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Review on Core Designs for Prevention of Severe Accidents in SFRs

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1. Introduction

Since the core of SFRs is not designed in its maximum reactivity configuration, sodium boiling and material relocation in core have potential of significant reactivity insertion [1]. Based on this characteristic of fast reactor core, potential impact of CDA (Core Disruptive Accident) caused by ATWS has been considered as an important safety issue, although it is extremely unlikely. In order to prevent and mitigate the severe accident, the fast reactor core has been designed with various safety features. In this paper, as a part of study to develop the domestic regulatory requirements and guidelines related to SFR core safety, international trends on safety features which have been considered in current SFR cores are reviewed.

2. Review on SFR Core Safety Features

In order to prevent the severe accident, core safety features as follows has been considered in current SFR cores: (1) passive shutdown systems, (2) core designs with low void effect, and (3) specific provisions for core with conventional positive void effect. Three safety features are reviewed below.

2.1 Passive Shutdown Systems

In order to enhance the passive safety and prevent the CDA initiating events such as ULOF, UTOP, ULOHS, etc., various passive and diversified shutdown mechanisms has been considered in most SFR cores. Especially, as shown in Fig 1, SASS (Self-Actuated Shutdown System) [2] based on temperature sensitive electromagnet will be employed in JSFR (Japan). Also, in CFBR (India), both temperature sensitive electromagnet and liquid poison injection system [3] are being considered.

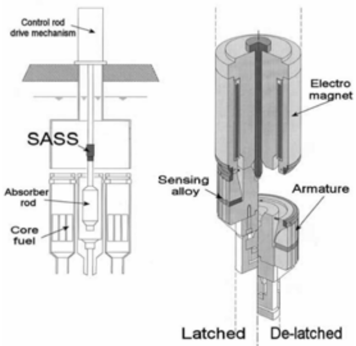

Fig 1. Self-Actuated Shutdown System in JSFR

2.2 Core Designs for Low Void Effect

The reactivity change that occurs when sodium coolant region in a core is voided can be resolved into spectral hardening, increased leakage, and elimination of sodium capture components. The first two effects are large and of opposite sign, and the last effect is a relatively small. Accordingly, in order to reduce a sodium void reactivity effect, a SFR core has been designed to increase the neutron leakage and soften the neutron spectrum. The extensive studies on void worth reduction had been implemented in Argonne National Laboratory [4], General Electric [5], Westinghouse, etc. The conclusions were as follows:

- Sodium void worth can be reduced to near zero or negative, but the results will be an unfavorable change in the other safety parameters. For example, a core with lower void effect has a larger burnup swing, leading to the need for more control rods, possibly of higher individual reactivity worth.
- There is no general best way to reduce sodium void worth, because the relative importance of the several other performance changes will depend upon the specific design criteria.

In recent, further study for low void effect has been implemented in ASTRID (EU) [6] and BN-1200 (Russia). In order to achieve low void effect, two SFR cores employs sodium plenum at the top of the core and/or heterogeneous core concept as shown in Fig 2.

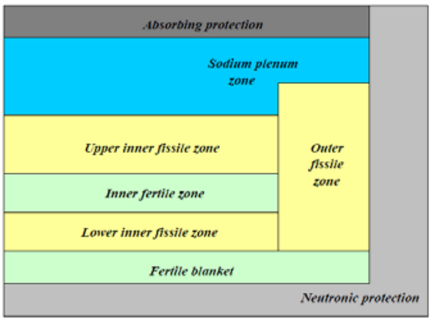

Fig 2. Axial View of ASTRID Core of CFV Concept

Related to the void effect issue, positions of U.S.A., Russia, Japan, etc. are as follows:

- U.S.A. [7,8]: In preapplication safety evaluation for PRISM, the positions of the PSER and the ACRS (Advisory Committee on Reactor Safeguards) of U.S.A. on positive void worth issue are summarized as (1) the positive sodium void reactivity coefficient should be reduced as much as practical, (2) if the positive voiding coefficient is accepted, such events must be shown to be of extremely low probability, and (3) the loss of all EM pump flow without adequate EM pump coastdown has the potential to lead to sodium boiling.

- Russia [9]: Before 2009, in the Russian regulatory documents, the limitations on sodium density effect were imposed. In order to satisfy these criteria, Russian SFR specialists had developed the core with "zero" void reactivity effect. Main concept for "zero" void effect was the core design with sodium plenum assuring integral void reactivity effect close to zero. Recently, the regulatory documents were modified to admit positive sodium void worth.
- Japan [10]: In JSFR, in order to prevent severe mechanical energy release, maximum sodium void worth is limited below 6.0 $.

2.3 Specific Provisions for Core with Conventional Positive Void Effect

In the transition phase of severe accident sequence, researches to prevent the core re-criticality under the CDA have been implemented. In JSFR, molten fuel discharge capability is utilized by FAIDUS (Fuel Assembly with Inner Duct Structure) [11] as shown in Fig 3. In order to obtain experimental data applied to an evaluation of FAIDUS, an experimental program named as the EAGLE project is being carried out. In CAPRA/CADRA cores, as a measure to enable a controlled material relocation, diluent assemblies and control rod guide tubes are being considered to accept molten fuels.

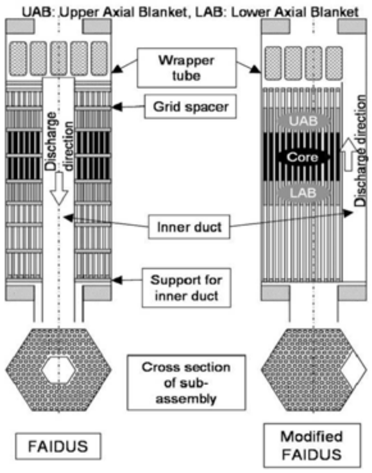

Fig 3. JSFR Fuel Assembly Design with the Discharge Duct

3. Conclusions

In order to develop the regulatory requirements and guidelines related to a SFR core design for prevention of CDA, the core safety features were reviewed. The safety features considered in current SFR cores have a function that prevents to progress into next step in accident sequences. The trends on current safety features are as follows:

- "passive shutdown systems" to prevent initiating events such as ULOF, UTOP, ULOHS, etc
- "core designs with low void effect" to prevent the large void reactivity insertion in initiating phase
- "specific provisions for core with conventional positive void effect" to prevent the core re-criticality in transition phase

Consequently, in regulatory review requirements and guidelines developed for SFR, contents for not only reduction of positive void effect but also features to ensure the safety of overall system should be reflected.

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