Spent Fuel Project Office
Interim Staff Guidance - 12
Revision 1

Issue: **Buckling of Irradiated Fuel Under Bottom End Drop Conditions**

Discussion:

Fuel rod buckling analyses under bottom end drop conditions have traditionally been performed to demonstrate integrity of the fuel following a cask drop accident. The methodology described by Lawrence Livermore National Laboratory (LLNL) to analyze the buckling of irradiated spent fuel assembly under a bottom end drop in their report UCID-21246 is a simplified approach. It assumed that buckling occurred when the fuel rod segment between the bottom two spacer grids reached the Euler buckling limit. The weight of fuel pellets was neglected in the analysis; only the weight of the cladding was considered. Material properties for irradiated cladding were used. The buckling analysis also neglected the stiffness of the pellets which could have been fused or locked to the cladding. It assumed the total weight of the cladding to be on top of the fuel rod segment between the bottom two spacer grids. In addition, it also assumed that the fuel rod segment between the bottom two spacer grids was pin-connected. The restraint and lateral support of the fuel basket structure to the fuel assemblies were ignored in the analysis.

The weight of pellets and irradiated material properties should be included in any end drop analysis. With these changes, the simplistic method of UCID-21246 may not yield acceptable results. For example, the staff conducted calculations using the same methodology as LLNL report UCID-21246, except that irradiated material properties for the cladding and the weight of fuel pellets were included in the calculations. The most vulnerable fuel assembly in the LLNL report, a 17x17 Westinghouse fuel assembly, was chosen for this exercise. Euler buckling loads for the clad were calculated using the following formula:

$$P_{cr} = \pi^2 EI/L^2$$

where

$$E_{clad} = 10.47 \times 10^6 \text{ psi}$$

$$I_{clad} = 1/4\pi \times (r_o^4 - r_i^4) = 1/4\pi \times (0.187^4 - 0.1645^4) = 3.85 \times 10^{-4} \text{ in}^4$$

$$L = 24 \text{ inches}$$

The results indicate that

$$P_{cr} = 69 \text{ lb}$$

Since the weight of cladding and pellets for the 144 inch-long fuel rod is about 4.98 lb, the buckling load in terms of gravitational acceleration (g) is

$$P_{cr}/W = 69/4.98 = 13.86 \text{ g}$$

This is considerably smaller than the 82 g reported in the LLNL report UCID-21246. However, there are several bounding assumptions in this approach which make the results unrealistically low for predicting cladding failure.

Conclusion:

Analyses of fuel rod buckling performed to demonstrate fuel integrity following a cask drop accident yield results which contain a large margin to actual failure. The calculated onset of buckling does not imply fuel or cladding failure. Where such analyses yield unacceptable results, more realistic analyses of dynamic fuel behavior are appropriate and acceptable. If the cladding stress remains below yield strength, the fuel integrity is assured.

Recommendation:

If the analytical approach described in the LLNL report UCID-21246 for axial buckling is used to assess fuel integrity for the cask drop accident, the analysis should use the irradiated material properties and should include the weight of fuel pellets.

Alternately, an analysis of fuel integrity which considers the dynamic nature of the drop accident and any restraints on fuel movement resulting from cask design is acceptable if it demonstrates that the cladding stress remains below yield. If a finite element analysis is performed, the analysis model may consider the entire fuel rod length with intermediate supports at each grid support (spacer). Irradiated material properties and weight of fuel pellets should be included in the analysis.

The appropriate section of Standard Review Plan, NUREG-1536, should be revised to clearly reflect analytical approach for fuel rod bucking analyses.

Approved ____

E. William Brach **Date**