**23. Provide fiber penetration test results and penetration model assumptions that are based on the testing to the extent that the NRC staff can perform confirmatory calculations to validate the in-vessel fiber values used in the analysis.**

The NRC staff reviewed the fiber penetration test report. The licensee performed three preliminary tests and a final quality assured test (Test 2) to quantify penetration. The NRC staff was unable to confirm that the model used to calculate the amount of penetration at various strainer loads was realistic or conservative compared to the test results. Specifically, the NRC staff identified that Equation A-50 in the strainer penetration test report (ALION-CAL-CEC-9345-003, Rev. 0) underpredicted the amount of fiber penetration when compared to strainer fiber penetration Test 2 data. The licensee stated that equation A-50 was not directly used to calculate the fiber amounts in the core for the submittal, but that the issue would be investigated because Equation A-50 was pertinent for conditions in the tests. Differences between Equation A-50 and Test 2 results may indicate artifacts in estimates of parameters of empirical fiber penetration functions. The licensee will provide information in a supplement that includes details on the method used to calculate the fiber penetration as the strainer fiber loading changes so that the staff can confirm that the values are realistic when compared to the test results.

Ameren Missouri Response:

Laboratory test data measuring fiber penetration through Callaway Plant ECCS strainer modules are analyzed in ALION-CAL-CEC-9345-003, Rev. 0 (Reference [1]) to determine two model parameters describing prompt penetration while the debris bed is building and two parameters describing long-term shedding during continued flow erosion. Data available for analysis and comparison include three 3-hour duration tests (Test 1a, Test 1b, and Test 1c) that were performed as non-safety-related exploratory exercises to examine possible effects of pH on fiber penetration, and one 20-hour test (Test 2) that was performed as the safety-related test of record under the Alden Research Laboratory Appendix B quality assurance program and Nuclear Procurement Issues Committee (NUPIC) guidelines. Test 1c bag-filter masses indicated the largest amount of fiber penetration, so Test 2 used the same pH and initial fiber loading schedule but continued with additional fiber batch loads and additional filter collections during shedding. The Test 2 fiber load spans the 300-lbm equivalent determined by full-debris-load testing to be the RoverD fiber capacity for a single ECCS strainer and includes shedding rate data over a much longer time needed to more accurately model shedding during 30-days of core cooling.

Figure Q23.1 illustrates cumulative fiber penetration data for all four tests. Although Test 1c and Test 2 used the same solution pH and loading schedule, Test 2 results are fully consistent with Test 1a and Test 1b data, indicating a negligible pH effect on fiber penetration at the tested flow velocity. At all fiber loads, Test 1c cumulative fiber penetration mass lies above the 95$^{th}$ percentile of cumulative fiber penetration mass obtained from the other three tests, indicating a possible anomaly in fiber preparation or test procedure implementation under the exploratory, abbreviated test format. Because the close agreement between Test 1a, Test 1b, and Test 2, is typical of replicates performed under the same test procedure, Test 1c is not considered to represent a realistic fiber penetration result.

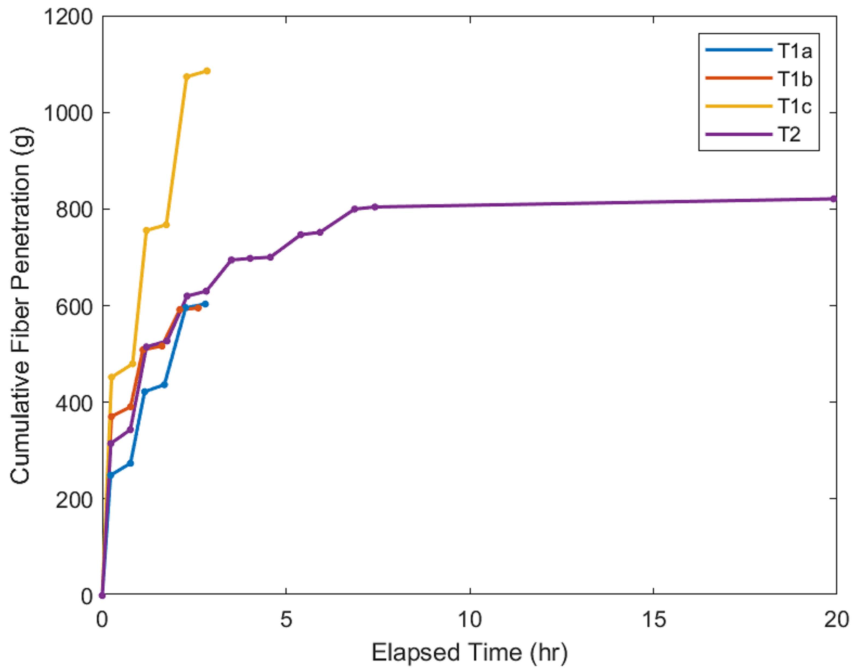


Figure Q23.1. Cumulative fiber penetration mass from four independent tests.

First-order differential equations describing fiber inventory on the strainer were used to fit four model parameters in an optimization search that minimizes the sum of squared errors between Test 2 measured bag-filter masses and simulated bag-filter masses. Separate equations were used to simulate bag-filter measurements when fiber was being loaded (loading filters) and bag-filter measurements when only shedding occurred (shedding filters), but squared errors were minimized over all Test 2 data points combined. A correlation coefficient of 0.96 was obtained for Test 2 filter data. Although not as strong as the coefficients obtained for Test 1a and Test 1b, the fit is judged to be relatively good for a simple four-parameter model describing complex dynamic debris-bed phenomena. Model parameters were not fit to sequentially cumulative fiber penetration mass, because cumulative mass is a derived quantity that can smooth variability present in direct measurements.

Simulation accuracy is improved by using separate equations to model shedding and penetration during a fiber load, but global minimum least squares optimization tends to emphasize better model agreement with large filter bag masses arising from direct penetration observed during early fiber batches. Less precise agreement is obtained for the smaller shedding-only filter-bag measurements, which affects the two model parameter values that predict shedding.

Equation A-50 in Reference [1] was developed to provide a high-level estimate of total fiber penetration occurring after infinite sump recirculation time using model parameters calibrated to individual downstream filter-bag masses collected during strainer testing and assuming that prompt penetration and delayed shedding proceed as two separate process that do not interact. In a real debris bed, prompt penetration and delayed shedding both depend on the amount of fiber resident in the debris bed as a function of time, so a solution of the coupled differential equations is needed to obtain the highest fidelity comparisons to time-dependent test data. However, Equation A-50 is useful for confirming the reasonableness of Test 2 fiber penetration parameters because the test procedure intentionally separates, to the maximum extent practical, direct penetration that occurs during fiber loading from continual shedding.

Figure Q23.2 (left graph) shows the correlation between measured cumulative fiber penetration (x axis) and cumulative fiber penetration modeled by Eq. A-50 (y axis) using reported Test 2 optimized parameters. The later, small-increment measurements controlled by shedding phenomena (upper right correlation points) are underestimated by the model prediction. Equation A-50 essentially adds the entire “sheddable” fiber inventory (a fixed fraction of the sequential cumulative load) to the cumulative prompt penetration mass, so the graph suggests that the Test 2 parameter describing the amount of sheddable fiber is too small to provide a close fit to the data. (It should be noted that full solutions of the time-dependent equations show the same trend, confirming that Eq. A-50 is a useful approximation).

Figure Q23.2 (right graph) shows the improved correlation obtained by doubling the Test 2 sheddable inventory. The agreement between Eq A-50 predictions of total fiber penetration and test data for cumulative fiber penetration is now very good. It is possible that the same result can be obtained by separately minimizing the sum of squared errors for filter data obtained during fiber loading and filter data obtained for shedding only.

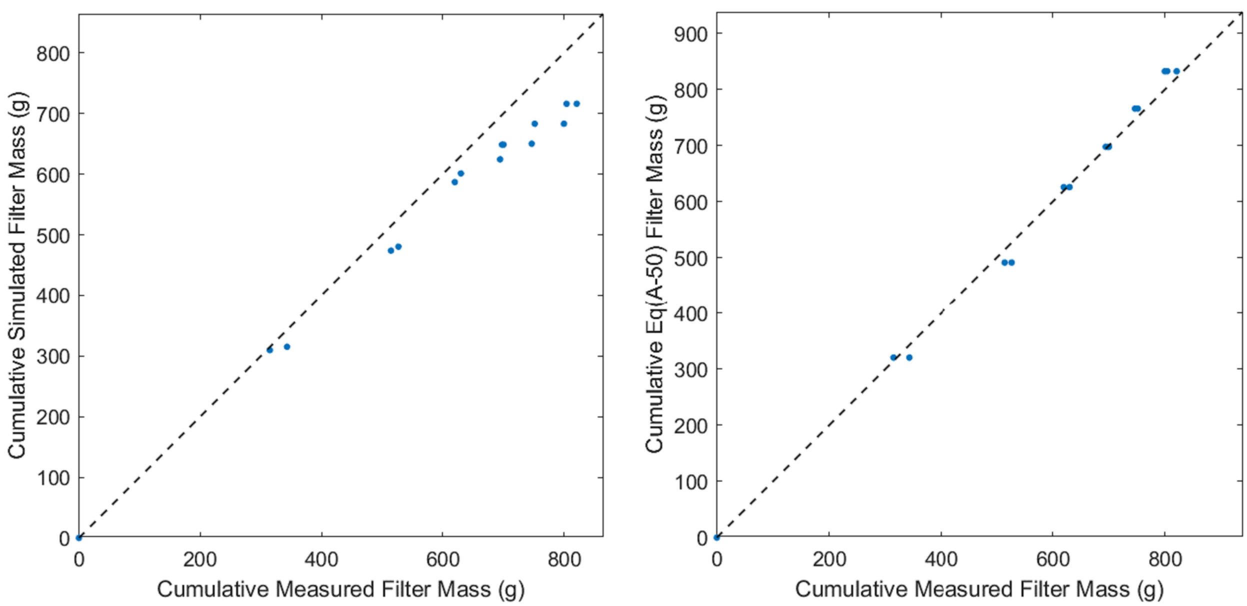


Figure Q23.2. Comparison of Test 2 cumulative fiber penetration correlation with derived sheddable fiber (left) and doubled sheddable fiber (right).

Doubling the Test 2 sheddable fiber fraction parameter is observed to raise the predicted final cumulative fiber penetration mass by approximately 13% at the final plant-equivalent total fiber load of 300 lbm. The implications of this increase for downstream in-vessel effects are examined by revisiting fiber histories presented in Reference [2]. Four cases are considered in Reference.[2]: 1) dual strainer and dual spray train operation with maximum flow split to alternate flow paths, 2) dual strainer and dual spray train operation with minimum flow split to alternate flow paths, 3) Maximum Safeguards conditions with dual strainer and single spray train operation with maximum flow split to alternate flow paths, and 4) Maximum Safeguards conditions with dual strainer and single spray train operation with minimum flow split to alternate flow paths.  Although dual train plant LOCA response is expected with high reliability, the Maximum Safeguards configuration having one failed CS train maximizes debris delivery to the reactor vessel, because less fiber is returned to the pool through spray flow.  Therefore, Cases 3 and 4 were reevaluated to account for doubling the fraction of Test 2 sheddable fiber.  Figure Q23.3 (left graph) illustrates adjusted fiber histories assuming minimum flow to alternate flow paths, and Figure Q23.3 (right graph) illustrates adjusted fiber histories assuming maximum flow to alternate flow paths.

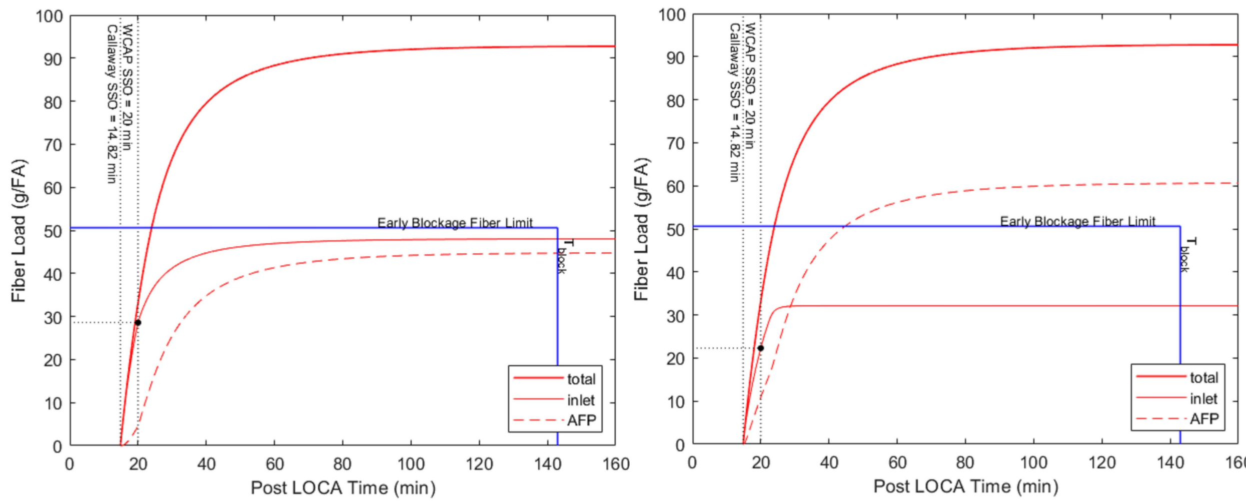


Fig. Q23.3. Core fiber histories with Maximum Safeguards configuration (one spray train failed), double Test 2 sheddable fiber, and minimum AFP flow (left) vs maximum AFP flow (right).

Comparison of Figure Q23.3 to Figure 3.n-4 and Figure 3n-5 in Reference [2] shows that total fiber in the vessel is now approximately 92 g/FA rather than 89 g/FA.  The flow split assigned to alternate flow paths changes the partition of debris between the core inlet and the heated core region but does not change the total vessel fiber inventory.  All of the WCAP-17788-P performance requirements are still satisfied even with increased Test 2 fiber shedding.

Downstream ex-vessel analyses were performed using a maximum DEGB generated and transported fiber source term of 1157 lbm.  Using Eq. A-50 and the reported Test 2 sheddable fiber fraction yields a fiber penetration source term of 53.15 lbm against which all internal ex-vessel components were evaluated and found to sustain acceptable wear (Reference [3]).  Using the RoverD transported fiber load of 300 lbm in Eq. A-50 with double the reported Test 2 sheddable fiber fraction yields a fiber penetration source term of 46.5 lbm.  Therefore, the increased sheddable fiber fraction cannot increase risk of core damage caused by internal wear and erosion with respect to the RoverD strainer load.  Further evaluation of the maximum transported fiber source (1157 lbm) yields a fiber penetration source term of 60.8 lbm when shedding is doubled, which also passes all internal wear and erosion criteria.

This analysis confirms that a simple change to Test 2 fiber penetration parameters (doubling the sheddable fiber fraction) improves agreement of the model with cumulative fiber penetration data and does not increase risk of core blockage caused by scenarios with less than 300 lbm of fiber debris arriving at two operable strainers.  The core blockage analysis is based on the most conservative pump configuration with two strainers operating at maximum ECCS flow but with only one train of spray flow. Similarly, doubling the sheddable fiber fraction does not increase the risk of core damage caused by downstream ex-vessel component failures. For the purpose of documentation simplicity, the sheddable fiber fraction applied in the baseline risk calculation has not been changed. The sensitivity cases presented here confirm that no additional risk is introduced by doubling the fiber penetration model parameter.

References:

[1] Strainer Penetration Test Report, ALION-CAL-CEC-9345-003, Rev. 0 (December 2017).

[2] ULNRC-06651, July 7, 2021, (ADAMS Accession No. ML21203A192) Enclosure 3, Section 3.n., "Downstream Effects – Fuel and Vessel," (pp. 99-106 of 126).

[3] CEC Downstream Ex-Vessel Effects Evaluation for ECCS Components, ALION-CAL-CEC-9143-020, Rev 0.