Third Joint GIF – IAEA Workshop on

SAFETY DESIGN CRITERIA FOR SODIUM-COOLED FAST REACTORS

26 – 27 February 2013

IAEA HQ, Vienna. Building M, Meeting Room: ***M5***

Summary Report

List of participants

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France	Mr Dufour Phillippe	CEA
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India	Mr Kumar Prabhat	BHAVINI
India	Mr Pillai Puthiyavinayagam	IGCAR
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Background

Sodium-cooled Fast reactors (SFR) have brought in the last decades to a certain level of maturity by the design, construction and operation of experimental and prototype reactors, such as the *Fast Flux Test Facility* (FFTF) in USA, the small size *Prototype Fast Reactor* (PFR) in the United Kingdom, the prototype PHÉNIX in France, the BN-350 in Kazakhstan, the demonstration plant BN-600 in Russia, JOYO and MONJU in Japan, the commercial size SUPERPHÉNIX in France, etc.

Several countries are currently engaged in SFR design and construction projects. In China, the 65 MW(th) (20 MW(e)) pool-type *China Experimental Fast Reactor* (CEFR) reached criticality for the first time on 25 July 2010 and was connected to the grid on 21 July 2011. Fast reactors commercialization in China will follow with the realization of the demonstrative plant CFR-1000 expected to be developed also thanks to international collaborations. Construction works for the India's 500 MW(e) *Prototype Fast Breeder Reactor* (PFBR) at Kalpakkam are well under way: the commissioning is planned for 2013. Based on the PFBR project achievements, the Indian programme for fast reactors deployment foresees the construction of several CFBR units around 2020-2025 and the development of the future FBRs with metallic fuel and higher breeding ratio beyond 2025. In the Russian Federation, which operates in Beloyarsk the currently most powerful commercial fast reactor BN-600, the construction of the BN-800 on the same site is progressing. Construction completion and start-up of the commissioning phase are planned for 2014. Russian Federation has also recently launched the Federal Target Programme *New generation nuclear power technologies for 2010-2015 with outlook to 2020* aimed, in particular, at the development of the advanced SFR BN-1200, and the new *Multipurpose Research Na-cooled Fast Reactor* called MBIR. Under its *Strategic Energy Technology Plan* (SET-Plan), Europe has recently defined the technological pathway for developing fast neutron reactors, which includes the SFR concept as a first track aligned with Europe's prior experience. The related demonstration and implementation programme ESNII (*European Sustainable Nuclear Industrial Initiative)* foresees the realization in France of the GENIV SFR prototype called ASTRID. Japan has been developing the 1500 MW(e) GEN-IV JSFR (*Japan Sodium-cooled Fast Reactor*) in the frame of its *Fast Reactor Cycle Technology* (FaCT) project and Republic of Korea is carrying out a broad R&D programme in support of the 150 MW(e) PGSFR (Prototype Generation-IV Sodium-cooled Fast Reactor).

Besides the national projects, relevant international initiatives have been established in the last few years in order to promote cooperation among countries with development programmes for advanced SFR. The most relevant are the ones carried out under the auspices of the Generation IV International Forum (GIF) and the International Atomic Energy Agency (IAEA).

GIF and IAEA have jointly committed to collaboration between the programmes and to share information in selected areas of mutual interest. One of the key areas of emphasis in both the GIF and the IAEA programmes is the safety of SFR and in particular the harmonization of safety approach, safety requirements and safety design criteria for the GENIV SFRs under development worldwide. The first GIF – IAEA joint SFR workshop, titled *Operational and Safety Aspects of Sodium-Cooled Fast Reactors* was held 23-25 June 2010 at IAEA. This was followed by a second Workshop titled *Safety Aspects of Sodium-cooled Fast Reactors*, held 30 November – 1 December 2011 at IAEA. More recently the IAEA has organized the following other events on safety of SFR:

- Technical Meeting on *Impact of the Fukushima event on current and future fast reactor designs*, Dresden (Germany), 19-23 March 2012
- *IAEA/JAEA International Workshop on prevention and mitigation of severe accidents in Sodium-cooled Fast Reactors*, Tsuruga (Japan), 11-13 June 2012.

Finally, the IAEA is organizing an "*International Conference on Fast Reactors and Related Fuel Cycles: Safe Technologies and Sustainable Scenarios (FR13)*", Paris, 4-7 March 2013; the conference include a track on *Fast reactor safety: post-Fukushima lessons and goals for next-generation reactors* and a panel on *Safety Design Criteria*.

In all these contexts, it has been underlined the need to develop safety design criteria for innovative (GENIV) SFR which should be harmonized - to the maximum extent - at international level and become part of IAEA recommendations within the set of Safety Requirements for innovative SFRs.

Objectives of the Meeting

The main objectives of the meeting were to:

- Present and share information on the work carried out by GIF, the IAEA and the Member States on the definition of safety design criteria for SFR, including safety approach and requirements on general plant design;
- Present the document prepared by the GIF-SFR Task Force on Safety Design Criteria;
- Present and discuss safety design concepts of SFRs under development in Member States, with particular emphasis on design measures against Design Basis Accidents and Design Extended Conditions, as well as the associated safety evaluations and supporting R&D;
- Draft a room document which should be the basis of the discussion for the Panel on Safety Design Criteria of the FR13 Conference in Paris .

- Discuss the results and agree on the future actions of the 3rd Joint GIF-IAEA Workshop on Safety of Sodium-Cooled Fast Reactors;

Meeting Report

- More than 30 experts in the field of safety of Sodium-cooled Fast Reactors (SFR) took part in the third GIF-IAEA Workshop on Safety Design Criteria for SFRs. The experts were representatives from the GIF countries involved in GEN-IV SFR development - i.e. China, France, Japan, Republic of Korea, Russian Federation and the USA, as well as the European Commission and the OECD Nuclear Energy Agency - from Germany, India and the IAEA.
- After a short welcome by Mr Monti, Scientific Secretary, the Workshop was introduced by Mr J.K. Park, Director of the IAEA Nuclear Power Division, and by Mr Y. Sagayama, vice-Chair of the GIF.

- Mr. Park, on behalf of the IAEA, welcomed the participants noticing that this meeting is the first step of a 2-week "marathon" for the Fast Reactor community: the present workshop and the GIF/IAEA-INPRO Interface Meeting this Thursday and Friday, and finally, the FR13 Conference next week in Paris, which also includes a Panel where the outcomes of this Workshop will be presented to, and discussed with, about 700 participants from all over the world. Mr Park also underlined that the Workshop has a particular meaning as it represents a fundamental milestone in the close collaboration between the Generation IV International Forum and the IAEA in the field of safety of sodium-cooled fast reactors. He reminded that the first GIF – IAEA joint SFR workshop, titled *Operational and Safety Aspects of Sodium-Cooled Fast Reactors*, was held in June 2010 and mainly addressed the operating experience and the safety fundamentals of SFR designs, as well as the safety characteristics and goals of the future SFRs. The second joint Workshop held in November 2011, just some months after the March 11th tragic event, was particularly focused on the safety implications of the lessons learned from the Fukushima-Daiichi accident on the design of innovative SFRs. Another important issue discussed in the second Workshop was how to harmonize the safety approaches and goals for the next generation SFRs, thus contributing to the harmonization of the safety criteria for GEN IV sodium-cooled fast reactors. As a natural follow-up of the second GIF-IAEA Joint Workshop, this Workshop is devoted to the safety design criteria for SFR, including safety approach and requirements on general plant design. Mr Park continued his opening remarks observing that the discussion on the safety design criteria for innovative SFRs comes at a very timely moment as, on one side the GIF has just released its first interim report on the subject which will constitute the basis for the discussion in this workshop, and on the other side the IAEA has been starting to critically review the applicability of its Safety Requirements for *Design of Nuclear Power Plants* and for *Safety Assessment for Facilities and Activities* to advanced reactor designs, and in particular to innovative SFRs. In the end Mr Park expressed his sincere appreciations to the participants from GIF members, representatives of US-NRC, KINS, IRSN, other Technical Support Organizations and his colleagues from the Department of Nuclear Safety and Security. He also thanked the Scientific Secretaries of the Agency for the preparation of this Workshop.

- Mr Sagayama, former chair of GIF, informed that Mr. John Kelly became the GIF chair since the beginning of this year. Now Mr Sagayama is acting as vice-chair of GIF. Mr Sagayama expressed his pleasure to have this GIF-IAEA SFR safety workshop, being safety essential for the nuclear energy R&D and deployment. After the Fukushima accident, securing safety is becoming most crucial issue. He also reminded that this is the third SFR Safety workshop. In previous two workshops, it was reviewed basic approaches and methods on the SFR safety in each country and discussed the requirements of design and how to share them to achieve the higher degree of safety, considering also the lessons from the Fukushima accident. Mr Sagayama continued his opening remarks observing that GIF has been formulating safety design criteria, SDC, for SFR over the past two years and the GIF SFR/SDC task force has almost finished the drafting of the criteria. This 2-day workshop is a valuable opportunity to review the SDC and to have fruitful discussion with members of the IAEA. Mr Sagayama concluded recognizing that comments and contributions from IAEA are most important to improve the draft of SDC. He also expressed his expectation that the SDC of GIF would be developed into the criteria of IAEA and be applied internationally in the future.

- After the opening remarks and the self-introduction of the participants, Mr H. McFarlane was nominated Chairman of the workshop. He presented the agenda of the meeting (see annex I) which was approved with the inclusion of a presentation on Topic 2 by Mr Liu from CIAE (China).

- On the first day the experts discussed safety design criteria and more broadly safety design approaches (e.g. Defence-in-Depth [DiD], practical elimination, risk-informed, built-in safety function, implementation of passive safety features, etc.). for next generation SFRs, whilst the second day focussed on specific safety requirements (e.g. fast neutron cores, sodium technology, etc.) and examples of design measures for Design Basis Accidents (DBAs) and Design Extension Conditions (DECs) as well as related R&D.

- The discussion on safety design criteria was introduced by Mr R. Nakai, chairman of the GIF task force on SDC for SFR, who presented the GIF interim report *Safety Design Criteria for GEN-IV SFR System*, dated January 15, 2013 and distributed at the Workshop to all the participants.

- Mr Nakai, presenting the well known IAEA hierarchy of safety standards, noticed that only “upper level” safety standards for GENIV systems have been developed so far, i.e.:

  - Safety and reliability goals (GIF Roadmap, 2002);

  - Basis for safety approach for design and assessment of GEN-IV Nuclear Systems (2008);

- Design requirements of the SFRs systems (SFR System Research Plan, 2007).

The GIF SFR/SDC document is intended to partially cover the gap between "upper level" of safety requirements and "base level" of codes and standards to be used for designing GEN-IV SFR. Once the SDCs are consolidated even by means of successive interactions with the IAEA and other international initiatives (e.g. MDEP), there will be the need to develop international specific safety guides which should be the basis of the national codes and standards.

- After briefly reviewing the GIF's Safety and Reliability Goals and basic GENIV SFR Design Tracks, Mr Nakai outlined the basic scheme adopted for drafting the SDC document. Starting from the high level safety fundamentals and safety design goals, the SDC are structured according to the IAEA SSR 2/1 taking also into account the particular issues for SFRs as well as the lessons learned from the Fukushima Dai-ichi accident. Mr Nakai concluded this first part of the presentation with the enunciation of the basic policy adopted for the SDC.
- The 83 SDCs developed by GIF are grouped in 4 main chapters:
  - Management of safety in design (Criteria 1-3);
  - Principal Technical Criteria (Criteria 4-12);
  - General Plant Design (Criteria 13-42);
  - Design of specific plant systems (Criteria 42bis-82).

  During the presentation Mr Nakai provided some specific examples in particular as for criterion # 20 on Design Extension Conditions, highlighting the specific aspects of SFR (e.g. the fast core is not in the most reactive configuration), the main differences with respect to safety goals for GEN-III reactors and the implementation of the lessons learned from the Fukushima Dai-ichi accident.
- The GIF SFR/SDC document also includes a glossary and an appendix with a first formulation of some SFR safety guides based on the developed SDCs, e.g.: guide to DEC, guide to practical elimination of accident situations, guide to utilisation of passive/inherent features.
- In order to frame the SFR SDC in the more general context of the IAEA safety standards, Mr Yllera of the IAEA Department of Nuclear Safety and Security discussed the limits of applicability of current IAEA Safety Requirements to SFR. The new requirements document SSR 2/1 was approved in 2011 after the Fukushima accident. It is to be noted that the document explicitly states that SSR 2/1 "*will be used primarily for land based stationary nuclear power plants with water cooled reactors*". Therefore it is not conceived for a direct application to innovative reactor designs. This is even more true for the associated safety guides. Hence specific safety guides have to be developed for innovative SFRs. After reviewing the SSR 2/1 document, Mr Yllera pointed out the main differences between this document and the GIF SFR/SDC report. The main areas/reasons for differences are:

- Fuel, core and reactor design;
- Coolant properties;
- Operating conditions and impact on materials;
- Plant systems: primary and secondary coolant systems, RHR containment systems and auxiliary systems, fuel handling, etc.;
- Different phenomena associated with operational events and accident conditions, including DECs;
- Passive system features.

Mr Yllera concluded his presentation with an overview of the IAEA activities being implemented in order to take into account the lessons learned from the Fukushima accident, with special emphasis on the review of the IAEA Safety Standards. Possible amendments to SSR 2/1 for NPP design are: Defence-in-Depth (DiD), external events, use of alternative/mobile equipment, ultimate heat sink, station black-out. As for Safety Guides in the area of NPPs design, first priority has been given to SGs on reactor coolant systems, containment systems and severe accident management.

- After reviewing the main safety systems of PFBR, Mr Pillai from IGCAR (India) focused his presentation on the SDC adopted for this reactor, i.e. IAEA NS-R-1 and the Atomic Energy Regulatory Board (AERB) Code. As a part of the project approval, the compliance of PFBR to IAEA NS-R-1 (2000) was verified in 2006 by AERB in interaction with IGCAR. Major differences with respect to LWR were also identified. Safety Design Criteria were then reviewed on the basis of the experience gathered during PFBR design. Recently as a part of post Fukushima safety review, many BDBE scenarios were conceived for which safety margins were established for PFBR. Finally, Mr Pillai discussed the improved safety features and directions for next generation Indian SFRs, recognizing the need of comprehensive and specific safety criteria for future SFRs. Towards this purpose, IGCAR formed a task force in 2006 for assisting AERB. Specific criteria for MOX fuelled pool type FBRs of 500 MWe as twin units were developed. They are broadly classified in two categories: I) general safety requirements applicable to all types of reactors; II) requirements which are reactor system specific. Requirements for NSSS (Nuclear Steam Supply System) design are part of the second category. The safety design criteria document has been thoroughly reviewed by AERB. Mr Pillai concluded his presentation with some examples of safety design criteria, e.g. for DEC, core & shutdown systems, reactor assembly, heat transport systems, PSA, plant layout, containment, etc. and stressed the importance of continuing the international co-operation towards establishing a robust design safety criteria.
- Mr Flanagan from ORNL (US) presented the US standard ANS 54.1 *Nuclear Safety Criteria and Design Process for SFR NPPs*. The Standard defines safety objective, general design criteria (GDC), selection of Licensing Basis Events (LBE) and classification of SSCs (Structures, Systems, Components) that may be

used by designers and regulators of SFR NPPs. The standard applies to all SFR irrespective of level of power production and energy end use. The major subject of ANS 54.1 is design criteria, construction and operation being outside the scope of this standard. Consideration is given to:

- regulatory interface;
- defense in depth;
- probabilistic and deterministic design criteria (risk informed/performance based);
- high level safety objectives;
- use of PRA for informing the design process;
- plant/design maturity level.

SFR General Design Criteria (GDC) are based on GDC from Appendix A of 10CFR50 but also consider new design requirements specific or not to SFR. Mr. Flanagan gave some examples of GDCs which had minor changes, that had major changes specific to SFR (e.g. residual heat removal), new GDC specific to SFRs (e.g. intermediate coolant system), additional design requirement not specific to SFR, BDBA (e.g. SBO and severe accidents). The standard encourages but doesn't require the use of PRA in order to identify LBEs. Tables for LBE frequency and LBE acceptance were developed. ANS 54.1 standard was compared to the GIF SFR/SDC document. The following differences were noted:

- ANS did not consider design management, construction, nor operations in the GDC;
- ANS did not consider DEC requirements, except as BDBA;
- The following requirements were included in the ANS criteria but were not found in the GIF/SDC:
    - inspection requirements for both RHR and containment,
    - aircraft impact,
    - intermediate loop design requirements, and
    - fuel failure detection requirements.
- Wording of the requirements is significantly different in that ANS used the NRC wording GIF/SDC used IAEA.

- Mr L. Ammirabile of the European Commission made a presentation on the European project SARGEN_IV, focusing on safety approach and assessment of GEN-IV reactors in Europe. In line with the GEN_IV safety goals, the safety objectives have the general aim to reduce potential radiological consequences and impact on public, workers and environment as well as to reduce the occurrence/frequency of failures, incidental and accidental situations. An overall reinforcement of DiD is expected for GEN_IV NPP, including improved independence between all levels of DiD. An inherent approach combined with the implementation of passive systems should reinforce the fulfilment of fundamental safety functions. The need of complementary and integrated deterministic and probabilistic analyses was also reiterated. Assessment of hazards represents a challenging aspect of the safety assessment of next generation NPPs and needs to be improved as confirmed by the first insights of Fukushima Daiichi accident.

- Mr Kubo complemented GIF SFR/SDC by addressing the fundamental orientation on safety, which includes utilisation of passive safety features, prevention of cliff edge effect, containment function, provision against hazards and non-radiological and chemical risks, guide to design extension conditions and practically elimination of accident situations. He emphasised that requirements on total reactivity feedback and molten fuel discharge, as well as alternative or enhanced cooling measures are crucial issues as SFR specific design guides. He also emphasised the importance of the identification of the situations practically eliminated, as well specific design requirements for each situation.

- The presentations on SDC were complemented the second day with the one by Mr Okano who reviewed all the 83 criteria as well as the glossary of the GIF SFR/SDC document, with the aim to identify SFR specific criteria which take into account the unique technical characteristics of SFR. His presentation covered the overview of the SDC contents, SFR specific criteria and cross-cutting viewpoints on some SFR specific technical issues. He pointed out as key contents in the GIF SFR/SDC document: three principles of the SDC formulation (Chapter 1), and basic and common safety orientation, SFR concepts under GIF, and technical viewpoints to derive criteria specific to Gen-IV SFR (Chapter 2). With reference to Chapters 3 - 6 which include 82 criteria and 206 paragraphs, he explained specific updates/modifications for the SFR/SDC from the IAEA SSR 2/1. For example: roles of research organization and research results in Criteria 1-2, safety design on severe accident mitigation/prevention and passive feature incorporation in Criteria 7, operating experience feedback in Criteria 16 and 20, DiD level 4 and associated safety design in Criterion 20, safety classification in Criterion 22, SFR operating condition in Criterion 31 and sodium chemistry in Criterion 34. With reference to Chapter 6, which includes Criteria #42bis - 82 specific to SFR plant system, he summarized the criteria from the SFR specific features/issues --- overall plant system, reactor core reactivity, reactor shutdown, prevention/mitigation of severe accident, sodium chemical reaction, operating conditions, boundaries of SFR system, and lesson learned from Fukushima Dai-ichi accidents. He pointed out that in future further specifications will be possible to include, for example, guides related to structures, systems and components of Gen-IV SFRs (including design conditions such as initiating events, design constraint, etc.) and safety assessment (safety-related parameters and their limits)

- During both meeting days the experts discussed several important issues concerning the current draft of the GIF SFR/SDC report as well as generic safety design approaches and orientations which will be followed in the development of innovative SFRs. The following points were addressed during the discussion:

    - How to interpret “practical eliminations” of certain events in SFRs, given the fact that there are different definitions e.g. in IAEA SSR 2/1, GIF SFR/SDC report, etc.. In particular the participants discussed the meaning of “physical impossible” and “extremely unlikely”, terms used for instance in the frame of the accident initiators analysis;

- harmonization at international level of safety requirements and safety guides, as already done for existing LWRs;
- Establishing of quantitative safety criteria, e.g. through definition of the “core damage frequency” for internal events;
- Enhanced independence between the different levels of defence in depth;
- Deterministic and probabilistic safety approach;
- SDCs as guidelines for designers to be translated into specific safety guides such as safety assessment including initiators categorization specific to SFR;
- Standards for radioactive releases even in case of severe accidents in order to avoid off-site emergency responses.

- It was agreed by the participants to provide specific comments to the GIF SFR/SDC report directly to Mr Nakai by the end of March, in order to have a reviewed version ready for the GIF Policy group by May 2013.

- The meeting participants encourage the involvement of the innovative SFR designers in the discussion on safety design criteria at the international level. In particular, it was proposed to organize future meetings/workshops in order to discuss how safety criteria can be incorporated in the design.

- On the second day there were 8 presentations concerning safety design concept of SFRs under development in Member States, also providing examples of design measures for DBAs and DECs, safety evaluations and related R&D.

- Mr Y.Z. Liu from CIAE (China) presented safety features designed to eliminate the need for off-site emergency response. To avoid DiD failure, the design shall limit or eliminate the effects of operating errors on safety and prevent the possibility of harmful consequences of errors in operation, maintenance and emergency response. Large radioactive releases could be eliminated by reduction of human errors, control of the coolant system and containment conditions in postulated severe accidents with core degradation.

- Mr P. Anzieu from CEA (France) presented proposal for safety orientations for GENIV SFR in France. The French organizations involved in the ASTRID development have been proposing a set of criteria for discussion at international level. They also take into account the lessons learned from Fukushima. They concern: approach of SFRs severe accidents, probabilistic objective, cliff-edge effects, failure of equipment subject to extreme external aggressions, design arrangements related to common failure hazards, grace period and autonomy, chemical risk, other radiological risks, progressivity in accidents used for design, safety demonstration.

- Mr A. Rineiski from KIT (Germany) presented some results of safety analyses for the *European Sodium-cooled Fast Reactor* (ESFR) which was studied in 2009-2012 in the FP7 EURATOM Framework program. An ESFR core with a reduced sodium cooled effect was obtained as a result of optimization activities, but the possibility of power excursions under design extended conditions cannot be excluded completely. Therefore design measures for preventing multiple re-criticalities in case of core melting may decrease the maximum possible mechanical energy release. This can be achieved by fuel relocation through special paths, such as control rod guide tubes, already existing in SFRs and by incorporation of additional subassemblies, e.g., similar to control rod guide tubes. It was also mentioned that incorporation of thick oxide pins in ESFR enhances appreciably a particular reactivity feedback related to homogenization of fuel and structure in case of fuel melting.
- Mr. Prabhat Kumar from BHAVINI (India) gave an overview of the design extensions in PFBR in wake of December 2004 Tsunami in India and March 2011 Tsunami in Fukushima. He mentioned that each accident has added new requirements for nuclear plant globally. It appears that to reach near zero accident in the reactor, the design extensions will be very costly. He suggested that future goals need to be redefined and the global community could review whether safety of the environment should be the main goal. He observed that the world nuclear community has spent large resources in improving the reactor safety but has not paid commensurate attention on R&D for protection of environment and to restrict release in public domain in the event of accident. Mr Kumar further stated need for enhancement design features for heat removal from core in the event of accident in SFRs. He also emphasised on need for mixed of active and passive back fits in SGDHR in future. He also emphasized the need to look a fresh on innovative features in future fast reactors for enhanced safety rather than incremental improvements in existing concepts of SFRs.
- Mr S. Kubo of JAEA (Japan) presented safety design approach for JSFR and specific design measures adopted in JSFR. Their aim is to apply the SDC developed within GIF. 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. They consider the different time scale and power in case of ATWS (Anticipated Transient Without Scram) or LOHRS (Loss Of Heat Removal System). As a consequence, also the measures to be implemented are different in the two cases, i.e., for ATWS passive shutdown capability, prevention of severe mechanical energy release and in-vessel retention, for LOHRS natural circulation decay heat removal and alternative cooling measures. The scenarios which can threat the containment and which may cause containment failure have to be practically eliminated by design measures.
- Mr H.-Y. Jeong from KAERI (RoK) presented safety approaches for the *Prototype Generation-IV Sodium-cooled Fast Reactor* (PGSFR) in Korea. The PGSFR design aims at achieving IAEA's safety objectives and GIF's safety goals for Generation-IV reactors. The most important safety design principle is the implementation of defence-in-depth (DID) for abnormality prevention, accident prevention,

accident control, accident mitigation, and accident termination. For the harmonization of deterministic approach with probabilistic approach, PSA is applied to identify the weak points of the design and to achieve the design optimization. The safety concept and top-tier safety requirements of PGSFR were followed in his presentation. He also summarized key design features of PGSFR on core design, fluid system design, mechanical design, and safety evaluation.

- Mr Y. Ashurko from IPPE (Russian Federation) presented a safety concept of the BN-1200 sodium-cooled fast reactor design developed now in Russia as integral part of the *Breakthrough Project* aimed at the creation of the new technological platform based on fast neutron reactors and closed nuclear fuel cycle. In accordance with the safety requirements formulated in the *Breakthrough Project* this design implies implementation of natural safety principle assuming application of inherent safety features and passive safety systems providing deterministic elimination of severe accidents that require evacuation of the inhabitants from the area adjacent to the NPP. There are design solutions realized in the BN-1200 design that permit to meet these safety requirements
- T. Sofu from ANL (USA) provided a summary of U.S. safety approach, safety performance goals, safety requirements, and licensing framework for SFR design and reviewed applicable design criteria. He explained that the DiD principles guide the design, construction, and operation of nuclear facilities in the U.S. as fundamentally implemented by multiple, successive barriers to guard against the escape of radioactivity from nuclear facilities but also extended to all aspects of nuclear facility design, construction, and operation, so that all safety critical functions are achieved by multiple systems/procedures/processes that are diverse and independent. He provided a review of the nuclear reactor safety design criteria catalogued in the Code of Federal Regulations (10CFR50 Appendix A), ANSI/ANS 54.1 standards, and U.S.DOE Order for research facilities with the aim of identifying common themes in application to Sodium-cooled Fast Reactor (SFR) designs. He concluded that, based on past experience and safety demonstrations, large radioactive releases from an SFR may be virtually eliminated if only mechanistic, physically-realizable accident conditions are considered to be relevant for safety.

Conclusions and future actions

In conclusion of the workshops, participants agreed on the following points and actions:

- The GIF SFR Safety Design Criteria have been under development for 2 years. They are intended to be a consensus by international R&D community on safety performance directions for Gen-IV SFRs. At the same time, the actual SFR design is the choice of the developers and it is not the intent of the SDC to define/select one specific design.

- IAEA SSR 2/1 is considered as a reference document in terms of its basic structure, comprehensive formulation, terms & definitions. Safety-related terms are basically of the IAEA Safety Glossary (2007). New definitions are for terms specific to the Generation-IV SFR.
- The concurrent development of ANS Standard 54.1 on Nuclear Safety Criteria and Design Process for Liquid Sodium Cooled Reactor Nuclear Power Plants was presented. The parallels are very strong and the two groups cooperate and coordinate. Differences in the two approaches were contrasted, notably that the ANS Standard uses NRC language rather than IAEA language. The GIF document has more emphasis on design extension conditions, while the ANS considers some issues such as aircraft impact that GIF considers a security issue.
- There was a consensus that the requirement for core damage frequency due to internal events should be at least an order of magnitude lower than current regulatory requirements for LWRs.
- India reported on the progress of PBFR and explained how that experience plus international guidelines are being used to influence their design of their next fast reactors which are expected to have more Gen-IV features. India also gave several examples of questions that arise when detailed design work intersects with high-level safety principles.
- Differences relative to LWR requirements were highlighted in the papers by Mr Yllera, Mr Okano and Mr Kubo.
- Safety design concepts of SFRs which are being developed in Member States were also presented and discussed, with an emphasis on design measures against Design Basis Accidents (DBA) and Design Extended Conditions (DEC), as well as associated safety evaluations and supporting R&D.
- The scientific secretary of the workshop will provides Mr Peter Lyons, Chairperson of the Panel on "Safety Design Criteria" at the forthcoming FR13 Conference, with the present workshop summary report as a contribution to the topics to be discussed at the FR13 Panel;
- The contribution by Mr Nakai to the FR13 Panel on "Safety Design Criteria" will be focused on the GIF interim report "Safety Design Criteria for GEN-IV SFR System";
- The main outcomes of the workshop will be presented by Mr S. Monti at the "GIF-IAEA/INPRO interface meeting", which is going to be held on 28 February – 1 March 2013 at the IAEA headquarters in Vienna;
- The participants will provide specific comments to the GIF SFR/SDC report directly to Mr Nakai by the end of March 2013;
- Participants agreed on the possibility to organize a fourth GIF-IAEA workshop on safety of SFR in 2014, focused on:
    - development of safety guides, after the finalization of the safety design criteria;

- Involvement of design organizations of innovative SFRs currently under development, with the aim to present engineering solutions able to meet the safety design criteria.

The date of the workshop will be fixed with an advance period of 6 months, depending on the achievement of the two points above mentioned.

ANNEX I

Third Joint GIF – IAEA Workshop on

SAFETY DESIGN CRITERIA FOR SODIUM-COOLED FAST REACTORS

26 – 27 February 2013

IAEA HQ, Vienna. Building M, Meeting Room: ***VIC M5***

Final Agenda

1st Day - Tuesday, 26 February 2013

Time	Topic	Participant
09:30 – 10:00	Opening remarks Introductory remarks by GIF Self-introduction of the participants Approval of the Agenda Nomination of the workshop Chairman	Mr J.K. Park (I) Mr Y. Sagayama (G) All
Topic-1: Safety Design Criteria for next generation SFR		
10:00 – 11:00	GIF-SFR-SDC Task Force: ➢ Safety approach & requirement on general plant design ➢ Requirement on specific plant design ➢ List of key discussion points and future direction	Mr R. Nakai (G)
Coffee break		
11:30 – 12:15	Overview of the IAEA Activities ➢ Safety requirements/design criteria for SFR ➢ Lessons learned from Fukushima Daiichi Accident	Mr J. Yllera (I)
12:15 – 12:45	Safety Design Criteria of Indian Sodium Cooled Fast Reactors	Mr P. Pillai (IGCAR, India)
12:45 – 13:15	European project SARGEN_IV: safety approach and assessment of GENIV reactors	Mr L. Ammirabile (European Commission)
Lunch break		
14:30 – 15:30	ANS Sodium Fast Reactor Safety Design Standard (ANS 54.1)	Mr G. Flanagan (ORNL, USA)
Break		
16:00 – 18:00	Key Discussion Points on Gen-IV safety design criteria ➢ Introduction to the discussion: Safety Design Approach based on Gen-IV SDC ➢ Discussion ➢ Conclusions	Mr. S. Kubo (G) All Chairman
18:00	Adjourn	
18:30	*Welcome reception organized by the IAEA*	All

2nd Day - Wednesday, 27 February 2013

09:00 – 10:00	Specific SFR requirements ➢ Technical Specification of the SDC including fast neutron core and sodium technology ➢ Conclusions	Mr. Y. Okano (G) Chairman
Topic-2: Safety Design Concept of SFRs under development in member states: Example of Design measures for DBAs and DECs, safety evaluations and related R&D (e.g. Typical postulated events for DBAs and DECs, PSA, Core characteristics and reactivity control, Decay heat removal, Coolant boundary failure and core cooling, Sodium chemical reactions, Containment, Fuel handling and storage, External events)		
10:00 – 13:00 *Including coffee break 11:00 – 11:30*	➢ Safety features designed to eliminate the need for off-site emergency response	Mr Y. Z. Liu, (CIAE)
	➢ Proposal of Safety Orientations for Generation IV SFRs	Mr P Anzieu (CEA, France)
	➢ Severe accidents and ESFR design issues	Mr A. Rineiski (KIT, Germany)
	➢ Safety approach and measures for design extension conditions for PFBR in post Fukushima Scenario	Mr P. Kumar (BHAVINI, India)
	➢ Safety approach on severe accidents specific to SFR systems, in light of L.L. from Fukushima Dai-ichi NPPs accident [*working title*]	Mr. S. Kubo (JAEA, Japan)
	➢ Safety approach of PGSFR in Korea	Mr. H-Y Jeong (KAERI, RoK)
	➢ Safety concept of the BN-1200	Mr. Y. Ashurko (IPPE, Russian Federation)
	➢ An overview and evaluation of U.S. SFR safety approach	Mr T. Sofu (ANL, USA)
Lunch break		
Concluding Session		
14:30 – 15:30	Drafting of Presentation at Panel 1 of FR13 Conference	Workshop Chair / GIF-SFR-SDC Chair All
15:30 – 16:00	Conclusions and future actions Discussion. Final outcome of the workshop	Workshop Chair All
16:00	*Adjourn*	

(**I**): IAEA Representatives; (**G**): GIF Representatives

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