SUNSI Review Complete Template = ADM-013, E-RIDS=ADM-03
ADD= Wendy Reed, Ricardo Torres

COMMENT (25)
PUBLICATION DATE: 8/9/2018
CITATION: 83 FR 39475

From: Waldrop, Keith
To: Torres, Ricardo
Subject: [External_Sender] Comments on structural analysis for NUREG-2224
Date: Wednesday, February 13, 2019 10:04:53 AM

Ricardo,
As I mentioned at the ASTM meeting a couple weeks ago, I have gotten some comments on the structural analysis supporting the draft High Burnup NUREG-2224.

The concern is that the structural analysis only considered lateral inertial loads on the fuel rod supported from the bottom and does not consider the pinch load that would occur in a drop accident from rods above providing a force on top of the rod being analyzed. This treatment is first described on pg 1-24 lines 43-45 and pg 1-25 lines 1-2 and Figure 1-15.

Lines 5-7 on page 1-25 state “Given the forces and displacements in the RCT are measurably different from the actual forces and displacements applied to the rod at the grid support, it is not likely that the pinch-mode of failure will play a significant role in undermining cladding integrity.” It should be noted that the DOE report SAND90-2406, referenced in NUREG-2224, thoroughly evaluated a pinch load mode (forces from the top and bottom as in the RCT, calculating a failure probability 2E-5 for the axial split mode and 5E-5 for the rod breakage mode). This part of the analysis documented in SAND90-2406 is not considered in the draft NUREG-2224; only the lateral inertial load case is. This was an important distinction in SAND90-2406 because it changes the whole picture, by shifting the failure mode from that of cladding longitudinal fracture, which would be very short and more benign relative to fuel dispersal, to a guillotine break with more severe implications to fuel dispersal.

So, although we support the staff's conclusions based on the work documented in EPRI Report 1009929[1], the pinch load should not be ignored. Additional arguments supporting the staff’s conclusion could include:

1. Reorientation is not an issue given that cladding is subjected to stress and temperature conditions that are not conducive to enabling hydride reorientation because of design features (inner liner) in BWR fuel rods[2] and low rod internal pressures in PWR fuel rods.[3]-[4].
2. There is no significant fuel-cladding gap over large fractions of the fuel rod areas. This may be what the staff has assumed all along. In this case, ovalization of the cladding could be neglected due to the stiffness provided by the fuel column.

It is relevant to mention that SAND90-2406 dealt with low burnup fuel, no fuel bonding and no modeling of radial hydrides, which may have been the reasons for the Staff to disregard the results of SAND90-2406. However, a careful assessment of the impact of these differences on the results, juxtaposed against NUREG-2224 methodology, reveals the following: (a) Except for the hydrogen content the low burnup has neutral effect for both methodologies because of the early saturation of cladding mechanical properties (note that NUREG-2224 acceptance criteria is based on a force metric which is not sensitive to the hydrogen content); (b) the no-bonding condition makes the SAND90-2406 results more conservative than the NUREG results; (c) not considering the effects of radial hydrides is the same in both methodologies. This semi-heuristic analysis makes it imprudent to throw out the pinch mode without proper evaluation. Pinch loading and bending loading, and a smaller but not negligible axial force, are additive in the sense that they become coupled because of plasticity that develops in the cladding under the combined loading modes which are maximized simultaneously at the grid spacers. This state of plasticity in the cladding cross section, which is caused by pinch loading, bending loading and axial force, induces what is called inertia load shedding which begins at the onset of plasticity in the cladding cross-section and continues until the rod fails completely or a state of equilibrium is reached. This inertia load shedding is described in a failure analysis EPRI Report, “Spent Fuel Transportation Applications: Modeling of Spent Fuel Rod Transverse Tearing and Rod Breakage Resulting from Transportation Accidents”, 1013447, October 2006, which shows that the maximum moment at the onset of load shedding is 150 lb-in (17 N-m), reduced to 80 lb-in (9 N-m) at equilibrium. Compare this to the 34 N-m elastically calculated in NUREG-2224. Note that, this inertia load shedding behavior is characteristic of the bending mode. The pinch mode is not subject to the same behavior because the loading is due to the impact forces above the rod being analyzed.

---

[1] The important role of the fuel column under accident conditions was illustrated in EPRI Report 1009929, *Spent Fuel Transportation Applications: Fuel Rod Failure Evaluation under Simulated Cask Side Drop Conditions* (2005)

[2] Q. Auzoux et al., *“Hydride reorientation and its impact on ambient temperature mechanical properties of high burn-up irradiated and unirradiated recrystallized Zircaloy-2 nuclear fuel cladding with an inner liner,”* Journal of Nuclear Materials, Vol. 494 (2017) pp. 114 – 126.

[3] A. Machiels et al., *“Characterization of end-of-life rod internal pressure in PWR fuel,”* Nuclear Engineering and Design, Vol. 324 (2017) pp. 250 – 259.

[4] R. Montgomery et al., *“Post-Irradiation Examinations of High-Burnup Pressurized Water Reactor Fuel Rods,”* EPRI ESCP Meeting (Charlotte, NC, November 6, 2018), Slide #5.

Thanks,

Keith Waldrop
Used Fuel and HLW Management Program
Electric Power Research Institute
1300 West WT Harris Blvd. | Charlotte, NC 28262

Tel: 704-595-2887 | Fax: 704-595-2860

---

[1] The important role of the fuel column under accident conditions was illustrated in EPRI Report 1009929, *Spent Fuel Transportation Applications: Fuel Rod Failure Evaluation under Simulated Cask Side Drop Conditions* (2005)

[2] Q. Auzoux et al., *“Hydride reorientation and its impact on ambient temperature mechanical properties of high burn-up irradiated and unirradiated recrystallized Zircaloy-2 nuclear fuel cladding with an inner liner,”* Journal of Nuclear Materials, Vol. 494 (2017) pp. 114 – 126.

[3] A. Machiels et al., *“Characterization of end-of-life rod internal pressure in PWR fuel,”* Nuclear Engineering and Design, Vol. 324 (2017) pp. 250 – 259.

[4] R. Montgomery et al., *“Post-Irradiation Examinations of High-Burnup Pressurized Water Reactor Fuel Rods,”* EPRI ESCP Meeting (Charlotte, NC, November 6, 2018), Slide #5.