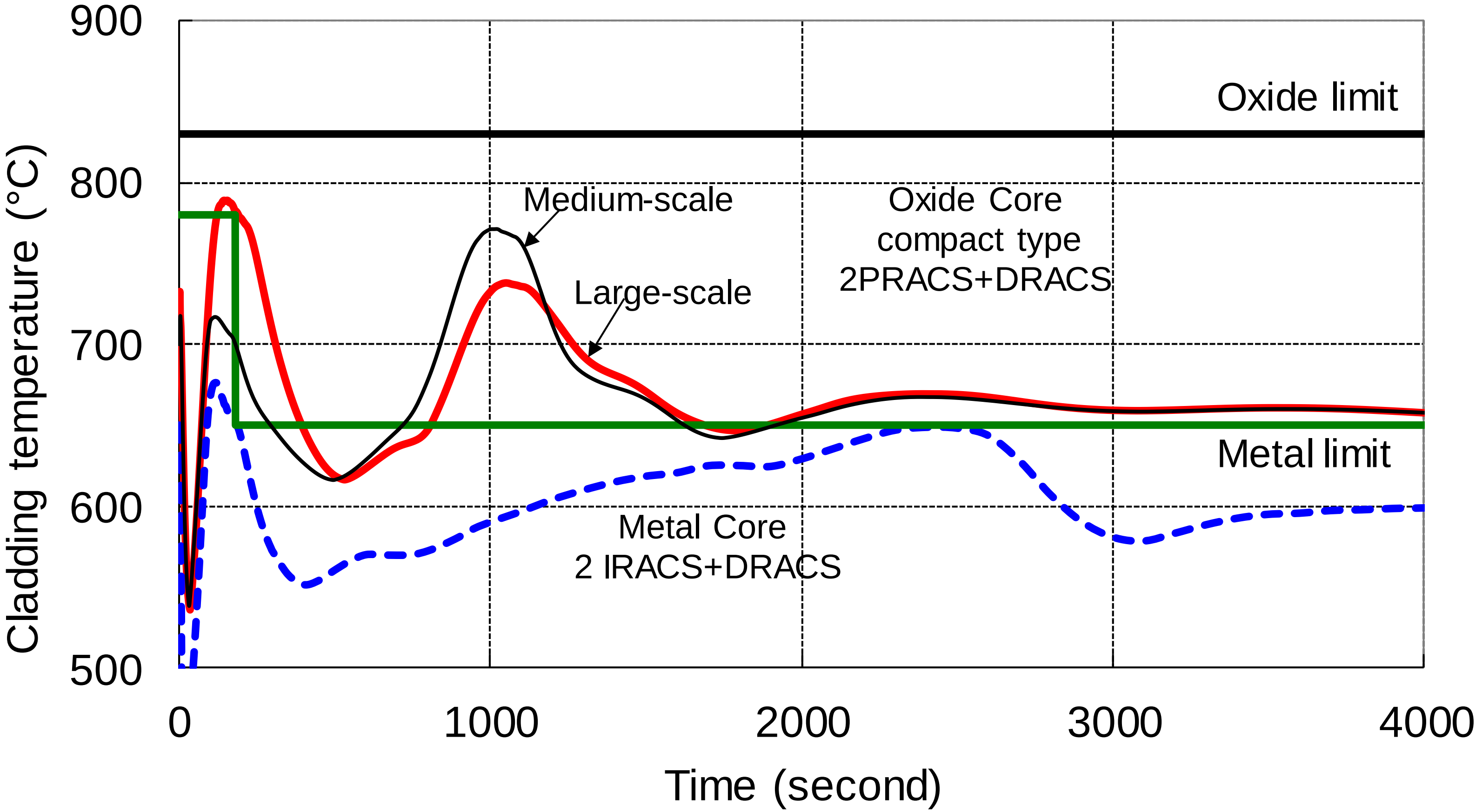


Evaluation of AOO & DBA (3/3)

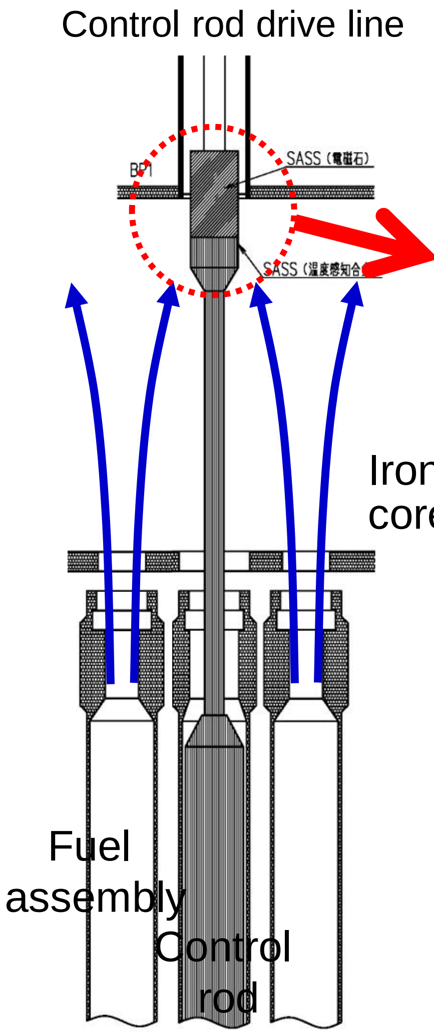
Decay heat removal (Loss of offsite power)

Conditions

◆Scram signal: Low voltage of station power supply (65%)

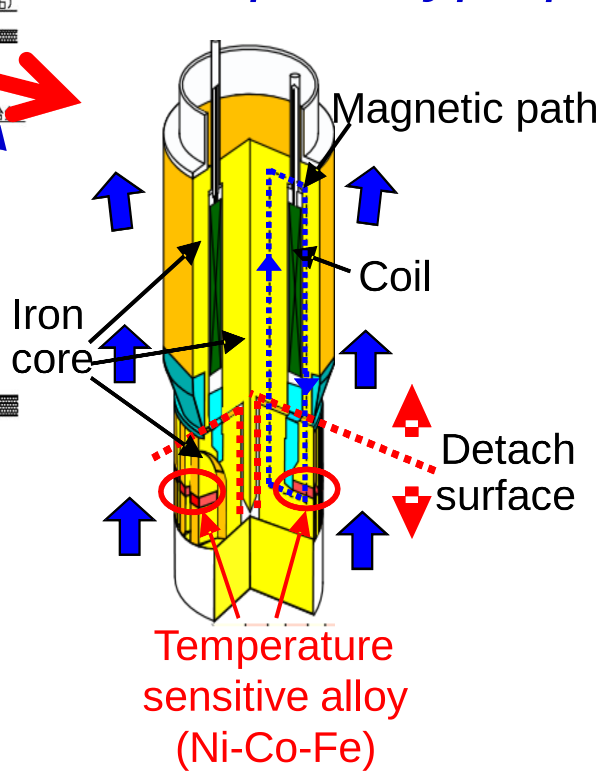


Passive shutdown capability for DEC



Self Actuated Shutdown System (SASS)

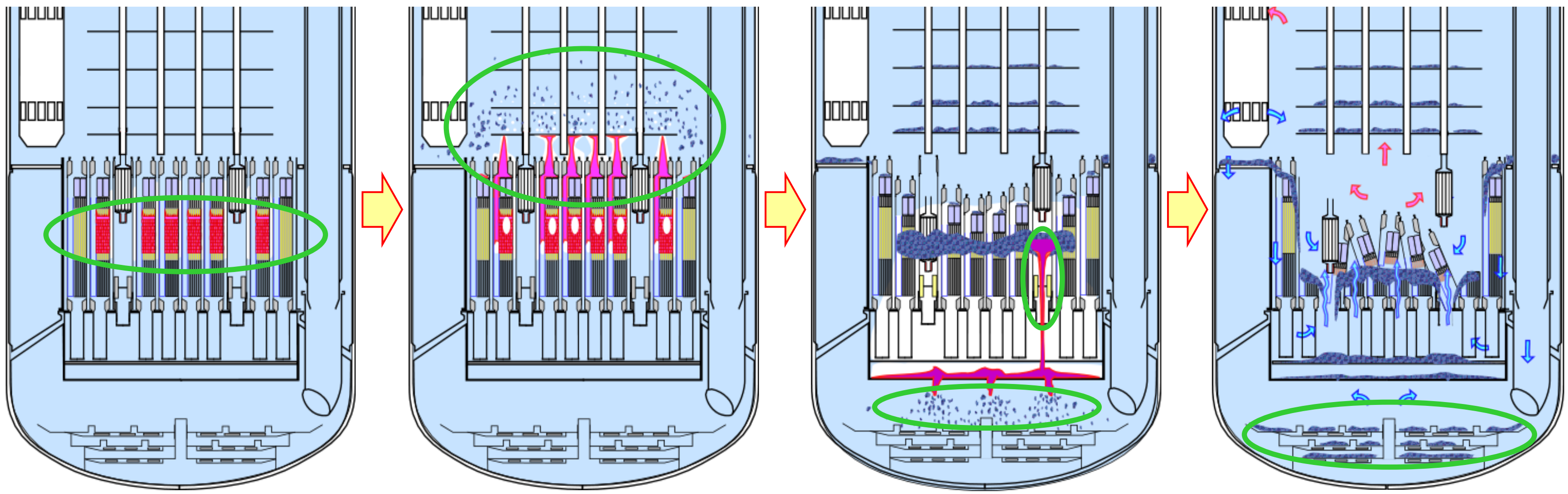
Curie point type passive CR insertion mechanism



- SASS will be feasible both for oxide fuel and metal fuel.
- Activation temperature should be adjusted according to the core outlet coolant temperature.

Mitigation of core damage for DEC

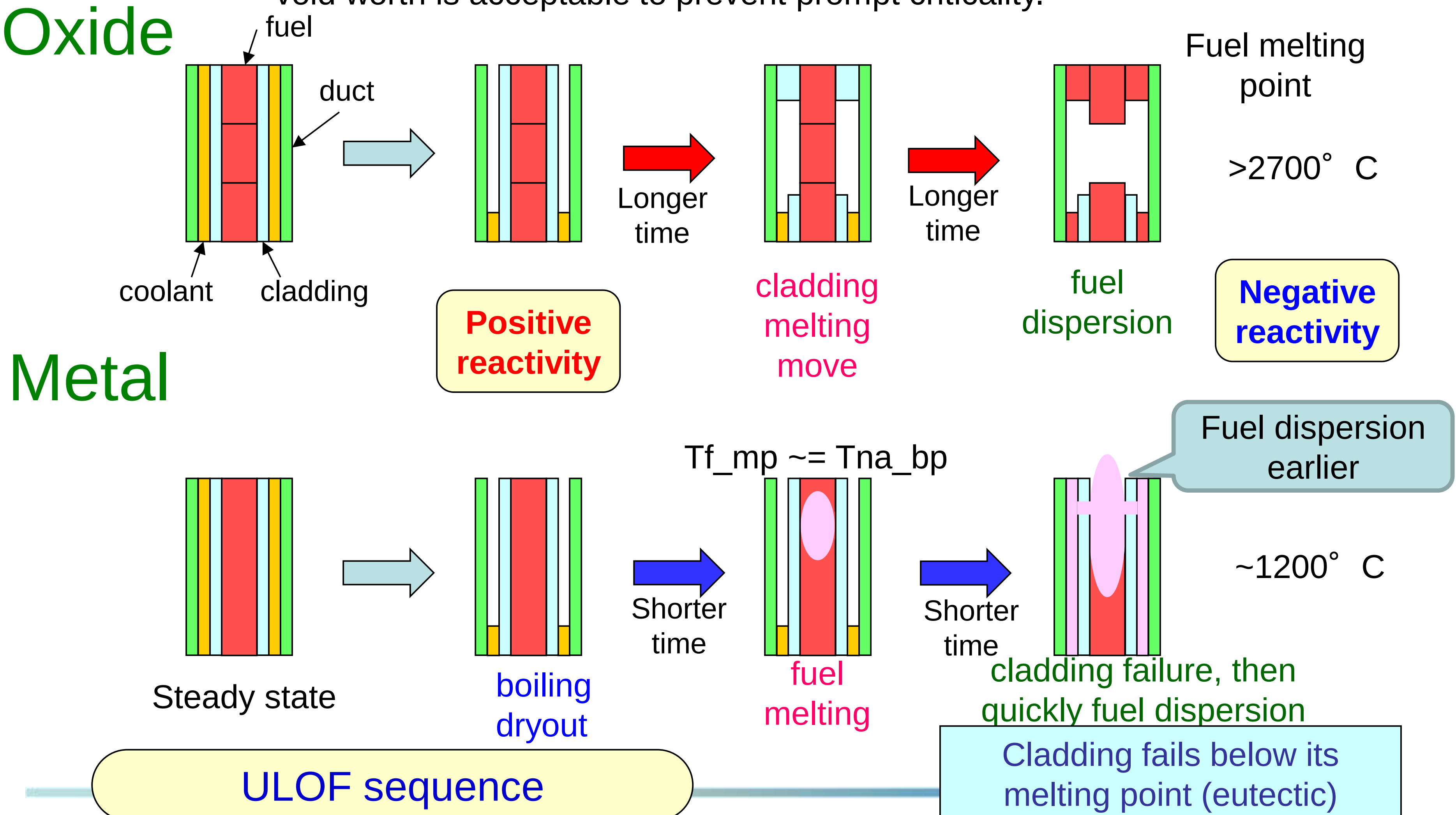
IVR concept for ULOF: Unprotected Loss of Flow (Oxide Fuel)



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

Fuel Failure Progression Differences

- For both case, negative reactivity due to fuel dispersion can overcome positive reactivity due to sodium boiling.
- For metal fuel case, since the fuel dispersion occurs earlier, larger sodium void worth is acceptable to prevent prompt criticality.



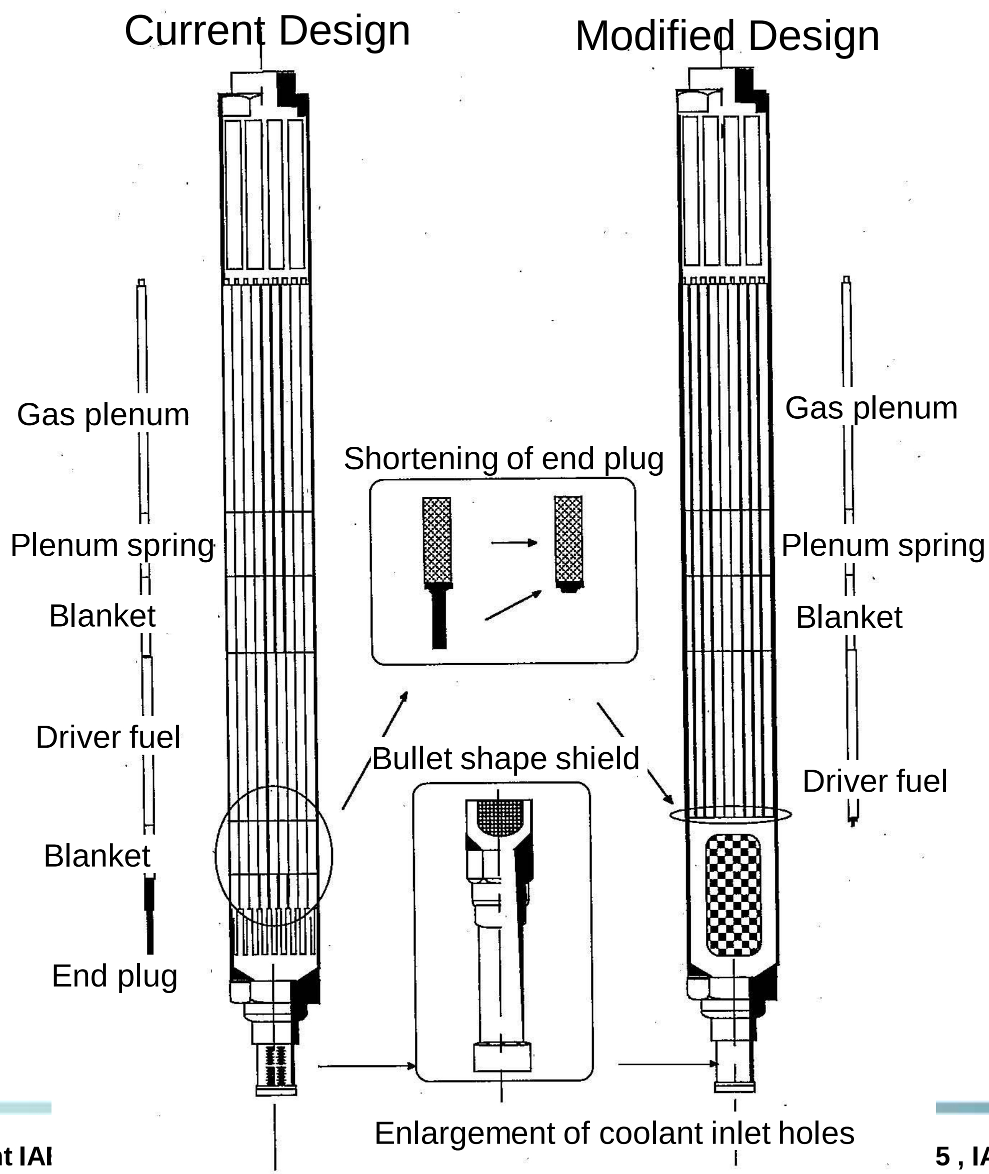
Mitigation measures for metal fuel core

IVR: In Vessel Retention

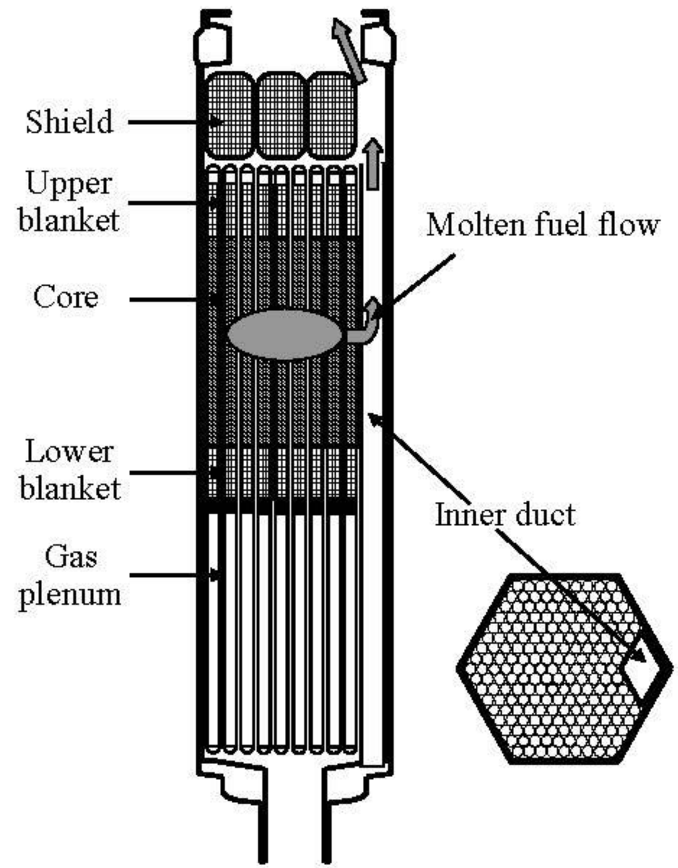
- Initiating phase
  - Limit sodium void worth : less than 8$ (cf. 6$ for oxide)
- Transition phase
  - Molten fuel discharge; ABLE (Axial BLanket fuel Elimination) concept, which shortens the length of lower axial blanket (cf. FAIDUS for oxide)
- Post-accident material relocation and heat removal phase
  - In-vessel core catcher (Protection against eutectic reaction)

Molten fuel discharge to prevent prompt criticality

For metal fuel; ABLE



For oxide fuel; FAIDUS



Concluding Remarks

- Safety design shall utilize the characteristics of materials such as oxide fuel and metal fuel.
  – Characteristics of metal fuel; higher thermal conductivity, lower melting point, lower stored energy, eutectic reaction

- Metal fuel is feasible for JSFR.
  – For AOO & DBA, active reactor shutdown and natural circulation decay heat removal
  – For DEC, passive reactor shutdown, IVR for mitigation of core damage