Comparison of Design Concepts for SFR under Development

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1. Introduction

On January 2006, the President of France has fixed the year 2020 as a target year of operation for Gen-IV prototype reactor. Since then, the CEA was charged to develop the prototype reactor named ASTRID (Advanced Sodium Technological Reactor for Industrial Demonstration). The goal of ASTRID with a capacity of 600 MWe is to study the technical demonstration that can be scaled up to commercial reactor. It was expected that the success of ASTRID project could eventually lead to operation of industrial reactor around 2040. On 2012, ASTRID designer has submitted the DOrS (Dossier d'Orientations de Sûreté, Safety Orientation Document) for ASTRID to IRSN and IRSN has issued a report [1] after reviewing the DOrS. The report DOrS itself is not available publicly, intellectual property might be the reason, but the review document of IRSN is open to public, so we can understand the basic concept of ASTRID by IRSN report.

Meanwhile, the PGSFR (Prototype Gen-IV Sodium cooled Fast Reactor) of 150 MWe is also under development by KAERI. The basic design concept is presented in the Top Tier Report for PGSFR.

The DOrS reflects the lessons of Phenix/Super-phenix design and operation. Thus, comparing it with the TTR for PGSFR gives a good chance to understand the level of PGSFR safety. This paper compares the design concept in DOrS for ASTRID with the TTR for PGSFR and recommends what should be pursued in PGSFR design to increase the safety level, at least to be comparable with ASTRID.

2. Design Concept of ASTRID

In this section, we will summarize some major concepts of ASTRID proposed by designer and the review comments of IRSN.

2.1 Safety Objective of ASTRID

ASTRID design	IRSN comment
The safety level of ASTRID will be at least equivalent to Gen-III reactors and incorporate the Fukushima lessons. Also it will integrate the specific improvements based on the experiences of all the past French reactors.	The safety objective needs to be defined quantitatively and to be completed taking into account the particular objective of ASTRID demonstrator's role with regard to the future Gen-IV platforms.

2.2 Defense in Depth

ASTRID design	IRSN comment
The concept of DID will be applied in designing the facilities for prevention of incidents and accidents. Line of mitigation is utilized to design the facilities to limit the consequences of accidents with core melting.	The line of defense is useful in structuring the design. IRSN will review the principle of definition and the implementation later. The demonstration should not rely solely on the concept, be complemented by probabilistic analysis.

2.3 Consideration of Severe Accident in Design

ASTRID design	IRSN comment
The design will reinforce the prevention of all the predictable situations which could lead to severe accident. The melting of fuel and the resulting consequences will be considered in the design as a 4th level of DID.	The approach is acceptable in general. But taking into account the lessons of Fukushima, the long term management of severe accident and also the absence of cutting-edge effect should be assured.

2.4 Conditions of Practical Elimination

IAEA Safety Guide NS-G-1.10 [2] defines the possibility of certain conditions occurring is considered to have been practically eliminated if it is physically impossible for the conditions to occur or if the conditions can be considered with a high degree of confidence to be extremely unlikely to arise. Pursuing to be a Gen-IV platform, the concept is implemented in the ASTRID design.

ASTRID design	IRSN comment
Proposed list of situations that should be practically eliminated and facilities to prevent and mitigate them. The design is based on the deterministic approach, complemented by	IRSN finds the identification of situations, though needs to be prudent at this stage of design, and the proposed approach are generally acceptable. But the specific examples

probabilistic analysis. The essential SSCs involved in prevention and mitigation will have the highest level of safety	presented will be discussed later. The measures for prevention and mitigation should be particularly robust.

2.5 Integrity of Barriers

ASTRID design	IRSN comment
The design will improve the core surveillance and assure that the events like blockage or failure of cooling during the fuel handling do not lead to local melting of cladding.	IRSN finds the improved core surveillance will contribute to reinforce the prevention of accidents. Also aiming the integrity of cladding during these events will be preferable.

2.6 Design of Safety Functions

ASTRID design	IRSN comment
O Reactivity Control : The design pursues to improve the natural behaviour of core during transients and accidents. The third automatic reactor shutdown system is also envisaged. O Heat Removal: The diversified circuits dedicated to residual heat removal which can operate in case the core melts are implemented.	O Reactivity Control : The optimization of the core should take into account also the reactivity effect of local sodium void. O Heat Removal: The concept is acceptable and the use of probabilistic evaluation in the design is important. The possibility needs to be considered to introduce the mobile measures to establish the function when the core melts.
O Confinement of Radioactive and Toxic Materials: The zone with radiological risk is separated with the zone with toxic risk. This requires new solution to handle the non-radioactive sodium fire occurring in the reactor building. The design of confinement is not presented yet.	O Confinement of Radioactive and Toxic Materials: IRSN will evaluate the design measures to achieve this objective, later. IRSN stresses that the fuel storage and handling zones need to be designed with particular attention to increase the efficiency of confinement.

3. Review of PGSFR Design Concept

The TTR of PGSFR was developed referencing the format of SMART reactor. [3] KINS is reviewing the requirements as a part of research activities for SFR. In this section, we will introduce the basic design concepts of PGSFR and our review comments on them in view of the ASTRID design concepts mentioned in section 2 above.

3.1 Safety Objective of PGSFR

TTR proposes the safety objective as a CDF (Core Damage Frequency) of 1.0×10^{-6} /reactor-year and a LRF (large release frequency) of 1.0×10^{-7}/reactor-year. The target value is lower than the current fleet of reactors, but because the PGSFR is a first-of-a-kind reactor, the PSA data utilized in the analysis need deep and cautious evaluation. Also the safety objective as a prototype reactor which will be built to test new design features needs to be clearly defined and implemented in the design.

3.2 Defence in Depth

The DID concept will be utilized also in the PGSFR design. The concept needs to be implemented in the specific system design and the probabilistic analysis needs to complement the deterministic structuring of the line of defence.

3.3 Consideration of Severe Accident in Design

The plant will be designed to satisfy the performance criteria and the safety requirements in terms of CDF and LRF. Severe accident management guideline will be provided and the in-vessel retention of corium will envisaged. We find the proposed concept is borrowed from the current operating plants and does not clearly define the requirements expected for a Gen-IV reactor. The design implementation of in-vessel retention for SFR is not clear and needs further analysis.

3.4 Conditions of Practical Elimination

The TTR does not show the list of situations which should be practically eliminated. Considering that the PE is required already in the IAEA requirements for the current fleet of reactors and it is generally expected that the Gen-IV reactor should have at least equivalent or higher level of safety to the current reactors, the practically eliminated situations should be implemented in the PGSFR design.

3.5 Integrity of Barriers

The TTR is not structured to clearly show how the integrity of barriers will be assured. In implementing the DID in the design, it might be better restructure the TTR to show clearly the integrity of barriers will be assured.

3.6 Design of Safety Functions

The core will be designed to have a negative reactivity against the power. The residual heat removal system will be designed as a safety class and the redundancy will be secured to prevent the common cause failure.

We find the above design concept of PGSFR is not well organized and sufficient enough to satisfy the general expectations people could have for Gen-IV reactor. The residual heat needs to be removed even after accidents and the core design needs to reflect the recent research results and also the past operating experiences. The phenomenon like an abrupt shutdown by negative reactivity which occurred in Phenix needs to be considered in the core design.

4. Conclusions

The DOrS of ASTRID and the TTR for PGSFR have not the same format and also the same purpose, so it is not easy to compare the two design concepts directly. But, still, we think the concepts could be compared in a very general way. Thus, in this paper we have presented the very short comparison results of the two SFR design.

Our opinion after first reviewing the TTR is that the PGSFR needs to be designed in a more systematic way. The requirements are coming basically from the previous document used for SMART licensing and do not show prototype reactor specific characters.

Especially the design needs to be strengthened against severe accident, implementing in an affordable way the concept of practical elimination.

REFERENCES

[1] Synthèse du rapport de l'IRSN sur son analyse du dossier d'orientation de sûreté (DOrS) du projet de réacteur ASTRID, IRSN, June 2013
[2] IAEA Safety Guide, Design of Reactor Containment Systems for Nuclear Power Plants, NS-G-1.10, IAEA, 2004
[3] Top-Tier Requirements for SMART Standard Design, 000-PT414-001, KAERI, 2010