Evaluation for the initial conditions of domestic spent fuel

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1. Introduction

As the amount of spent nuclear fuels substantially increased, in 2020, it is expected that domestic spent fuel pools at a nuclear plant are filled to their licensed capacity[1]. US and Japan government are planning demonstration program to evaluate the integrity of spent nuclear fuel for 120 and 50 years respectively. And in Korea, dry storage conditions on spent fuel integrity have recently been initiated.

Under dry storage conditions, creep and hydride reorientation have been considered as major degradation mechanisms. Therefore, the criteria of spent fuel for dry storage conditions is related to hoop stress and cladding temperature limit which prevent the creep rupture and hydride reorientation.

In present study, the initial conditions of spent fuel cladding such as oxide thickness, hydrogen contents and internal pressure were evaluated which affects the spent fuel degradation mechanisms.

2. Methods and Results

In order to evaluate the initial conditions of domestic spent fuel claddings, the maximum and minimum burn-up and enrichment of fuels were investigated and fuel design and power history were also analyzed.

According to the research results, the internal pressure and oxide thickness and hydrogen contents and hoop stress of the domestic spent nuclear fuels were evaluated by Frapcon code[2].

2.1 Burn up and enrichment

It has been investigated that the minimum, average and maximum burn-up are 27, 42, and 55 GWd/MTU respectively. In addition, based on the NDR, 17×17 W.H. type and 16×16 KNSP type fuel assembly were also investigated. In case of 16×16 KNSP type fuels, average burn-up and enrichment have been increased from 33 to 50 GWd/MTU and 1.3 to 4.51 w/o respectively and 17×17 W.H. type fuels, average burn-up and enrichment have been increased 30 to 50 GWd/MTU and 1.6 to 4.5 w/o. Average burn-up of these fuels are 42 and 42.4 GWd/MTU.

2.2 Power history

According to the rod power history, the spent fuel cladding has different oxide thickness and hydrogen contents. Above all, internal pressure is much affected. It is known that deviation of the internal pressure, oxide thickness and hydrogen contents are increased with increasing burn-up. To evaluate the spent fuel cladding conditions, fuel design parameters and power histories are needed. However, it is impossible to demonstrate the power history of each fuel rod without fuel histories database and it is also difficult to find the regularity of power histories. Because, there were 21 type of Fuel assembly and each fuel has a unique burn-up and heat generation rate.

Therefore, In this paper, NDR was used to find extend of spent fuel burn-up and power history and bounding approach is also used to evaluate spent fuel cladding conditions.

2.3 Oxide thickness and hydrogen contents

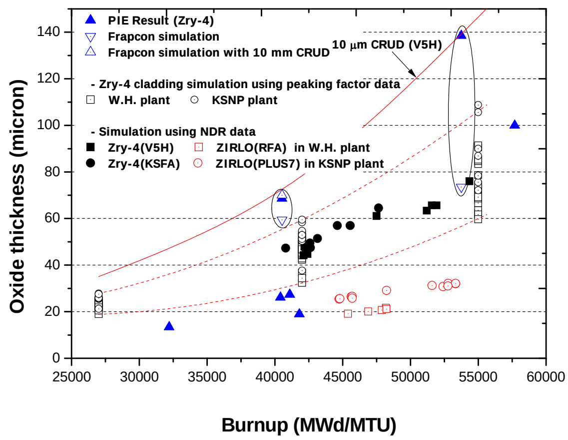

Figure 1. Cladding Oxide thickness versus Rod Average Burn-up (Simulation results and PIE data)

Fig. 1. show the distribution of the oxide thickness at minimum average maximum burn-up. Even though, it is difficult to compare results with insufficient domestic PIE data, it belong to foreign oxidation data[3]. Oxide thickness of Zircaloy-4 has a significant deviation over the 45 GWd/MTU and it is believed that oxide scale can reach up to 140 μm. In average burn-up range, 42 Gwd/MTU, oxide thickness has been varied in a range from 30 to 60 μm.

In case of hydrogen contents analysis in cladding, hydrogen contents were only measured by a hot-cell test. Consequently, many of research laboratory developed a hydrogen pick up model and estimate the hydrogen contents because limited and insufficient data.

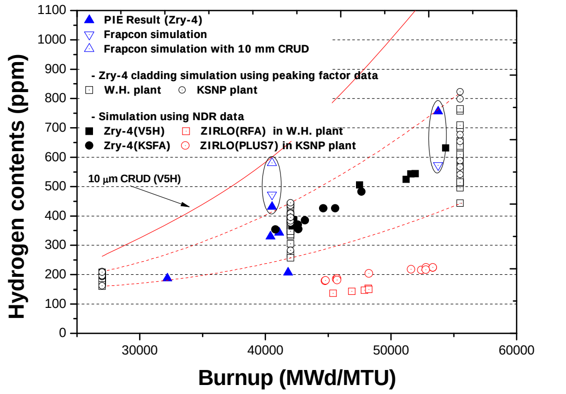

Figure 2. Hydrogen contents in Cladding versus Burn-up (Simulation results and PIE data*)*

Frapcon also predict the hydrogen pick up by using fuel damage index. As a results, in average burn-up range (42 Gwd/MTU), hydrogen contents has been varied in a range from 250 to 450 wppm and over the 50 Gwd/MTU it will be about 600 wppm(Fig. 2). In addition, it is well known that Zirlo has enhanced water corrosion resistance, so it is estimated that Zirlo has a relatively low hydrogen contents compare with zircaloy-4

2.4 Internal pressure and hoop stress

Internal pressure was measured only by a hot cell experiment as well as hydrogen contents. Internal pressure was affected by a charged helium gas and released fission gas during reactor operations and gap thickness. According to the results of internal pressure analyses, up to 30-40 GWd/MTU, initial charging pressure has a dominant effect. However, with increasing burn up, fission gas release are accelerated.

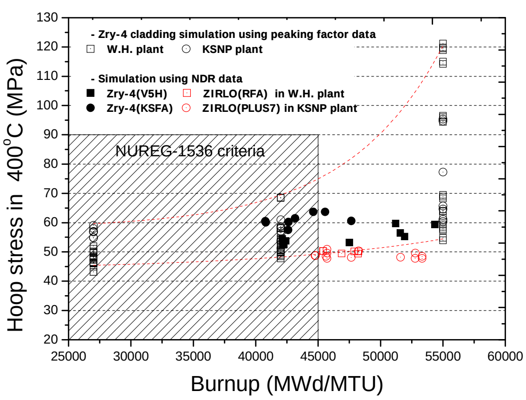

Figure 3. Cladding Hoop Stress vs Burn-up at 400℃

In order to convert hoop stress from the internal pressure, it might be considered the fuel type. Because Hoop stress is affected by internal pressure and void volume of fuel rods. For example, at low burn-up, KSFA type fuel (initial charging pressure: 2.6MPa) has a larger internal pressure than W.H. type fuel(initial charging pressure: 2.1MPa). However with increasing burn-up, W.H. type fuel has a large value because of void volume. The hoop stress of cladding was calculated through the equations.

$$\sigma_\theta = \frac{r_i P_i - r_o P_o}{t}$$

where, σ_θ = hoop stress(MPa)

r_i = inner radius of cladding

r_o = outer radius of cladding

P_i = internal pressure

P_o = outer pressure

t = effective cladding thickness

As a consequence, in a various burn-up and power history, hoop stress was evaluated considering the void volume and oxide thickness(Figure 3). As a results, there were minor differences between KSFA and V5H fuel and in case of low burn-up fuel (<45 GWd/MTU) satisfy the hoop stresses below 90MPa which proposed by NRC[4].

3. Conclusions

Based on wide ranging investigations on spent fuel burn-up and power history, Initial conditions of domestic spent fuel cladding were analyzed.

As a result, hoop stresses and hydrogen contents are about 47-70MPa and 292-402wppm, respectively, below 45 GWd/MTU fuel. It is believed that which value are conservative for low burn-up domestic spent fuel under dry storage conditions.

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