Evaluation of a high burnup spent fuel regarding the regulations for a spent fuel dry storage

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1. Introduction

All nuclear plants have storage pools for spent fuel. These pools are typically 40 or more feet deep. In many countries, the spent fuels are stored under water. The water serves 2 purposes: 1) It serves as a shield to reduce the radiation levels. 2) It cools the fuel assemblies that continue to produce heat (called decay heat). But Korean nuclear plant expects the storage capacity to reach its limit by the year 2016. So, the research for the spent fuel dry storage facilities is necessary. The purpose of this study was to overview the regulatory basis for spent fuel dry storage and to evaluate its applicability for high burnup spent fuel.

2. Methods and Results

2.1 Background for guidance

Creep is the dominant mechanism for a cladding deformation under a normal stroage condition. Some experimental data and analyses support the conclusions that (1) deformation caused by creep will proceed slowly over time and will decrease the rod pressure, (2) the decreasing cladding temperature also decreases the hoop stress, and (3) in the unlikely event that a breach of the cladding due to creep occurs, it is believed that this will not result in gross rupture [1].

The formation of radial hydrides is highly dependent on the hoop stress in the cladding [2, 3, 4]. These data indicate that stresses greater than 120 MPa (17.4 ksi) are required to initiate the formation of radial hydrides. Other data obtained from unirradiated zirconium-based cladding materials indicate that radial hydrides can form at stresses as low as 90 MPa [5]. It is expected that fuel assemblies with burnups less than 45,000 MWd/MTU are not likely to have a significant amount of hydride reorientation due to limited hydride content.

2.1 Regulatory Basis for a Spent Fuel Dry Storage

Dry storage for a spent fuel is not a permanent storage facility but an interim storage. Someday the spent fuel would be handled for fuel reprocessing or permanent disposal. For this reason, the spent fuel must be maintained the integrity during the storage period.

The 10 CFR 72.122(h)(1) states, in part - “The spent fuel cladding must be protected during storage against degradation that leads to gross ruptures or the fuel must be otherwise confined such that the degradation of the fuel during storage will not pose operational safety problems with respect to its removal from storage.”[6].

U.S. NRC staff proposes that zircaloy fuel cladding temperature limits at the beginning of dry storage are typically below 380℃ (716°F) for a 5-year cooled fuel assembly and 340℃ (612°F) for a 10-year cooled fuel assembly for normal conditions and a minimum of 20 years cask storage [7, 8, 9]. The short term off-normal and accident temperature of 570℃ (1058°F) for zircaloy-clad fuel assemblies is currently accepted as a suitable criterion for fuel assembly transfer operations. This limit may be lowered for high burnup fuel assembly (e.g., greater than 28,000 MWD/MTU) due to increased internal rod pressure from fission gas buildup.

The staff may approve the storage of fuel assemblies having burnups greater than 45,000 MWd/MTU provided that the applicant can demonstrate that the cladding will be protected from a degradation which could lead to a gross rupture (10 CFR 72.122 (h)(1)) and that the storage system is designed to allow a ready retrieval of the spent fuel from the storage system (10 CFR 72.122(l)).

2.3 Applicability for a High Burnup Spent Fuel

Typically, a decay heat is calculated using the same computer codes as those used to determine radiation source terms. Heat generation rate of high burnup spent fuel is 40-60% higher than low burnup spent fuel, which has bad effect on the temperature of cladding (figure 1).

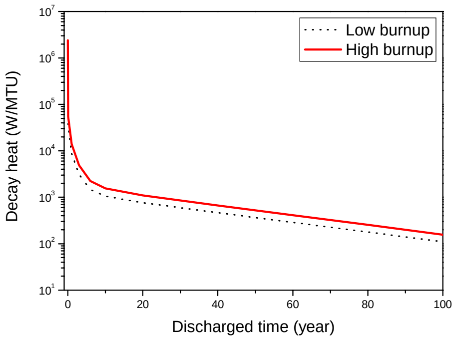

Fig. 1. Calculated decay heat in low and high burnup spent fuel rod.

The EOL rod pressure of high burnup fuel is shown in figure 2. The inner pressure is higher than 90 MPa which has proposed by PNNL.

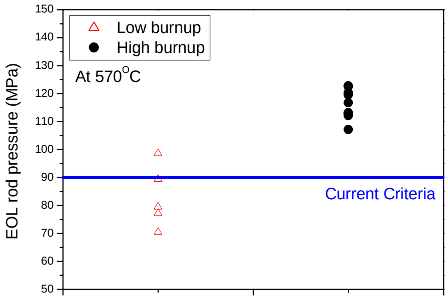

Fig. 2. EOL rod pressure in low and high burnup spent fuel rod.

Waterside corrosion of the clad tube results in a gradual increase of the materials hydrogen content, since hydrogen is liberated in the corrosion process. Moreover, hydrogen is known to have a detrimental effect on the clad strength and ductility, since it precipitates as brittle zirconium hydrides at a hydrogen concentration above the terminal solid solubility.

Figure 3 shows the radial average hydrogen content in a high burnup spent fuel cladding. As shown in figure 3 and 4, hydrogen content of high burnup spent fuel is higher than low burnup spent fuel. Precipitation of zirconium hydrides in the clad tube leads to embrittlement, which means that the materials ability to endure a plastic deformation is reduced

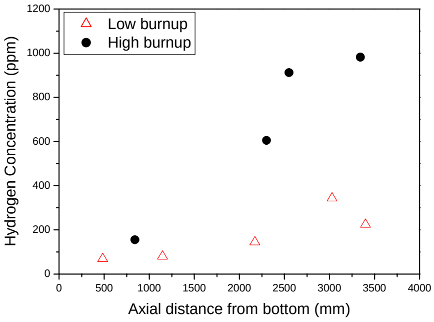

Fig. 3. Hydrogen concentration in low and high burnup spent fuel rod.

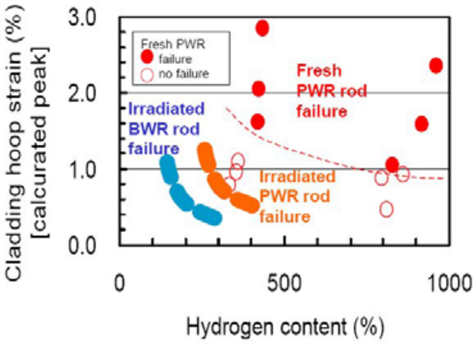

Fig 4. Estimated peak strains to cause the failure were larger in fresh fuel tests, suggesting influence of the irradiation embrittlement of the cladding .

3. Conclusions

For the development of the current regulatory limit, many tests had been performed to find a cladding failure mechanism during a dry storage period. And then, the maximum cladding temperature limit was presented to protect against cladding damage from a creep rupture and hydride re-orientation. But, when compared with the spent fuels which were used for the regulatory limit development, the fuel discharge burnup is increased from ~45,000MWd/MTU to ~57,000MWd/MTU due to the economic needs. The recently discharged spent fuel has a higher rod internal pressure and cladding's hydrogen contents due to a high fission gas release and cladding surface oxidation respectively. In addition, the decay heat of the recent spent fuel is higher about 40~60% than a low burnup spent fuel.

So, the test results, which were used for the generation of the current a dry storage regulatory limit, are insufficient to ensure the spent fuel integrity during dry storage because the fuel integrity is greatly affected by the fuel burnup. Consequently, the current regulatory limit for the spent fuel dry storage must be reexamined to guarantee the high burnup spent fuel safety during a dry storage.

REFERENCES

[1] SFST-ISG-11, Rev. 3, "Cladding Considerations for the Transportation and Storage of Spent Fuel", November 17, 2003.

[2] R. E. Einziger and R. Kohli, "Low Temperature Rupture Behavior of Zircaloy-Clad Pressurized Water Reactor Spent Fuel Rods under Dry Storage Conditions", Nuclear Technology, v. 67, p. 107, 1984.

[3] C. Cappelaere, R. Limon, T. Bredel, P. Herter, D. Gilbon, S. Allegre, P. Bouffioux and J.P. Mardon, "Long Term Behaviour of the Spent Fuel Cladding in Dry Storage Conditions," 8th International Conference on Radioactive Waste Management and Environmental Remediation, October 2001. Bruges, Belgium, 2001.

[4] W. Goll, H. Spilker and E. H. Toscano, "Short-Term Creep and Rupture Tests on High Burnup Fuel Rod Cladding.", Journal of Nuclear Materials, v. 289, p. 247, 2001.

[5] K. Kese, "Hydride Re-Orientation in Zircaloy and its Effect on the Tensile Properties", SKI Report 98:32, 1998.

[6] U.S. Code of Federal Regulations (CFR), "Licensing Requirements for the Independent Storage of Spent Nuclear Fuel, High-Level Radioactive Waste, and Reactor-Related Greater Than Class C Waste", Title 10, Part 72, January 1, 2007.

[7] Johnson, A.B., and Gilbert, E.R., "Technical Basis for Storage of Zircalloy-Clad Spent Fuel in Inert Gasses", Pacific Northwest Laboratories, PNL-4835, September 1983.

[8] Levy, I.S., et al., "Recommended Temperature Limits for Dry Storage of Spent Light Water Zircalloy Clad Fuel Rods in Inert Gas", PNL-6189, PNL, May 1987.

[9] Cunningham, M.E., et al., "Control of Degradation of Spent LWR Fuel during Dry Storage in Inert Atmosphere", PNL-6364, PNL, October 1987.