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Development of Regulatory Audit Technology for Design Basis Accidents with Fuel Burnup Effects

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1. Introduction

Current discharge burnup of PWR fuels in Korea has reached to ~55MWd/kgU(max. assembly average), and it is about twice as great as expected when the fuels were discharged firstly in 1979[1]. Accordingly fuels have experienced embrittlement even though advanced fuel materials were used. Absorbed hydrogen content in the zirconium alloy cladding is close to the design limit of 600 wppm, and thickness of oxide layer reaches to 60~80 microns at the maximum licensing fuel burnup. Fuel pellet embrittlement has also been intensified due to the formation of high burnup structure and accumulated fission gases in the pellet. These embrittlement phenomena of fuel can influence fuel integrity not only in normal operating conditions but more significantly in postulated accident conditions. Research works have been conducted in the worldwide for many years to find out the failure limits and to assure the core coolability. Based on the results, new fuel safety criteria for design basis accidents such as loss-of-coolant accident(LOCA) and reactivity initiated accident(RIA) are being established[2,3]. KINS has also been trying to revise the ECCS acceptance criteria[4,5].

Under these circumstances, KINS has selected regulatory research items to establish fuel safety criteria and to develop regulatory audit technologies of design basis accidents with fuel burnup effects for next five years. In this paper short summaries on the research items are described.

2. Safety Research

2.1 New safety criteria

2.1.1 ECCS acceptance criteria

KINS has announced a plan of revising the ECCS acceptance criteria of PWR plants in 2016. Technical basis and draft revision of the criteria(NSSC Notice reactor.24) with relevant two regulatory guidances are prepared[4,5]. It includes the change of oxidation limit of zirconium alloy with hydrogen content. Prevention of occurrence of breakaway oxidation at a given time scale of LOCA is also included. And factorization of effects of inner surface oxidation, oxide and crud layer effects as a thermal barrier, and fuel relocation and dispersal in the safety analysis is added as modeling requirements. These changes are being talked with stakeholders and hopefully will finalize by the end of this year, 2018.

2.1.2 RIA criteria

NRC proposed new RIA criteria in DG-1327 in 2016, and this is somewhat differing from the interim RIA criteria described in NUREG-0800. KINS will investigate the differences, and will establish RIA criteria and relevant guidance based on analytical experimental data analysis. As a part of the activities, KINS has participated the OECD/NEA CABRI research project since 2000.

2.2 Development of audit computer code

2.2.1 Validation

To factorize the fuel burnup effects in safety analysis, fully coupled integration of regulatory audit codes between detailed fuel rod analysis and thermal-hydraulic system is strongly required. In this context, recently KINS has been developing a coupled audit code by using FRAPTRAN and MARS-KS. And for the successful development, validation works will be performed by utilizing the experimental data and code to code comparison. Results of OECD Halden LOCA tests and LOFT tests can be used in the works.

2.2.2 Model development/improvement

As accumulation of crud on the fuel rod surface can occur, it is added as one of the modeling requirements in the draft ECCS acceptance criteria[5]. But reliable thermal property models are not established and also not included in the audit codes. Recent experimental study performed in EPRI revealed that the effective thermal conductivity can be varied depending on the coolant conditions[6]. Based on these characteristics, models of thermal conductivity and specific heat have to be developed.

Fuel relocation can occur during LOCA process. If cladding is ballooned largely enough during LOCA, fragmented fuel pellets can be piled up at the ballooned region[7]. This will produce higher heat source than the normal condition. And possibly it will induce harmful effects in cladding integrity. Models for simulation of such phenomena need to be developed.

Heat conduction from fuel to coolant in the coupled MARS-KS/FRAPTRAN code needs to be improved by considering the cladding deformation. If fuel cladding deforms, flow area of coolant in fuel assembly can be reduced. And in significant cases, due to the reduction of flow area, substantial amount of coolant will be bypassed. But current MARS-KS/FRAPTRAN coupled code has limitations on simulation on these phenomena. Additionally, current MARS-KS/FRAPTRAN code can not simulate heat conduction through oxide and crud layer, and capability of multi rod calculation for simulation of core wide fuel rods is not equipped. Improvements for these are also planned.

2.3 Audit methodology in design basis accidents

2.3.1 LOCA

KINS has developed a realistic audit calculation methodology for large break loss-of-coolant accident(LBLOCA) in PWR plants[8]. It was developed based on the beginning of life fuel condition. But, for the implementation of draft ECCS acceptance criteria and resolving the thermal conductivity degradation issue of UO_2 pellet, revision of the methodology, which can cover whole ranges of licensing fuel burnup, is strongly required. Uncertainty parameters and their uncertainties have to be selected and also validated for assurance of peak cladding temperature(PCT) and peak local oxidation(PLO). Statistical treatment methods for the assurance of 95%/95% probability/confidence levels have to be developed for multiple performance parameters(PCT, PLO).

Fuel dispersal during the LBLOCA process can occur as a result of rod burst. Preliminary assessment of core-wide fuel dispersal was performed by US NRC in Westinghouse 4-loop PWR plant[9]. According to the results, dispersed fuel mass into the core was estimated about 207 kgUO_2 in severe conditions. This implies that significant impacts on safety analysis can be encountered depending on the plant characteristics and operating conditions. Fraction of rods burst and subsequent amount of fuel dispersal will be investigated on domestic PWR plants such as OPR1000 and/or APR1400 plants, and core coolability will be assessed.

2.3.2 Non-LOCA

Among non-LOCA transients, reactivity related accidents are strongly related to the fuel burnup effects. Control rod ejection, boron dilution, steam line break accidents etc. are primarily concerns for developing audit methodologies. Typically, licensed methodologies of non-LOCA safety analysis are based on the conservative approaches. But, as the fuel safety criteria become more stringent than before, licensee are trying to change the methodologies as more realistic ones. Thereby, there are strong need to develop audit methodologies based on realistic approaches.

For the control rod ejection accident, methodology on abrupt power insertion was established in three-dimentional space-time kinetic analysis. However, fuel performance evaluation including various uncertainties are not established completely. For the boron dilution and steam line break accidents etc, detailed flow characteristics within the reactor will be evaluated by using a system and computational fluid dynamics code. Neutronics and subchannel analysis will be performed to evaluate fuel temperature and departure from nucleate boiling ratio(DNBR).

3. Summary

KINS has selected research items for design basis accidents for next five years. Research items are followings.

- Establishment of new safety criteria on ECCS and RIA
- Development/improvement of a fully coupled fuel and thermal-hydraulic safety analysis code including fuel models
- Development/improvement of LOCA audit methodology(KINS-REM) including fuel rod burst and dispersal evaluation
- Development of non-LOCA audit methodology such as control rod ejection, boron dilution, steam line break etc.

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