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Identification of Licensing Issues for SFR Nuclear Safety

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1. Introduction

A conceptual design of sodium-cooled fast reactor (SFR) in Korea has been developed by KAERI. An application for the design approval of a prototype SFR is scheduled in 2017. In order to prepare the licensing of a prototype SFR, KINS is developing the regulatory technologies for SFR since 2010.

Fast reactors such as SFRs have fundamental differences in nuclear characteristics compared to thermal reactors such as LWRs. As a result, there are significant differences in reactivity feedback mechanism to assure the inherent safety of reactors. Especially, positive coolant density coefficient and void worth are main concern in passive safety argument. However, the current safety guidelines for nuclear facilities in Korea specify to regulate nuclear facilities targeting on LWRs, and therefore the development of regulatory guidelines reflecting SFR nuclear features is required.

In this paper, the licensing issues for SFR nuclear safety, especially reactivity coefficients, are identified to derive the licensing issues and develop the regulatory review guidelines. In order to identify the issues, (1) the SFR nuclear characteristics and the preapplication safety evaluation report of PRISM are reviewed, and (2) the applicability of guideline for LWR nuclear safety to SFR is evaluated.

2. Review on SFR Nuclear Characteristics and PRISM Nuclear Safety Issues

2.1 Nuclear Characteristics of SFR

SFRs have distinct nuclear characteristics from LWRs, in which many assumptions employed in traditional LWR analysis methods are not applicable [1, 2]. The significant differences are as follows: hard neutron spectrum in the keV and MeV, high neutron leakage by a large mean free path, low delayed neutron fraction dominated by Pu-239 as a key fission isotope, scattering resonances of intermediate atomic mass nuclides such as Na-23 and Fe-56, lack of 1/E spectrum for the calculation of heavy isotope resonance absorption, etc.

Especially, the long mean free path in fast reactors makes the reactivity effect sensitive to minor geometric changes, which causes dominant negative reactivity feedback by radial core expansion. Also, because the density decrease of sodium coolant causes the negative feedback, there is a possibility that the sodium voiding leads to severe accident with the rapid reactivity insertion. A typical set of feedback coefficients considered in fast reactors includes [3]: the coolant density coefficient and void worth, the fuel and structural material Doppler coefficients, the fuel and structural material worth distributions, the axial expansion coefficient, the radial core expansion coefficient, and the control rod driveline expansion coefficient. It is noted that the temperature variation of Doppler coefficient (=dk/dT) is approximately $T^{1} \sim T^{3/2}$ for typical fast reactors (for thermal reactor, $T^{1/2}$) as shown in Table 1.

Table 1. Doppler Coefficients for Various Reactors

Reactor Type		Doppler Coefficients
Fast Reactor	Metal Fuel	$\frac{dk}{dT} = \frac{\alpha_D}{T^{3/2}}$
	Oxide Fuel	$\frac{dk}{dT} = \frac{\alpha_D}{T}$
Thermal Reactor		$\frac{dk}{dT} = \frac{\alpha_D}{T^{1/2}}$

In general, all reactivity coefficients except for the coolant density coefficients and void worth give negative feedback effects. However, the role of specific reactivity coefficient depends on the transient. For example, the negative Doppler coefficient can play an adverse role in loss-of-flow accidents.

2.2 Nuclear Safety Issues of PRISM

In the PSER for PRISM of U.S.NRC [4], the nuclear safety issues considered in the nuclear design and passive safety system design of PRISM are identified as shown in Table 2.

Table 2. Nuclear Safety Issues of PRISM

Nuclear Design	Passive Safety System
• Analytical Methods • Physics Calculations during Voiding • Reactivity Coefficients • Core Power Fractions	• Adequacy of Reactivity Coefficients • Positive Void Worth • Reactivity Swing due to Burnup

Through the review on the above nuclear safety issues of PRISM, the specific issues related to reactivity coefficients are identified as follows: prediction and accuracy verification of reactivity coefficients, evaluation of positive sodium void worth, evaluation of possibility of sodium voiding, uncertainties of reactivity coefficients, selection of accident scenarios.

3. Evaluation of Applicability of LWR Guidelines to SFR Nuclear Safety

The current review guidelines for LWR [5] in Korea were developed based on SRP of U.S. NRC. In the guidelines, the review plan for nuclear designs including reactivity coefficients is described in section 4.3.

For the development of the regulatory guidelines for SFR nuclear safety, the applicability of LWR guidelines to SFR nuclear safety was evaluated as follows: (1) the guidelines to be newly added due to the nuclear characteristics of SFR, (2) the guidelines to be modified due to the nuclear design differences between SFR and LWR, (3) the guidelines not applicable to SFR, and (4) the guidelines applicable to SFR as it is. For example, the areas of review described in the LWR guidelines related to reactivity coefficients and analytical methods are applicable to SFR as it is, however the specific reactivity coefficients of SFR such as radial and axial expansion coefficients need to be newly added in the areas of review.

4. Identification of Licensing Issues for SFR Nuclear Safety

The development strategy of regulatory review guideline for SFR nuclear safety is shown in Figure 1. The guideline will be developed based on the current regulatory guideline for LWR. The SFR nuclear characteristics and the preapplication safety evaluation to PRISM are reflected in the guidelines.

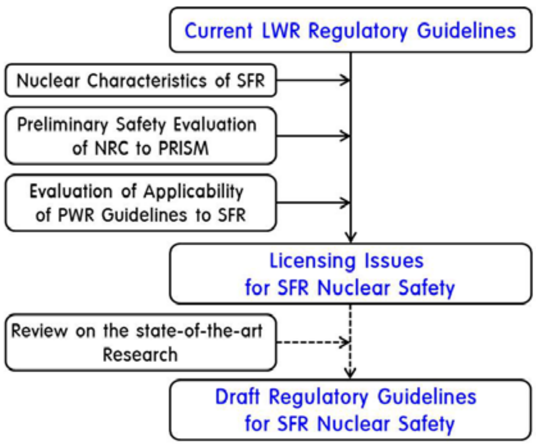

Figure 1. Development Strategy of Regulatory Review Guidelines for SFR reactivity Coefficients

Based on the above procedure, the licensing issues for SFR nuclear safety are identified as shown in Table 3. The identified licensing issues for SFR nuclear safety were mainly focused on reactivity coefficients and analytical methods. Especially, it is highly important to establish the evaluation method for uncertainties of reactivity coefficients, because the data to verify the calculated reactivity coefficients are insufficient and the reactivity coefficients play an important role in passive safety concerns of SFR.

In order to develop the draft regulatory review guidelines reflecting these safety issues, the technical review of the issues should be performed by the review on state-of-the-art researches.

Table 3. Licensing Issues for SFR Nuclear Safety

Licensing Issues
Reactivity Coefficients • Identification and characteristics of SFR reactivity coefficients • Selection of accident scenarios related to reactivity coefficients • Positive sodium density coefficients and void worth • Evaluation of possibility of sodium voiding , and effect if sodium voids • Evaluation of uncertainties of reactivity coefficients • Adequacy of reactivity coefficient values used in accident analyses
Analytical Methods • Evaluation of nuclear data for generation of reactivity coefficients and kinetic parameters • Sensitivity evaluation of energy groups for neutronic calculations

5. Conclusions

In order to identify the licensing issues for SFR nuclear safety, the SFR nuclear characteristics and the PSER to PRISM are reviewed, and the applicability of guideline for LWR nuclear safety to SFR is evaluated. As the results, 8 licensing issues were identified in review areas of reactivity coefficients and analytical methods. The draft regulatory review guidelines will be developed reflecting the identified issues to the current LWR guidelines.

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