A Review of Crud Mitigation and Management Strategy

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1. Introduction

In Korea Nuclear Fuel Co.(KNFC), the database of domestic fuel failures has been developed and the study to find the causes of the fuel failures has been performed. With a severe operating conditions and aged reactor coolant system, crud induced localized corrosion (CILC) has been one of the causes of the fuel failures. Since 1991, all 14 fuel failures related to the crud and corrosion has been reported in US PWR plants. Even though no fuel failures by crud and corrosion have occurred in Korean plants, the possibilities of fuel failure by CILC have increased because of higher burnup, longer cycle and power uprating program.

In this study, international trend for the crud mitigation and management strategy will be reviewed to establish an integrated program that is to be used in KNFC.

2. Case Study

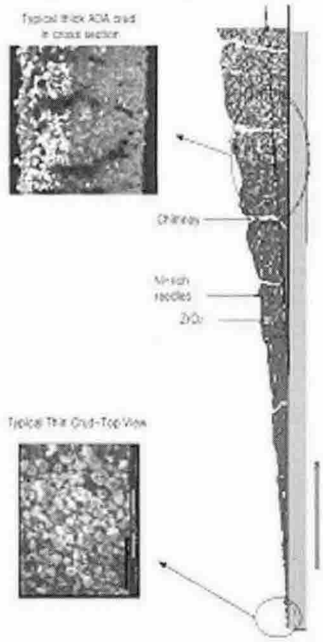
In this section some of the fuel failures by CILC are described. Recently, enhanced clad corrosion due to crud deposits was also reported from a few US PWR plants. Three Mile Island Unit 1 experienced 10 failed rods owing to an unusual buildup of corrosion products in 1995. Also the 10 failed rods due to the tenacious crud deposits occurred in Palo Verde-2 Cycle 9.

2.1 Three Mile Island Unit 1 Cycle 10

Some of the fresh fuel in TMI-1 experienced localized cladding corrosion damage during cycle 10. The damage was characterized by a distinct corrosion pattern between the fifth and seventh intermediate fuel rod spacer girds from the bottom of the fuel assembly. This crud build up and the fuel failures occurred in the first cycle with highly enriched fuel of 4.75%. According to preliminary evaluations the problem is attributed to a combination of high temperature due to higher power and some flux tilt with the fresh assemblies, and a low pH value with the applied high level of boron poison for a two-year cycle.

2.2 Palo Verde Unit 2 Cycle 9

Ultrasonic testing (UT) was performed for all assemblies in PV-2 Cycle 9 as they were offloaded from the core. All ten of the rods identified as failed by UT were confirmed failed by visual inspection. Visual inspection of the assemblies with failed rods and other assemblies for diagnostic purposes determined that significant tenacious crud deposits were present on all high power assemblies. Elevations that correspond to Spacer Grid Spans 7, 8 and 9 were most affected. Based on the observed crud deposition patterns, it is sure that tenacious crud deposits are typically more extensive on the periphery of an assembly when two high power assemblies are coupled to create an assembly-to-assembly interface where sub-cooled boiling occurs at that interface.



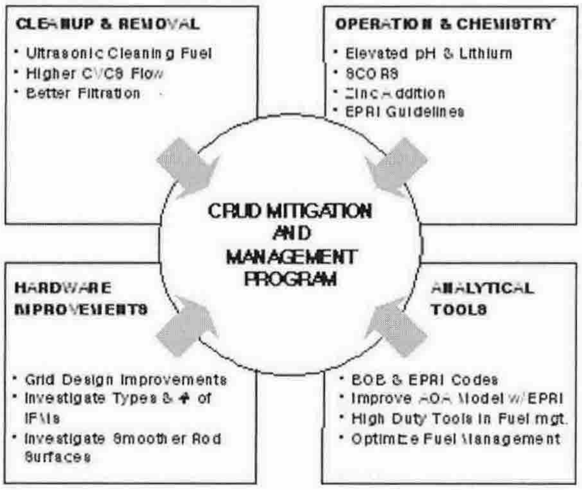
The nine failed rods were located on peripheral faces of the assemblies and those faces were adjacent to other fresh assemblies in Cycle 9 and the examinations identified through-wall penetrations for eight of the ten failed rods. Those penetrations had similar characteristics and are believed to be the primary failure locations. Based on information generated by the diagnostic inspections, it is believed that a relatively thick layer of tenacious crud deposits on high power rods directly contributed to the observed fuel failures.

3. Crud Induced Localized Corrosion Failure

It has been generally observed that the corrosion of standard Zircaloy-4 tends to accelerate towards high burnup. Several mechanisms have been proposed for the accelerated corrosion. One is that the thermal conductivity of zirconium oxide is low and the accumulation of oxide has a feedback effect on the oxidation of Zircaloy via enhanced temperatures at the metal surface. Another is that the zirconium hydrides tend to precipitate at the outer surface of the cladding, and corrosion of the hydrides is known to be much faster than that of the cladding material.

4. Crud Mitigation and Management Strategy

In 1999, Westinghouse established the crud mitigation and management strategy with a joint effort of EPRI as shown in the figure below. It had been based on the Palo Verde failures. Since all of the failed were located at the periphery of grid, it is believed that the un-desirable geometry of the outer strap of grid could be a root cause of the failure.



4.1 Crud Cleanup and Removal

Some companies have developed various crud cleanup or removal systems to minimize the axial offset anomaly, e.g., chemical operation, ice injection, ultrasonic shakedown. One of the commercialized cleanup systems was initially developed by EPRI. Dominion Engineering Inc. has revised the system and has implemented to Callaway plant to verify its acceptability. All the fuels that cleaned by the system were reloaded with no sign of defect. The system uses an ultrasonic to shakedown heavily deposited crud from clad surface. All the integrities related to this process were evaluated, e.g., PCI, fretting wear, pellet cracking, etc.

4.2 Hardware Improvements

A localized hot region on clad surface could cause a heavy oxide layer as described above. The mixing vane geometries, e.g., vane angle, vane length, vane tip, weld nugget, etc., are effect on the clad surface temperature. There is an extensive effort to develop good vane geometry during the joint development program, Next Generation Fuel Development (NGF), was performed by Westinghouse and KNFC from 2001 to 2003. In addition, additional mixing grids (IFMs) were added at high temperature region to improve mixing performance.

It is believed that a smooth surface on cladding reduces crud deposits. The cladding surfaces are being rough during loading process into skeleton. To reduce scratches on cladding, a lacquering process or electro-polishing process can be applied. In Japan, so-called 'key-in' fuel rod loading process is used to exclude any surface scratching.

4.3 Operation and Chemistry

It had been suggested that elevated pH and Lithium in coolant could mitigate crud. A support demo programs applied to Comanche Peak and Calvert Cliffs plant. Schedule improvement for Chemistry Operations at Restart and Shutdown (SCORS) and Zinc addition also suggested reducing susceptibility of crud deposition.

4.4 Analytical Tools

EPRI and Westinghouse kept improving the analytical tools under the crud characterization by the crud scraping investigation. Their goal is to develop best AOA model for crud deposition and boron buildup including chemistry effects and to develop automated tools for high duty core design to manage crud mitigation, corrosion, fuel duty and meet fuel limits eventually.

5. Current Status and Future Activities in KNFC

5.1 Current Status

Weak symptoms of AOA had been occurred at several Westinghouse type plant as well as KSNP. AOA signal occurred at Ulchin Unit 2 Cycle 10 was relatively higher than other plant ($\Delta I > -7.0$, limit = -11.2). KNFC started a research program to assess the root cause of the AOA in 2003 and decided to use BOB code that is used to evaluate the core-loading pattern with respect to the crud deposit as well as a symptom of axial offset anomaly. In addition, KNFC has started another program to develop an ultrasonic based crud cleaning system that is funded by government.

Some of rods were transmitted to the hot cell test facility in KAERI (Korea Atomic Energy Research Institute). One of rods was scrapped to get some crud to assess its chemical components. This data was not yet compared to the reference data, which came from other country.

5.2 Future Activities

KNFC performs intensive researches in many aspects related to prevent AOA, e.g., BOB code implementation, PSE & PIE, crud scraping, crud cleanup system, etc. However, those efforts should be integrated to maximize synergy effect under a certain management strategy.

REFERENCES

[1] Review of Fuel Failures in Water Cooled Reactors, International Atomic Energy Agency, 1998.

[2] The Diagnostic Examinations of Failed Fuel Assemblies from Palo Verde Unit 2 Cycle 9, Westinghouse Electric Company, 2001