Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 24-25, 2013

A Study on Licensing Requirement for Severe Accident of PGSFR in Korea

Kilyoo Kim*, SangHoon Han, K.S. Ha
Integrated Safety Assessment Division, Korea Atomic Energy Research Institute,
P.O. Box 105, Yuseong, Daejeon 305-600, South Korea,
**Corresponding author: kykim@kaeri.re.kr*

1. Introduction

A Prototype Generation IV Sodium Fast Reactor (PGSFR) is under design with defense in depth concept with active, passive, and inherent safety features to acquire a design approval for PGSFR from Korean regulatory authority by around 2017.

There are two types of fuel in Sodium Fast Reactors (SFRs); 1) oxide-fueled, 2) metal-fueled. The inherent safety characteristics of oxide-fueled SFRs such as CRBR [1], Japanese SFR, Super Phenix, etc. require serious severe accidents (SAs) research and even core catcher when 'unprotected loss of flow' (ULOF) or 'unprotected transient overpower' (UTOP) is used as a SA scenario.

Meanwhile, metal-fueled SFRs such as PRISM [2], 4S [3], etc. do not have serious SA research since they are inherently safe with low melting point, high boiling temperature, good thermal inertia due to good conductivity, and passive safety systems, etc. Since PGSFR is one of the metal-fueled SFRs which have been developed to overcome the SAs drawbacks of oxide fueled SFRs, there would occur no SAs in view of the then-current criteria of SAs.

Unfortunately, there is no SA regulatory requirement for SFR in Korea and in USA. Thus, we can think the following two options to get the design approval for PGSFR.

1) Option 1: Methods and strategies to prevent and mitigate SAs of PGSFR should be reported, and for which required research should be performed. After Fukushima accident, it seems that this SA perspective becomes important.
2) Option 2: Since PGSFR or a metal-fueled SFR such as PRISM [2] is inherently too safe, there is no SA as proved by the EBR II experiment. Thus, the issues of SAs were already solved, and SA research is not necessary.

In this paper, by reviewing of the recent nuclear regulation trend in Korean and in USA, and by checking of PGSFR PSA model, which option is better in the design approval for PGSFR is discussed.

2. U.S regulatory trend

In 1985, the U.S. NRC Policy Statement on Severe Accidents [4] states that the Commission expects new plants to achieve a higher standard of SA safety performance than prior designs.

In the pre-application of PRISM in 1994 [2], ULOF and UTOP are used for SAs, and 'full fuel cladding failure' was assumed in emergency planning zone (EPZ) calculation.

In 2003, NRC decided [5], "... reactor designers are expected to propose designs with enhanced safety characteristics and the staff reviews each design on its own merits and, on as needed basis, recommends additional enhancements in areas of high uncertainty subject.."

In 2007, risk-informed licensing basis events (LBE) selection method introduced in the technology neutral framework (TNF) report [6]. In 2010, the risk-informed LBE was applied to SFRs, and SA caused by rare earthquakes was predicted before Fukushima accident as like "Typical designs of SFRs cannot meet the TNF due to the requirement of including sequences initiated by very rare earthquakes."[7]

In 4S reactor design pre-application [3] in 2011, ATWS events were used for SA, and the 'full fuel cladding failure' was assumed in new EPZ (Emergency Planning Zone) application, in a similar manner of PRISM pre-application.

In 2012, after Fukushima accident, the Near-Term Task Force (NTTF) recommended to enhance the ability of nuclear power plants to deal with the effects of prolonged SBO (station blackout) conditions, and to enhance the capability to prevent or mitigate seismically induced fires and floods [8]. Also, the Task Force recommends to strengthen SBO mitigation capability at new reactors for design-basis and beyond-design-basis external events [8].

In 2012, after accepting the recommendations of NTTF, a safety analysis of the prolonged SBO condition and 30 days cooling ability were performed in NuSCALE reactor after Fukushima accident [9].

In 2012, SFR gap report [10] mentioned the following research areas were important after Fukushima; containment response modeling, source term analysis, severe accident code such as MELCOR for SFRs, and seismic related modeling.

3. Korean regulatory trend

After reviewing TNF report [6], Korean independent regulatory expert organization called 'KINS'(Korea Institute of Nuclear Safety) regarded the risk-informed LBE selection as a premature one in Korea, and rather, showed a LBE selection and acceptance criteria for SFR as shown in Table 1 in a research report [11]. As shown in Table 1, we can see that KINS expects SA scenario in SFR and the related research to mitigate the SA.

Also, KINS indirectly mentioned the necessity of SA research by quoting [12] the research need in mechanical modeling of the source term from the SFR gap report [10].

4. PSA perspective

Currently, only level 1, internal PSA was performed for PGSFR. Next year, an external PSA would be done. In Table 2, the important minimal cutsets consisting of triple basic events are shown with the assumption that RVACS (Reactor Vessel Auxiliary Cooling System) is not designed in PGSFR. As we can see in Table 2, PDRC (Passive Decay-heat Removal Circuit) damper is the most important component. However, if RVACS is designed in PGSFR, sodium water reaction becomes the most important triple faults since RVACS can be a backup of PDRC for a long term cooling. Since it looks like that PDRC and RVACS are vulnerable in the strong earthquake, a SA scenario related to common cause failure of PDRC & RVACS caused by a earthquake could be selected after performing an external PSA for PGSFR.

5. Conclusions

Although the inherent and passive safety measures of PGSFR could satisfy with the then-current regulatory requirement used in the pre-application of PRISM [2], the trend in U.S and Korean nuclear regulatory after Fukushima accident shows that SA cannot be treated in residual risk category. Rather, after setting SA scenario, further SA research should be done which has not been well performed after PRISM pre-application in 1994. Especially, PGSFR should cope with the extended SBO requirement and triple failures issued in Fukushima accident. Although accurate SA scenarios for PGSFR would be identified after performing the external PSA for PGSFR, some triple faults are suggested as SA scenarios.

Acknowledgement

This work was supported by Nuclear Research & Development Program of the National Research Foundation of Korea (NRF) grant, funded by the Korean government, Ministry of Science, Ict & future Planning (MSIP).

REFERENCES

[1] U.S. NRC, "Safety Evaluation Report Related to the Construction of the Clinch River Breeder Reactor Plant," NUREG-0968, Volume 1, March 1983.

[2] NUREG-1368, Pre-Application Safety Evaluation Report for the Power Reactor Innovative Small Module (PRISM) Liquid-Metal Reactor, USNRC. 1994.

[3] TOSHIBA Corp., Evaluation for 4S EPZ, AFT-2011-000080revOO4(2), Sept. 2011

[4] U.S. NRC, "Policy Statement on Severe Reactor Accidents Regarding Future Designs and Existing Plants", 50 FR 32138, August 8, 1985.

[5] U.S. NRC, Policy Issues Related to Licensing Non-LWR Designs, SECY-03-0047, Aug. 2003

[6] U.S. NRC, Feasibility Study for a Risk-Informed and Performance-Based Regulatory Structure for Future Plant Licensing. NUREG-1860, December 2007.

[7] Brian C. Johnson, "Application of the Technology Neutral Framework to SFR" Ph.D Thesis, MIT, 2010

[8] Recommendations for enhancing reactor safety in the 21st Century, The Near-Term Task Force review of insights from the Fukushima Dai-Ichi accident, 2012

[9] JOSÉ N. REYES, Jr., "NuSCALE Plant Safety in Response to Extreme Events", Nuclear Technology, Vol. 178, May, 2012

[10] M. Denman et al., "Sodium Fast Reactor Research Plan-Volume I", SAND2012-4260, May, 2012

[11] K.T., Kim, et al., Investigation of System Safety Evaluation Technology for Sodium-cooled Fast Reactors, KINS/RR-829, 2011

[12] N.D Suh, et al., Literature Review on Metallic Fuel Source Term for SFR, Trans. of KNS, Korea, Oct., 2012

Table 1. Acceptance Criteria for SFR Licensing Basis Events

Initiating Event Freq.	Event		Physical Barrier: Fuel	Physical Barrier: Contain-ment	EAB, LPZ Dose Limit (whole body)
f ≥ 1	Normal Operation		No Damage	No Damage	Equivalent Dose 1mSv/yr
1 > f ≥ 10-2	Anticipated Operational Occurrences (AOO)				Equivalent Dose 1mSv/yr
10-2 > f ≥ 10-7	DBA	DBA 1	Partial Damage (small fraction)		10% 10CFR100 (25mSv/event)
		DBA 2	Partial Damage, Maintain Coolable Geometry		100% 10CFR100 (250mSv/event)
NA	Severe Accident		CDF Safety Goal	LERF Safety Goal	-

Table 2. Important triple basic events in Level 1 internal PSA of PGSFR

Value	BE#1	BE#2	BE#3
3.720e-8	%LOSF	PDDMW-ABCD	PDOPH-DAMPER
3.000e-8	%SWR	SWRPRS	VPE
7.440e-9	%LEP	PDDMW-ABCD	PDOPH-DAMPER
5.580e-9	%SWR	PDDMW-ABCD	PDOPH-DAMPER

%LOSF : Loss of Secondary Flow
%SWR : Steam Generator Tube Rupture (Sodium Water Reaction)
%LEP : Loss of Electric Power
PDDMW-ABCD: CCF (4/4) Damper
PDOPH-DAMPER : Operator fails to open manually
VPE : Failure of Vessel Protection against SWR