Overview of the activity of GIF Risk and Safety Working Group

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GIF Risk & Safety Working Group

12th INPRO Dialogue Forum on Generation IV Nuclear Energy Systems
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Contents

• **GIF Risk & Safety Working Group**
  – Mission
  – **GIF Safety Approach**
  – **Main Outputs**
  – **Current Activities**
• **Six Gen-IV reactor concepts:**
  – *A Diverse set of design and safety issues*
  – *A number of issues are different from current LWR designs;*
• **Overall success of Gen-IV program depends on, among other factors,**
  – *The ability to develop, demonstrate, and deploy advanced system designs that exhibit excellent safety characteristics.*
GIF Risk & Safety Working Group [RSWG]

Important Mission of GIF RSWG

• “Promote a consistent approach on safety, risk, and regulatory issues between Generation IV systems”, in collaboration with and in support of all the six GIF System Steering Committees.

• Advise and assist particularly on matters of:
  – Generation IV safety goals and evaluation methodologies to be considered in the design
  – Interactions with the nuclear safety regulatory community, the IAEA, and relevant stakeholders
  – Development of a Safety Assessment Methodology
GIF Risk & Safety Working Group [RSWG]

Important Outcomes

• **Basis for Safety Approach [BSA] (2008)**
  – Fundamental Safety Approach for all the six Gen-IV reactor systems,
    to achieve Gen-IV Safety and Reliability Goals

• **Integrated Safety Assessment Methodology [ISAM](2011)**
  – Five safety assessment tools,
    to be utilized through Gen-IV reactor design process

  – Guidebook with good examples of ISAM utilization
    in Gen-IV reactor design and safety assessment processes
**Explanation* of Safety & Reliability Goals**

- **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 without 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

*GIF RSWG BSA, **GIF Technology Roadmap*
Generation IV Safety Philosophy (1/2)

- Opportunities exist to further improve on nuclear power’s already excellent safety record in most countries.
- The principle of “defence in depth” has served the nuclear power industry well, and must be preserved in the design of Generation IV systems.
- The Generation IV design process should be driven by a “risk-informed” approach (i.e. considering both deterministic and probabilistic methods).
- For Gen IV systems, in addition to prototyping and demonstration, modelling and simulation should play a large role in the design and the assessment.
Further safety improvement for Generation IV systems are possible through progress in knowledge and technologies and the application of a safety philosophy early in the design process.

Such improvements will, in particular, will be achieved by “built-in” to the fundamental design, rather than “added on” to the system architecture.
Five tools of ISAM [Integrated Safety Assessment Methodology] and their application timings

Pre-Conceptual Design
- Primarily Qualitative

Conceptual Design
- Formulation → Refinement of Safety Requirements and Criteria

Final Design
- Primarily Quantitative

Licensing and Operation

QSR (Qualitative Safety Requirements/Characteristic Review)
- Identify important phenomena
- Characterize state of knowledge

PIRT
- List provisions that assure implementation of DiD
- DiD level → safety function → challenge/mechanism → provisions

OPT

Probabilistic Safety Assessment (PSA)
- Provides integrated understanding of risk and safety issues
- Allows assessment of risk implications of design variations
- In principle, allows comparison to technology neutral risk metrics

Deterministic and Phenomenological Analysis (DPA)
- Demonstrate conformance with design intent and assumptions
- Characterize response in event sequences resulting from postulated initiating events
- Establish margins to limits, success criteria for SSFs in PRA, and consequences


Five tools of ISAM

1. Qualitative Safety Requirements/Characteristics Review (QSR)
   QSR provides a systematic means of ensuring and documenting that a Gen-IV design incorporates desirable safety-related attributes and characteristics.

2. Phenomena Identification and Ranking Table (PIRT)
   PIRT allows to systematically identify system and component vulnerabilities and generates ranked tables for identifying relative contributions to safety and risk. PIRT also helps to identify the gaps in knowledge areas requiring additional research and data collection.

3. Objective Provision Tree (OPT)
   The OPT purpose is to ensure and document on “provisions” of essential “lines of protection” to ensure successful prevention, control or mitigation of phenomena that could potentially damage the reactor.
4. **Deterministic and Phenomenological Analyses (DPA)**

Traditional deterministic analyses will be used as needed to understand a wide range of safety issues that must guide concept and design development, and will form inputs into the PSA. These analyses typically involve the use of familiar deterministic safety analysis codes.

5. **Probabilistic Safety Analysis (PSA)**

- PSA is to be performed and iterated, beginning in the late pre-conceptual design phase, and continuing through the final design stages addressing licensing and regulatory concerns.

- PSA provides a structured means of identifying the answers to three basic questions related to the safety of Generation IV systems:
  - What can go wrong?
  - How likely is it?
  - What are the consequences?

*White Paper report, now under being developed, will summarize good practices of the ISAM applications in six reactor systems.*
RSGW Current Activity

- Safety Assessment Report
  - Review and identify main safety advantages and challenges of Gen-IV six systems,
    - With the aim of providing a snapshot of the major safety concerns of the technologies, at the timing of one decade after starting GIF collaboration.
    - Assess the current status of safety related R&Ds and allow selecting direction of future R&D needs for each system.
      - Not a competition of pro/con safety features
  - With the six system steering committees, a safety assessment document is now being developed to identify:
    - Strengths of the system relying on existing technology and equipment, and
    - Not-yet-mature technologies that need further development, in order to satisfy the GIF safety goals.
“Safety Design Criteria” for Gen-IV Sodium-cooled Fast Reactor (SFR)

Yasushi OKANO
GIF Safety Design Criteria Tack Force

12th INPRO Dialogue Forum on Generation IV Nuclear Energy Systems
IAEA, 13-15 April 2016
Contents

• Safety Design Criteria [SDC] for Gen-IV SFR
  – Background and Objectives
  – SDC developments
    » Development Scheme
    » Key Safety Approach for Gen-IV
  – SDC Phase 1 Report
    » Table-of-Contents
    » Examples of criteria

• Current status and Phase-2 activity
  – Status of International Reviews on the SDC
  – Safety Design Guideline [SDG] development
SDC Development Context

- **Context**

  *Safety Design Criteria (SDC) development for Gen-IV Sodium-cooled Fast Reactor (SFR)*
  
  - Proposed at the GIF Policy Group (PG) meeting in Oct. 2010
  - Developed by the GIF SDC Task Force, from 2011 to 2013
  - “SDC Phase 1 Report” approved and issued by GIF PG in May 2013, and
  - Now international review process ongoing
  
  - As the second phase activity, the SDC Task Force is developing “Safety Design Guideline (SDG)” from 2013
    
    » SDG is the guide of SDC when applying on the Gen-IV SFR design, including recommendations and design options
SDC Development Background

• Background

Upper level safety standards for Gen-IV had been developed:

– Safety and reliability goals in the “GIF Roadmap” (2002)
– “Basis for safety approach” (2008)
– SFR design tracks in “SFR System Research Plan” (2007)

• Motivation

“Harmonization” of safety approach is highly important for:

– Realization of enhanced safety designs common to SFR systems,
– Preparation for forthcoming licensing in near future
– Because Gen-IV SFR are progressing into conceptual design stage
Hierarchy of Safety Standard

- Safety Goals: Fundamental safety principles and common safety goals for all Gen-IV systems.
- Safety Design Criteria: A set of criteria reflecting GIF safety approach to achieve harmonized safety requirements of SFR system.
- Safety Design Guidelines: A set of guidelines on how to implement the design criteria and address SFR-specific safety topics.
- Country-specific codes and standards: Domestic regulations for design of reactor core, cooling system, and other structures, systems, and components.
## Defence-in-depth (DiD) & Plant States

based on IAEA INSAG-12 & SSR-2/1

### DiD Levels

<table>
<thead>
<tr>
<th>Level 1</th>
<th>Level 2</th>
<th>Level 3</th>
<th>Level 4</th>
<th>Level 5</th>
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</thead>
<tbody>
<tr>
<td>plant states (considered in design)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normal operation</td>
<td>AOO</td>
<td>DBA</td>
<td>DEC</td>
<td>Off-site emergency response (out of the design)</td>
</tr>
<tr>
<td>Operational states</td>
<td>Accident conditions</td>
<td>Design extension conditions</td>
<td>(including Severe Accident conditions)</td>
<td></td>
</tr>
<tr>
<td>Normal operation</td>
<td>Anticipated operational occurrences</td>
<td>Design basis accidents</td>
<td></td>
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</tbody>
</table>
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
- SFR System Research Plan

1) Related to SFR system
- Characteristic of Sodium-cooled Fast Reactor
  - Core Reactivity…
  - Sodium chemistry…
- Consideration on Severe Accident
- High Temperature & Low pressure system
  - No LOCA and no need of ECCS…
- Fundamental Safety Approach
  - Utilization of passive mechanism…

2) Reference of SDC Structure
- IAEA SSR 2/1

3) Lessons learned from Fukushima Dai-ichi NPPs accident
- Common cause failure by external event
- Loss of power for longer period
- Containment function on spent fuel in the pool
- Preparing accident managements…
# Table-Of-Contents of “SDC Phase 1 Report”*

1. INTRODUCTION
   1.1 Background and Objectives
   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
   2.2 Fundamental Orientations on Safety
   2.3 Safety approach of the Generation-IV SFR systems

3. MANAGEMENT OF SAFETY IN DESIGN  
   Criteria 1-3

4. PRINCIPAL TECHNICAL CRITERIA  
   Criteria 4-12

5. GENERAL PLANT DESIGN  
   Criteria 13-28
   5.1 Design Basis
   5.2 Design for Safe Operation over the Lifetime of the Plant  
   Criteria 29-31
   5.3 Human Factors
   5.4 Other Design Considerations  
   Criteria 33-41
   5.5 Safety Analysis  
   Criterion 42

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*SDC-TF/2013/01, May 1, 2013

6. DESIGN OF SPECIFIC PLANT SYSTEMS

6.1 Overall Plant System
6.2 Reactor Core and Associated Features
6.3 Reactor Coolant Systems
6.4 Containment Structure and Containment System
6.5 Instrumentation and Control Systems
6.6 Emergency Power Supply
6.7 Supporting Systems and Auxiliary Systems
6.8 Other Power Conversion Systems
6.9 Treatment of Radioactive Effluents and Radioactive Waste
6.10 Fuel Handling and Storage Systems
6.11 Radiation Protection

GLOSSARY

APPENDIX:

(A) Definitions of Boundaries of SFR systems
(B) Guide to Design Extension Conditions
(C) Guide to Practical Elimination of accident situations
(D) Guide to Utilisation of Passive/Inherent Features
(E) Approach to Extreme External Events
Example of SDC Criteria & Paragraphs

Criterion 13: Categories of plant states

Plant states shall be identified and shall be grouped into a limited number of categories primarily on the basis of their frequency of occurrence at the nuclear power plant.

5.1. On the basis of their frequency, plant states shall typically cover:

- (a) Normal operation;
- (b) Anticipated operational occurrences, which are expected to occur over the operating lifetime of the plant;
- (c) Design basis accidents;
- In addition, despite their low frequency, plant states with potential severe consequences shall be considered:
- (d) Design extension conditions including:
  » Prevention of core degradation
  » Accidents with significant degradation of the reactor core.
Example of SDC Criteria & Paragraphs

- SDC Criterion 46: Reactor shutdown

  Means shall be provided to ensure to shut down the reactor of the nuclear power plant in operational states and in accident conditions, and that the shutdown condition can be maintained even for the most reactive conditions of the reactor core.

  - Paras. 6.7-6.8…
  - Para.6.9:
    The means for shutting down the reactor shall consist of at least two diverse and independent systems.

    For design extension conditions, passive or inherent reactor shutdown capabilities shall be provided to prevent severe core degradation and to avoid re-criticality in the long run.
International reviews on SDC

- GIF SFR “SDC Phase 1 Report”
  - Review requests for the SDC Report from GIF
    » for “Review by external organizations” and
    » for “Enhancing interaction with regulatory bodies”
  - Sent the report (ca. July 2013) to
    » International organizations
      IAEA, MDEP, OECD/NEA/CNRA
    » Regulatory authorities at national level
      China (NNSA), Euratom (ENSREG), France (ASN),
      Japan (NRA), Republic of Korea (NSSC),
      Russia (Rostechnadzor), USA (NRC)
  - Review feedbacks from:
    » IAEA, IRSN (FR), NNSA(China), NRC (US)
Safety Design Guidelines [SDG] development

• **Background & Motivation**

  The needs recognized during the SDC development are:
  
  – More detailed discussions on specific items, such as
    
    » Practical Elimination [PE] of Accident Situations
    
    » “Design Basis” of components (e.g. Containment Vessel...)
    
    » Quantification/Qualification of key aspects

  – Common understandings on technical issues; e.g.
    
    » Measures against sodium fire…
    
    » Core not being in its most reactive configurations and implications of positive reactivity (void reactivity…)

• **Two SDGs**

  – **Safety Approach SDG** – will be approved soon
  
  – **Structures, Systems and Components SDG** – ca. End of 2016
Example of SDG & relationship to SDC

Reactivity Issue (Prevention and Mitigation of severe accidents)

SDC: Performance requirements

SDG: Functional requirements &
Set of design conditions*

Criterion 20: Design extension conditions
Paragraph 5.31

(a) Additional reactor shutdown measures against failure of active reactor shutdown systems,

(b) ....

Functional requirements:
Activation by core condition change,
Achieve sub-criticality under hot-shutdown
Maintain primary coolant boundary integrity for long-term

Set of design conditions:
✓ Postulated events:
  ATWS (ULOF, UTOP...),...
✓ Design limits:
  Coolant temperature below boiling point…
✓ Testing/Demonstration...

List of examples of “design choices”

* It does not mean setting frequency or consequence boundaries.
Remarks

• Risk and Safety Working Group
  – Promote consistent evaluation methodologies
  – Interactions with the nuclear safety regulatory community, the IAEA, and relevant stakeholders
  – Outcomes: BSA, ISAM and GDI
  – Safety Assessment Repost development now ongoing.

• “SDC Phase 1 Report”
  – Issued by the GIF on May 2013
  – Circulated for international review
  – Important feedbacks from IAEA, IRSN, NNSA, USNRC
  – “SDG” development is now ongoing.