Attachment 1: Responses to NRC RAIs Specific to WCAP-17788, Volume 3 Supporting the Closure of GSI-191 (PA-SEE-1090) and Mark-ups to WCAP-17788, Volume 3 NON-PROPRIETARY Attachment

The RAIs addressed herein were provided to the Pressurized Water Reactor Owners Group (PWROG) via the following documents:

NRC Correspondence, "Request for Additional Information RE: Pressurized Water Reactor Owners Group Topical Report WCAP-17788, 'Comprehensive Analysis and Test Program for GSI-191 Closure,'" August 2016, ADAMS Accession No. ML16102A357.

RAI-3.1

In Table 1 of Volume 3, the input for fraction of fiber concentration lost to Containment Spray System has a value of 0.0. The comment says "Use non-zero value when justified or defendable value is available." Would the non-zero value be a result of testing? How would a justifiable value be determined?

Response

As requested by licensees, the Cold Leg Break (CLB) method described in Volume 3 was developed to be generic with sufficient flexibility to allow for plant specific inputs, should licensees choose to develop them. This parameter is one such instance of the flexibility made available to licensees. A non-zero entry for this parameter is left to the licensee to develop and justify, should they chose to do so. Therefore, Volume 3 of WCAP-17788 does not and will not provide guidance as to how a non-zero value would be determined or justified.

Proposed Revision to WCAP-17788, Volume 3:

The WCAP-17788, Volume 3 text in question will be revised to clarify the input values to this parameter as follows:

Use a zero value (no fibrous debris depletion due to the Containment Spray System) unless plant-specific data or analyses support the use of a non-zero value. Note that technical justification must support the use of a non-zero value for this input parameter.

RAI-3.2

On page 3-9 of Volume 3, parameter c_2 is defined as 0.0022026 grams per pound mass (g/lbm). It appears to be the inverse of the intended value. Using this value will have a significantly non-conservative effect. The correct value should be 454 g/lbm (or 0.0022026 lbm/g). Clarify whether the value will be revised.

Response

The conversion factor, c_2, for converting pound mass to grams that is given on page 3-9 of Volume 3 of WCAP-17788 is the inverse of the correct conversion factor, which is $454\ grams/lbm$. This typographical error will be corrected in the –A version of WCAP-17788, Volume 3.

Proposed Revision to WCAP-17788, Volume 3:

The text of WCAP-17788, Volume 3 will be revised as follows:

Where the parameter c_2 is defined as:

c_2 = *Is a constant for converting lbm to grams;* $453.6\ g/lbm$.

RAI-3.3

The use of average core boil off values as discussed in Section 5.1 of Volume 3 may result in unrealistic values of fiber at the core inlet. Most of the fiber will penetrate the strainer early in the loss-of-coolant accident (LOCA) response. Using an average value when the actual flow rate decreases during the event can result in unrealistic values of debris transported to the core. Provide justification that the use of an average value results in realistic or conservative values for debris entering the core.

Response

While an initial "puff" of fibrous debris may or may not initially pass through the sump strainer, the following is noted:

1. Testing of scaled sump strainer screens at scaled volumetric flow yielding prototypic flow rates has demonstrated that fiber build-up on these screens is rapid with fibrous beds being formed within minutes of initiation of simulated recirculation operation.
2. For a Cold Leg Break, the break of interest in Volume 3 of WCAP-17788, the coolant flow to the core is small, essentially matching boil-off in the core. For example;
    a. At the time of initiation of recirculation from the reactor containment building sump, about 97% of the coolant being recirculated from the reactor containment sump is either spilled out the break or is ducted to the containment spray system (CSS); only about 3% of the recirculation flow is ducted to the core.
    b. As the transient progresses and core decay heat continues to exponentially decrease, the flow rate to the core also exponentially decreases as boil-off continues to decrease.
3. Figure RAI-3.3-1 displays a boil-off curve for a typical Westinghouse 4-loop pressurized water reactor.

    a. The solid black line represents the calculated boil-off rate as a function of time after the accident. The total amount of debris-laden coolant provided to the core is calculated as the integral under the curve between the time that recirculation is initiated and the time of hot-leg switch-over.

    b. The solid red line connects the boil-off rate at the start of recirculation to the sump to boil-off rate at the start of hot-leg switch-over estimated to be at two hours after the event initiation. The total amount of debris laden coolant provided to the core using the Alternate Simplified Method of WCAP-17788, Volume 3, Section 5.0 is calculated by the trapezoidal rule.

    c. Similarly, the blue dashed line connects the boil-off rate at the start of recirculation to the boil-off rate at the start of hot-leg switchover that is estimated to be at five hours after the event initiation. Again, the total amount of debris laden coolant provided to the core using the Alternate Simplified Method of WCAP-17788, Volume 3, Section 5.0 is calculated by the trapezoidal rule

The area under the exponential core boil-off (black) curve is less than the area under either the red solid line or the blue dashed line. This would be the case for all PWRs.

It is further noted that this example demonstrates that the greater the time span between start of recirculation from the sump to the start of hot-leg recirculation, the greater the conservatism in coolant mass evaluated using the Simplified Alternate Method (see the blue dashed line).

Thus, the use of the average boil-off rates conservatively overestimates the total debris laden coolant provided to the core for the Simplified Alternate Method. Thus, the Simplified Alternate Method provides for a conservatively large amount of debris-laden coolant to the core compared to a computed exponential boil-off curve.

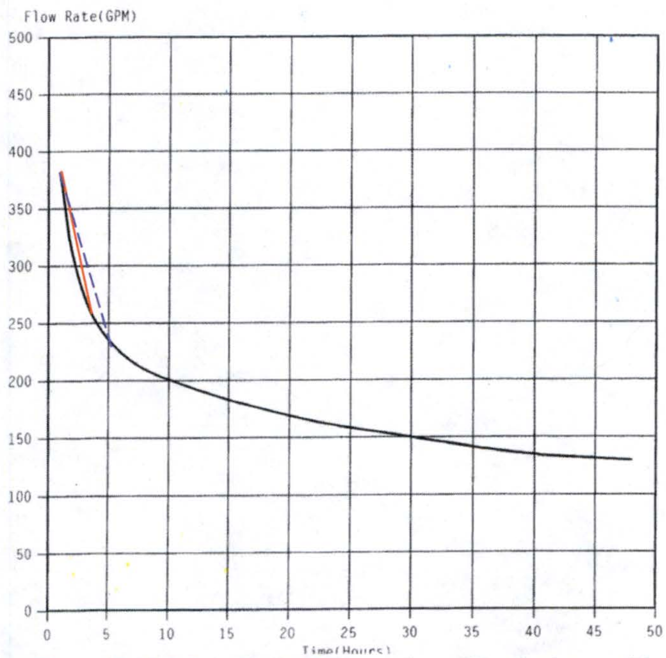

Figure RAI-3.3-1 - Boil-off Curve for a Westinghouse 4-loop PWR

Given the sum of the discussion above, the use of the average core flow rate is taken to be a reasonable approximation employed in the Simplified Alternate Method of Section 5.0 to assess the deposition of fibrous debris at the core inlet for a CLB loss-of-coolant-accident (LOCA).

RAI-3.22

Section 5.1 states that "the worst-case single failure that maximizes the flow rate to the core is the case that should be utilized." At the same time, the quantity is defined as "total flow rate of emergency core cooling through the strainer." This is not necessarily an accurate statement. Clarify that the STRN concept, defined as the total flow rate through the strainer, which is the sum of the emergency core cooling (ECC) flow and containment spray flow should be to minimize the flow through the strainer in relation to the flow that enters the core.

Response

The statement that, "the worst-case single failure that maximizes the flow rate to the core is the case that should be utilized" is correct as written. The effect of flow rate on the amount of fibrous debris that is passed by sump screens was experimentally studied by the US Nuclear Regulatory Commission and is reported in NUREG/CR-6885 (ML053000064). The parametric test data presented in Table 5-1 of NUREG/CR-6885 shows that the amount of fiber penetrating a sump screen with a given hole size increases with an increase in velocity of the fluid. As the amount of coolant going to the core is dependent upon decay heat, and not the flow rate of ECCS, maximizing the flow through the sump screen maximizes the concentration of fibrous debris, and therefore the mass of fibrous debris, to the core.

RAI-3.23

As described for the cold leg break (CLB) method in Section 3.5.4, Step 4 uses a dimensionless quantity, θ, which is identified as the decay heat (DH) curve.

In the simplified alternate CLB method described in Section 5, an average core boil-off flow is used to calculate the expected core fiber load.

Confirm that the quantity, θ, and the average core boil off flow will be calculated based on "the ANSI/ANS (American National Standards Institute/American Nuclear Society) 1971 + 20% decay heat curve" in accordance with Item 8 in Section 3.6.2, unless explicitly stated otherwise.

Response

The dimensionless quantity, θ, that is identified as the Decay Heat (DH) curve in WCAP-17788, Volume 3, Section 3.5.4, Step 4, represents a decay heat curve that has been normalized to full power. This was done to provide for the calculation method to be generically applicable to all plants by having the full-power thermal output of a given plant be an input parameter that is supplied by the licensee.

Both calculation methods, Section 3 "Method Discussion," and Section 5 "Simplified Alternate Method," of WCAP-17788-NP Volume 3, employ the ANSI/ANS 1971 + 20% decay heat curve as a default.

Both methods are sufficiently flexible as to allow licensees to employ an alternate decay heat curve. However, should a licensee choose to use a decay heat curve other than ANSI/ANS 1971 + 20%, the licensee is responsible for providing the justification for its use.

Proposed Revision to Volume 3:

The following text will be added to Section 3.6.1, "Overview of Required Inputs" of Volume 3 of WCAP-17788:

*10. Decay heat curve, starting at recirculation initiation****

**** The use of the normalized ANSI/ANS 1971+20% decay heat curve is recommended as the default decay heat curve for use in this calculation. Note that a different decay heat curve, such as the ANSI/ANS 1979+2σ decay heat curve, may be used when accompanied with appropriate technical justification.*

Likewise, the following clarification will replace the last bulleted item of the first paragraph of Section 5.1:

- *The core boil-off expected at the time of transfer to sump recirculation and at the time of hot leg recirculation is calculated using the product of the value of the reactor full power, plus uncertainty, times the appropriate value of the normalized ANSI/ANS 1971+20% decay heat* *curve. Note that a different decay heat curve, such as the ANSI/ANS 1979+*2σ *decay heat curve, may be used when accompanied with appropriate technical justification.*

RAI-3.24

As described for the base CLB method in Section 3.5.4, Step 4, a quantity representing the mass of coolant needed to remove the DH generated over one time step by boiling, $M_{Boil\text{-}off,\ i}$, is used to calculate the coolant mass delivered to the core at each time step, $M_{Core,\ i}$. Section 3.5.4 explains that the method increases the boil-off coolant mass by 20% to determine the coolant mass delivered to the core at each time step. Section 3.5.4 explains that the "20% factor is added" to the boil-off mass to "to account for uncertainties."

For the simplified alternate CLB method described in Section 5, a multiplication constant of 1.2 is used to calculate the expected core fiber load. Section 5.1 clarifies that it is "the average core boil-off from the initiation of cold leg recirculation to the transfer to hot leg (HL) recirculation," which is "conservatively increased by 20%" in the derived formula thus relating the 1.2 multiplier to the boil-off rate in a manner similar to the base CLB method.

a. Confirm that the multiplication factor of 1.2 used to calculate the amount of coolant "needed to match boil-off plus margin" for both the base and the simplified alternate CLB methods accounts for uncertainties other than the uncertainty related to the DH model, which is accounted for separately when calculating the applied DH generation rate.
b. Identify the major factors that contribute to uncertainty and explain how uncertainties associated with these factors were assessed and accounted for by application of the multiplication factor of 1.2.

Response

a. The method detailed in WCAP-17788, Volume 3, Section 3.5 does provide for the calculation of the amount of coolant needed to remove decay heat from the core at each time step.

   The multiplication factor of 1.2 is a conservative adder applied to the <u>fibrous debris</u> delivered to the core to ensure that the resultant accumulated fiber quantity is conservative, considering the step-wise hand calculation used to project fiber collection in the core.

   - To that end, the multiplication factor <u>does not</u> increase the flow into the core; rather, the 1.2 multiplier serves to <u>only increase</u> the <u>debris load entering the core</u> by 20%.
   - Therefore, the 1.2 multiplier identified in Section 3.5.4, Step 4, is intended to account for unknowns and uncertainties associated with the delivery of fibrous debris transported to the core independent of flow itself.
   - The 1.2 multiplier is not related to uncertainties in the decay heat model.

   To summarize, the 1.2 multiplier does not add additional flow to the core, only additional debris. Also, the 1.2 multiplier on debris delivered to the core is applied throughout the 30 day time period of interest, thereby providing for a conservatively large amount of fibrous debris to be captured by the core above that needed to match boil-off.

b. The same explanation of the 1.2 multiplier given in Part (a.), above, applies to the response to Part (b.). The unknowns and/or uncertainties associated with the 1.2 multiplier on debris added to the core for each time step are related to variations in the concentration of fibrous debris in the recirculating Emergency Core Coolant (ECC) flow. The selected value of 20% was based on engineering judgement gained from observing testing of replacement sump screens and fuel assembly debris capture testing.

Proposed Revision to Volume 3:

To clarify that the 1.2 multiplier is to account for additional debris provided to the core without increasing the flow to the core, the text of Item 5 of WCAP-17788, Volume 3, Section 3.3, "Assumptions," will be amended as follows:

5. To allow for uncertainties **in the debris concentration of the coolant entering the core**, the fluid volume entering the fuel is assumed to be 1.2 times the boil-off flow rate requirement based on the decay heat at any given time in the transient starting at recirculation initiation. **Although t**he 1.2 multiplier on boil-off flow is consistent with the guidance of NSAL-95-001 (Reference 9), **it is not related to the guidance of NSAL-95-001.** ~~**and accounts for both the possibility of extended boiling in both the downcomer and lower plenum during injection and CL recirculation, as well as the potential for insufficient ECCS flow to the RCS cold legs during CL recirculation for plants which use either residual heat removal, low head safety injection, low pressure safety injection, or recirculation pumps to supply both ECCS recirculation and containment spray flow.**~~ As noted, the 20% increase in the amount of fiber laden fluid reaching the core accounts for uncertainties in the stepwise hand calculation.

Also, the text of WCAP-17788, Volume 3, Section 3.5.4 will be amended as follows:

A 20% factor is added to $M_{Boil-off,t=0}$ to account for uncertainties **in the amount of fibrous debris delivered to the core**. Thus, the method increases the coolant mass, and therefore the amount of fibrous debris, delivered to the core at each time step by 20% as follows:

$$M_{Core,i} = 1.2 \times M_{Boil-off,i}$$

This is the value of the coolant mass that is used to calculate the amount of fibrous debris deposited at the core entrance for each time step. **Note that the 1.2 multiplier is only used to increase the debris provided to the core; it does not affect the mass of coolant used for decay heat removal.**

Text of Item 6 of WCAP-17788, Volume 3, Section 5.1 will be amended as follows:

6. The quantity of fiber expected to be transferred to the core is increased by 20% to provide additional margin to allow for uncertainties in the **fibrous debris concentration provided to the core**.

RAI-3.25

Section 3.3, "Assumptions of the Method," attempts to establish a basis to allow for uncertainties in calculating the amount of fibrous debris deposition at the core entrance. The uncertainty in the debris load is based on the uncertainty in the rate at which the coolant enters the core region. The proposed margin in the assessed debris load is introduced by assuming that the rate at which coolant enters the core can be calculated from the current core boil-off rate multiplied by a constant.

Nuclear Safety Advisory Letter (NSAL) 95-001 (Reference 9) considered criteria for minimum ECC System (ECCS) flow during cold leg recirculation, which if met or exceeded, ensures compliance with Title 10 of the Code of Federal Regulations (10 CFR) Section 50.46, "Acceptance criteria for emergency core cooling systems for light-water nuclear power reactors." It was determined that it should be ensured that ECCS flow during cold leg recirculation is at least equivalent to 1.2 times the DH boil-off at the time cold leg recirculation is initiated. As such, Reference 9 does not justify the application of a multiplier of 1.2, or any other value (e.g, 1.5 as recommended in NSAL 92-010), when it comes to describing the rate at which coolant is delivered to the core following recirculation initiation and during the period for which the CLB methods in Volume 3 will be applied.

Verify that the flow assumed to reach the core inlet accounts for phenomena and uncertainties such as those discussed in NSAL 95-001 and 92-010. Provide a justification that the margin added to the calculation by using the multiplier of 1.2 is adequate to account for uncertainties in all plant designs covered by the TR. The methodology assumes that the flow into the core is solely based on fluid boil-off. However, there is likely to be liquid exiting the core. How is the additional flow from any liquid phase accounted for?

Response

As noted in the response to RAI #3.24, the method detailed in WCAP-17788, Volume 3, Section 3.5 provides for the calculation of the amount of coolant needed to remove decay heat from the core at each time step.

However, the multiplication factor of 1.2 is a conservative adder applied to the <u>fibrous debris</u> delivered to the core to ensure that the resultant accumulated fiber quantity is conservative, considering the step-wise hand calculation used to project fiber collection in the core, and not an adder to the flow provided to the core.

- To that end, the multiplication factor <u>does not</u> increase the flow into the core; rather, the 1.2 multiplier serves to <u>only increase</u> the <u>debris load entering the core</u> by 20%.
- Therefore, the 1.2 multiplier identified in Section 3.5.4, Step 4, is intended to account for unknowns and uncertainties associated with the delivery of fibrous debris transported to the core independent of flow itself.
- The 1.2 multiplier is not related to uncertainties in the decay heat model.

To summarize, the 1.2 multiplier does not add additional flow to the core, only additional debris. Also, the 1.2 multiplier on debris delivered to the core is applied throughout the 30 day time period of interest, thereby providing for a conservatively large amount of fibrous debris to be captured by the core above that needed to match boil-off.

Therefore, the application of the discussion of NSAL-95-001 and NSAL-92-010 is not applicable to the 1.2 multiplier used in this method of evaluating debris fibrous debris collection in the core.

RAI-3.26

Section 3.4, "Overview of the Method Logic," in describing the calculation logic for the CLB method, clarifies the need to "account for sensible heat and heat of vaporization" when determining the core boil-off requirement based on DH and sump fluid temperature. In addition to the sump fluid temperature, the Reactor Coolant System pressure should be considered as a contributing factor as it defines the boil-off saturation temperature, which determines the degree of subcooling of the coolant. In addition, the system pressure has an effect on the latent heat of evaporation, which is also used to calculate the boil-off rate.

In the list of required inputs to calculate the debris deposition at the core entrance provided in Section 3.6.1, Parameter 11 is identified as "sump fluid temperature curve starting at recirculation initiation," and Parameter 12 is identified as "containment pressure curve starting at recirculation initiation."

What factors and conditions were considered when determining the inputs for Parameters 11 and 12? The response should support the concept that "a method has been developed to conservatively predict and assess the time-dependent delivery of fibrous debris to the RV and core for a CLB." Confirm that the response also applies when determining the "average core boil-off flow" used in the simplified alternate method described in Section 5.

Response

The basis for using the "containment pressure curve starting at recirculation initiation" is as follows:

1) The pressure in the reactor vessel is slightly higher than the containment pressure.
2) Therefore, using the containment pressure to evaluate steaming provides for the following:
    a. A conservatively smaller total enthalpy change in the coolant to boil than if the reactor vessel pressure were used which, in turn, provides for:
    b. A conservatively larger boiling rate than would be predicted using the reactor vessel pressure.
3) The larger boiling provides for a conservatively larger mass of debris-laden coolant to be provided to the core.

To summarize, the use of the containment pressure curve provides for a conservatively large boiling of debris-laden coolant which, in turn, maximizes the debris delivered to the core.

The basis for using the "sump fluid temperature curve starting at recirculation initiation" is as follows:

1) The sump inventory temperature is taken from containment integrity calculations.
2) These temperature histories tend to maximize sump temperatures.

3) The sump temperature history does not credit cooling of the fluid from heat exchangers as it passes from the sump to the core.

To summarize, the use of maximum sump fluid temperatures and neglecting cooling of the pumped fluid to the core also maximizes the boiling of debris-laden coolant in the core which, in turn, maximizes the debris delivered to the core.

No attempt was made to determine the magnitude of the conservatism associated with the use of the containment pressure and the sump fluid temperature. Rather, it was recognized that the use of these values provided additional conservatism to the overall method.

Similarly, the Simplified Alternate Method uses the parameter, CB_{AVG}, which is defined as, "Average core boil-off flow, determined by summing the core boil-off flow at transfer to cold-leg recirculation and the core boil-off flow at transfer to hot-leg recirculation, and dividing by 2." Considering that the decay heat is an exponential function, it is readily observed that the use of the average of the core boil-off at transfer to cold-leg recirculation and the core boil-off flow at transfer to hot-leg recirculation provides for a conservatively large amount of debris-laden coolant to be transported to the core.

For example, Figure RAI-3.26-1 contains a boil-off curve for a typical Westinghouse 4-loop pressurized water reactor. The solid black line represents the calculated boil-off rate as a function of time after the accident. The solid red line connects the boil-off rate at the start of recirculation from the sump to boil-off at the start of hot-leg switch-over estimated to be at 5 hours after the event initiation. The total amount of debris-laden coolant provided to the core is calculated as the integral under the curve. Clearly, the area under the core boil-off curve is less than the area under the red curve. Furthermore, the greater the time span between start of recirculation from the sump to the start of hot-leg recirculation, the greater the conservatism in coolant mass evaluated using the Simplified Alternate Method (see the blue dashed line). Thus, the Simplified Alternate Method provides for a conservatively large amount of debris-laden coolant to the core compared to the computed boil-off curves.

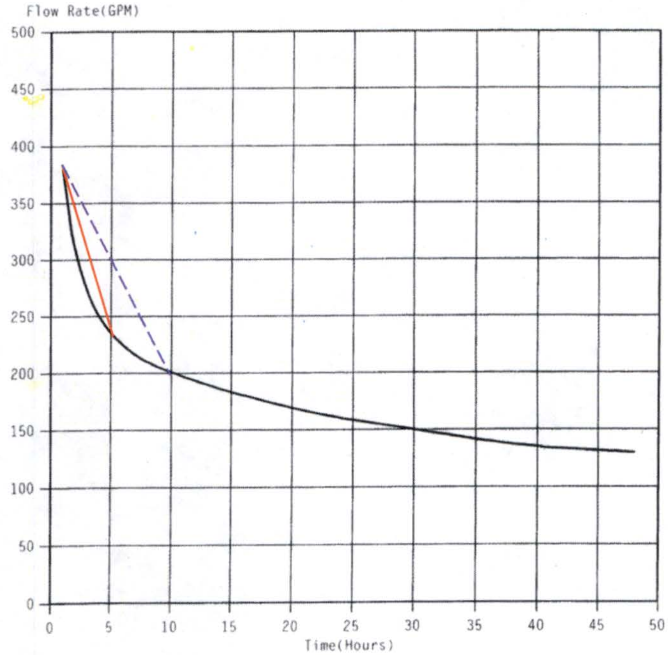

Figure RAI-3.26-2 Boil-off Curve for a Westinghouse 4-loop PWR

Again, no attempt was made to determine the magnitude of the conservatism associated with the use of the average of the boil-off rate at the start of recirculation and the boil-off rate at the start of hot-leg switch-over. Rather, it was recognized that the use of this value provided additional conservatism to the overall method.

RAI-3.32

Section 3.5 "Equations," explains that the equations for calculating the amount of fiber delivered to the core inlet are solved explicitly as a difference from time step to time step and that they can be easily solved by hand. In addition, Section 3.5.8, "Suggested Time Step Interval," states in part that "for this evaluation, a time step of one minute is suggested."

Section 6.5 of Volume 1, Subsection 6.5.2.1, "Time Step," also discusses time steps for the hot leg break (HLB) methodology. The HLB method states that an iterative solution with respect to time is necessary and recommends that time step sensitivity be performed. The method suggests that the time step should be small enough to ensure that the important processes behave linearly over each time step. A starting time step value of 100 seconds is recommended.

a. Provide results for an example case analyzed with the CLB method to illustrate the effect of the time step size. Provide the results from two calculations performed with time step sizes of 1 second and 10 seconds and compare the results from the calculation using the recommended time step size of 60 seconds.
b. Provide results for an example case analyzed with the HLB method to illustrate the effect of the time step size. Provide the results from two calculations performed with time step sizes of 1 second and 10 seconds and compare the results from the calculation using the recommended time step size of 100 seconds.
c. Provide quantitative criteria for assuring that the results from a calculation performed with both the CLB and HLB methods produce "stable results" along with justification as to how these criteria will be assured. State how the proposed process assures that an appropriate time step size will be applied to the proposed methods.

Response

a. The method described in Section 3 of Volume 3 of WCAP-17788 calculates the mass of fibrous debris collected on the sump screen and in the reactor vessel for a large cold leg break scenario. The method uses an explicit solution technique for the calculation scheme, which implies that the error in calculated solution from the previous time step is sufficiently small that it has negligible effect on the calculations performed for the next time step, and so on. An explicit calculation scheme works well when changes in the governing parameters of interest are small from time-step to time-step.

   The method description in Section 3 of Volume 3 of WCAP-17788 suggests the use of a one minute (60 second) time step to calculate the change in accumulated fibrous debris on the sump screen and in the vessel, as well as a change in fibrous debris concentration remaining in the coolant inventory of the reactor containment building sump. This approach approximates the integral of the rate of fibrous debris captured on the sump screen and in the vessel, as well as the rate of depletion of the fibrous concentration in the sump fluid inventory. There are several factors that favor the use of a one minute time interval, one of which is that minutes are a common unit of time measure for many of the input parameters (e.g., time of sump recirculation (minutes), initiation and termination of ECCS and the CSS (minutes), Hot Leg switchover (hours or minutes), and ECCS and CSS flow (gallons per minute)).

Using a constant time step for explicit calculations may be likened to the application of trapezoidal rule for integrating the area under a curve. As is the case with the trapezoidal rule, the use of successively smaller time steps in the method of Section 3 of Volume 3 of WCAP-17788 may be expected to provide for an increasingly accurate approximation of the area under a curve (i.e., the integral of the amount of fibrous debris capture on the sump screen and in the vessel, as well as the depletion of the concentration of fibrous debris in the sump inventory).

It is noted that the initial debris concentration in the sump inventory is relatively small when compared to the mass of the coolant inventory. During the long-term cooling period associated with recirculation of sump fluid by the ECCS and CSS of a plant, all plant parameters affecting the ECCS and CSS flows, and hence fibrous buildup at screens and depletion in the sump inventory, are either constant or slowly changing relative to the size of the suggested one minute (60 second) time step.

1) ECCS and CSS flows are constant.
2) At this time during the transient, the decay heat is decreasing in a slow and gradual manner.

Also, as the decay heat slowly decreases, the mass of coolant needed to match boil-off also decreases, thereby minimizing the delivery of debris-laden coolant to the core while increasing the mass of water returned to the sump inventory through the break and re-filtered by the sump screen, further decreasing the fibrous debris concentration supplied to the vessel in the next time step.

To demonstrate the acceptability of a one minute or 60 second time step, sensitivity calculations were performed for three different time step sizes; the recommended one minute (60 second) time step, a ½ minute (30 second) time step, and a 1 second time step. For these sensitivity calculations, calculation inputs were representative of a large 4-loop PWR. Specific inputs to the calculations were:

1) The time of switch-over from injection from the RWST to recirculation from the inventory of the sump was assumed to be at 25 minutes after initiation of the LOCA.
2) The ECCS and CSS flow rates were taken to be 3800 gpm and 3000 gpm, respectively.
3) The active volume of coolant in the reactor containment building sump was taken to be 47,343.93 ft^3. At the ECCS and CSS flow rated used in the calculations, the coolant inventory in the sump was turned over once every 52.08 minutes.
4) The initial amount of fibrous debris in the reactor containment sump fluid is 20.4 ft^3, or, assuming a density of 2.4 lbs/ft^3, 49.44 lbs. of fibrous debris. As there are 193 fuel assemblies in a Westinghouse 4-loop PWR, this mass equates to a fibrous debris loading of 116.2 grams/fuel assembly upstream of the sump screen.
5) A capture efficiency of 55% was assumed for the sump screen. This provided for a maximum of 52.3 grams of fibrous debris per fuel assembly to be available

immediately downstream of the sump screen (assuming a single-pass of the initial sump coolant volume through the vessel).

6) For the purposes of this sensitivity evaluation, the decay heat was held constant at its 25 minute value. This assumption maximized the flow to the core for the duration of interest for the calculation and therefore maximizes the amount of debris calculated to collect in the vessel which, in turn emphasizes the difference in calculated debris deposition in the vessel as a function of the size of the time step used in the calculation.

The calculations were run for 12 hours of problem time after initiation of recirculation from the reactor containment building sump. The results of the sensitivity calculations are shown in Figure RAI-3.32-1. Time t=0 of the plot is to be taken as the start of recirculation; 25 minutes after initiation of the LOCA. A green line with green triangles as markers represents the results using a 60 second time step, a red line with red squares as markers represents the results of the 30 second time step, and a light blue line with solid diamonds as markers represents the results of the 1 second time step (see the legend on the right-hand side of Figure RAI-3.32-1). The difference between the results of the three time step durations are sufficiently small that they overlay one another on the plot of Figure RAI-3.32-1 and are indiscernible.

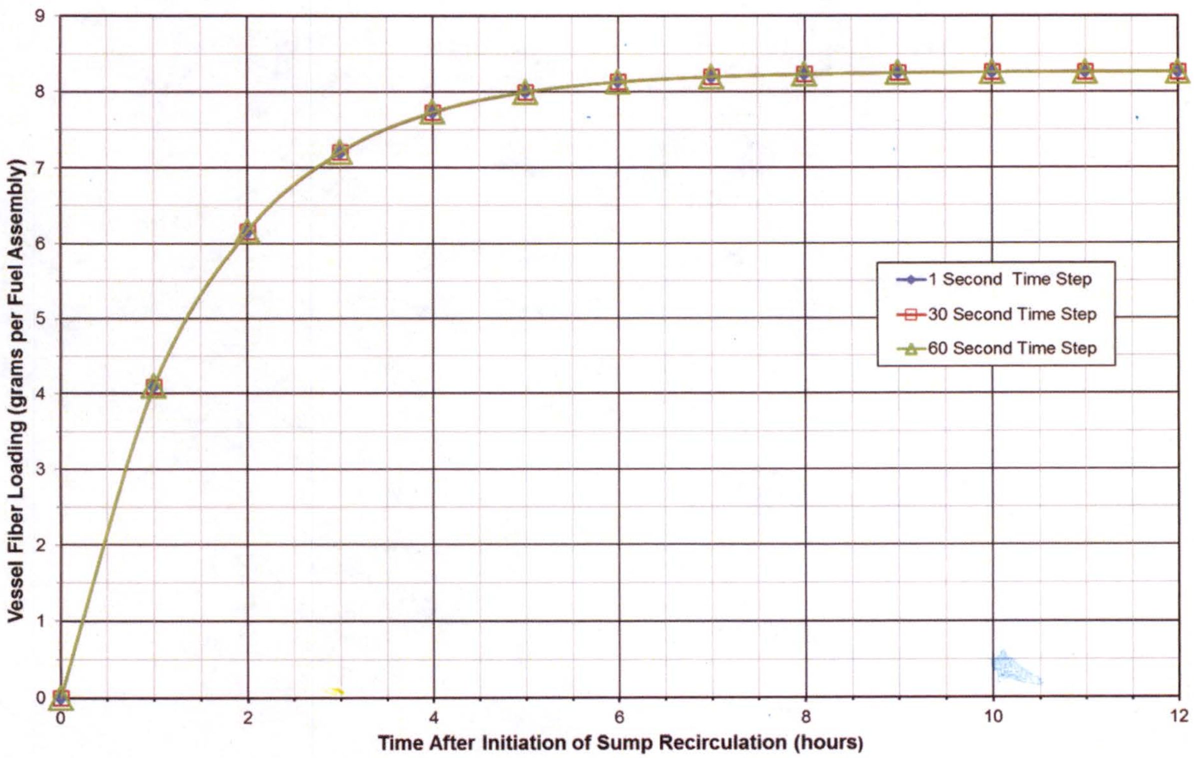

Figure RAI-3.32-1 Reactor Vessel Fibrous Debris Collection as a Function of Time Step Selection

From the plot of Figure RAI-3.32-1, it is concluded that following initiation of recirculation from the reactor containment building sump (time = 0), there is negligible difference between the three sets of results using three different time steps.

The hour-by-hour differences between the calculations performed using the three time steps are summarized in Table RAI-3.32-1.

Table RAI-3.32-1 Comparison of Reactor Vessel Fibrous Debris Collection as a Function of Time Step Size

	Fibrous Debris Collected (grams per fuel assembly)			Comparison	
Time (hours)	1 Second Time Step	30 Second Time Step	60 Second Time Step	Absolute Difference (60 sec -1 sec)	Percent Difference
0	0.0000	0.0000	0.0000	0.0000	0.0000
1	4.0869	4.0948	4.1029	0.0160	0.3920
2	6.1528	6.1608	6.1690	0.0162	0.2628
3	7.1972	7.2032	7.2094	0.0122	0.1701
4	7.7251	7.7291	7.7333	0.0082	0.1065
5	7.9920	7.9945	7.9972	0.0052	0.0649
6	8.1269	8.1284	8.1300	0.0031	0.0386
7	8.1951	8.1960	8.1969	0.0018	0.0226
8	8.2295	8.2300	8.2306	0.0011	0.0130
9	8.2470	8.2472	8.2476	0.0006	0.0073
10	8.2558	8.2559	8.2561	0.0003	0.0041
11	8.2602	8.2603	8.2607	0.0005	0.0058
12	8.2625	8.2625	8.2626	0.0001	0.0012

From the tabular listing given in Table RAI-3.32-1, the following observations are made:

1) Using a smaller time step for the calculations results in a slightly smaller amount of fibrous debris collection in the reactor vessel.

2) Over the range of time steps studied, the maximum difference in calculated debris collection is less than 0.4% at 1 hour after initiation of recirculation from the reactor containment building sump.

3) At the time range of most interest, from 3 to 6 hours after initiation of recirculation from the reactor containment building sump, the difference in calculated fibrous debris collected is:

    a. Less than 0.2% at 3 hours, and,

   b. Less than 0.04% at 6 hours.

4) At 12 hours after initiation of recirculation from the reactor containment building sump, there is essentially no difference in the calculation of fibrous debris collection for any of the three time steps considered.

This small variation is expected for the following reasons; the majority of the ECCS coolant, along with all of the CSS flow (approximately 93% of the total of the ECCS and CSS flow), is recirculated back to reactor containment building sump inventory where it is again filtered by the sump strainer before being made available to enter the core, and the governing parameters in the calculation are changing slowly.

Although this exercise is performed to evaluate the impact of time step on the calculated debris collection in the vessel, the assumptions made for this comparison are conservative as they maximize the differences between calculated fibrous debris collection for the following reasons:

1) The decay heat was held at a constant value equal to the decay heat at the time of switchover from RWST (volume of borated water outside of the reactor containment building) injection to sump recirculation for the 12 hour duration of the calculations. As the decay heat remained high, the flow drawn into the core remained high, maximizing the deposition of fiber in the reactor vessel.

2) The coolant inventory of the reactor containment sump will cool down as the event progresses. The time step evaluation presented here conservatively neglects this cooldown, thereby also neglecting the increase in sensible heating of the coolant entering the core that is required before steam is generated. The assumption of maintaining the high temperature of the coolant in the sump at the time of switchover from injection from the RWST to recirculation from the reactor containment building sump maximizes the steaming rate, and consequently the mass of coolant delivered to the core during the time step assessment.

3) Conservative methods are used to estimate the amount of fibrous debris that is generated and transported to the sump during the initial blowdown from a large cold leg break and the washdown of that debris into the sump fluid during the drain down of the RWST (no credit is taken for the deposition of fibrous debris on intervening structures in the flow of spilled coolant as it flows to the sump screen). This provides for a conservatively large initial debris concentration of fibrous debris in the sump fluid.

4) The evaluation of fibrous debris accumulation in the vessel is based on the time to switchover from cold leg injection to hot leg recirculation which ranges from about 2 to 3 hours to about 6 to 8 hours for most plants with a 2 or 3 plants possibly extending to about 12 hours. However, the amount of fibrous debris used to calculate an initial fibrous debris concentration is the 30 day limit used to evaluate sump screen performance, which also accounts for erosion for those plants that generate fiberglass debris. This is an additional conservatism in the CLB calculation method.

Considering the above, the use of a one minute time step, or smaller, used in the calculation method of Section 3 of Volume 3 of WCAP-17788 to estimate the delivery of fibrous debris to the reactor vessel for a cold leg break will result in essentially the same result. Therefore, a time step of one minute (60 second) or less is reasonable and appropriate for this calculation method.

b. The response to this question is provided in the WCAP-17788, Volume 1 RAI response.

c. The acceptability of a one minute (60 second) time step for the cold leg break calculation method has been established in the response to RAI 3.32 (a). In fact, a one minute (60 second) time step provides slightly conservative calculation of fuel assembly debris loading compared to a 1 second time step.

   The acceptability of the time step for the HLB method is addressed in the WCAP-17788, Volume 1 RAI response.

Proposed Revision to Volume 3:

WCAP-17788, Volume 3, Section 3.5.8 "Suggested Time Step Interval" will be revised as follows:

For this evaluation, a time step of one minute is suggested for the following reasons:

- The mass of fluid inventory in the recirculation sump is large compared to the mass of the ECCS and CSS over a one minute time step. The one minute time step provides for a relatively slow "clean up" of fibrous debris by both the recirculation sump screen and the core. The results of the calculations are therefore insensitive to variations in time step sizes around the one minute value.
- The use of a one minute time step provides for small changes in the decay heat curve from time step to time step in the time period of start of recirculation from the sump and beyond. This provides for an accurate calculation of core boil-off mass needed for long-term core cooling.
- The use of a one minute time step is convenient for the calculations as the ECCS and CSS flow rates are generally defined in units of gallons per minute.
- The use of time steps smaller than one minute have been evaluated and determined to have a negligible impact on the calculated results.

Thus, for the reasons noted above and from a practical consideration, a one minute time step for this calculation is suggested. This recommendation, however, does not preclude the use of a smaller time step.

WCAP-17788-NP Mark-ups

Proposed revisions to WCAP-17788-NP, Volume 3 are included in this section. After receipt of the Final Safety Evaluation, the NRC Approved version of the TR will incorporate the proposed revisions. Revisions are identified with revision bars in the left margin. Deleted text is identified as blue font with a single strikethrough and new text is identified as red font.

Proposed revisions to the TR are summarized as follows:

- WCAP-17788-NP, Volume 3, pg. 4-2: Updates to the 'Comment' column of Table 1 for the 'Fraction of fiber concentration lost to CSS' parameter are made consistent with the response to RAI-3.1.
- WCAP-17788-NP, Volume 3, pg. 3-9: Updates to the Section 3.5.5 are made consistent with the response to RAI-3.2.
- WCAP-17788-NP, Volume 3, pg. 3-12 and pg. 5-1: Updates to the Section 3.6.1 (*** note added) and the last bullet of the list in Section 5-1, pg 5-1 are made consistent with the response to RAI-3.23. In addition 'Section 3.6.1' was corrected to refer to 'Section 3.6.2' on page 3-12.
- WCAP-17788-NP, Volume 3, pg. 3-3, pg. 3-9 and pg. 5-2: Updates to the Section 3.3 Section 3.5.4 and Section 5.1, item 6 are made consistent with the response to RAI-3.24.
- WCAP-17788-NP, Volume 3, pg. 3-11: Updates to the Section 3.5.8 are made consistent with the response to RAI-3.32.

3.3 ASSUMPTIONS OF THE METHOD

The following assumptions are made for the method to calculate fibrous debris deposition at the core entrance for a CLB.

1. The fiber is in its constituent form, i.e., individual fibers. This is consistent with maximum transport assumptions.
2. The fibrous debris remains suspended in the recirculating fluid and does not settle out. Suspended fibers are easily transported throughout containment, and assuming no settling is conservative.
3. The fiber in the sump pool is uniformly mixed at all times. Uniform mixing in the sump pool maintains a uniform fiber concentration as it transports throughout containment.
4. The fiber in the ECCS and CSS flow is uniformly mixed for each time step. Uniform mixing in the ECCS and CSS maintains a uniform fiber concentration as it transports to downstream locations.
5. To allow for uncertainties in the debris concentration of the coolant entering the core, the fluid volume entering the fuel is assumed to be 1.2 times the boil-off flow rate requirement based on the decay heat at any given time in the transient starting at recirculation initiation. Although t~~T~~he 1.2 multiplier on boil-off flow is consistent with the guidance of NSAL-95-001 (Reference 9), it is not related to the guidance of NSAL-95-001. ~~and accounts for both the possibility of extended boiling in both the downcomer and lower plenum during injection and CL recirculation, as well as the potential for insufficient ECCS flow to the RCS cold legs during CL recirculation for plants which use either residual heat removal, low head safety injection, low pressure safety injection, or recirculation pumps to supply both ECCS recirculation and containment spray flow.~~ A 20% increase in the flow required to satisfy boil-off requirements increases the amount of fiber laden fluid reaching the core.
6. The core entrance is assumed to capture 100% of the fibrous debris delivered in the boil-off mass.
7. The mass of coolant in the recirculation sump remains constant in time.
8. The concentration of fiber in the sump volume is reduced in each time step by the amount of fiber captured by the recirculation sump screen and at the core entrance. All fiber not captured by either the recirculation sump screen or the entrance to the core in a single time step is returned to the sump and accounted for in the sump fiber concentration for the next time step.
9. In the absence of plant specific recirculation screen performance, a recirculation screen bypass fraction of 45% is suggested (Reference 8). If a licensee has either a constant bypass fraction or time-dependent fiber bypass fraction for their recirculation sump screen(s) based on testing, the licensee may use that data in the calculation scheme. The licensee assumes the responsibility for justifying the use of the fiber bypass fraction with the NRC.

$Boil-off$ = Refers to the mass of coolant needed to remove all of the decay heat generated in one time step by heating the coolant from sump temperature to saturation temperature at containment pressure and then boiling the coolant.

A 20% factor is added to $M_{Boil-off,t=0}$ to account for uncertainties in the amount of fibrous debris delivered to the core. Thus, the method increases the coolant mass, and therefore the amount of fibrous debris, delivered to the core at each time step by 20% as follows;

$$M_{Core,i} = 1.2 \times M_{Boil-off,i}$$

This is the value of the coolant mass that is used to calculate the amount of fibrous debris deposited at the core entrance for each time step. Note that the 1.2 multiplier is only used to increase the debris provided to the core; it does not affect the mass of coolant used for decay heat removal.

3.5.5 Step 5: Sum the Mass of Fibrous Debris Deposited at the Core Entrance

The mass of fiber deposited at the core entrance is calculated by multiplying the coolant mass delivered to the core by the fibrous debris concentration that was calculated in Step 3.

$$M_{Core\,Fiber,i} = c_2 \times \Delta C_i^* \times M_{Core,i}$$

Where the parameter c_2 is defined as:

c_2 = Is a constant for converting lbm~~M~~ to grams; $453.6\ g/lm$~~0.0022026 g/lb~~~~M~~.

And the subscript is defined as:

$Core\ Fiber$ = Refers to the fiber delivered to the core with the coolant mass needed to removed decay heat + 20% to address uncertainties.

The running total mass of fibrous debris delivered to the core is calculated by summing the fibrous debris delivered for each time step. This is calculated as follows.

$$M_{Total\,Core\,Fiber} = \sum_{i=0}^{i=N} M_{Core\,Fiber,i}$$

Where $M_{Total\,Core\,Fiber}$ is the running total of fibrous debris delivered to the core from time step $i = 1$ (switchover from ECCS injection from the RWST/BWST to recirculation from the recirculation sump) to time step $i = N$.

The running loading of fibrous debris per fuel assembly (F/A) is also readily calculated by dividing $M_{Total\,Core\,Fiber}$ by the number of fuel assemblies in the core.

$$M_{Fiber\,per\,F/A} = \frac{M_{Total\,Core\,Fiber}}{No.\,of\,F/A\,in\,core}$$

The calculations of Step 1 through and including Step 6 are then repeated for N time steps, or until a decision is made to terminate the calculation.

3.5.8 Suggested Time Step Interval

For this evaluation, a time step of one minute is suggested for the following reasons:

- The mass of fluid inventory in the recirculation sump is large compared to the mass of the ECCS and CSS over a one minute time step. The one minute time step provides for a relatively slow "clean up" of fibrous debris by both the recirculation sump screen and the core. The results of the calculations are therefore insensitive to variations in time step sizes about the one minute value.
- The use of a one minute time step provides for small changes in the decay heat curve from time step to time step in the time period of start of recirculation from the sump and beyond. This provides for an accurate calculation of core boil-off mass needed for long-term core cooling.
- The use of a one minute time step is convenient for the calculations as the ECCS and CSS flow rates are generally defined in units of gallons per minute.
- The use of time steps smaller than one minute have been evaluated and determined to have a negligible impact on the calculated results.

Thus, for the reasons noted above and from a practical consideration, a one minute time step for this calculation is suggested. This recommendation, however, does not preclude the use of a smaller time step.

3.5.9 Additional Discussion

It is important to note that this is a plant-specific calculation based on plant-specific parameters. The method provides for the calculation of both the mass of fibrous debris past sump screen, and the mass of fibrous debris delivered to the core inlet following a postulated CLB. The method also allows for the calculation of the maximum allowable fiber that may past through (bypass) the sump screen for a CLB at a plant and still meet the at-fuel fiber limit determined in Volume 1 of this WCAP.

3.6 INPUT REQUIRED

This section identified and discusses the input parameters needed for the calculations of this method.

3.6.1 Overview of Required Inputs

The inputs required for the method for calculating debris deposition at the core entrance are as follows. These inputs should be readily available in current plant documentation and the values should be consistent with the plant design basis. See Section 3.6.2~~1~~, "Design Basis Inputs," for additional discussion regarding use of design basis and conservative inputs.

	PARAMETER	UNITS
1.	Earliest time of sump recirculation initiation after the LOCA	– minutes
2.	Minimum sump volume at recirculation initiation	– ft^3
3.	Screen bypass fraction	– dimensionless
4.	Core power (thermal) plus uncertainty	– MWt
5.	Latest time of HL switch over (or the equivalent) following a LOCA	– hours
6.	ECCS flow at recirculation; design basis value*	– gpm
	a. ECCS initiation and termination or flow reduction times following a LOCA	– minutes
7.	CSS flow at recirculation; design basis value*	– gpm
	a. CSS initiation and termination or flow reduction times following a LOCA	– minutes
8.	Total volume of fiber fines transported to the sump screen**	– ft^3
9.	Number of FAs	– dimensionless
10.	Decay heat curve, starting at recirculation initiation***	– dimensionless
11.	Sump fluid temperature curve starting at recirculation initiation	– °F
12.	Containment pressure curve starting at recirculation initiation	– psia

* ECCS and CSS flows should account for the limiting single failure in the ECC and CS system. Also, "flow reduction" refers to throttling as well as other means of flow reduction for both ECCS and CSS flows.

** When converting the volume of fiber fines transported to the sump screen to a mass value, care should be taken to use the appropriate density. A density of 2.4 lb_M/ft^3 may be used for low-density fiberglass and latent fibrous debris. An appropriate as-manufactured density value should be used for high-density fiberglass.

*** The use of the normalized ANSI/ANS 1971+20% decay heat curve is recommended as the default decay heat curve for use in this calculation. Note that a different decay heat curve, such as the ANSI/ANS 1979+2σ decay heat curve, may be used when accompanied with appropriate technical justification.

Page 4-2, Table 1 – Input Collection

Fraction of fiber concentration lost to CSS	fraction	0.0	Use a zero value (no fibrous debris depletion due to the Containment Spray System) unless plant-specific data or analyses support the use of a non-zero value. Note that technical justification must support the use of a non-zero value for this input parameter. ~~Use non-zero value when justified or defendable value is available.~~

5 SIMPLIFIED ALTERNATE METHOD

5.1 METHOD DISCUSSION

As an alternative to the CLB method described Section 3, a simplified method is presented below. The input used in the simplified method is consistent with the input gathered for the CLB method described in Section 3 and is described as follows.

- The total quantity of fiber expected to bypass the strainer. This can be either the quantity determined from testing, or if testing was not performed, the quantity determined using the Clean Plant Criteria described in Reference 8.
- The earliest time a plant could transfer from injection to sump recirculation.
- The earliest time a plant could transfer from CL recirculation to HL recirculation.
- The expected flow rates for both the ECCS and CSS. The flow rates for these systems determined by the plant's hydraulic analysis should be used. The worst-case single failure that maximizes the flow rate to the core is the case that should be utilized. Typically this would be the case where a single containment spray pump is not operating but could be the case where an entire train of core cooling and spray flow is not available.
- The core boil-off expected at the time of transfer to sump recirculation and at the time of hot leg recirculation is calculated using the product of the value of the reactor full power, plus uncertainty, times the appropriate value of the normalized ANSI/ANS 1971+20% decay heat curve. Note that a different decay heat curve, such as the ANSI/ANS 1979+2σ decay heat curve, may be used when accompanied with appropriate technical justification.
- ~~The core boil-off expected at the time of transfer to sump recirculation and at the time of hot leg recirculation.~~

The acceptability of this approach is based on the following contributors:

1. The determination of the quantity of fiber that bypasses the strainer does not consider the agglomeration effects that would be prototypical in the plant environment. In other words, testing was performed to maximize the quantity of individual fibers that would reach the strainer, maximizing the quantity that would pass through or bypass the strainer.
2. The 30-day quantity of fiber that bypasses the strainer is used as the total quantity of fiber that is available for transport. Most plants will transfer to HL recirculation in the 4 to 12 hour time frame, which results in a significant reduction of fiber that would be expected to bypass the strainer and available for transport to the core.
3. That fraction of fiber that passes through the strainer and enters the containment spray system would result in a significant quantity of the fiber being dispersed throughout containment, allowing for significant holdup or capture by plant features. Some of the fiber would return to the strainer, where a majority would be expected to be captured by the strainer.
4. 100% of all fiber that enters the ECCS is assumed to be available for transport.
5. Use of the core boil-off values from the earliest time of transfer to CL recirculation and transfer to HL recirculation maximizes the core boil-off flow rate and thus the quantity of fiber delivered to the core.
6. The quantity of fiber expected to be transferred to the core is increased by 20% to provide additional margin to allow for uncertainties in the ~~methodology~~fibrous debris concentration provided to the core.