Experience of Safety Design Criteria (SDC) and Safety Design Guidelines (SDGs) development for Generation-IV Sodium-cooled Fast Reactor System

Shigenobu Kubo
GIF SDC Task Force

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• Introduction
• Safety Design Criteria (SDC)
• Safety Design Guideline (SDG) on Safety Approach and Design Conditions
• SDG on Key Structures, Systems and Components
• Interaction with IAEA
• Summary
Introduction

• Safety Design Criteria (SDC) development for Generation-IV systems was proposed at GIF Policy Group meeting in October 2010
  » SDC “harmonization” is increasingly important for:
    – Realization of enhanced safety designs common to SFR systems,
    – Preparation for the forthcoming licensing in the near future
    – SFR system was selected as the initial application since it represents one of the more mature next generation nuclear energy concepts
• SDC Task Force (TF) started work in 2011
  – Members: CIAE (China), CEA (France), JAEA (Japan), KAERI, KINS (Republic of Korea), IPPE (Russia), ANL, INL, ORNL (United States of America), EC and IAEA.
Safety Design Guidelines Development

- SDC (Phase I report, updated in 2018)
- SDG on Safety Approach and Design Conditions
- SDG on Key Structures, Systems and Components
SFR Design Options under GIF

- A large size (600 to 1,500 MWe) loop-type reactor with mixed uranium-plutonium oxide fuel and potentially minor actinides, supported by a fuel cycle based upon advanced aqueous processing at a central location serving a number of reactors
- An intermediate-to-large size (300 to 1,500 MWe) pool-type reactor with oxide or metal fuel
- A small size (50 to 150 MWe) modular pool-type reactor with metal alloy fuel, supported by a fuel cycle based on pyrometallurgical processing in facilities integrated with the reactor
Safety Design Criteria

(Phase I report)
Basic Scheme to outline the SDC

High level safety fundamentals, and safety design goals
- GIF's Goals for safety & reliability
- Basis for safety approach for design & assessment
- Requirements in SFR System Research Plan

1) Particular issues for SFR
- Characteristic of Sodium-cooled Fast Reactor
  - Reactivity (void) ...
  - Sodium fire & Sodium-water reaction...
- Consideration on Severe Accident
  - Re-criticality during Core Disruptive Accident
- High Temperature & Low pressure system
  - Creep property, Leak-Before-Break...
  - No LOCA and no need of ECCS...
- Enhanced Safety Approach
  - Passive system for shutdown & cooling

2) Reference of SDC Structure
- IAEA SSR 2/1
  - Management of safety in design
  - Principal technical requirement
  - General Plant design
  - Design of specific plant system

3) Lessons learned from Fukushima Dai-ichi NPPs accident
- Common cause failure by external event
- Loss of power for longer period
  - Decay heat removal, Fuel pool cooling
- Containment function on spent fuel in the pool
- Preparing multiple AMs, e.t.c.

GIF SFR SDC
GIF’s Safety & Reliability Goals and Safety Approach

SR-1: Excel in Operational Safety and Reliability
Safety and reliability during normal operation, and likely operational events that assume forced outage rate

SR-2: Very low likelihood & degree of reactor core damage
Minimizing frequency of initiating events, and design features for controlling & mitigating any initiating events w/o causing core damage

SR-3: Eliminate the need for offsite emergency response
Safety architecture to manage & mitigate severe plant conditions, for minimizing the possibility and the amount of releases of radiation

- Defence-in-depth
- Risk-informed
- Built-in safety function, and not add-on
- Utilization of passive safety features
- Prevention of cliff edge effect
- Provisions against hazards
- Simulation, Prototyping, and Demonstration
## Defence-in-depth (DiD) & Plant States

From GIF SFR SDC based on IAEA INSAG-12 & SSR-2/1

<table>
<thead>
<tr>
<th>Defence-in-Depth Levels</th>
<th>Level 1</th>
<th>Level 2</th>
<th>Level 3</th>
<th>Level 4</th>
<th>Level 5</th>
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<td>Operational States</td>
<td>Accident conditions</td>
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<td>Normal operation</td>
<td>Anticipated operational occurrences</td>
<td>Design basis accidents</td>
<td>Design extension conditions</td>
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<td>Without significant fuel degradation</td>
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<td>With core melting</td>
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<td>Off-site emergency response (out of the design)</td>
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</tbody>
</table>
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   1.2 Principles of the SDC formulation

2. SAFETY APPROACH TO THE SFR AS A GENERATION-IV REACTOR SYSTEM
   2.1 GIF Safety Goals and Basic Safety Approach
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      2.2.2 Relationship among plant states, probabilistic and deterministic approaches
      2.2.3 Utilisation of passive safety features
      2.2.4 Prevention of cliff edge effect
      2.2.5 Containment function
      2.2.6 Provision against hazards
      2.2.7 Non-radiological and chemical risks
   2.3 Safety approach of the Generation-IV SFR systems
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      2.3.2 Approach based on basic characteristics of the SFR
      2.3.3 SFR specific safety approach in relation to the plant states
      2.3.4 Lessons Learned from TEPCO’s Fukushima Dai-ichi Nuclear Power Plants Accidents
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      - External hazards
      - Combinations of events and failures
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   5.3 Human Factors (Criterion 32)
   5.4 Other Design Considerations (Criterion 33~41)
   5.5 Safety Analysis (Criterion 42)
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      - Probabilistic approach
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   6.2 Reactor Core and Associated Features (Criterion 43~46)
   6.3 Reactor Coolant Systems (Criterion 47~53)
   6.4 Containment Structure and Containment System (Criterion 54~58)
   6.5 Instrumentation and Control Systems (Criterion 59~67)
   6.6 Emergency Power Supply (Criterion 68)
   6.7 Supporting Systems and Auxiliary Systems (Criterion 69~76ter)
   6.8 Other Power Conversion Systems (Criterion 77)
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INDICATION OF DIFFERENCES BETWEEN IAEA SSR-2/1 AND GIF SFR SDC
GLOSSARY
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   (A) Definitions of Boundaries of SFR systems
   (B) Guide to Utilisation of Passive/Inherent Features
   (C) Approach to Extreme External Events
## Difference between “GIF SDC Criteria” and “IAEA SSR 2/1 Requirements”

SDC Criteria (total 83): Modified 20, Added 2, Deleted 1, Un-changed 60

[Added: Overall Plant System & Sodium heating systems / Deleted: ECCS]

### Example:

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<th>Paragraph #</th>
<th>Criterion #</th>
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**IAEA SSR 2/1**

**GIF SFR SDC**

**Status**

*M: Modified
*A: Added
*D: Deleted
*U: Unchanged

### REACTOR COOLANT SYSTEMS

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*incl. in #51*
SDC Update

» The revised SDC report (Rev.1) was approved in 39th EG and published on GIF web site.

(https://www.gen-4.org/gif/jcms/c_93020/safety-design-criteria)

✓ The original SDC report was delivered to external entities for review such as national nuclear regulators and international organization in 2013.

✓ The SDC TF received the comments from China’s NNSA, USNRC, IAEA and IRSN. SDC TF has produced the revision of SDC as well as the resolution documents that include the response to the comment.

✓ The revised SDC also reflects the revision of IAEA SSR 2/1.
Safety Design Guideline on Safety Approach and Design Conditions

(First SDG report)
Scope of SDG on Safety Approach

• This report is intended to provide recommendations and guidance on how to comply with the GIF SFR Safety Design Criteria. It presents examples for the measures stated in criteria as the best practices to help the designers achieve high levels of safety.

• Initially, the guidelines will focus on specific safety concerns, such as reactivity characteristics of SFRs and heat removal issues.

• To address the potential consequences of such accidents, this report focuses on providing examples of design approaches for “prevention and mitigation of severe accidents” and for “loss-of-decay heat removal capability as a situation that needs to be practically eliminated”.
# Table of contents

1. INTRODUCTION
   1.1. Background and Objectives
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   4.2. Decay Heat Removal Issues
   4.3. Postulated Initiating Events and Design Limits
   4.4. Testability
   4.5. Demonstration

5. CLARIFICATION AND QUANTIFICATION OF TECHNICAL POINTS CONCERNING SAFETY DESIGN CRITERIA
   5.1. Consideration concerning SFR Reactivity Characteristics
Development Status

- **SDG on Safety Approach and Design Conditions**
  - **Focus on Prevention and Mitigation of Severe Accidents, and Use of Inherent/Passive Safety Features**
  - **Approved for External Review by PG on March, 2016**
  - **Delivered the SDG report on Safety Approach and Design Conditions to GSAR and IAEA for External Review on April 4, 2016**
  - **The SDG on Safety Approach report is available on the GIF website.**

GSAR: OECD/NEA Joint CNRA/CSNI Ad-hoc Group on the Safety of Advanced Reactors, currently WGSAR
• **SDG on Safety Approach and Design Conditions**

**Status**

• Resolution to WGSAR and IAEA comments was discussed in the 14th and 15th TF. Update was made.

• The update version was sent to EG member for comments in the beginning of June 2019.

• The resolution and the update version were sent to WGSAR and IAEA by the beginning of September 2019.
SDG on Key Structures, Systems and Components
(Second SDG report)
• SDG on Key Structures, Systems and Components (Second SDG report)
  » To provide detailed guidelines for SFR designers to support the practical application of the SDC in design process to ensure the highest level of safety in SFR design.
  » To show recommendations and guidance to comply with the SDC Report and the Safety Approach SDG with examples, which can be applied to Gen-IV SFR systems in general.
  » The GIF SDC TF expects that these recommendations and examples will be appropriately considered in design according to each design characteristic.
• **SDG on Key Structures, Systems and Components (Second SDG report)**

  » **SDG on reactor core, reactor coolant system and containment system for Gen-IV SFR referring to IAEA NSG series**

  » **Identified 14 focal points on SFR specific parts to be investigated**

  » **Link to related “SDC” and “SDG on Safety Approach”**

  » **Development of SDG on SSC based on GIF SFR design options and design conditions**
Process of SDG on SSC Development

Safety Design Criteria (SDC)
- 83 criteria, 205 paragraphs

Safety Design Guideline (SDG)
On Safety Approach
- Reactivity issue
- Decay heat removal issue

Gen-IV SFR
Design Options
- Passive reactivity reduction
- Passive decay heat removal
- High burnup fuel
- Containment vessel

Set of Design Conditions
- Event list, etc

SDG on Structures, Systems and Components
- Reactor core (e.g. passive reactivity reduction)
- Coolant system (e.g. decay heat removal system)

General & Common issues

IAEA SSR 2/1 Rev.1
Safety Glossary (2016)

Terminology

IAEA NS-G Series

## Focal Points related to SFR-specific Safety Features

<table>
<thead>
<tr>
<th>Systems</th>
<th>Safety features</th>
<th>Focal points</th>
<th>SDC</th>
<th>SDG on Safety Approac</th>
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<tr>
<td>Reactor Core systems</td>
<td>Integrity maintenance of core fuels</td>
<td>1. Fuel design to withstand high temperature, high inner pressure, and high radiation conditions ✔</td>
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<td>2. Core design to keep the core coolability                                   ✔ ✔</td>
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<td>Reactivity control</td>
<td>3. Active reactor shutdown                                                     ✔ ✔</td>
<td>✔ ✔</td>
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<td>4. Reactor shutdown using inherent reactivity feedback and passive reactivity reduction ✔ ✔</td>
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<td>5. Prevention of significant energy release during a core damage accident, In-Vessel Retention ✔ ✔</td>
<td>✔ ✔</td>
<td>✔ ✔</td>
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<td>Coolant systems</td>
<td>Integrity maintenance of components</td>
<td>6. Component design to withstand high temperature and low pressure conditions ✔</td>
<td>✔</td>
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<td>Primary coolant system</td>
<td>7. Cover gas and its boundary                                                  ✔</td>
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<td>8. Measures to keep the reactor coolant level                                   ✔ ✔</td>
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<td>Measures against chemical reactions of sodium</td>
<td>9. Measures against sodium leakage                                             ✔</td>
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<td>10. Measures against sodium-water reaction                                     ✔</td>
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<td>Decay heat removal</td>
<td>11. Application of natural circulation of sodium                               ✔ ✔</td>
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<td>12. Reliability maintenance (diversity and redundancy)                         ✔ ✔</td>
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<td>Containment systems</td>
<td>Design concept and load factors</td>
<td>13. Formation of containment boundary and loads on it                          ✔</td>
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<td>Containment boundary</td>
<td>14. Containment function of secondary coolant system                           ✔</td>
<td>✔</td>
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</table>
Table of contents of SDG on SSC
14 Focal points + Other important points*

1. INTRODUCTION
   1.1. Background and Objectives
   1.2. Scope and Structure

2. GUIDELINES FOR REACTOR CORE SYSTEM
   2.1. Integrity Maintenance of Reactor Core Fuels
   2.2. Reactivity Control

3. GUIDELINES FOR COOLANT SYSTEMS
   3.1. General Considerations in Design
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   3.4. Measures against Sodium Chemical Reactivity

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   4.4. Tests and Inspections

I. APPENDIX
II. ANNEX
III. GLOSSARY

For example, "Local fault" is in 2.1.
## Table of contents of SDG on SSC

### APPENDIX and ANNEX

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[Table of contents of SDG on SSC APPENDIX and ANNEX](#)
## SFR Design Options under GIF

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<thead>
<tr>
<th>Core size</th>
<th>Fuel</th>
<th>Primary Coolant System</th>
<th>Reactivity reduction under DEC</th>
<th>Decay heat removal</th>
<th>Containment/confinement</th>
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<tbody>
<tr>
<td>Small (50-150MWe)</td>
<td>Oxide</td>
<td>Pool-type</td>
<td>Inherent feedback (Doppler, core expansion etc.)</td>
<td>DRACS PRACS IRACS RVACS SGACS ....</td>
<td>Reactor Building</td>
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<tr>
<td>Middle (300-600MWe)</td>
<td>Metal</td>
<td>Loop-type</td>
<td>Passive mechanism (absorber insertion, etc.)</td>
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<td>Guard vessel + Upper dome</td>
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<tr>
<td>Large (600-1500MWe)</td>
<td>Nitride</td>
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</tbody>
</table>

- Commonly covered by SDC and SA-SDG
- Variety of SFR design options
  - Pool/Loop type primary coolant systems
  - Reactivity reduction under DEC
How to summarize

Main body of SSC SDG

✔ Extract common things from presented work sheets and summarize texts for the main body.
✔ Harmonize different expressions and different contents
✔ Utilize texts in NS-G series as much as possible.

Appendix or Annex

✔ Extract design specific things from presented work sheets and summarize to be included in appendixes or annexes.

Identify

Common things / Design specific things

Harmonize differences in common things

Discussion in SDC-TF

Summarize typical design concepts for appendix / annex

Main body of SSC SDG

Common things

Appendix

Same status as main body

Annex

Typical design concepts
Development Status

• **SDG on Key Structures, Systems and Components (Second SDG report)**
  
  » **First draft report of SDG on SSC was confirmed by SDC TF, and got approval for external review by WGSAR and IAEA.**
  
  » **Invitation letters were sent to IAEA Department of Nuclear Energy in 13th March 2019, WGSAR in 15th March 2019. Both accepted the invitation.**
  
  » **Presentation was made in the 8th Joint IAEA-GIF Workshop on LMFR Safety held in 20-22 March 2019**
  
  » **A related paper “Development of SDG on SSC for Gen-IV SFR” was presented in GIF symposium in 16-17, October 2018.**
Development Status

• SDG on Key Structures, Systems and Components (Second SDG report)
  » A presentation was made in the 4th WGSAR meeting in October 2019.
  » Both of WGSAR and IAEA review are in progress.
Interaction with IAEA
Interaction with IAEA (1/2)

- IAEA had already been contributing significantly to the GIF efforts on the SDC/SDG development
  - IAEA expert of Department of Nuclear Safety and Security has been a member of GIF Task Force in charge of developing SDC/SDG
  - IAEA Department of Nuclear Energy, jointly with the GIF, a yearly Workshop of safety of SFR and specifically on SDC/SDG
- IAEA Department of Nuclear Energy provided the comments on SDC in the letter, dated 28 April 2014, to the GIF Chair.
- Progress of IAEA’s review was presented at 6th GIF-IAEA Joint Workshop on SFR Safety on November 2016. Comments received on 22nd March 2018
Interaction with IAEA (2/2)

- 7th Joint IAEA-GIF Workshop on LMFR Safety was held on 27-29 March 2018
  - Background on GIF SDC TF, outline of SDG on Safety Approach report and development status of the second SDG report on SFR systems, structures and components
  - GSAR and IAEA comments on the SDG on Safety Approach report
- Presentation on the development status and the second SDG report was made in the 8th Joint IAEA-GIF Workshop on LMFR Safety held in 20-22 March 2019
- 9th Joint IAEA-GIF Workshop on LMFR Safety will be held on 18-20 March 2020
  - IAEA’s comments on the second SDG report
Summary

• *In order to respond a growing needs on international safety standard for advanced reactors, GIF started development of safety design criteria (SDC) in 2011.*

• GIF SFR SDC was formulated in 2013, external review and update are continuously conducted since then.

• *For quantification and qualification of SDC, development of safety design guidelines for GIF SFR was started in 2013.*

• SDC/SDG are extended to the other design tracks.

• *Interaction with IAEA gives important feedbacks for the development.*
Thank you for your attention !!
Reference

GIF Documents:

- Sodium-cooled Fast Reactor (SFR) System Safety Assessment (2017)

IAEA Documents:

- Safety of Nuclear Power Plants: Design, SSR-2/1, (2016), Requirement 1-42
- Considerations on the Application of the IAEA Safety Requirements for the Design of Nuclear Power Plants, TECDOC-1791 (2016), except LWR specific issues
- DS508: Assessment of the Application of General Requirements for Design of Nuclear Power Plants