Status of
“Safety Approach and Design Conditions SDG”

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Hierarchy of Safety Standards

Safety Fundamentals

e.g. IAEA SF-1: Fundamental Safety Principles

Safety Requirements

e.g. IAEA SSR 2/1*:
Safety of Nuclear Power Plants: Design

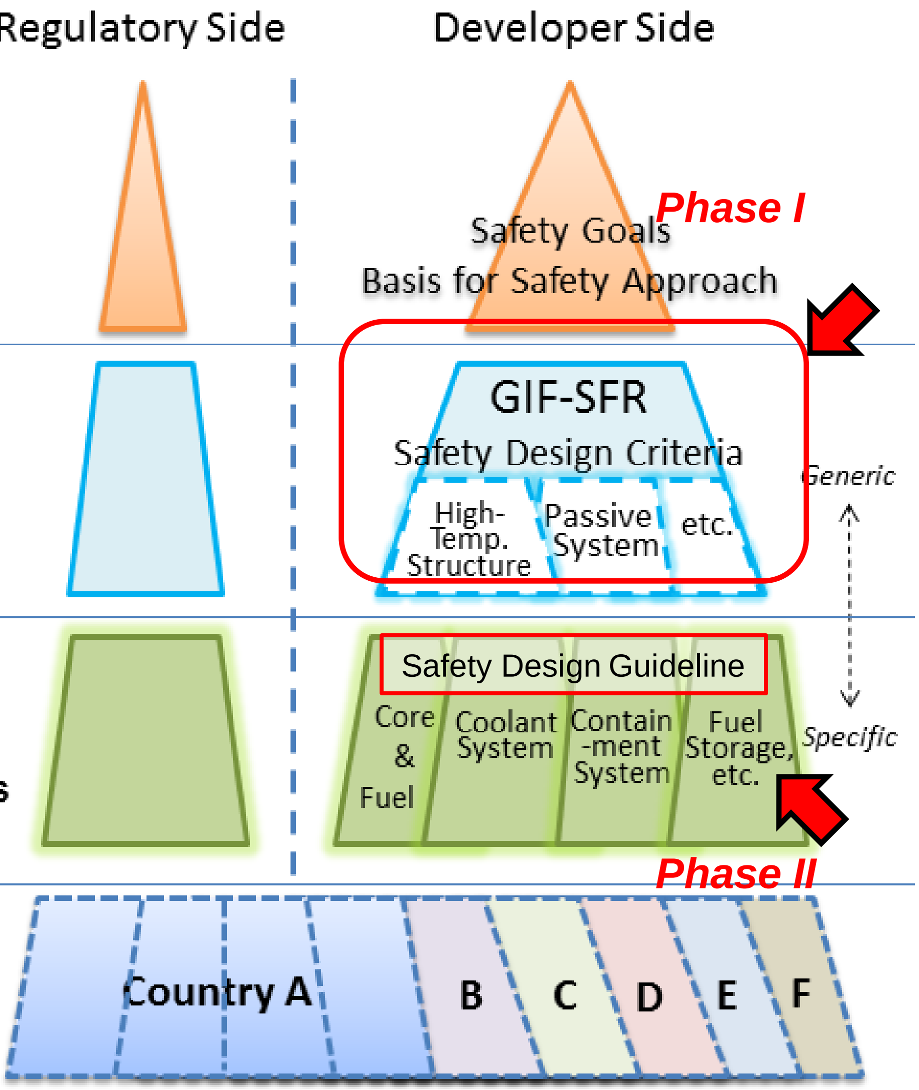
Safety Guides

e.g. IAEA NS-G-1.9*:
Design of the Reactor Coolant System and Associated Systems in Nuclear Power Plants

*These are for Light Water Reactors; but not for Gen-IV reactor systems.

Codes and Standards

Domestic Codes & Standards



Regulatory Side

Developer Side

Phase I

Safety Goals

Basis for Safety Approach

GIF-SFR

Safety Design Criteria

High-Temp. Structure

Passive System

etc.

Generic

Specific

Safety Design Guideline

Core & Fuel

Coolant System

Contain-ment System

Fuel Storage, etc.

Phase II

Country A

B

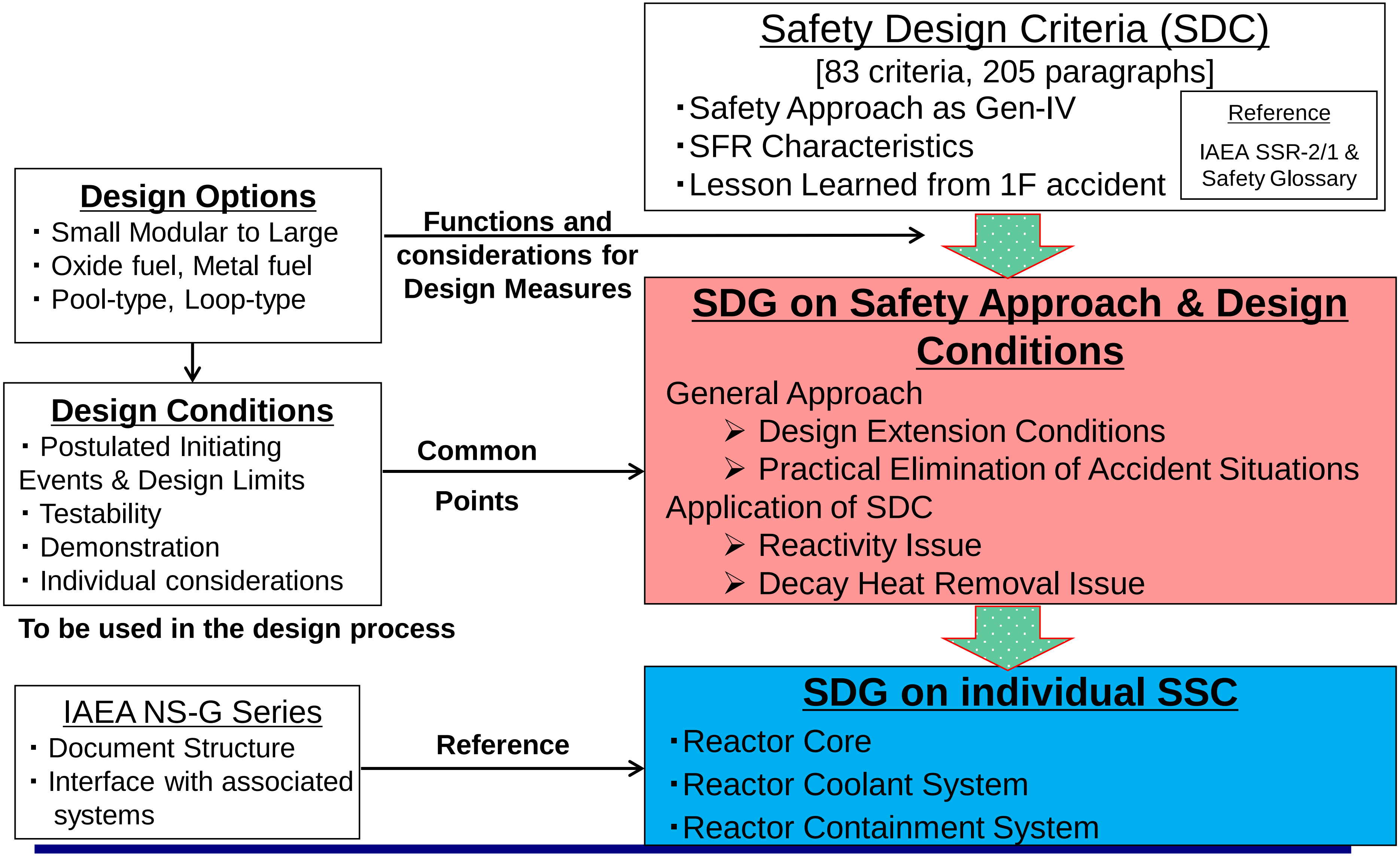
C

D

E

F

Development of SDG



Safety Design Criteria (SDC)

[83 criteria, 205 paragraphs]

- Safety Approach as Gen-IV
- SFR Characteristics
- Lesson Learned from 1F accident

Reference

IAEA SSR-2/1 &
Safety Glossary

Design Options

- Small Modular to Large
- Oxide fuel, Metal fuel
- Pool-type, Loop-type

Functions and considerations for Design Measures

Design Conditions

- Postulated Initiating Events & Design Limits
- Testability
- Demonstration
- Individual considerations

Common Points

SDG on Safety Approach & Design Conditions

General Approach

- Design Extension Conditions
- Practical Elimination of Accident Situations

Application of SDC

- Reactivity Issue
- Decay Heat Removal Issue

To be used in the design process

IAEA NS-G Series

- Document Structure
- Interface with associated systems

Reference

SDG on individual SSC

- Reactor Core
- Reactor Coolant System
- Reactor Containment System

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Table of contents (Draft)(3/3)

4. GUIDELINES FOR APPLICATION OF SAFETY DESIGN CRITERIA

- **4.1. Reactivity Issue**
  - **4.1.1. Prevention of Core Damage**
  - **4.1.2. Mitigation of Core Damage**
- **4.2. Decay Heat Removal Issue**
  - **4.2.1. Prevention of Core Uncovering**
  - **4.2.2. Decay Heat Removal for DBA**
  - **4.2.3. Decay Heat Removal for DEC**
- 4.3. Postulated Initiating Events and Design Limits
  - 4.3.1. AOO and DBA
  - 4.3.2. DEC
- 4.4. Testability
- 4.5. Demonstration

5. CLARIFICATION AND QUANTIFICATION OF TECHNICAL POINTS OF SAFETY DESIGN CRITERIA

- **5.1. Consideration for SFR Reactivity Characteristics**

Points of Safety Approach and Design Conditions SDG

Design considerations (Draft) are summarized.

- ***Exploiting SFR Characteristics to Enhance Safety***
  - ***Passive/Inherent reactivity control***
  - ***passive decay heat removal***
  - ***In-Vessel Retention***
- ***Practical Elimination of Accident Situations***
- ***Quantification of requirement on reactivity characteristics***

Exploiting SFR Characteristics to Enhance Safety

- ***Passive/Inherent safety for DEC***
  - ***On reactivity***
    - ***Inherent reactivity feedback to reduce the power as core temperatures rise or***
    - ***Passive mechanism are applicable for shutdown systems, such as SASS, HSR, and GEM***
  - ***On decay heat removal***
    - ***Natural circulation of single phase sodium coolant***
    - ***can be placed in different locations for enhancing diversity***

Design considerations for Passive/Inherent reactivity control (1/2)

- ***Passive reactor shutdown and/or inherent power reduction capability** should be provided in case of active reactor shutdown systems failure during an AOO, to avoid exceeding design limits for DEC. This should be achieved by passive shutdown mechanism or inherent reactivity feedback or their combination.*
  - ***Passive shutdown mechanism** should be designed to provide sufficient negative reactivity within allowable time. Passive shutdown mechanism should be designed to activate and operate responding directly to natural phenomena (such as increased coolant temperature or reduced coolant pressure) without any active signals, activation mechanisms and power source.*

Design considerations for Passive/Inherent reactivity control (2/2)

- ***Inherent reactivity feedback** based on total power coefficient, isothermal temperature coefficient and power/flow coefficient should be negative to reduce the core power at elevated temperatures in balance with available heat rejection capacity during ATWS. Complementary reactor shutdown measure should be provided in order to make reactor core subcritical in the long term.*

Design considerations for passive decay heat removal

- ***In order to enhance the reliability of decay heat removal function and to maintain the function under long term loss of all AC power, natural circulation capability should be properly incorporated into the decay heat removal system.***
- ***Reactor cooling system should be designed to have adequate height difference between core and heat exchangers, and adequate pressure drop for coolant circulation for enhancing natural circulation capability.***
- ***Use of active devices and the instrumentation and control should be limited. They should have sufficient grace time in both automatic and manual operation capability.***

Exploiting SFR Characteristics to Enhance Safety

- ***In-Vessel Retention***
  - ***In the course of core degradation during unprotected transients, measures should be provided to prevent prompt criticality***
  - ***Reactor coolant boundary should maintain the boundary function against pressure load including fuel-coolant interaction***
  - ***Measures should be provided for ensuring long term cooling of core materials inside the reactor vessel under sub-critical condition***

Design considerations for mitigation of core damage

Design measures against core damage should be implemented for the following accident phases in unprotected transients.

- ***Initiating phase; up to inter-subassembly material motion on set***
- ***Transition phase; up to establishment of stable cooling condition***
- ***Post accident heat removal; stable cooling condition for long term***

Initiating Phase

Prevent prompt criticality, i.e., $\rho_{net} < 1$dollar, due to coolant boiling and fuel failure

Positive coolant void reactivity should be overcome by negative reactivity of doppler, fuel axial expansion, molten fuel dispersal.

Transition Phase

Prevent prompt criticality due to material motion

Molten fuel discharge, absorber mixing, in-place cooling

Core material relocation to stable cooling condition

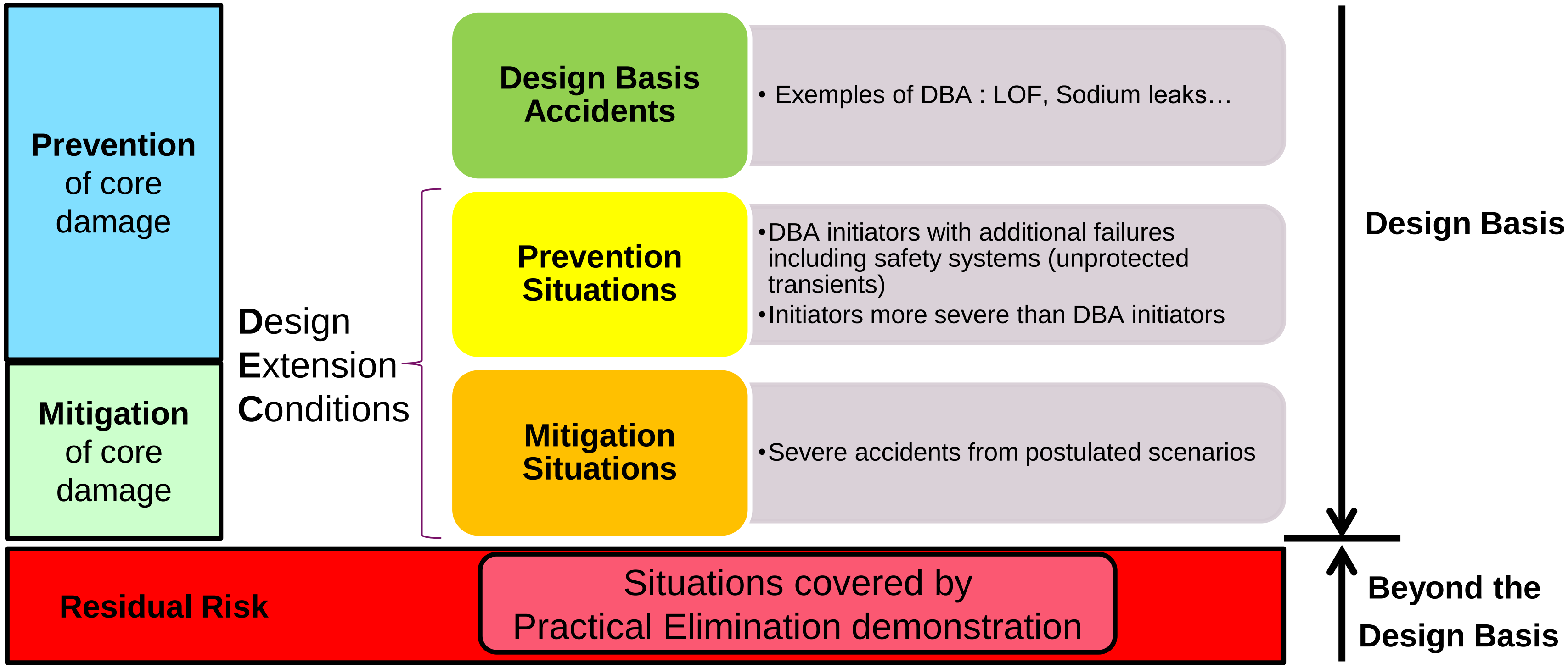
Post Accident Heat Removal

Retention of degraded core materials in coolable condition without re-criticality

Provide coolant path and heat sink for long term

Practical Elimination of Accident Situations:

•A specific situation whose consequences can lead to early or large radioactive release and which cannot be manageable by the design at acceptable economic conditions has to be practically eliminated by implementing design measures.



Prevention of core damage

Mitigation of core damage

Design **E**xtension **C**onditions

Design Basis Accidents

- Exemples of DBA : LOF, Sodium leaks…

Prevention Situations

- DBA initiators with additional failures including safety systems (unprotected transients)
- Initiators more severe than DBA initiators

Mitigation Situations

- Severe accidents from postulated scenarios

Residual Risk

Situations covered by Practical Elimination demonstration

Design Basis

Beyond the Design Basis

Practical Elimination of Accident Situations:

- ***Severe accidents with mechanical energy release higher than the containment capability***
  - *Power excursions for intact core situations*
    - *Large gas flow through the core*
    - *Large-scale core compaction*
    - *Collapse of the core support structures*
- ***Situations leading to the failure of the containment with risk of fuel damage***
  - *Complete loss of decay heat removal function that leads to core damage and failure of primary coolant boundary*
  - *Core uncovering due to sodium inventory loss*
- ***Fuel degradation in fuel storage or during when the containment may not be functional due to maintenance***
  - *Core damage during maintenance*
  - *Spent fuel melting in the storage*

Design considerations for practical elimination of complete loss of heat removal function (1/2)

- ***For DBA**, decay heat removal system is required to deal with postulated initiating events typically caused by single failure of SSC.*
- ***For DEC**, design measures are required against initiating events more severe than DBA or multiple failure of SSCs.*
- ***Proven technology** based on the design, construction and operation experience of SFRs shall be applied for the basic design of decay heat removal system.*
- ***Extension of capabilities** (e.g. additional decay heat removal system, increased capacity of heat removal, operation with natural circulation as well as forced circulation) is necessary to deal with DEC. Application of mobile power source and manual operation in case of loss of power are one of the extension of capabilities.*

Design considerations for practical elimination of complete loss of heat removal function (2/2)

- *Ensuring diversity* ***in systems is essential to improve the overall reliability, not by adding the same systems. It is required to prevent complete loss of heat removal function even under the postulation of*** *severe external hazards* ***such as earthquake, flooding, tsunami and missile that can lead to a common cause failure.***
- ***SFR should proactively utilize the*** *natural circulation capability* ***to an ultimate heat sink (atmosphere) since it is applicable and can significantly contribute to improve the reliability of heat removal capability. SFR should be able to maintain decay heat removal function even under long-term loss of power supplies by utilizing the natural circulation. The natural circulation can be used as a measure for DBA as well as for DEC.***
- ***In addition,*** *independent decay heat removal system* ***should be installed as ultimate measure. (This is additional consideration for the practical elimination of complete loss.)***
- ***It is necessary to clarify*** *all credible factors leading to loss of function* ***and to confirm that measures can overcome all of them.***
- ***Each system related to decay heat removal should be demonstrated that it can perform its function as expected.***

Quantification of requirement on reactivity characteristics

- ***For Normal operation, AOO and DBA***
  - » ***Power reactivity coefficient < 0 (Negative)***
  - » ***Reactor shutdown capability with inherent feedback > Postulated reactivity insertion***
- ***For Design Extension Condition***
  - » ***Before core damage: same as the requirement for DBA,***
    - – ***Achieved by passive measures or inherent features***
  - » ***After core damage:***
    - – ***Total reactor core reactivity < 1$ (below prompt criticality)***

  - » ***Sodium void worth can be positive as far as the above conditions are satisfied.***

General considerations for SFR reactivity characteristics (1/3)

Normal operation and DBA

- ***Reactivity feedback***
  - ***The core characteristics are commonly represented by integral effect of these reactivity coefficients, e.g., total power coefficient, isothermal temperature coefficient and power/flow coefficient.***
  - ***For normal operation, these integral coefficients are required to have certain characteristics to allow stable operation and reliable control of the reactor, such as a negative power coefficient.***
  - ***Within AOO and DBA domain, reactor shutdown by the reactor protection system determines the outcome; therefore, there are no definitive requirements related to reactivity feedback as long as design limits are not exceeded.***

General considerations for SFR reactivity characteristics (2/3)

DEC

- ***Prevention of core damage***
  - ***As long as the coolant boiling is prevented, effect of sodium void worth does not appear.***

Passive shutdown for ATWS

- ***Same as the requirement for DBA***

Inherent power reduction for ATWS

- ***Total power coefficient, isothermal temperature coefficient and power/flow coefficient should be negative.***
- ***In ULOF transient coolant temperature reactivity could pose a challenge. It should be limited within a range for which negative reactivity effects such as core radial expansion can compensate.***

General considerations for SFR reactivity characteristics (3/3)

DEC

- ***Mitigation of core damage***
  - ***Coolant phase change and material relocation of degraded core can have significant reactivity consequences, both favorable and unfavorable, depending on design choices.***
  - ***When core damage and material relocation occur, prompt criticality should be avoided in order to prevent large mechanical energy release. For this purpose, the maximum net reactivity during a transient must be limited below 1 dollar.***
  - ***Positive reactivity effects such as sodium boiling should be limited so that other negative reactivity components from Doppler effect, fuel expansion and failed fuel dispersion can overcome them during entire phases of the transients.***
  - ***Sodium void worth is usually not relevant after sodium boiling off (during transition phase), since the larger reactivity effects of molten fuel and cladding motions dominate overall reactivity.***

Concluding Remarks

- ***Safety Approach and Design Conditions SDG in final drafting stage***
  - ***Summarize general safety design approach and specific design consideration for reactivity issue and decay heat removal issue for Gen-IV SFR***
  - ***Design approach for DEC and PE is mainly addressed, since it could be important factors of design.***
    - ***Passive/Inherent reactivity control and decay heat removal***
    - ***In-Vessel Retention***
    - ***Practical Elimination, e.g. complete loss of decay heat removal function, core uncovering***
  - ***Clarification and quantification are made for reactivity***

Thank you

for your attention !!