28705 Hope Circle
Easton, MD 21601
August 7, 2016

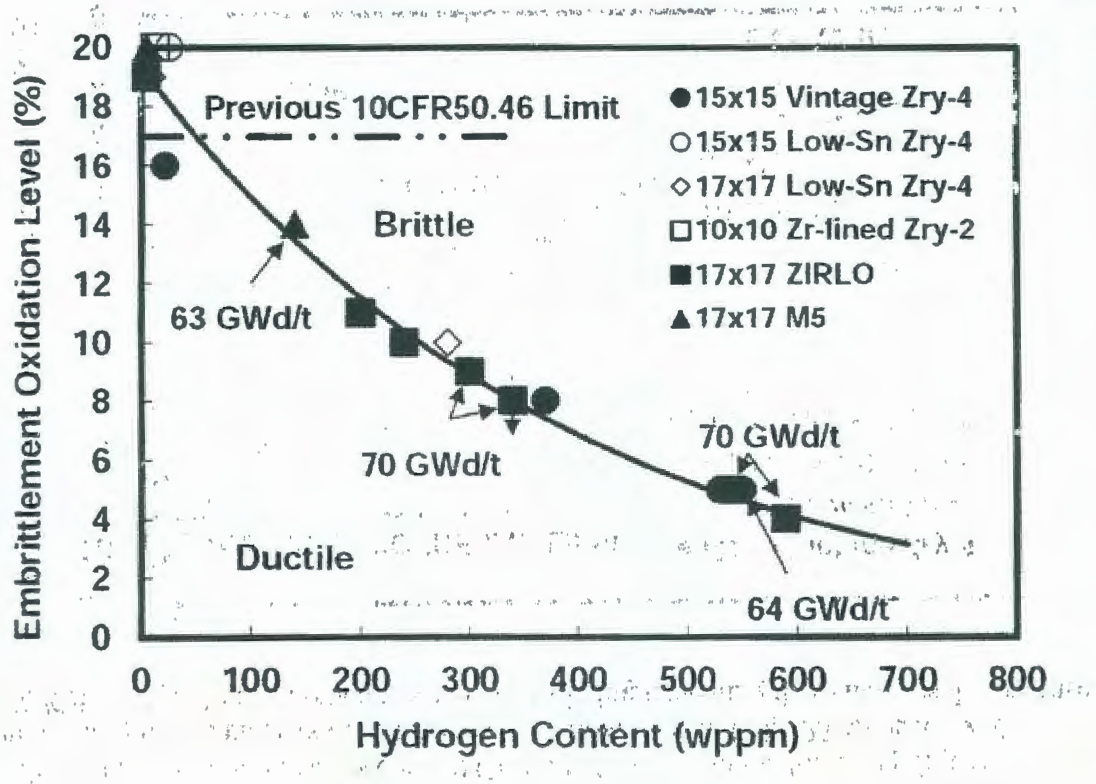
Mr. Victor M. McCree
Executive Director for Operations
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

Dear Mr. McCree:

According to provisions of 10 CFR 2.206, I hereby petition the NRC to perform *de novo* reviews of ballooning (swelling) and rupture models used in licensees' loss-of-coolant accident analyses required by 10 CFR 50.46, and further to require licensees to incorporate any modifications needed to obtain NRC approval and then use only such models that have been so reviewed and approved by the NRC in all such licensing analyses.

The Issue

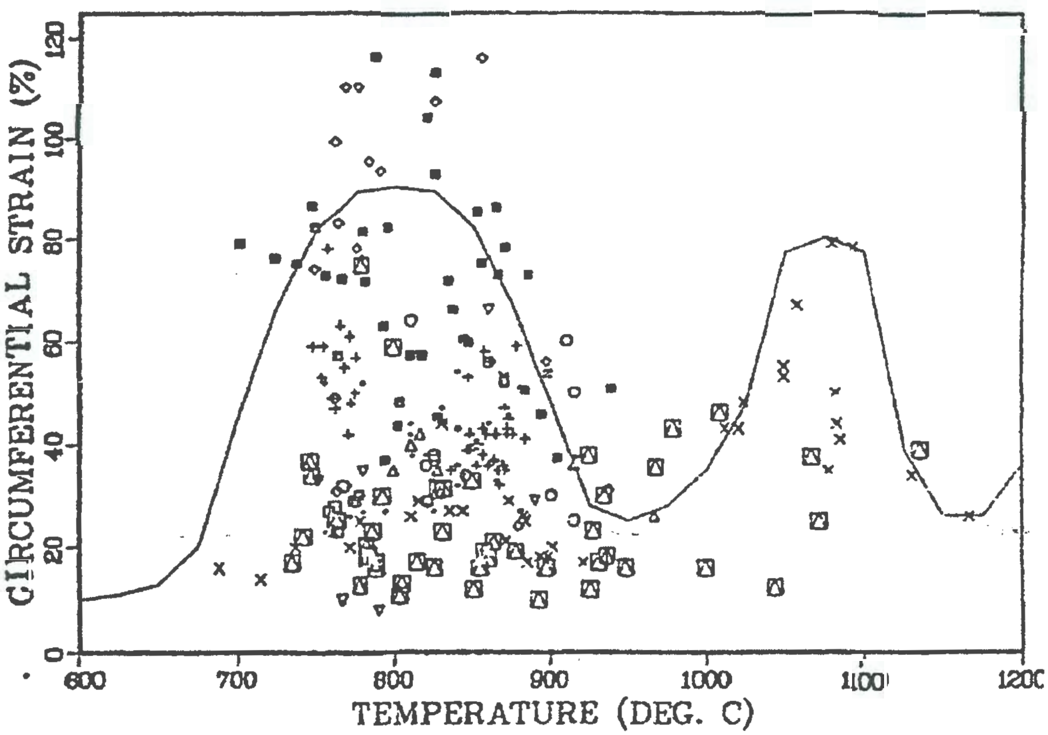
Recent research results show that the limiting oxidation level for high-burnup fuel will be far below the 17 percent limit prescribed by 10 CFR 50.46 as seen in the following figure (unnumbered figure on page xxxii of the Executive Summary and Fig. 25 on page 59 of NUREG/CR-7219). Relaxed schedules and delays in implementing these new results are based



on a safety assessment and audit which confirmed that sufficient safety margin exists for operating reactors and determined that immediate regulatory action was not required (Clifford to Ruland, February 10, 2012, ML12041A078). This assessment was based on industry calculations with models that may be flawed because of inadequate ballooning and rupture models.

A key parameter, which is used under the old rule (10 CFR 50.46(b)) to demonstrate limited oxidation and under the new rule (10 CFR 50.46c) to demonstrate adequate ductility, is equivalent cladding reacted (ECR). It is defined as the percentage of the cladding wall thickness that is oxidized during a LOCA temperature excursion. The most limiting case is almost always found in the ballooned and ruptured region of a fuel rod. In these cases, the wall is considerably thinner than the as-fabricated thickness because of swelling, and analytical models are used to calculate the reduced thickness.

In light of recent research results, the ballooning and rupture models used in licensing analyses to calculate ECR are probably non-conservative. The basis for this statement can be explained with the following figure from NUREG-0630. This figure shows the size of the balloons (larger balloons have thinner walls) as a function of rupture temperature for fresh or low-burnup Zircaloy. There are two peaks: alpha-phase cladding on the left and beta-phase cladding on the right. The valley in the middle is in the mixed-phase region. It was previously believed that fill pressures could be engineered such that rupture would occur in the mixed-phase valley and therefore balloons would be relatively small. Most or all current ballooning and rupture models used in licensing predict relatively small balloons. This was not considered a concern by NRC because ECR was seldom if ever limiting and a more critical review seemed unnecessary.



Recent research has shown several things that change this picture (see NUREG/CR-7219). First, allowable ECR values are now known to be substantially reduced by hydrogen that is absorbed during normal burnup operation. This effect has been captured in the new rule. Now that ECR is more likely to be limiting, a more critical review of the ballooning and rupture models should be done.

The second finding is that the peaks-and-valley character of balloon size, as shown in the above figure, shifts along the temperature axis with the addition of niobium to zirconium in the more modern ZIRLO and M5 cladding materials. Although we now know that niobium causes a shift, there are not enough data to define the new peaks and valley for ZIRLO and M5 such that one could claim that ruptures only occurred in the valley.

A third finding is that hydrogen, which is absorbed during the normal burnup process, also shifts the peaks and valley along the temperature axis. Further, there is now evidence that hydrogen also weakens the cladding and results in even larger balloons and hence thinner cladding.

As a fuel rod accumulates burnup, fission gas will increase its design pressure. Hydrogen will also be absorbed in the cladding. Therefore, the rupture temperature and hence ballooning strain will change such that a strain that might occur in the valley at low burnup might occur at a peak at high burnup. In addition, cores might have fuel with a mixture of burnups and even different cladding alloys such that a distinct valley (i.e., a low strain) would not exist that could be used on a core-wide basis.

Finally, one should recognize that the curve drawn through the scattered data in the above figure is a best estimate and was not intended as a conservative representation of the data. As an author of that report, I know that many of the tests that resulted in smaller balloon sizes had atypical test conditions that biased their results. Therefore, we drew the best-estimate curve through the larger balloon sizes. Thus, any model that predicts ballooning strains less than about 90%, based on the above figure, should be suspected of being non-conservative.

Quality of Needed Review

In performing a *de novo* review of current ballooning and rupture models, it is important to utilize results from tests that were performed with internal heating to determine the magnitude of ballooning strains. External heaters can significantly bias the results, as discussed in NUREG-0536 and NUREG-0630. Heating methods that utilize furnaces or ovens can generate atypically uniform temperatures that will result in balloons that are too large. Heating methods that utilize discrete external heat sources, such as the quad-elliptical furnace used recently in NRC research, can generate atypically non-uniform temperatures that will result in balloons that are too small. As reported in NUREG/CR-7219, such a furnace was perfectly adequate for producing balloons whose properties could be studied, but would not be adequate for determining expected balloon sizes. Unfortunately, there are probably not many more qualified data beyond those reported in NUREG-0630, but a careful search for additional data should be made.

It is well known that rupture results from a plastic instability that is set off by local temperature hot spots. There are many causes of local temperature variations that lead to the unpredictable character of the rupture process, as seen in the large data scatter in the above figure. Mechanistic models cannot represent the stochastic nature of this process. Therefore a statistical approach, which represents all of the data without favoring strains in the mixed-phase valley, is probably needed and should provide some modest conservatism of the ensemble of data.

Because of the technical complexity of this subject, reviewers should have a strong background in zirconium metallurgy. Since most of this type of expertise resides in RES, concurrence of RES should be sought. And because of the potential impact of such reviews, the staff work should be reviewed by the ACRS.

Limitations of the Review

Although the subject is complex and the impact of subsequent model revisions might be significant, the affected portion of the computer codes used by licensees is quite small. Ballooning and rupture models are just small subroutines in these large computer codes and widespread revision of the codes should not be needed. Although there might be some interest in tuning other models within the codes to reduce the impact, the burden on the industry to support ballooning and rupture model reviews should be small.

Qualifications of the Petitioner

After doing thesis and post-doctoral research on diffusion in metals, I spent five years at Argonne National Laboratory doing related experimental and modeling work on reactor fuel. During ten years in NRR's Reactor Fuels Section, I co-authored NUREG-0536 and NUREG-O630, both of which are on the ballooning and rupture subject. It is worth noting that RES assisted with this work, and draft reports were reviewed by ACRS. Later in RES, I brought together about two dozen fuel experts from industry, universities, and laboratories in the U.S. and other countries to identify important phenomena that should be investigated in high-burnup fuel under transient and accident conditions. I then wrote NUREG-1749 to describe implications from the eight multi-day sessions. I also initiated and provided technical direction for the large LOCA research program at Argonne National Laboratory (see NUREG/CR-7219) and a smaller LOCA program at the Kurchatov Institute in Russia (see NUREG/IA-0211). When I retired, I was given a gold medal (Distinguished Service Award) and re-hired to work half time as an annuitant. At the end of the first year, I wrote Research Information Letter 0801, which was used as the basis for initiating the 50.46 rulemaking, and at the end of the second year I finished a tutorial on fuel behavior under abnormal conditions (NUREG/KM-0004). After this two-year appointment ended, I went to work part time for Argonne National Laboratory, helping with data evaluation and report writing that ended with the recent completion of NUREG/CR-7219.

Sincerely,

Ralph Meyer

Ralph O. Meyer, Ph.D.