Transactions of the Korean Nuclear Society Autumn Meeting
Pyeongchang, Korea, October 30-31, 2014

Perspective on Regulatory Review of SFR Flow Blockage Safety Issue

Yong Won Choi*, Andong SHIN, Moo-Hoon BAE, Namduk SUH
Korea Institute of Nuclear Safety, Goosong-dong, Yusong-gu, Daejeon, 19
**Corresponding author: k722cyw@kins.re.kr*

1. Introduction

A sub-channel flow blockage could occur by an introduction of damaged fuel debris or foreign obstacles into a core fuel subassembly in Sodium-cooled Fast Reactor (SFR). This phenomenon is expected to be one of the safety issues in SFR because of the geometrical compactness of the SFR core design. A flow recirculation induced by the blockage could increase the local coolant temperature adjacent to the blocked channels during the incident and it might eventually lead to the degradation of the fuel rods. An in-depth study is needed to prevent core damage by flow blockage and to maintain the safety of the reactor core for the accident caused by the flow blockage.

In this study, the state of the art on a sub-channel flow blockage for SFR is reviewed and the direction on how to evaluate the safety issue during the licensing review is suggested.

2. Flow Blockage of Sodium-cooled Fast Reactor

The high heat capacity and the large heat transfer coefficient of a liquid metal allows the compact core design of SFR, in which the heat flux from the fuel rods is usually higher than the other types of nuclear reactors. Therefore, it is important to maintain the integrity of the fuel rod configuration during the continuous operation of SFR. Especially, a local blockage in a subassembly of SFR is of particular importance. When an obstacle or a blockage is formed in a flow path, the local temperature of the coolant increases at the downstream of the blockage and then the integrity of the fuel clad might be threatened. The flow blockage could be formed either by the introduction of foreign materials remaining in the primary coolant system or by the degraded fuel itself. A channel blockage in the fuel assemblies of SFR also can be caused by the swelling and bending of fuel pins. **[1]**

3. State of the Art Review – Flow Blockage for SFRs

In this section, the current status of domestic and oversea research activities and positions on the flow blockage for SFRs is reviewed.

3.1 Position of Foreign Countries on Flow Blockage Issue

3.1.1 USNRC [2]

NRC (Nuclear Regulatory Commission) staffs reviewed the PRISM conceptual design in 1994. As the result, PSER (Preapplication Safety Evaluation Report)[2] for PRISM was published. According to this PSER, the flow blockage is one of key safety issues. And the following is a summary of the review results for flow blockage.

- In BE(Bounding Event) for PRISM, the flow blockage is involved.
- To ensure that margin is retained in the design to accommodate a blocked assembly, the NRC staff requests the following commitments.
  - Technical specification limits are provided that require establishing full reactor sodium flow before withdrawal of control rods and limit the startup rate to less than 1 percent per minute.
  - Technical specification limits are provided on DNM (Delayed Neutron Monitor) operability and alarm setpoints sufficient for rapid detection of fuel melting.
- GDC (General Design Criteria) related to fuel assembly flow blockage was suggested by NRC

3.1.2 France [3]

In the past, large experimental programs focused on understanding TIB (Total Instantaneous Blockage) accidental phenomenology. So Phenix TIB calculations were already performed. However, because of modifications to the Phenix operating conditions and to the core configuration in 2005, the TIB sequence analysis needed to be updated before restarting the Phenix reactor after its renovation. The following is the summary of evaluation of the accident scenario initiated by TIB [3].

- Because of the size of the Phenix core, the French Safety Authorities have studied a TIB scenario at the fuel subassembly inlet occurring under operating conditions.
- This TIB scenario has been widely investigated through SCARABEE program. And the TIB scenario is evaluated with the SIMMER code, particularly in terms of key phenomena and event chronology, and the recriticality risks have been calculated.
- The SIMMER results have shown that the core degradation is limited in any case to the neighboring subassemblies. The hexagonal wrappers in contact with the faulty subassembly as well as the closest subassemblies can start to melt because the time interval between the TIB and melting is very low. But, before propagating to the rest of the core, the reactor will be stopped since the time between

detection and propagation is large enough that this risk of propagation has a very low probability.

▫ In order to rapidly detect TIB, redundant measurement can be used; reactivity, temperature and DND (Delayed Neutron Detector).

3.1.3 China [4]

China has been studying SFR technologies since 1986. And the construction of CEFR (China Experimental Fast Reactor) had started in 1998. Then, the first criticality was achieved in 2010. In the process of issue of first fuel loading license, National Nuclear Security Administration (NNSA) reviewed the flow blockage safety issue. The results are as follows.

▫ NNSA and China Institute of Atomic Energy (CIAE) agreed that a total local blockage seems to be too conservative.

▫ So, it is agreed that a partial local blockage is defined as DBA, and a total local blockage is defined as BDBA, however, for DBA analysis, the size of a local blockage is still an issue

▫ NNSA evaluated the measuring devices for flow blockage as follows.

- For ″Fuel S.A. outlet temperature measuring device″, because the thermocouples cannot cover all fuel SAs, reviewer recognized that outlet temperature measuring device is not valid and functional for fuel subassembly blockage events;
- Since partial fuel SA local blockage event progressed slowly, ″Cover gas radiation monitoring system″ and ″Delayed neutron detection system″ could provide detection and protection of the event;
- However, for ″Cover gas radiation monitoring system″ and ″Delayed neutron detection system″, the instruments are not 1E grade, and don′t satisfy the requirements of protection parameters. CIAE should promise that the two systems be remodified later;
- Since TIB progressed very quickly, outlet temperature, cover gas radiation and delayed neutron systems could not satisfy the requirements of timely detection. ″Specially designed Regulation control rod overspeed alarming signal for TIB″ was considered valid for TIB.

3.2 Domestic Activities on Flow Blockage Safety Issue

In Korea, the PGSFR(Prototype Gen-IV SFR) is under development by KAERI (Korea Atomic Energy Research Institute). The flow blockage is one of the key safety issues similar to other SFR. So, for the analysis of the flow blockage accident, KAERI developed MARTRA-LMR/FB code. Then, the flow blockage accident of KALIMER-600 was analyzed.

3.2.1 Development of MATRA-LMR/FB[1]

The MATRA-LMR-FB code developed by KAERI utilizes the distributed resistance model (DRM) to describe the sweeping flow formed by the wire-wrap around the fuel rods and to model the re-circulation flow formed in the downstream of the blockage. The hybrid difference scheme is also adopted for the description of the convective terms in the re-circulating wake region of a low velocity. Also some turbulent mixing models are implemented in the code. Since the practical blockage usually makes a permeable medium rather than an impermeable one, a porous blockage model was incorporated into it by employing the correlation suggested by Ergun. The MATRA-LMR-FB had been qualified based on available experimental data, and a code-to-code comparative study was also performed as part of an effort to supplement a qualification

3.2.2 Analysis of Flow Blockage for KALIMER-600 [1]

A sub-channel flow blockage for KALIMER-600 was analyzed by KAERI using MATRA-LMR/FB. The radial channel blockage position and the blockage size in the subassembly are main parameters taken into account in the analysis. KAERI classified a size of 6 sub-channel blockage as the DBE. Also, the analysis is further extended to blockage sizes of 24 and 54 sub-channels to analyze BDBE. The three radial positions are examined for each blockage size. They are the center, the middle between the subassembly center and the duct wall, and the edge of the subassembly, as marked in Fig. 1.

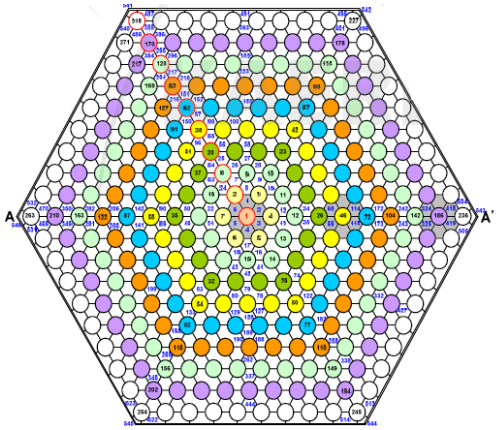

Fig. 1. Numbering of the Sub-channels and Fuel Rods, and Blockage Positions for the Analysis [1]

The analysis results of the coolant maximum and the exit average temperatures in the subassembly for the 6

sub-channel blockage are summarized in Table 1[1]. The 6 sub-channel blockage satisfied the safety criteria for both the peak cladding and the core outlet average temperatures with a margin of at least about 40℃ regardless of the core designs and the blockage positions. Therefore, the design basis event, i.e. the 6 sub-channel blockage was evaluated to satisfy the safety limits.

Table 1. Analysis Results for the 6-Sub-channel Blockage[1]

Blockage Size	Uranium core			L_TRU core			M-TRU core		
Blockage Position	C *	M **	E ***	C *	M **	E ***	C *	M **	E ***
Max temp. (℃)	611	609	597	630	629	617	630	629	617
Core outlet average temp. (℃)	541.4			557.5			556.		

*Center, **Middle, ***Edge

4. Direction on Licensing Review of Flow Blockage Safety Issue

Reviewing the foreign and domestic research activities and positions on the flow blockage safety issue, we found that the phenomenon is still a safety issue not resolved. Thus, when KAERI applies the licensing review of the Prototype Gen-IV SFR under development, it is suggested that the safety reviewer needs to take into account the following;

1) The computer codes utilized in the analysis need to be verified and validated.
2) The phenomenon of flow blockage should be monitored. The monitoring could be done by the thermocouples in the upper regions of reactor core or other equipments. The reliability and feasibility of system or equipments should be confirmed.
3) If the reliable monitoring is not guaranteed, the measured parameters of the flow blockage monitoring system should not be used safety analysis.
4) The accident ensued by flow blockage should be classified in accident classification conservatively.

5. Conclusions

In this study, the foreign and the domestic activities and positions on the flow blockage safety issue are reviewed. And the direction to take into account for a licensing reviewer is suggested.

REFERENCES

[1] KAERI, "Conceptual Design Report of SFR Demonstration Reactor of 600MWe Capacity", KAERI/TR-4598/2012, Mar. 2012.

[2] U.S. NRC, "Preapplication Safety Evaluation Report for the PRISM Liquid-Metal Reactor", NUREG-1368, 1994.

[3] T. Cadiou and J. Louvet, "Evaluation of the Accident Scenario Initiated by a Total Instantaneous Blockage in a Phenix Subassembly", Nucl. Tech., Vol.153, 2006.

[4] L. Ren, "SFR Licensing and Experiences and Issues in China", IAEA-GIF Workshop on Operational and Safety Aspects of SFR, June 23-25, 2010.