UNITED STATES
NUCLEAR REGULATORY COMMISSION
ADVISORY COMMITTEE ON REACTOR SAFEGUARDS
WASHINGTON, DC 20555 - 0001

July 27, 2017

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

SUBJECT: SAFETY EVALUATION FOR WCAP-17642-P, REVISION 1, “WESTINGHOUSE PERFORMANCE ANALYSIS AND DESIGN MODEL (PAD5)”

Dear Mr. McCree:

During the 645th meeting of the Advisory Committee on Reactor Safeguards, July 12-14, 2017, we completed our review of the report, WCAP-17642-P, Revision 1, “Westinghouse Performance Analysis and Design Model (PAD5),” and the associated NRC staff’s safety evaluation (SE). Our Subcommittee on Thermal-Hydraulic Phenomena also reviewed this matter on May 16, 2017. During these reviews, we benefitted from discussions with representatives of the NRC staff and the Westinghouse Electric Company (Westinghouse). We also benefitted from the referenced documents.

RECOMMENDATIONS AND CONCLUSIONS

1. The updates to the Performance Analysis and Design (PAD5) code, including fuel and cladding thermal-mechanical properties, have been validated against an extensive set of experimental data. The staff SE should be published.
2. The limitations imposed in the staff SE are justified. They ensure that PAD5 is applied only within its validated ranges.
3. The requirement for continued validation of PAD5 models and their uncertainty is justified.

BACKGROUND

The PAD5 code is an integrated set of fuel and cladding performance models that computes fuel thermal-mechanical properties (fuel and cladding temperatures and mechanical properties) based on the interrelated effects of fuel and cladding deformations, which include: fuel densification, fuel swelling, fuel relocation, fuel rod and cladding temperatures, fill and fission gas release, and rod internal pressure as a function of time and linear power. The methodology is applicable to rod analyses for U.S. pressurized water reactor fuel fabricated by Westinghouse, and it integrates the two methodologies formerly used for Combustion Engineering and Westinghouse applications. Revision 1 of WCAP-17642-P documents the PAD5 models and their validation, and it is the subject of the staff’s SE.

The PAD5 code is an update to PAD4, which has been in use since 2000. The main change in the methodology is the explicit treatment of thermal conductivity degradation as a function of burnup. A number of other code improvements have been incorporated to predict more accurately recent high-burnup experimental data. These include: more detailed radial power distribution within the pellet; updated fission gas release models; updated helium release from zirconium diboride coating; updated pellet relocation and axial growth models; and updated fuel and cladding properties, including the burnup-dependence of the fuel melting temperature. The validation dataset is extensive and includes experimental results for high-burnup ZIRLO® and Optimized ZIRLO® cladding.

DISCUSSION

The PAD5 upgrade addresses NRC Information Notice 2009-23, "Nuclear Fuel Thermal Conductivity Degradation" and incorporates into the Westinghouse methodologies the burnup dependence of fuel thermal conductivity. The new models have been validated against data from tests conducted in the Halden Reactor Project, the Studsvik Clad Integrity Project, and the Studsvik power ramp test projects. The staff reviewed the comparisons of available data against PAD5 predictions and concluded that PAD5 is validated for the target linear heat generation rates and up to a rod-average burnup of 62 GWd/MTU.

The staff concentrated their evaluation on the major performance models in PAD5 and found them acceptable. These major models are:

1. Thermal model, including thermal conductivity degradation with burnup
2. Fission gas release and helium release models and their impact on internal rod pressure model
3. Cladding corrosion model
4. Fuel densification and swelling model
5. Modeling of fuel and clad mechanical properties
6. Pellet void volume model and growth assessment

The staff evaluation was informed by extensive confirmatory calculations with the NRC code FRAPCON, which are documented in the SE. FRAPCON was used not only to compare steady state parameter values, but also to reproduce sensitivities to changes in operating conditions. This comprehensive use of an independent methodology significantly increases the confidence on the validity of the PAD5 results.

The staff reviewed the treatment of uncertainties and found it acceptable to calculate upper bound values for the outputs of interest. To develop the uncertainties, Westinghouse divided the available experimental data into two sets. Roughly, half of the data was used for model development, and the uncertainties were evaluated on the complete dataset. Statistical analyses were then used to develop upper and lower bounds that meet at least a 95/95 acceptance criterion. These uncertainties are finally converted into effective model penalties that are applied to the relevant output of interest to bring it to an upper bound level. The model penalties to be used with PAD5 safety analyses are documented in the topical report and have been confirmed to be conservative by the staff.

To verify the proposed model penalties, Westinghouse provided sample calculations for each of the safety analysis calculations that will be performed with PAD5. The staff performed these same calculations using FRAPCON and concluded that the proposed methods yield a reasonable prediction of the 95/95 percent upper bound for the outputs of interest.

The topical report proposed a Models and Methods Improvement Process (MMIP) that would establish a streamlined process for fuel performance model and PAD5 methodology improvements, without NRC review and approval. An MMIP process provides value because it can expedite the response to changes in the state of the art that may occur as more data and operating experience becomes available. We concur with the staff position that MMIP is an important issue and should be developed generically rather than approving it for this specific application. We intend to follow this topic separately.

The state of the art on irradiated-fuel properties continues to advance as more data and operating experience are collected and analyzed. To ensure that Westinghouse methodologies take advantage of these advances, the staff SE requires continued validation of PAD5 models and their uncertainty. Documentation of the validation results is required on a recurring 10-year interval.

SUMMARY

The updates to the PAD5 code, including fuel and cladding thermal-mechanical properties, have been validated against an extensive set of experimental data. The staff confirmatory analyses increase significantly the confidence in the validity of the PAD5 results and confirm that the proposed model penalties bound the 95/95 acceptance criteria. The staff SE provides an excellent evaluation of the PAD5 model improvements and should be published.

Additional comments by ACRS Members Ronald Ballinger, Walter Kirchner, and Michael Corradini are presented below.

Sincerely,

/RA/

Dennis Bley
Chairman

Additional Comments by ACRS Members Ronald Ballinger, Walter Kirchner, and Michael Corradini

The current PAD5 letter specifies that the code be certified to the NRC every 10 years. In our opinion, the interval is without any engineering or safety basis, is arbitrary, and is an unnecessary burden. The arbitrary nature of the interval specification is demonstrated by the fact that other fuel vendors are required to certify their fuel performance codes at different intervals for the same fuel type operating histories. The operational fuel performance database is now constrained by the 5% enrichment limit, which limits the peak burnup. New claddings are now in full use with more than adequate performance. Fuel failure rates are dominated by non-materials related events, mostly debris. It is unlikely that there will be any “surprises” in the future that would not be identified by other means. The argument is made by the staff that burnup dependent conductivity has been a known phenomenon for at least two decades, yet the fuel vendors have only recently modified their fuel performance codes to explicitly account for this. This is correct but largely irrelevant. All of the fuel performance codes are dominated by empirical correlations that are, and have been, tied to fuel irradiation data. This irradiation data have the burnup dependence of fuel conductivity “built in”. Thus, while technically pleasing, the explicit accounting of burnup depended fuel conductivity, does not add to safety. Moreover, the explicit inclusion of burnup dependent fuel conductivity has not eliminated the empirical nature of the codes. It is the author’s opinion that the fuel vendors will find it in their own best interest to keep their models consistent with available data and do not need an explicit certification interval. At the very least, if there must be a certification interval, the interval should be consistent among the fuel vendors. They all have been calibrated against the same test rod irradiation data and all now have a large operating database. In spite of this, should there be an imposed interval, a significant, unanticipated change in fuel behavior that affects safety would be a more compelling basis to revisit a fuels code and its underlying database, particularly in instances where the critical correlations in the code are empirically based (vs. predictive), e.g., fuel conductivity as a function of burnup. The mere advent of more data does not necessarily drive the need for a code revision. New fuel designs would of course be handled separately.

REFERENCES

1. Westinghouse Electric Company, WCAP-17642-P, "Westinghouse Performance Analysis and Design Model (PAD5)," Revision 1, May 2016 (ML16159A334).

2. U.S. Nuclear Regulatory Commission, Draft Safety Evaluation Report for Topical Report WCAP-17642-P, “Westinghouse performance Analysis and Design Model PAD5,” Revision 1, April 2017 (ML17106A000).

3. Westinghouse Electric Company, WCAP-15063-P-A, with Errata, “Westinghouse Improved Performance Analysis and Design Model (PAD 4.0),” Revision 1, July 2000 (ML003735390).

4. Westinghouse Electric Company, WCAP-15064-NP-A, with Errata, “Westinghouse Improved Performance Analysis and Design Model (PAD 4.0),” Revision 1, July 2000 (ML003735452) [PUBLIC VERSION].

5. U.S. Nuclear Regulatory Commission, Information Notice 2009-23, “Nuclear Fuel Thermal Conductivity Degradation,” October 8, 2009 (ML091550527).

6. Pacific Northwest National Laboratory, “FRAPCON-4.0: A Computer Code for the Calculation of Steady-State, Thermal-Mechanical Behavior of Oxide Fuel Rods for High Burnup,” PNNL-19418, Volume 1, Revision 2, September 2015 (ML16118A427).

7. Pacific Northwest National Laboratory, “FRAPCON-4.0: Integral Assessment,” PNNL-19418, Volume 2, Revision 2, September 2015 (ML16118A434).

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1. Westinghouse Electric Company, WCAP-17642-P, "Westinghouse Performance Analysis and Design Model (PAD5)," Revision 1, May 2016 (ML16159A334).

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7. Pacific Northwest National Laboratory, "FRAPCON-4.0: Integral Assessment," PNNL-19418, Volume 2, Revision 2, September 2015 (ML16118A434).

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