Recent Fuel Safety Concerns in KINS

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1. Introduction

Current discharge burnup of PWR fuels in Korea has been increased above twice as great as expected when fuel was discharged firstly in 1979. Fig. 1 shows the changes of average and maximum discharge burnup. In 1979, the burnup was about 17MWd/kgU, and then it increased continuously. Recently average and maximum burnup was almost saturated about 45 and 55MWd/kgU, respectively. Fuel enrichment increased also in accordance with the burnup changes. Maximum enrichment of U-235 was 2.1% in 1979. And it reached about 4.6% since 2000s. Accordingly embrittlement of fuel cladding and pellet has been intensified even in use of an advanced fuel cladding. For example, thickness of zirconia that was formed on the cladding outer surface was about 60~80 microns, and absorbed hydrogen content showed very little margins to the design basis.

Related to the burnup increase, several fuel safety concerns interested in KINS are described briefly in this paper. These are fuel cladding corrosion, crud accumulation, fuel seismic on spacer grid, fuel relocation and dispersal during loss-of-coolant accidents(LOCAs). Concern to the fuel performance analysis methodology in CANDU fuels is described as well.

2. Several safety issues

2.1 Cladding corrosion

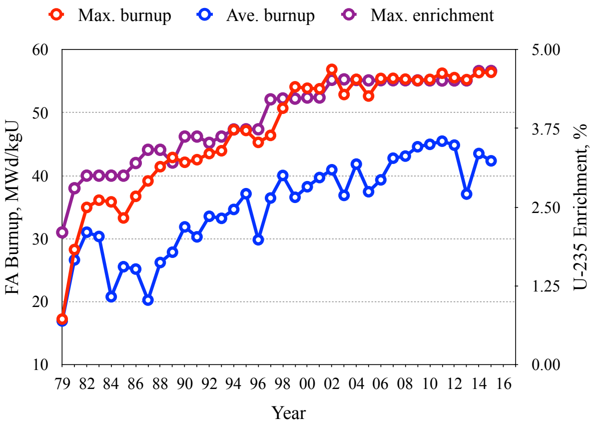

Fig. 1. Changes of discharge burnup and maximum enrichment of U-235 in domestic PWR fuels

Some amounts of hydrogen released from corrosion reaction between zirconium alloy and coolant are absorbed in the cladding metal. In ZIRLO cladding, it is believed that the absorption fraction is about 12~13 %. But in NRC audit code of FRAPCON-3.5, it was changed from 12.5 to 17.5 %. The change was made based on the assessment of high burnup data such as North Anna, CABRI, NSRR[1]. NRC RG 1.224 adapts this revised absorption fraction as a best-estimate pickup model in ZIRLO cladding, and also recommends 25 % as an acceptable upper bounding fraction[2]. If this revised fraction is utilized to the current PWR core designs, it seems to be difficult to meet the current design basis of hydrogen content, 600 ppm. Revision of analysis methodology, core design and absorption fraction based on the extensive experimental data will be necessary.

2.2 Crud accumulation

Accumulation of crud on the fuel rod surface in PWR plants has been relieved continuously by use of chemistry controls, Zn injection in primary coolant and so on. Nevertheless, significant amount of accumulation happens sometimes in the plants. Recently Hanul Unit 4 experienced a strong axial offset anomaly event during reactor operation. This indicates the significant amount of crud seems to be deposited on the fuel surfaces. Generally, crud is a porous media that is composed of solid oxide and liquid coolant. Thereby thermal properties is not as good as the cladding metal has. Recent experimental study performed in EPRI revealed that the effective thermal conductivity was 0.78 W/m-K for non-boiling cases, and it increased as high as 6.1 W/m-K where sub-cooled boiling was initiated. And it then decreased when the coolant was near the saturation temperature[3]. And the conductivity seems to be much lowered in steam coolant environments due to the even lower thermal conductivity of the steam phase.

Such a low thermal conductivity of crud will produce the adverse effects on cladding integrity not only for the steady-state operation but for the accident conditions. For the assessment of impacts of crud on the safety analysis, reliable models have to be established. Even though several analytical modeling works have been performed to assess the effective thermal conductivity, they do not explain the conductivity changes with coolant environments successfully[4]. Measurements and modeling works are required further.

2.3 Fuel seismic evaluation

In Korea, approved analysis methodology on the integrity analysis of fuel assembly under seismic forces is based on the beginning-of-life condition. Since the irradiation hardening will increase the crushing load of spacer grid, it is believed that the approved methodology is conservative. But the spacer grid spring relaxation due to irradiation could have significant affects on spacer grid strength[5]. In this aspect, NRC issued an information notice 2012-09[6]. According to the NRC's evaluation, significant grid cell relaxation occurs by the end of first irradiation cycle with about 90~95 % reduction. Grid crush strength also significantly reduced by the end of first cycle with about 30 % reduction[7].

KINS also requested to demonstrate the validity of current analysis methodology on PLUS7 fuel assembly. In the methodology, credit such as damping ratio reduction in high speed flowing water can be acceptable.

2.4 Fuel relocation and dispersal

Fuel relocation is defined as the any movement of fragmented fuel pellets inside of fuel cladding in axial and radial direction. And fuel dispersal is defined as the ejection of fragmented fuel pellets through the burst opening of the cladding. In this context, fuel relocation and dispersal can occur during LBLOCA. Actually these phenomena were identified from the end of 1970s, but it was not paid much attention. But in 2006, one of Halden LOCA test results showed a significant fuel relocation and dispersal phenomena. And, recently published OECD/NEA report provides the comprehensive research results on fuel fragmentation, relocation and dispersal including Halden, Studsvik test results[8].

If cladding is ballooned largely enough during LOCA, fragmented fuel pellets can be piled up at the ballooned region. This will produce higher heat source than the normal condition. According to the scoping analysis, if significant relocation occurs, cladding temperature can increase about 100~200K with respect to the normal condition[9,10]. Core wide fuel dispersal was assessed preliminarily by NRC in Westinghouse 4-loop PWR plant[11]. According to the results, dispersed fuel mass into the core was estimated about 207 kgUO_2 in severe conditions. These indicate that significant impacts on safety analysis can be encountered. Therefore further experimental and modeling works are strongly required.

2.5 CANDU fuel evaluation methodology

Fuel performance of CANDU fuel for a normal operating condition has been analyzed by ELESTRES computer code with the enveloping power history. Validation report of ELESTRES showed a bias and significant uncertainty on the fuel temperature, rod internal pressure, fission gas release, sheath strain[12]. Generally fuel performances are evaluated by best-estimate performance combined with uncertainty quantification. And various uncertainty sources such as manufacturing, models, and power should take into account for uncertainty quantification. Therefore it is necessary to demonstrate that current enveloping power methodology is conservative to cover the known bias and uncertainty of the ELESTRES code.

3. Summary

Several fuel safety issues recently concerned in KINS are described in the paper. To resolve these in a timely manner, extensive research works will be required in industry and in regulatory body also.

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