UNITED STATES
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September 4, 2019

MEMORANDUM TO: Jane E. Marshall, Acting Director
Division of Safety Systems
Office of Nuclear Reactor Regulation

FROM: Victor G. Cusumano, Chief ***/RA/***
Technical Specifications Branch
Division of Safety Systems
Office of Nuclear Reactor Regulation

SUBJECT: U.S. NUCLEAR REGULATORY COMMISSION STAFF REVIEW GUIDANCE FOR IN-VESSEL DOWNSTREAM EFFECTS SUPPORTING REVIEW OF GENERIC LETTER 2004-02 RESPONSES

The U.S. Nuclear Regulatory Commission (NRC) issued Generic Letter 2004-02, "Potential Impact of Debris Blockage on Emergency Recirculation During Design Basis Accidents at Pressurized-Water Reactors," (Agencywide Documents Access and Management System (ADAMS) Accession No. ML042360586), dated September 13, 2004, to confirm that pressurized-water reactor licensees comply with applicable regulatory requirements, including Section 50.46, "Acceptance Criteria for Emergency Core Cooling Systems for Light-Water Nuclear Power Reactors," of Title 10 of the *Code of Federal Regulations* (10 CFR). In particular, 10 CFR 50.46(b)(5) requires adequate long-term core cooling following a postulated loss-of-coolant accident (LOCA) such that:

> …the calculated core temperature shall be maintained at an acceptably low value and decay heat shall be removed for the extended period of time required by the long-lived radioactivity remaining in the core.

This review guidance document pertains specifically to the impacts of post-LOCA debris inside the reactor vessel. The NRC staff previously concluded in a technical evaluation report (TER) that post-LOCA debris inside the reactor vessel has low safety significance (ADAMS Accession No. ML19073A044). However, that evaluation did not attempt to address the subject of regulatory compliance. In fact, some of the assumptions used in the TER are realistic and do not fully satisfy the applicable regulatory requirements. For example, the mechanistic evaluations contained in the TER assume a 6-inch hot-leg pipe break instead of a double-ended guillotine break, whereas 10 CFR 50.46(a)(1)(i) requires assurance that the most severe postulated LOCAs are calculated.

CONTACTS: Ashley Smith 301-415-3201; Stephen Smith 301-415-3190; Paul Klein 301-415-3040; Ben Parks 301-415-0979
Matt Yoder 301-415-4017; John Lehning 301-415-1015; Andrea Russell 301-415-8553

This review guidance outlines approaches that the NRC staff would deem sufficient to demonstrate compliance with the requirements of 10 CFR 50.46(b)(5) for addressing impacts of post-LOCA debris in the reactor vessel.

Enclosure:
Staff Review Guidance

SUBJECT: NRC STAFF REVIEW GUIDANCE FOR IN-VESSEL DOWNSTREAM EFFECTS SUPPORTING REVIEW OF GENERIC LETTER 2004-02 RESPONSES DATED: September 4, 2019

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NRC STAFF REVIEW GUIDANCE FOR IN-VESSEL DOWNSTREAM EFFECTS

SUPPORTING REVIEW OF GENERIC LETTER 2004-02 RESPONSES

1.0 INTRODUCTION

The U.S. Nuclear Regulatory Commission (NRC) issued Generic Letter (GL) 2004-02, "Potential Impact of Debris Blockage on Emergency Recirculation During Design Basis Accidents at Pressurized-Water Reactors," [1] to confirm that pressurized-water reactor (PWR) licensees comply with applicable regulatory requirements, including Section 50.46, "Acceptance Criteria for Emergency Core Cooling Systems for Light-Water Nuclear Power Reactors," of Title 10 of the U.S. *Code of Federal Regulations* (10 CFR). In particular, 10 CFR 50.46(b)(5) requires adequate long-term core cooling (LTCC) following a postulated loss-of-coolant accident (LOCA) such that:

> …the calculated core temperature shall be maintained at an acceptably low value and decay heat shall be removed for the extended period of time required by the long-lived radioactivity remaining in the core.

This review guidance document pertains specifically to the impacts of post-LOCA debris inside the reactor vessel. The NRC staff previously concluded in a technical evaluation report (TER) that post-LOCA debris inside the reactor vessel has low safety significance [2]. However, that evaluation did not attempt to address the subject of regulatory compliance. In fact, some of the assumptions used in the TER are realistic and do not fully satisfy the applicable regulatory requirements. For example, the mechanistic evaluations contained in the TER assume a 6-inch hot-leg pipe break instead of a double-ended guillotine break, whereas 10 CFR 50.46(a)(1)(i) requires assurance that the most severe postulated LOCAs are calculated.

This review guidance outlines approaches that the NRC staff would deem sufficient to demonstrate compliance with the requirements of 10 CFR 50.46(b)(5) for addressing impacts of post-LOCA debris in the reactor vessel.

The following sections of this review guidance document outline review criteria for assessing:

- The impacts of post-LOCA debris in the reactor vessel relative to the requirements 10 CFR 50.46(b)(5)
- The documentation submitted by PWR licensees to support the assessment of regulatory compliance

Licensees' demonstrations of compliance may rely on means not discussed in this review guidance document; however, additional NRC staff review effort may be necessary to confirm the acceptability of alternative methods.

As discussed in the TER, the NRC staff has performed a detailed review of licensing topical report (TR) WCAP-17788 [3]. Although the NRC staff did not approve WCAP-17788 for use, as discussed further in this review guidance document, the staff expects that many of the methods developed in the TR may be used by PWR licensees in demonstrating adequate LTCC. While the NRC staff anticipates that licensees will evaluate the applicability of the methods and analytical results from WCAP-17788, such evaluations should be relatively straightforward. In most cases, the NRC staff believes that detailed, plant-specific thermal-hydraulic (TH) analyses using the methods described in WCAP-17788 will not be necessary.

The NRC staff will review licensees' use of the TR information for acceptability. Reviewers should ensure that the responses are sufficiently detailed as to enable the staff to verify which approach was taken to address closure, and in the case of reference to WCAP-17788 analyses, which of the key parameters were bounded and which were evaluated.

In accordance with existing regulatory requirements in 10 CFR 50.59, licensees must assess changes to the facility, as described in the updated final safety analysis report or applicable procedures, to ensure, among other things, that the changes do not have adverse effects on plant safety analyses. This will assure that the plant-specific evaluations of in-vessel downstream effects (IVDEs) remain valid.

2.0 REVIEW CRITERIA

The staff has developed review criteria, based on the information, evaluations, and analyses summarized in the TER, to determine the level of plant-specific review activity needed to establish compliance. The staff will use a graded approach, based on these criteria:

- WCAP-16793-NP-A [4] applicability
- Nuclear steam supply system (NSSS) design considerations
- Chemical effects timing
- Applicability of alternate flow path (AFP) analyses

2.1 Generally Acceptable Parameters and Evaluations

The TER describes several aspects of the overall evaluation that the NRC staff determined were representative of all currently operating PWRs, as described in the following subsections. This includes evaluations performed using the Loss-of-Coolant Accident Deposition Model (LOCADM) and parameters from WCAP-17788, including the particulate debris amounts and the fiber limit for cold leg breaks.

2.1.1 LOCADM

LOCADM is a calculation tool that can be used to conservatively predict the build-up of chemical deposits on fuel cladding after a LOCA. The chemical product source term is the dissolved species resulting from the interaction between the post-LOCA environment and the containment building materials. LOCADM calculates the localized peak cladding temperature and deposit thicknesses as a function of time at a number of core locations. The NRC staff has reviewed multiple plant-specific LOCADM analyses, including results from a high fiber plant and a high chemical source term plant. All results have been significantly below the acceptance criteria established in the safety evaluation approving WCAP-16793. Additionally, the safety evaluation found that the assumptions used in the LOCADM analyses are conservative. Therefore, NRC staff review of plant-specific LOCADM analyses is not necessary to reasonably assure compliance with LTCC requirements.

2.1.2 Particulate Debris Amount

While developing the TER on IVDEs, the NRC staff performed calculations to determine the maximum amount of particulate debris that could be generated and transported to the reactor in a LOCA event prior to the initiation of BAP mitigation measures like hot-leg switchover (HLSO). Using conservative assumptions about the debris composition and transport behavior, the NRC staff calculations indicate that the amount of particulate debris that could enter the reactor vessel will not prevent LTCC. Particulate debris may concentrate in the core, similarly to boric acid. The staff evaluation assumed that all particulate debris generated in the first 24 hours following the LOCA collected in the reactor. All plants initiate BAP mitigation measures within 24 hours of the event initiation, which flushes any concentrated debris from the core. Therefore, NRC staff review of plant-specific particulate debris amounts is not necessary to reasonably assure compliance with LTCC requirements as long as BAP mitigation measures are initiated within 24 hours of event initiation.

2.1.3 CLB Fiber Amount

In its TER, the NRC staff referred to fibrous debris amounts for cold-leg breaks (CLBs) for two high fiber plants. Neither of these plants exceeded the CLB fiber limit in WCAP-17788. The staff included additional analysis of a CLB fiber limit in its TER. Based on the results referenced in the TER, the staff concluded that it is unlikely that any plant in the operating PWR fleet would exceed the fiber limit, even for the largest CLB pipe breaks. Even for those few plants that might exceed the fiber limit, the flow field at the core inlet will result in a non-uniform debris distribution, which is expected to provide significant additional margin that is not credited in the conservative analysis methodology. Based on the considerations above, NRC staff review of plant-specific CLB fiber amounts is not necessary to reasonably assure compliance with LTCC requirements.

2.2 Plant-Specific Disposition

For licensees with postulated fibrous debris loadings that are bounded by the limits contained in WCAP-16793-NP-A and choose to apply WCAP-16793-NP-A, the NRC staff review should be limited to a confirmation of applicability of WCAP-16793-NP-A (e.g., that the applicable conditions and limitations are addressed). Although WCAP-16793-NP-A does not explicitly address the potential for boric acid precipitation (BAP), the NRC staff has determined that plants that meet the hot leg break (HLB) fiber limit from WCAP-16793-NP-A can address BAP by maintaining their existing licensing basis and BAP mitigation timing. Plants that previously closed GL 2004-02 using WCAP-16793-NP-A have not formally resolved the BAP issue. The staff will address this issue by notifying such licensees that BAP has been addressed for their plants. The NRC staff can refer to Appendix A of this guidance document for further technical basis concerning the disposition of this phenomenon.

Certain classes of NSSS designs are less susceptible to an inhibition of LTCC due to IVDEs. These include Westinghouse two-loop and Babcock and Wilcox (B&W) plants. Because all Westinghouse two-loop plants have upper plenum injection (UPI), the NRC staff is reasonably assured that these plants will maintain adequate LTCC. Because of extensive flow communication between the barrel-baffle region and the core, the NRC staff is reasonably assured that B&W plants will maintain adequate LTCC. For these plants, the NRC staff reviewer need only confirm that the plant-specific debris amount is less than the total fiber limit provided in WCAP-17788. Similar to licensees choosing to reference WCAP-16793-NP-A, the

NRC staff can refer to Appendix A of this guidance document regarding the potential for boric acid precipitation.

If the above criteria (i.e., WCAP-16793-NP-A applicability and NSSS class considerations) are not satisfied, the NRC staff will need to perform a review of chemical effects and AFP analysis applicability. For licensees that can demonstrate that chemical effects would not occur before either the timing for implementing BAP mitigation measures or the complete core inlet blockage timing (i.e., t_{block}) determined by the applicable AFP analyses in WCAP-17788, consideration of the applicability of the AFP analyses is the only additional NRC staff review required. For plants that cannot demonstrate such chemical effects timing, additional NRC staff review will be required insofar as chemical effects are concerned.

When considering AFP analysis applicability, the staff devised further review criteria based on key assumptions and parameters used in the AFP analyses. These include:

- Fiber limits corresponding to the assumed, blocked core, inlet flow resistance (i.e., K_{max}) discussed in WCAP-17788-NP, Volume 1, Chapter 6 [5][1]

- Sump switchover (SSO) timing assumed in the analyses contained in WCAP-17788-NP, Vol, 4 [6] (i.e., 20 minutes)

- The plant rated thermal power level for the applicable plant class analyzed in WCAP-17788-NP, Vol. 4 [6]

- The AFP resistance modeled for the applicable plant class analyzed in WCAP-17788-NP, Vol. 4 [6][2]

In summary, plants that meet one of the following criteria have demonstrated adequate treatment of IVDEs with respect to LTCC. These criteria are illustrated schematically in Figure 1, below.

- Meets the fiber limit in WCAP-16793-NP-A (Box 1)

- Fuel design is equivalent or conservative with respect to headloss caused by captured debris when compared to the WCAP-16793-NP-A, Rev. 2 analyses

- Is a B&W NSSS design (Box 2)

  - Plant-specific debris amount is less than the total fiber limit provided in WCAP-17788

  - BAP mitigation measures are taken prior to 24 hours to prevent debris concentration in the core

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[1] Staff should verify that fiber limits used are representative of the predominant fuel assembly design(s) in the core. Fuel assembly designs that may have different debris and inlet headloss characteristics, but are installed in a limited number, and in non-limiting locations, are not expected to have a significant effect on LTCC.

[2] Specific AFP resistance values in actual plants and the WCAP-17788, Vol. 4, analyses are proprietary information.

- Is a Westinghouse 2-Loop NSSS design with UPI (Box 3)
  - Plant-specific debris amount is less than the total fiber limit provided in WCAP-17788
  - BAP mitigation measures are taken prior to 24 hours to prevent debris concentration in the core
- Meets the following aspects derived from WCAP-17788 (Box 4)
  - Fiber limit for NSSS design and fuel type
  - Rated thermal power is within the value from the TH analysis
  - AFP resistance is within the value assumed in the TH analysis
  - SSO occurs no earlier than 20 minutes after the LOCA initiation
  - BAP mitigation measures are taken before chemical effects
  - BAP mitigation measures are taken prior to 24 hours to prevent debris concentration in the core
  - Chemical effects occur after the complete core inlet blockage timing (t_{block}) associated with the RCS design

If a licensee can demonstrate that its plant characteristics are bounded by the above criteria, the remaining staff review effort will be limited to verifying plant-specific information submitted by the licensee is bounded by the existing analyses.

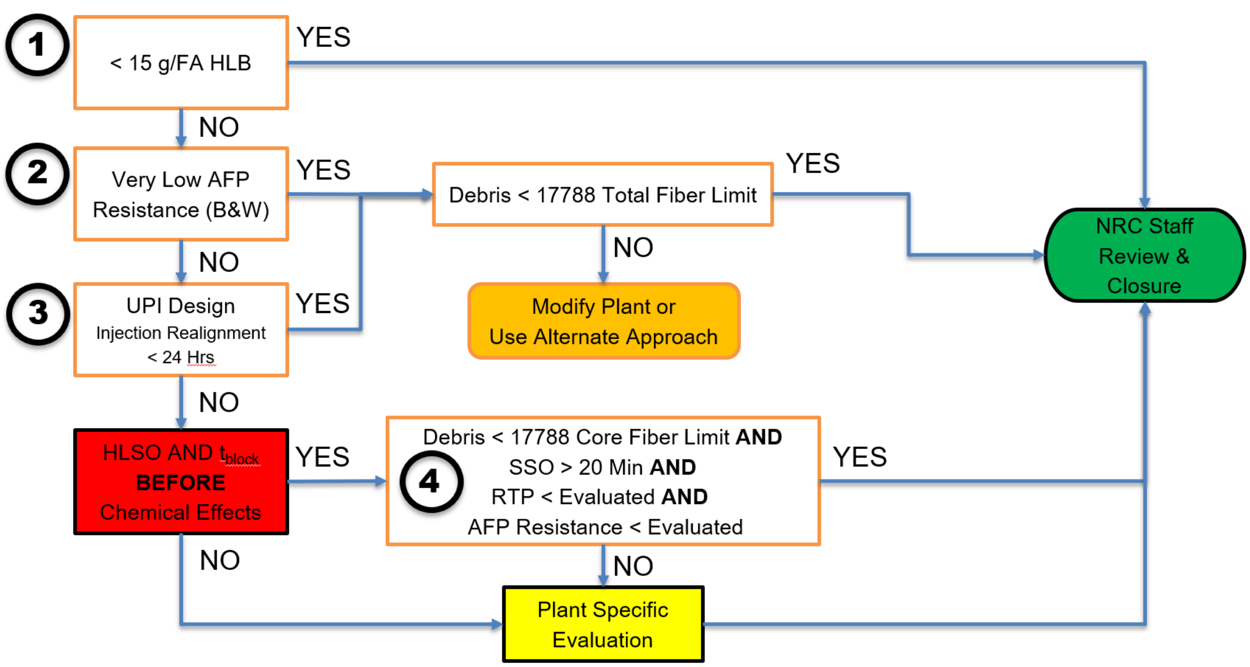

Figure 1. Flow Chart of Suggested Compliance Evaluation.

Figure 1 above depicts a simplified flow chart of the evaluation process. A licensee would begin at the top left point, establishing WCAP-16793-NP-A applicability first, and then proceed through the remaining criteria and evaluations until the applicable disposition is identified.

2.3 Plant-Specific Evaluation (Slightly Outside WCAP-17788 Criteria)

If one or more of the above criteria are not satisfied by incremental amounts, the licensee may be able to justify AFP analysis applicability by assessing the overall conservatism contained in the AFP analysis, the extent to which the other parameters are bounded, and comparing that to the extent to which unbounded parameters are outside the assumptions in the analysis. The NRC staff should verify that licensee submittals demonstrate how plant-specific conservatisms offset any unbounded parameters. The magnitude of the difference between the unbounded plant-specific parameter(s) and the corresponding generic analysis parameter(s) should be accounted for in the licensee demonstration. That is, plants slightly outside the WCAP-17788 parameter ranges would likely require a less rigorous evaluation than a plant that is well outside the bounds of the analysis.

Examples of plant-specific conservatisms that may be credited include:

- Conservatism in plant power level compared to the analyzed power
- Conservatism in the plant-specific AFP resistance compared to the analyzed AFP resistance
- More realistic debris arrival timing
- Later SSO than analyzed

Two examples are provided in the subsections below. Both examples illustrate that the staff should ensure that evaluations reference specific data, analyses, and sensitivity studies that have been previously submitted to the NRC, and plant-specific considerations, including simple calculations, as appropriate.

2.3.1 Example 1

A plant is within all of the bounding assumptions in the WCAP-17788 analysis except that it has an SSO time less than 20 minutes. This plant could undergo SSO following a double-ended hot-leg break (HLB) with a slightly higher amount of decay heat than assumed in the analyses contained in WCAP-17788, Volume 4 [6]. However, if the other key parameters remain bounded, the licensee could justify the earlier SSO time by crediting conservatism in the thermal power level assumed in the analysis relative to the plant's actual rated thermal power level, as well as by evaluating the debris transport behavior assumed at SSO, relative to a more realistic consideration of the possible debris transport.

If the plant rated thermal power level is bounded by the applicable TH analysis in WCAP-17788, then any difference between the analyzed and actual power level can be credited to compensate directly for the earlier SSO time and, correspondingly, higher decay power level. The reviewer would verify that the licensee evaluated the decay heat curve to determine how much higher the decay power level would be, given the earlier SSO time. That fractional increase in power may, to some extent, be offset by the fractional difference between the plant rated thermal power and the analyzed thermal power level.

The assumption that complete core blockage occurs at the time of SSO is substantially conservative. It is not possible for the entire amount of debris in the sump pool to arrive at the core inlet and form a uniform bed at the start of SSO. The NRC staff would review the completeness and adequacy of a licensee evaluation, ensuring the following or similar considerations are addressed:

- A determination of how long, after SSO, the SI flow may be interrupted while the realignment to sump recirculation is completed.
- An estimation, based on the expected SI flow velocity and the linear distance between the sump screen and the core inlet, how much additional time would be required for the potentially debris-laden flow to travel from the sump to the core inlet.
- A justification, based on the two items above, of the extent to which the instantaneous core blockage assumption is conservative, establishing a greater time between the early SSO time and the anticipated onset of core-wide blockage.

In its review, the NRC staff should consider that the evaluation described above still retains conservatism, because it assumes that sufficient debris to block the core is transported in a debris front that instantaneously forms a blockage at the core inlet. In reality, substantial mixing of the SI flow and existing, injected coolant would be anticipated, and testing has shown that building a debris bed capable of inhibiting flow takes time.

In cases where the licensee identifies low margins to compensate for the unbounded parameters, the staff should verify that the licensee has supported its plant-specific evaluation with relevant information provided to the NRC during its review of WCAP-17788, (i.e., in request for additional information (RAI) responses). This rationale relies on information contained in sensitivity studies in the RAI responses associated with WCAP-17788, Vol. 4, in particular, the Westinghouse responses to RAIs 4.7 and 4.19. Licensees providing this type of rationale may reference such sensitivity studies to demonstrate the nature and magnitude of the conservatisms that have been evaluated in the RAI responses relative to actual plant conditions. The response to RAI 4.7 discussed variations in the predicted plant response to the use of different decay heat assumptions, showing that lower decay heat resulted in less severe heatup behavior. The response to RAI 4.19 indicated that the potential for a debris-induced core-uncovery heatup is greatly reduced when the SSO time is increased from 1,200 seconds to 1,400 seconds. Although this particular example evaluates an SSO time earlier than 20 minutes, its rationale relies on evaluating how compensating conservatisms may affect the decay heat level applicable to the plant, essentially resulting in lower decay heat (analogous to longer SSO time) at the time complete core blockage may occur.

Figure 2 below provides a graphical summary of the plant-specific evaluation.

Key Parameter	Applicability Met?
Debris	Yes
SSO Timing	*No*
Rated Thermal Power	Yes
AFP Resistance	Yes

Compensating Conservatisms	Additional Information	Plant-Specific Evaluation
Debris Transport Behavior	WCAP-17788 RAI Response 4.19 Sensitivity Studies	1. Credit any potential interruption of SI flow during realignment to sump recirculation 2. Estimate time required to transport recirculated coolant from sump to core inlet
Margin to Rated Thermal Power	WCAP-17788 RAI Response 4.7 Sensitivity Studies	Compare actual plant decay power level at SSO time to the decay power level modeled in the WCAP-17788 analysis at 20 minutes

Figure 2. Summary of Example 1 Plant-Specific Evaluation.

In summary, this plant initiates SSO earlier than analyzed, so the fractional decay heat is higher than assumed in the corresponding WCAP-17788 analysis. To offset, the licensee determines that its rated thermal power level is sufficiently reduced relative to the value assumed in the WCAP-17788 analysis to compensate for the impact of the earlier SSO timing on the decay heat loading. In addition, the licensee justifies that a core-wide inlet blockage would take longer to form than assumed in the WCAP-17788 analysis due to SI interruption associated with SSO, and the delay time for the recirculated SI flow to transport to the core inlet. The NRC staff should review this evaluation and, if justified for the particular circumstances existing for this plant, determine that the licensee's evaluation has provided reasonable assurance that adequate LTCC is provided.

2.3.2 Example 2

A Westinghouse downflow design plant is not bounded by the thermal power used in the TH analysis for the downflow plant design. The plant power exceeds the analyzed power by about 10 percent. The plant has a minimum SSO time greater than 20 minutes. The AFP resistance for the plant is bounded by the analysis. The plant has 30 percent less fibrous debris than the analysis. While the AFP analysis in WCAP-17788 assumed that chemical effects would occur at 4.3 hours (t_{block}), the plant-specific chemical analysis shows that chemical precipitation will not occur before 24 hours. HLSO, the plant's BAP mitigation measure, occurs at 6 hours. In summary, the plant is bounded by all aspects of the TH analysis except thermal power.

The licensee for this plant should evaluate the non-bounding nature of the thermal power level in the applicable WCAP-17788 analyses by focusing on the compensating nature of conservatism in the following assumptions:

- Core inlet headloss following debris blockage based on the lower-than-analyzed amount of debris

- Debris bed uniformity based on actual plant radial peaking profile

Based on the subscale fuel assembly (FA) testing summarized in WCAP-17788 Volume 1 and discussed in greater detail in Volume 6, the headloss associated with the licensee's plant-specific debris loading may be less than 50 percent of the amount assumed in the WCAP-17788, Volume 4, analysis. The staff would thus verify that the licensee's estimation of headloss corresponding to the debris amount is appropriate. In addition, the licensee may identify that the subscale testing used conservatisms such as flow rates, particulate to fiber ratios, and particulate debris size distributions to determine the limiting fiber amount. If so, staff would evaluate the margin provided by these conservatisms relative to the applicable plant-specific conditions.

The evaluation model described in WCAP-17788 conservatively assumes that debris will accumulate uniformly across the entire core inlet. However, PWR cores are generally designed with higher power assemblies in the center of the core and lower power assemblies at the periphery. This results in increased flow to the central core region and therefore non-uniform debris distribution. Considering the limited amount of fiber available for deposit at the core inlet and the expected non-uniform debris distribution, it is likely that part of the core inlet will remain clear of a filtering debris bed. Even if the entire core inlet has debris across it, the flow resistance at the periphery, where less debris would collect, would be significantly lower than that associated with a uniform bed, which would allow increased cooling flow to the core. This behavior would delay the onset of effective core blockage, similar to crediting realistic accumulation rates of debris at the core inlet, as described in Example 1, above. Thus, the sensitivity studies provided in response to RAI 4.19(b) are relevant in terms of showing that the post-blockage cladding heatup is less severe than the cases analyzed in WCAP-17788, Volume 4.

Figure 3 below provides a graphical summary of the plant-specific evaluation.

Key Parameter	Applicability Met?
Debris	Yes
SSO Timing	Yes
Rated Thermal Power	*No*
AFP Resistance	Yes

Compensating Conservatisms	Additional Information	Plant-Specific Evaluation
Lower Debris Amounts	WCAP-17788, Vol. 1, Chapter 6, Form Loss Coefficients	Estimate the difference between the debris limit for analyzed inlet flow resistance and the flow resistance associated with the plant-specific amount
Debris Bed Non-Uniformity	WCAP-17788, Vol. 1, Section 4.2.5, Example Timelines and Section 6.5, Plant-Specific Debris Limits RAI Response 4.19 Sensitivity Studies (RAI 4.19(b), Case 3)	Estimate a realistic debris arrival timing using methods similar to those described in WCAP-17788, Vol. 1 Determine whether realistic debris accumulation would result in a delay in core inlet bed formation longer than that studied in Case 3 of the response to RAI 4.19(b).

Figure 3. Summary of Example 2 Plant-Specific Evaluation.

In summary, the plant has a rated thermal power level that is not bounded by the applicable analysis provided in WCAP-17788, Volume 4, but all other key parameters are bounded. The licensee provided a plant-specific evaluation crediting lower fiber amounts and realistic non-uniform debris accumulation to justify that the associated cladding heatup would be sufficiently less severe to offset the additional decay heat present due to the higher rated thermal power level. The NRC staff would evaluate the licensee's assessment and determine whether the licensee has reasonably demonstrated that adequate LTCC is provided, given the plant-specific conditions.

2.4 Plant-Specific Evaluation (Well Outside WCAP-17788 Criteria)

Failure to meet the review criteria specified herein does not necessarily imply regulatory noncompliance. However, if the above review criteria are not satisfied, further plant-specific evaluation may be necessary to demonstrate compliance. For example, if one or more key parameters associated with the AFP analysis in WCAP-17788 is significantly outside the bounding assumptions, alternatives should be considered to demonstrate LTCC adequacy. Two examples of alternative plant-specific evaluation methods include: (1) a risk-informed request demonstrating that break sizes of the magnitude required to generate such debris loadings are sufficiently unlikely; and (2) analyses using methods similar to those described in WCAP-17788, Volume 4, using parameters more reflective of the actual plant operating conditions.[3] Other plant-specific evaluations may also be acceptable; licensees are encouraged to discuss alternative approaches with the NRC staff in pre-submittal meetings.

Implementation of alternative plant-specific evaluation methods may involve additional complexity and new information and approaches that have not previously been reviewed by the NRC staff. As such, the review criteria specified in this document are not intended for application to submittals from licensees whose plants are significantly outside the WCAP-17788 parameter ranges.

3.0 CONTENT OF SUBMITTALS

Licensees should provide sufficient information to demonstrate which resolution path was used and that the applicable resolution path criteria in Section 2.2 are satisfied.

The following information should be provided for the resolution approach chosen for each plant:

- Plants within the WCAP-16793-NP-A HLB limit
  - Maximum amount of fiber that may arrive at the core inlet for the HLB case
  - Methodology used to calculate the fibrous debris amount (See Appendix B)
  - Confirmation that the debris amount is less than the WCAP-16793 limit
  - Confirmation that the blockage behavior associated with the fuel in use at the plant is equivalent to or less limiting than that associated with the assemblies used to establish the limits in WCAP-16793.
- Plants with B&W NSSS design
  - Confirm maximum combined amount of fiber that may arrive at the core inlet and heated core for HLB is below the WCAP-17788 fiber limit
  - Confirm BAP mitigation measures are taken prior to 24 hours to prevent debris concentration in the core
- Plants with Westinghouse two-loop NSSS design (UPI plants)
  - Confirmation that BAP mitigation measures are taken prior to 24 hours

[3] As discussed in Section 1.0, WCAP-17788 has not been approved for use by the NRC. As such, a licensee proposing to implement methods described in WCAP-17788 within its licensing basis may need to obtain prior approval from the NRC staff in accordance with 10 CFR 50.90.

- Confirm maximum combined amount of fiber that may arrive at the core inlet and heated core for HLB is below the WCAP-17788 fiber limit

- Plants that are within the key parameters of the staff TER and WCAP-17788 analysis
  - Fuel design
  - WCAP-17788 debris limit for the NSSS design/fuel combination
  - Confirm maximum combined amount of fiber that may arrive at the core inlet and heated core for HLB is below the WCAP-17788 fiber limit
  - Methodology used to calculate the fibrous debris amounts (See Appendix B)
  - Confirmation that the core inlet fiber amount is less than the WCAP-17788 threshold
  - Confirmation that earliest SSO time is 20 minutes or greater
  - Predicted chemical precipitation timing from WCAP-17788, Volume 5, testing, and the specific test group considered to be representative of the plant
  - Confirmation that chemical effects will not occur earlier than latest time to implement BAP mitigation measures
  - Confirmation that chemical effects do not occur prior to t_{block}
  - WCAP-17788 t_{block} value for the RCS design category
  - Plant rated thermal power compared to the analyzed power level for the RCS design category
  - Plant AFP resistance compared to the analyzed AFP resistance for the plant RCS design category[4]
  - Consistency between the minimum ECCS flow per FA assumed in the AFP analyses and that at the plant

- Plants that are slightly outside the bounds of the WCAP-17788 analysis, but demonstrate adequate margins in other key parameters such that LTCC is assured (see examples in Section 2.3)
  - All information requested for the plants that are within the key parameters of the staff TER and WCAP-17788 analysis from the list immediately above
  - Parameter(s) not bounded by the analysis
  - An evaluation that demonstrates adequate LTCC is assured
    - Excess margins in parameters that are met by the plant

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[4] If a licensee is attempting to avoid transmitting proprietary information, the NRC staff should consider accepting references to applicable information already transmitted to the NRC on the docket.

- If fiber amount is exceeded, then demonstrate conservatisms in analysis mitigate the additional amount of fiber

If any plant-specific parameter is not bounded by the WCAP-17788 analysis for the plant/fuel design, provide plant-specific information that LTCC is assured. A plant-specific analysis should focus on parameters not bounded by the WCAP-17788 TH analyses and provide plant-specific information that justifies that other plant-specific attributes are adequate to ensure LTCC will not be compromised due to the unbounded parameters.

Regardless of the resolution approach, the NRC staff should ensure that the responses are sufficiently detailed as to enable the staff to verify which approach was taken to address closure and confirm that all applicable review criteria are satisfied. In cases where licensees of plants slightly outside the WCAP-17788 parameter range perform plant-specific evaluations (see Section 2.3), the NRC staff should ensure that the response (1) identifies which of the key parameters from the relevant WCAP-17788 AFP analysis were bounded and which were evaluated and (2) contains adequate justification to support a determination that the results of the WCAP-17788 analysis remain applicable to the plant under consideration.

4.0 REFERENCES

[1] *Generic Letter 2004-02, "Potential Impact of Debris Blockage on Emergency Recirculation During Design Basis Accidents at Pressurized Water Reactors," September 13, 2004 (ADAMS Accession No. ML042360586).*

[2] *Technical Evaluation Report of In-Vessel Debris Effects, June 13, 2019 (ADAMS Accession No. ML19073A044)..*

[3] *PWR OWners Group, Submittal of WCAP-17788: "Comprehensive Analysis and Test Program for GSI-191 Closure (PA-SEE-1090)," July 17, 2015 (ADAMS Package Accession No. ML15210A667).*

[4] *Final Safety Evaluation for Topical Report WCAP-16793-NP-A, Rev. 2, "Evaluation of Long-Term Cooling Considering Particulate Fibrous and Chemical Debris in the Recirculating Fluid," April 8, 2013 (ADAMS Package Accession No. ML13084A161).*

[5] *WCAP-17788-NP, Vol. 1, Rev. 0, "Comprehensive Analysis and Test Program for GSI-191 Closure (PA-SEE-1090)," July 2015 (ADAMS Accession No. ML15210A669).*

[6] *WCAP-17788-NP, Vol. 4, Rev. 0, "Comprehensive Analysis and Test Program for GSI-191 Closure (PA-SE-1090) - Thermal-Hydraulic Analysis of Large Hot Leg Break with Simulation of Core Inlet Blockage," July 2015.*

[7] *Transmittal of GSI-191 Resolution Criteria for "Low Fiber" Plants, December 22, 2011 (ADAMS Accession No. ML113570219).*

[8] *GSI-191 Resolution Criteria Low/No Fiber Plants, December 22, 2011 (ADAMS Accession No. ML113570226).*

[9] *Transmittal of GSI-191 Resolution Criteria for "Low Fiber" Plants, December 22, 2011 (ADAMS Package Accession No. ML113570229).*

[10] *NRC Evaluation of NEI Clean Plant Acceptance Criteria for ECCs Systems, May 2, 2012 (ADAMS Accession No. ML120730181).*

[11] *WCAP-17788-P, Vol. 6, Rev. 0, "Comprehensive Analysis and Test Program for GSI-191 Closure (PA-SE-1090) - Subscale Head Loss Test Program Report," July 2015.*

[12] *WCAP-17788-P, Vol. 5, Rev. 0, "Comprehensive Analysis and Test Program for GSI-191 Closure (PA-SEE-1090) - Autoclave Chemical Effects Testing for GSI-191 Long-Term*

Cooling," July 2015 (ADAMS Accession Nos. ML15210A678, ML15210A680, ML15210A681).

[13] *WCAP-17788-NP, Vol. 3, Rev. 0, "Comprehensive Analysis and Test Program for GSI-191 Closure (PA-SEE-1090) - Cold Leg Break (CLB) Evaluation Method for GSI-191 Long-Term Cooling," July 2015.*

A. APPENDIX A

A.1 COMPLIANCE GUIDANCE – TECHNICAL AND REGULATORY BASIS FOR RESOLUTION APPROACHES

Regulations in Title 10 of the U.S. *Code of Federal Regulations*, Part 50, Section 46 (10 CFR 50.46), "Acceptance Criteria for Emergency Core Cooling Systems for Light Water Nuclear Power Reactors," paragraph (a)(1)(i), require the evaluation of emergency core cooling system (ECCS) performance using an acceptable evaluation model, and considering postulated loss-of-coolant accidents (LOCAs) of locations, sizes, and other properties sufficient to provide assurance that the most severe postulated LOCAs have been calculated. Requirements applicable to both realistic and Appendix K-conformant models require qualification using comparisons to applicable experimental data and an accounting for uncertainties.[5] Furthermore, of particular relevance to the in-vessel downstream effects issue, 10 CFR 50.46(b)(5) requires assurance that long term core cooling (LTCC) be provided to maintain the core temperature at an acceptably low value and decay heat be removed for the extended period of time required by the long-lived radioactivity remaining in the core.

Historically, LTCC calculations were performed using simple methods. The simplicity of these methods is attributable to two perceptions prevalent at the time of the original 10 CFR 50.46 rulemaking: (1) significant design margin was perceived in the performance of the ECCS in long-term cooling mode, and (2) the thermal-hydraulic phenomena associated with long-term core cooling were thought to be straightforward and to involve very low uncertainty. Absent post-LOCA debris considerations that were not adequately understood at the time, it appeared evident that an ECCS designed to reflood a PWR core rapidly, thereby removing both the heat stored in the fuel and the initially high rate of decay heat, should be readily capable of continuing to remove only the decay heat that slowly diminishes over time. In essence, early demonstrations of LTCC were limited to calculating an amount of recirculating coolant required to compensate for that boiled off by the decay heat. Based on the phenomenological understanding existent at that time, these simple methods formerly provided reasonable assurance of adequate LTCC.

Subsequently, through operating experience and research associated with Unresolved Safety Issue A-43, the boiling-water reactor ECCS strainer replacement effort in the mid-1990s, and Generic Safety Issue 191, the potential influence of post-LOCA debris on LTCC was appreciated. Potential adverse effects of debris were identified on ECCS suction strainers, ECCS components, and reactor core fuel assemblies. These findings prompted the NRC staff to request in Generic Letter (GL) 2004-02 that PWR licensees reexamine the adequacy of the ECCS design margin in long-term cooling mode. For example, the GL identified that the generic 50-percent blockage assumption for ECCS strainers should be replaced with a more comprehensive assessment of the effects of debris on a plant-specific basis. Similar evaluations should be made to assure IVDEs do not affect LTCC.

Furthermore, consideration of debris effects in LTCC calculations introduced significant uncertainties into these formerly simple evaluations. These uncertainties arise from several sources, including (1) an incomplete experimental database for some debris-related

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[5] While uncertainty quantification requirements are explicit for realistic evaluation models, Appendix K largely accounts for relevant uncertainties by imposing conservative modeling practices. Furthermore, the documentation requirements contained in Appendix K, which are applicable to both types of evaluation models, require "appropriate sensitivity studies" for each evaluation model.

phenomena, (2) the influence of numerous plant- and fuel-specific design features, and (3) the large variation in debris generation and transport, depending on the postulated break size and location. NRC staff-approved guidance related to post-LOCA debris generation and transport contains conservatism, albeit unquantified, that is intended to offset such uncertainties. The NRC staff will take into consideration applicable uncertainties when reviewing whether PWR licensees have provided reasonable assurance that compliance exists with LTCC regulations. The discussion for each resolution approach below focuses on the associated staff considerations of conservatism and uncertainties.

Each section below discusses one of the boxes or resolution paths in the staff IVDE evaluation flowchart that leads to a plant demonstration of adequate LTCC. Additionally, there is a general discussion of CLB criteria in Section A.6.

A.2 LESS THAN 15 GRAMS FIBER PER FUEL ASSEMBLY FOR HLB

A.2.1 Technical Considerations

WCAP-16793 found that plants that have a HLB fibrous debris amount of 15 g/FA or less would maintain adequate core cooling due to the low head loss at the core inlet, even with chemical precipitates present.

For the CLB, the SE approving WCAP-16793-NP-A found that the maximum CLB fiber amount would be about half of the HLB amount and that this small amount of fiber would not inhibit LTCC for the CLB. For plants with less than 15 g/FA fiber for the HLB, the maximum potential CLB fibrous debris amount is small enough that, even with chemical precipitates present, headloss will be very low. This limited amount of fiber cannot support a filtering debris bed.

The evaluations in WCAP-16793-NP-A did not address whether BAP could be affected by the CLB debris amount. However, both TRACE and SKBOR evaluations predict that BAP will not occur prior to HLSO, even with significant resistance at the core inlet [2].

Therefore, plants that have very little fibrous debris at the core inlet do not have to implement BAP mitigation measures prior to the time at which chemicals may precipitate. HLSO timing is maintained in accordance with the plant-specific licensing bases to prevent BAP.

The WCAP-16793-NP-A methodology assumed that the debris would be deposited uniformly at the core inlet. Following a LOCA, the core inlet flow velocity distribution varies significantly, such that debris will be deposited preferentially at locations where velocities into the core are the highest. The non-uniform deposition of debris at the core inlet increases the margins in the WCAP-16793-NP-A limits for both the CLB and HLB, which were determined to be acceptable even if a uniform bed formed.

A.2.2 Regulatory Considerations

In GL 2004-02, licensees were requested to demonstrate that LTCC is not adversely affected by post-LOCA debris, including debris that may enter the RCS. The staff issued an SE that provides a regulatory basis for accepting the WCAP-16793-NP-A debris limit for plants within the analyzed debris amounts.

A regulatory finding for BAP was not included in the WCAP-16793-NP-A SE. However, based on SKBOR and TRACE analyses, the NRC staff expects that BAP will not impact the acceptability of the WCAP-16793-NP-A debris limit. Based on its review of WCAP-17788, information from testing associated with WCAP-16793-NP-A, and recent TRACE modeling performed by RES, the staff does not anticipate that existing licensing bases for BAP will be affected by debris when plant specific HLB fiber amounts are limited to 15 g/FA or below.

For a given amount of fiber passing through the sump strainer, the amount of fiber that transports to the core inlet for a CLB will be one half or less of the fiber value for an HLB. Therefore, for plants meeting the 15 g/FA HLB limit from WCAP-16793-NP-A, the CLB amount is also expected to be met. In addition, the amount of fiber at the core inlet following a CLB is so low that it will not provide a filtering debris bed, even with chemical precipitates present.

Based on the considerations discussed above, the current plant design ensures that 10 CFR 50.46(b)(5) is met for plants that demonstrate that they meet the assumptions and limits in WCAP-16793-NP-A.

In accordance with existing regulations, licensees must evaluate relevant plant changes to ensure that LTCC would not be inhibited by their implementation.

A.3 VERY LOW AFP FLOW RESISTANCE (B&W PLANT)

A.3.1 Technical Considerations

WCAP-17788 modeling indicates that plants with very low AFP resistances (i.e., B&W-design NSSS) could incur 100% blockage at the core inlet at the time of SSO and maintain adequate LTCC with no cladding heatup. The AFP resistance for B&W plants is low enough that the staff expects that LTCC will be maintained, even with the core inlet completely blocked at a conservatively early time (resulting in conservatively high decay heat removal requirements). Based upon a review of the analyses for the B&W plants, including modeling conservatisms, the NRC staff expects that LTCC will be maintained even with a fully blocked core inlet at the earliest assumed time (SSO). Pressure relief holes, a design feature present in the B&W design, should allow adequate flow to maintain LTCC. In addition, TRACE analyses for plants with more restrictive AFPs indicate that BAP will not occur to an extent that would affect LTCC when core inlet blockage is applied at a conservative time following SSO. For B&W plants, the NRC staff expects that BAP would be prevented for both the HLB and CLB because of the abundant flowpaths that bypass the core inlet allowing the core to be flushed until BAP mitigation measures are initiated.

A.3.2 Regulatory Considerations

In GL 2004-02, licensees were requested to demonstrate that LTCC is not adversely affected by post-LOCA debris, including debris that may enter the RCS. The NRC staff expects that B&W plants have adequate AFPs such that cooling to the core will be unaffected by debris that may pass downstream of the plants' strainers. Additionally, the AFPs should provide adequate flow to ensure that boric acid and other potential contaminants will not concentrate in the core prior to initiating BAP mitigation measures as required by plant licensing bases. The NRC staff expects that large, low resistance flowpaths inherent in the B&W design would ensure LTCC considering the current plant strainer designs. Thus, the current plant design will ensure that 10 CFR 50.46(b)(5) is met for B&W plants.

In accordance with existing regulations, licensees must evaluate relevant plant changes to ensure that LTCC would not be inhibited by their implementation.

A.4 WESTINGHOUSE 2-LOOP DESIGN (UPI PLANT)

A.4.1 Technical Considerations

The low-head ECCS injection point for UPI plants is at the top of the core. This ensures that debris is injected into a location that has significant turbulence and relatively high velocity flow exiting the top of the core. These phenomena would preclude the formation of a debris bed at the core exit. UPI plants switch to cold-leg injection or combined cold-leg/upper plenum injection several hours after the initiation of a LOCA. By the time the change in injection alignment is performed, fibrous debris is depleted from the sump pool such that the amount of fiber injected at the core inlet (bottom of the core) in cold-leg injection will remain below the WCAP-17788 debris limit. Therefore, sufficient debris to inhibit LTCC cannot be deposited at either the core exit or inlet.

A.4.2 Regulatory Considerations

In GL 2004-02, licensees were requested to demonstrate that LTCC is not adversely affected by post-LOCA debris, including debris that may enter the RCS. The NRC staff expects that, due to the UPI configuration for Westinghouse 2-loop plants, even if debris enters the core, it will not form a blockage that can impede flow to the fuel. By switching to cold-leg injection in accordance with the current plant licensing basis (e.g., several hours after the LOCA), BAP should be prevented, and any debris collected in the core flushed. By the time the switch to CL injection is completed, the fiber in the sump will be depleted due to filtering, deposition, or settlement, such that a continuous debris bed will not form at the core inlet. The current plant design ensures that 10 CFR 50.46(b)(5) is met for UPI plants.

In accordance with existing regulations, licensees must evaluate relevant plant changes to ensure that LTCC would not be inhibited by their implementation.

A.5 PLANT WITHIN WCAP-17788 FIBER LIMIT AND AFP ANALYSIS ASSUMPTIONS

A.5.1 Technical Considerations

The NRC staff expects that LTCC can be maintained by plants that (1) demonstrate that the quantity of fiber reaching the core inlet is bounded by the WCAP-17788 limit for their plant design and (2) meet the important assumptions used in the WCAP-17788 TH analyses. Licensees should refer to the key parameters discussed in the staff TER [2] to understand what the staff considers to be the important assumptions in the analysis. The fiber limits in WCAP-17788 were established assuming a uniform debris bed, conservative test methods, and conservative assumptions in the TH analyses. The conservative assumption of a uniform bed at the core inlet assures that the debris limit is set at a level significantly below that which could challenge LTCC. The TH analyses conservatively assume that debris at the core inlet arrives earlier than realistically expected. The TH analyses also assume that complete blockage of the core inlet occurs prior to the time at which chemical precipitation may occur.

Analyses in Vol. 4 of WCAP-17788 further indicate that AFPs in the reactor vessel can supply the necessary coolant flow to the core in case of complete inlet blockage. Although the analyses and methods contained in WCAP-17788 have not been approved by the NRC staff, the staff applied considerable scrutiny to these analyses and expects that AFPs can provide an additional means to ensure adequate LTCC.

WCAP-17788 and independent TRACE analyses indicate that BAP is not expected to occur earlier than assumed by the plant licensing bases.

A.5.2 Regulatory Considerations

In GL 2004-02, licensees were requested to demonstrate that LTCC is not adversely affected by post-LOCA debris, including debris that may enter the RCS. The NRC staff expects that plants that are bounded by the WCAP-17788 debris and TH analyses will maintain adequate flow to ensure LTCC. BAP is prevented by switching to implementing BAP mitigation measures to flush the core in accordance with the current plant licensing basis (e.g., several hours after the LOCA). The current plant design ensures that 10 CFR 50.46(b)(5) is met for plants that demonstrate that they meet the assumptions and limits in WCAP-17788.

In accordance with existing regulations, licensees must evaluate relevant plant changes to ensure that LTCC would not be inhibited by their implementation.

A.6 COLD-LEG BREAK FOR A PLANT THAT MEETS WCAP-17788 ASSUMPTIONS

A.6.1 Technical Considerations

The NRC staff expects that operating PWRs that meet WCAP-17788 assumptions will not collect debris at the core inlet in a sufficient quantity to inhibit ECCS flow following a CLB if BAP mitigation measures are initiated prior to the formation of chemical precipitates. As discussed in Section 2.1.3 of this document, this conclusion is based on testing associated with WCAP-16793, which demonstrated, at tested debris amounts, that adequate flow to ensure LTCC following a CLB would be available, provided chemical precipitates are not present. The staff's judgment assumes a uniform debris bed, making it conservative with respect to realistic core flow inlet distributions that would result in non-uniform debris accumulation. WCAP-17788 and independent TRACE studies indicate that licensing bases for BAP mitigation timing are not adversely affected by IVDEs. Therefore, the NRC staff expects that adequate LTCC can be maintained for the CLB by all licensees because the amount of fiber that can reach the core for this scenario is limited by the flow that is diverted from the core and returns to the sump during a CLB. If a plant exceeds the CLB limit proposed by WCAP-17788, the staff determined that it would not be exceeded by a significant amount and the non-uniform flow into the core would allow some areas of the core inlet to maintain adequate flow for LTCC. Therefore, plant responses to GL 2004-02 need not address LTCC or BAP for a CLB if the plant fuel design is represented by the testing in WCAP-16793 and BAP mitigation measures are implemented before chemical effects occur.

A.6.2 Regulatory Considerations

In GL 2004-02, licensees were requested to demonstrate that LTCC is not adversely affected by post-LOCA debris, including debris that may enter the RCS. Based on industry testing, the staff expects that a fiber amount less than the WCAP-17788 CLB debris limit will not prevent LTCC following a CLB. The NRC staff expects that even the most challenging breaks at the highest fiber plants are unlikely to generate enough debris to reach the CLB limit. BAP is prevented by switching to cold-leg injection or equivalent mitigation measures to flush the core in accordance with the current plant licensing basis (e.g., several hours after the LOCA). The verification of fibrous debris within the limit ensures that 10 CFR 50.46(b)(5) is met for the fleet of operating PWR reactors following a CLB.

As described in Section 2.1.3, the NRC staff expects that operating PWRs will not accumulate enough debris at the core inlet following a CLB to prevent LTCC.

In accordance with existing regulations, licensees must evaluate relevant plant changes to ensure that LTCC would not be inhibited by their implementation.

B. APPENDIX B

CALCULATION OF FIBER PENETRATING THE SUMP STRAINER

The amount of fiber penetrating the strainer determined by each licensee should be based on plant testing or derived from testing under conditions similar to the plant condition. Alternately, a licensee may use low fiber plant assumptions as discussed below under the clean plant method. The NRC staff has not published guidance on strainer penetration testing but has visited multiple test facilities to observe testing. Test methods should consider factors that can influence penetration including debris preparation, debris addition technique, test strainer geometry compared to the plant strainer, flow rate, debris addition rate, filtering methods, and evaluation of the penetrated debris. The NRC staff should review the licensee's method for determination of fiber penetration to ensure it results in an appropriately conservative estimate of penetration for the plant-specific condition.

Plants may be able to justify other methods for estimation of strainer penetration or justify that their penetration amount will not exceed their plant specific in-vessel limit by using bounding assumptions and referring to other plant test results. The NRC staff review of an alternate method for justifying plant specific penetration would be more detailed than that of a plant using plant specific testing and should consider uncertainties and conservatism identified by the licensee.

Clean Plant Method

The clean plant method was developed to allow plants with very low amounts of fiber in their containments to calculate a conservative fiber penetration value. The method assumes 75% transport and 45% penetration of all fibrous debris in containment. These criteria will probably only provide satisfactory results for RMI plants. NEI transmitted the proposed clean plant criteria to the NRC in letter dated December 22, 2011 "Transmittal of GSI-191 Resolution Criteria for 'Low Fiber' Plants" [7]. The single attachment to the letter [8] contains the proposed NEI criteria. [9] The NRC staff responded to the NEI letter in letter dated May 2, 2012, "NRC Review of Nuclear Energy Institute Clean Plant Acceptance Criteria for Emergency Core Cooling Systems". [10] The NRC staff can refer to methods in these documents to apply the clean plant criteria.

General Information

Licensees may conservatively assume that all fiber calculated to penetrate the strainer arrives at the core inlet. However, as appropriate, licensees may justify reductions based on CSS operation, recirculation of fiber and additional filtering at the strainer based on plant specific conditions and penetration testing.

Licensees should assume the largest fibrous debris amount arriving at the sump strainer, including transport and erosion (based on the bounding fiber break for the plant).

Fibrous debris amount calculations should assume the single failure that results in the maximum value at the core inlet.

Licensees may use the WCAP-17788 methodologies to calculate the amount of fibrous debris that will reach the core. If such an approach is used, the NRC staff should review the calculations to ensure assumptions used are acceptable, given that the TR was not approved for use by the staff. Section 6.5 of Volume 1 of WCAP-17788 has a methodology for calculating the amount of fibrous debris arriving at the core following a HLB. This method includes credit for a debris split between the core inlet and AFPs so that some debris is assumed to enter the heated core instead of collecting at the core inlet. The debris split assumes that the debris deposition at the core inlet will be uniform. The NRC staff expects that the debris bed at the core inlet will not be uniform due to the variations in flow velocities at the core inlet. Therefore, it will take more debris than determined by WCAP-17788 to result in activation of the AFPs and redirection of some flow and debris to the heated core. Other aspects of the Volume 1 method reflect the expected physical behaviors following a LOCA. Because of the non-physical nature of the assumption that a uniform debris bed will form at the core inlet, credit for debris bypassing the core inlet and entering the heated core should not be used. However, the NRC staff recognizes that AFPs will provide flow to the core if the resistance to flow at the core inlet becomes high enough. It is not the intent of the staff to prevent credit for debris diversion when the debris predicted to be diverted will have no negative effect on flow into the core. Therefore, although the staff does not agree that the core split can be used to calculate an amount of debris that will bypass the core inlet via the AFPs, licensees may justify that a non-uniform debris bed will form at the core inlet allowing adequate flow to assure LTCC, even though the average debris load per FA metric is exceeded. If a licensee desires to perform an evaluation that credits debris reduction at the core inlet due to transport through the AFPs, a more detailed staff evaluation will be required because of the uncertainties associated with such an analysis.

Some licensees may choose to demonstrate that the amount of fiber passing through the strainer could not result in the exceedance of an established debris limit. For example, a site-specific analysis might determine that the quantity of fiber penetrating the strainer is insufficient to reach the core fiber limit. The quantity required for the plant to reach the limit would be compared against known strainer penetration behavior similar to the plant-specific conditions to verify that the threshold penetration value would not be exceeded.

For example, a plant might have a maximum of 500 pounds of fine fibrous debris arriving at a 3,000 ft^2 strainer. The plant could calculate the amount of debris that would have to penetrate the strainer to reach the limit. In the example, the plant has 193 FAs and the plant-specific core inlet limit is 50 g/FA. This implies that 9,650 grams of fiber is the maximum that can arrive at the core inlet to remain within the limit. This is about 21 pounds of fiber. This equates to 4.2 percent of 500 lb. If the plant can refer to testing that justifies that less than 4.2 percent of the fiber for a scaled fiber load of 500 pounds over 3,000 ft^2 (or 0.17 pounds/ft^2) will penetrate the strainer, it has shown that the limit will not be reached. As discussed above, testing should be justified to be similar or conservative compared to the plant conditions. The major parameters that should be evaluated when applying non-site-specific testing to a strainer include the mass of fiber per strainer area, flow velocity or velocity profile through the strainer, strainer geometry, potential for non-uniform debris bed formation, sacrificial area, potential number of strainers in service, and strainer perforation size. Plants should include margin in their calculations to account for uncertainties in applying non-plant specific testing to their plants.