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Estimation of penetration depth of fission products in Cladding Hull

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1. Introduction

A disposal and a reprocessing for spent fuel rod with high burnup need de-cladding procedure. Pellet in this rod has been separated from a cladding hull to reduce a radioactivity of hull by chemical and mechanical methods. But fission products and actinides(U,Pu) still remain inside of cladding hull by chemical bonding and fission spike, which is called as "contamination". More specific removal of this contamination would have been considered. In this study, the sorts of fission products and penetration depth in hull were observed by EPMA test. To analyze this behavior, SRIM 2000[1] code was also used as energies of fission products and an oxide thickness of hull.

2. Experimental and Results

2.1 Sample preparation

The PWR fuel rod with 47,000 MWd/MTU in commercial reactor was withdrawn and cooled down for about 2 years. It was cut down in Hot-cell and removed UO_2 pellet. After mounting and etching on surface of hull, it was moved to EPMA equipment by means of lead cask.

2.2 experimental Procedure

Before EPMA test, optical microscopy test was performed to observe small part of UO_2 pellet on surface and oxide thickness. In this study, the EPMA equipment is available to accept a sample with below 1 Ci of Cs-137, so this sample was made with consideration of radioactivity limit. After loading sample to EPMA, we took SEM pictures and obtained the results of fission products distribution as penetration depth of hull by WDS(Wavelength Dispersive Spectrometer) attached to EPMA. 20 μm of detecting line with 21 electron beam points was set up from surface of cladding hull to inside region.

2.3 Results

Small amount of pellet still remained locally and 5~10 μm of oxide thickness was found in several regions as shown in figure. 1.

Figure. 2 shows cladding hull with contaminated by pellet parts. Both contaminated and oxide layers were distributed locally with about 5~8 μm of thickness. It is more obvious to observe the each layer by graph of zirconium concentration. To analyze fission products in this 3 regions, WDS was activated on a-b line which was 21 electron beam points. The distance of each beam point set up by 1 μm. point "b" was near end of contaminated region and point "a" was inside of cladding hull region.

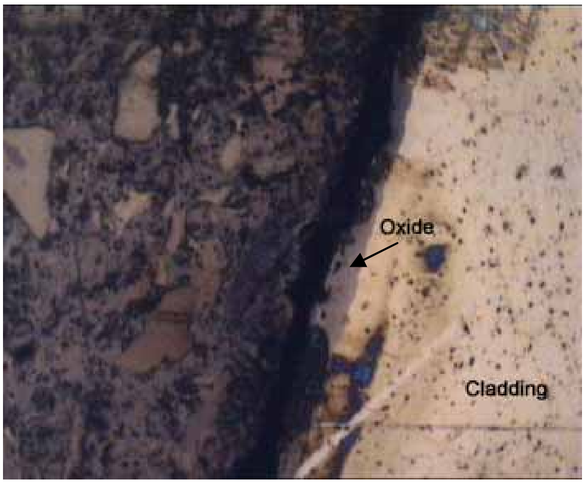

Figure 1. Inner surface of cladding hull.(optical microscope)

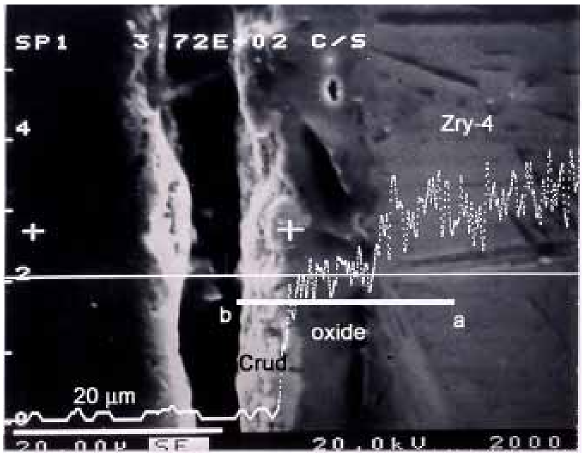

Figure 2. Inner surface of cladding hull (SEM) and Zr concentration profile.

As results, high concentration among the fission products was cesium, and others were below 1 w/o. In figure. 3, point range(#16~#20) was contaminated region and shows high concentration profile of fission products, and point range(#8~#16) was oxide layer with rapid decrease of profile. All fission products were implanted in cladding hull up to 12 μm of depth. But Nd, Ce and Mo were implanted below 5 μm.

3. Discussion

Fission products and actinides(U,Pu) are usually existed inside of cladding hull by chemical bonding and fission spike. Restani[2] observed Cs and Sr penetrated up to over 10 μm while uranium stopped at oxide layer. SRIM 2000(the Stopping and Range of Ions in Matter) code is available to predict penetration distance of fission products in cladding hull by fission spike.

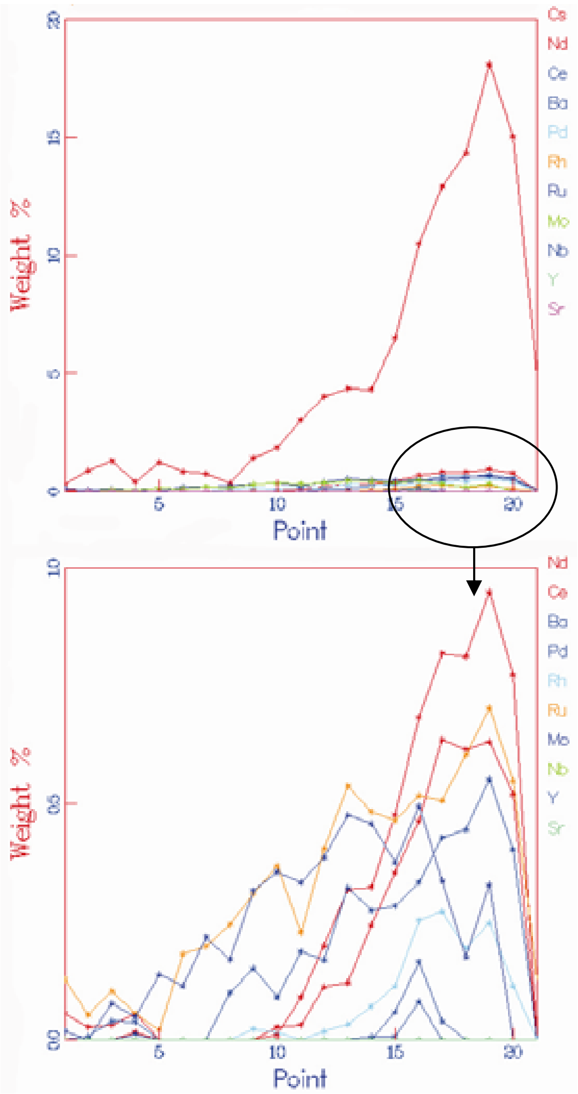

Figure 3. Distribution of fission products with cladding depth by position “a-b line in figure 2”

It was assumed that two fission products have 168 MeV of maximum energy based on the fission energy.(200 MeV)[3] Most fission events occur near UO_2 pellet surface so, we didn’t consider interaction of pellet material. In this assumption, each fission product energy in this study was set up 80 MeV and 160 MeV for SRIM calculations. The code calculation was performed with or without oxide layer and fission products candidated were Cs, Ce, and Nd. But thoss behavior was similar as shown in figure 4 and figure 5. Two figures show a little difference of depth by oxide layer. As thickness of oxide layer increases, penetration depth is longer. Based on the calculation results, Fission products with 80 MeV is good agreement with results of EPMA test.

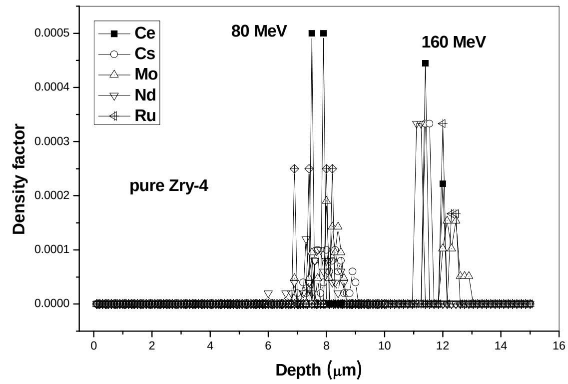

Figure 4. Distribution of penetration depth of fission products in cladding hull without oxide layer.

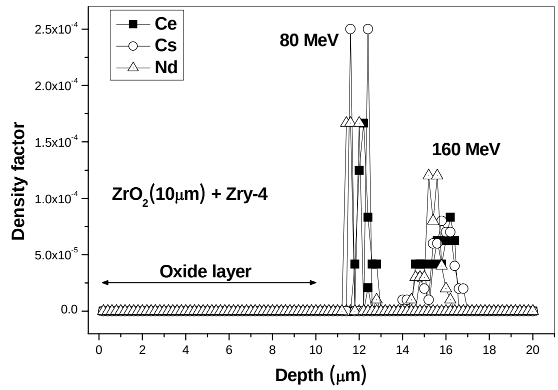

Figure 5. Distribution of penetration depth of fission products in cladding hull with oxide layer.

4. Conclusion

EPMA test for cladding hull was performed to observe penetration depth of fission products by fission spike. The thickness of oxide layer was about 8 μm and local contaminated region was found. High concentration of cesium was observed in each electron beam point. It was detected inside of cladding hull up to 12 μm of length. Based on the SRIM code, fission products with 80 MeV were penetrated to 12 μm of thickness via 10 μm of oxide layer. As results of code, penetration depth is longer with increase of oxide layer.

REFERENCES

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[2] R.Restani et al., “Characterization of PWR Cladding Hulls from Commercial Reprocessing”, NAGRA Technical Report 92-13(1992)

[3] J.R.Lamarsh, “Introduction to Nuclear Engineering”, Chapt.3, 3rd Edition, Prentice-Hall, Inc (2001)