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Plan for Structural Analysis of Fuel Assembly for Seismic and Loss of Coolant Accident Loading Considering End-Of-Life Condition for APR1400 NRC Design Certification

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1. Introduction

The evaluation of fuel assembly structural response to externally applied forces by earthquakes and postulated pipe breaks in the reactor coolant system is described in standard review plan (SRP) 4.2, appendix A[1]. The fuel assembly structural response to these externally applied forces is evaluated to ensure the fuel system satisfies requirements to maintain control rod insertability and core coolability.

SRP 4.2, appendix A, section III, states, “While P(crit) [the crushing load] will increase with irradiation, ductility will be reduced. The extra margin in P(crit) for irradiated spacer grids is thus assumed to offset the unknown deformation behavior of irradiated spacer grids beyond P(crit).” The assumption in the SRP concerning irradiated grids may suggest that only the beginning-of-life (BOL) condition for spacer grid strength needs to be evaluated for fuel assembly integrity under externally applied forces.

However, U.S. NRC issued the NRC Information Notice (IN) 2012-09[2] to inform of recent operating experience involving evaluations of fuel assembly structural response which challenges the assumption that only the BOL condition needs to be evaluated.

NRC IN 2012-09 states “Effects that can influence structural strength include neutron fluence (e.g., grid spring relaxation, irradiation hardening, growth, cladding creep down), corrosion (e.g., thinning, hydrogen uptake), and operating conditions (e.g., temperature) up to the approved limits on fuel assembly burnup and service life, as applicable.” Therefore the end-of-life (EOL) condition should be considered for structural analysis of fuel assembly for seismic and loss of coolant accident (LOCA) loading.

In this paper, plan to evaluate the fuel assembly structural integrity for seismic and LOCA loading considering the EOL conditions is studied for US NRC design certification.

2. Methods of Structural Analysis

A series of analyses is performed to obtain the response of fuel assemblies to seismic and pipe rupture excitation summarized in Figure 1[3]. First, the seismic responses and the pipe rupture responses of the reactor containment building and reactor coolant system (RCS) are calculated, and then the responses of the reactor vessel internal (RVI) are determined using the motion of the reactor vessel (RV) from the previous RCS analysis. The responses of fuel assemblies are analyzed using RVI horizontal analysis, detailed core horizontal analysis and RVI seismic analysis detailed core models and the core plate motion (CPM) which is obtained from the RVI structural analysis. The maximum responses from the detailed core analyses are used to calculate the stresses. The stresses by the seismic and LOCA loading are combined and used to evaluate the structural integrity of fuel assemblies.

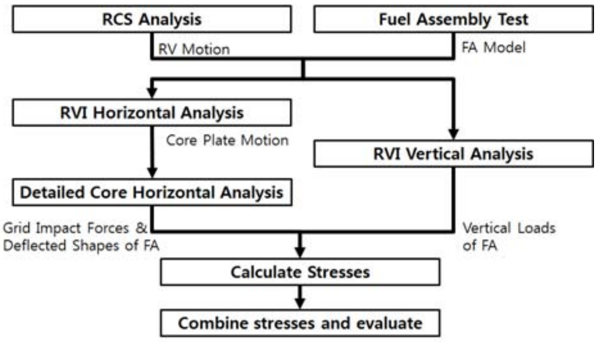

Fig. 1. Procedure for structural analysis of fuel assembly for seismic and LOCA loadings.

A simplified model of a fuel assembly which has the same characteristics as fuel assemblies for seismic and pipe rupture analyses in the core is used for the structural analysis. The model is developed based on the results of static and dynamic tests for the fuel assembly and the grid as shown the table 1.

Table I: Fuel Assembly Test Program

Test Item	Test Results
Fuel Assembly Lateral Vibration Test	Natural frequencies and mode shapes, and the structural damping
Fuel Assembly Lateral Stiffness Test	Lateral load deflection characteristics
Fuel Assembly Lateral Impact Test	Impact characteristics with the top/bottom nozzles constrained within core boundary conditions
Fuel Assembly Axial Stiffness Test	Fuel assembly components deflections as a function of axial load and the load distribution in guide thimble tubes
Mid Grid Crush (Through-Grid) Test	Through-grid impact strength/stiffness and coefficient of restitution
One-Sided Drop Test	One-sided impact strength

3. Plan to consider the irradiation effect

IN 2012-09 states, “Spacer grid spring relaxation could have a significant affect on two aspects of the core dynamics model: fuel bundle stiffness and spacer grid strength. Reduced spring force would lower the effective bundle stiffness and may lower the strength of the spacer grid. Both of these phenomena directly affect the fuel assembly structural evaluation.” To consider the irradiation effect, the spacer grid spring relaxation due to irradiation should be simulated. Using the simulated fuel assembly for the EOL conditions, the fuel assembly stiffness and spacer grid strength should be determined.

3.1 Simulated Fuel Assembly for End-of-Life

Gap between the grid springs and the fuel rods is formed due to irradiation induced spring relaxation, grid growth and cladding creep-down. To test the effect of crush strength of spacer grid and the spacer grid strength, the reduced spring force is simulated by determining gaps between the grid springs and the fuel rods. At EOL conditions, grid cell sizes are expected to increase. To make the simulated fuel assembly for EOL conditions, the grid cell size for the top, middle, bottom and protective grid and the out diameter of fuel rod may be determined by measuring the grid cell size of the irradiated fuel assembly.

3.2 Spacer Grid Test

Schmidt[4] and Lu et al.[5] compared the peak impact loads for EOL conditions with the BOL conditions. The local grid impact force reduced and the impact duration time increased. The peak impact loads of PLUS7 fuel assembly for EOL conditions shall be determined by the mid grid crush (through-grid) test and one-sided drop test.

3.3 Fuel Assembly Mechanical Test

Schmidt[4] and Lu et al.[5] also compared the natural frequency for EOL conditions with the BOL conditions. The natural frequency for EOL conditions is lower than that for BOL conditions. A decrease in natural frequency should be evaluated to determine the limiting grid impact load and component stresses. The fuel assembly dynamic characteristics, stiffness, natural frequencies and modal shapes used to benchmark fuel assembly analytic models shall be determined by fuel assembly mechanical and dynamic tests with a full size fuel assembly such as fuel assembly lateral vibration test, fuel assembly lateral stiffness test, fuel assembly lateral impact test, and fuel assembly axial stiffness test.

3.4 Flow damping test

The decreases of the impact load and the natural frequency for the EOL condition lower the safety margin of the fuel assembly. The damping ratio increase represents increased energy dissipation, lowering lateral displacements and reducing the impact forces.

The critical damping value is found to be larger in flow water than still water[6]. So, flow damping test should be conducted to determine the critical damping value in flow water. When considering the use of flow damping credit, the flow velocities, fluid temperatures, and the range of amplitudes tested are important[4].

During a seismic event, the reactor coolant pumps may trip resulting in a coast-down and reactor coolant flow decreases. The worst situation for flow rate should be considered by considering the coast down analysis.

4. Conclusions

To consider the EOL conditions for the structural analysis of the fuel assembly under a seismic and LOCA loading, the simulated fuel assembly for EOL conditions should be considered by determining the gap between the spacer grid and fuel rod. Using the simulated fuel assembly, spacer grid test and fuel assembly mechanical test should be conducted to determine the simplified model of fuel assembly which is used for the structural analysis. The structural analysis will be conducted using the fuel assembly model for EOL condition. The flow damping value will be also used for the structural analysis to reduce the impact force.

REFERENCES

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